United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

General Technical
Report NE-311

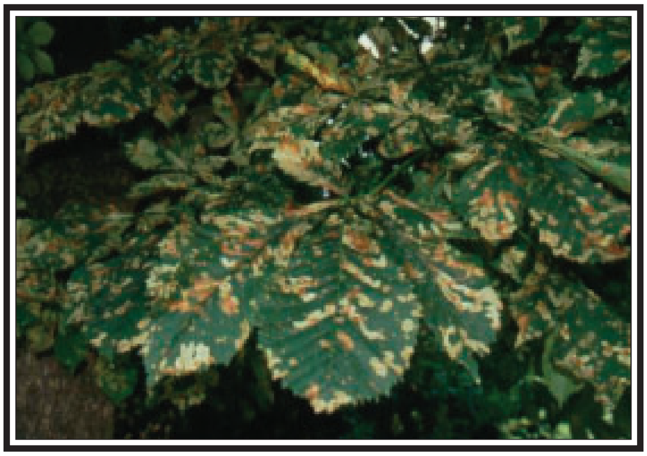
Proceedings

Ecology, Survey and Management of Forest Insects

Edited by:

**Michael L. McManus
Andrew M. Liebhold**

**Kraków, Poland
September 1-5, 2002**




Cover

The photographs on the cover (from the upper left corner going clockwise) are (photographer's name in parentheses): Leaf damage caused by the horse-chestnut leafminer, *Cameraria ohridella* (Gyuri Csóka), gypsy moth, *Lymantria dispar* late instar larva with eggs of the parasitoid, *Parasetigena silvestris* (Gyuri Csóka), extensive tree mortality caused by *Ips typographus* outbreak, Tatra National Park, Poland (Rose-Marie Muzika), and galleries of *Ips typographus* (Milos Knizek).

Most of the papers in this publication were submitted electronically and were edited to achieve a uniform format and typeface. Each contributor is responsible for the accuracy and content of his or her own paper. Statements of the contributors from outside the U.S. Department of Agriculture may not necessarily reflect the policy of the Department. Some participants did not submit papers so they have not been included.

The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Remarks about pesticides appear in some technical papers contained in these proceedings. Publication of these statements does not constitute endorsement or recommendation of them by the conference sponsors, nor does it imply that uses discussed have been registered. Use of most pesticides is regulated by State and Federal Law. Applicable regulations must be obtained from the appropriate regulatory agencies.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish and other wildlife - if they are not handled and applied properly. Use all pesticides selectively and carefully. Follow recommended practices given on the label for use and disposal of pesticides and pesticide containers.

Manuscript received for publication 22 July 2003

Published by:

USDA FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073-3294

November 2003

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152

For an online version:

www.fs.fed.us/ne/newtown_square/publications/technical_reports/pdfs/2003/gtrne311.pdf

Proceedings

Ecology, Survey and Management of Forest Insects[1]

Kraków, Poland
September 1-5, 2002

Edited by:

Michael L. McManus
USDA Forest Service, Northeastern Research Station, 51 Mill Pond Rd.,
Hamden, CT 06514-1703, USA

Andrew M. Liebhold
USDA Forest Service, Northeastern Research Station, 180 Canfield St.,
Morgantown, WV 26505, USA

Published by
USDA Forest Service
Northeastern Research Station
General Technical Report NE-311

2003

---

[1] A meeting sponsored by the International Union of Forestry Research Organizations (IUFRO) Working Party S7.03-06, "Integrated Management of Forest Defoliating Insects," and Working Party S7.03.07, "Population Dynamics of Forest Insects."

Preface

These proceedings result from a conference, “Ecology, Survey and Management of Forest Insects” held at the Congress Centre, Agricultural Academy in Kraków, Poland, 1-5 September, 2002. This meeting was hosted by the Agricultural Academy in Kraków and the Forest Research Institute, Warsaw and sponsored by IUFRO units 7.03.06 “Integrated management of forest defoliating insects”, 7.03.07 “Population dynamics of forest insects”, and 7.03.10 “Methodology of forest insect and disease survey in Central Europe.” The joint meeting was a great success and demonstrated the value of holding combined meetings among these three groups.

Local arrangements for the meeting were organized by Dr. Wojciech Grodzki, Forest Research Institute Warsaw, Department of Forest Management in Mountain Regions in Kraków. Dr. Grodzki did an excellent job of coordinating the meeting and organizing an informative and enjoyable field trip to the Tatra National Park to observe extensive damage caused by *Ips typographus*, and to managed forests in Podhale Upland, to view damage caused by wind and floods and related forest protection problems. Photographs taken during the meeting can be viewed on the Internet at http://iufro.boku.ac.at/iufro/iufronet/d7/wu70310/krakow/report.

Seventy-four delegates from 22 countries attended the meeting. There were 33 oral and 28 poster presentations. Delegates presented a broad array of topics and included methods for surveying forest insects, population dynamics of forest insects, effects of insects and diseases in forest ecosystems, integrated management and biological control of forest insects. Submission of a paper for inclusion in these proceedings was optional.

The success of an international conference such as this requires the assistance of many individuals, therefore we would like to recognize Wojciech Grodzki and colleagues from the Forest Research Institute, Kraków and Jerzy R. Starzyk and his staff at the Agricultural Academy of Kraków for organizing an excellent meeting. Their efforts in coordinating local arrangements and facilitating the field trip were outstanding and resulted in a truly memorable experience for all participants. We thank Director Pawel Skawiński and his staff at the Tatra National Park in Zakopane for hosting our group for that portion of the field trip, and Chief Forester Roman Latoń and his staff, State Forests, Forest Inspectorate Nowy Targ, for hosting the remainder of the field trip and evening party in the forest.

The USDA Forest Service Northeastern Research Station and the USDA Forest Service Forest Health Technology Enterprise Team sponsored the publication of these proceedings and we thank them for making this volume possible. The editors are indebted to Barbara Johnson for her assistance in preparing the manuscripts for these proceedings.

Contents

The Attack of *Aesculus hippocastanum* L. by *Cameraria ohridella* Deschka and Dimic (Lepidoptera: Gracillariidae) in Greece

Nikolaos Avtzis[1] *and Dimitrios Avtzis*[2]

[1]Technological Educational Institute of Kavala Dep. of Forestry in Drama, 66 100 Drama-Greece
[2]Std. at the Dept. of Forestry, Aristotelian University of Thessaloniki, Greece

Abstract

The horse chestnut leaf miner *Cameraria ohridella* is a relatively new insect in Europe, which was first observed at Lake Ohrid in 1984. Within the framework of the European Community Project "Controcam", in which Greece participates through the TEI of Kavala, Department of Forestry in Drama, we attempted for the first time to study the bio-ecology as well as the spread of this pest in Greece.

By using pheromone traps and visiting different areas with the technical support of the Greek Forest Service, it was possible to reach the following conclusions:

1. *C. ohridella* has at least three generations per year and there is a possibility for a fourth generation
2. It attacks horse chestnut when it occurs as natural stands of trees but it may also infest horse chestnuts that are grown in artificial plantings.
3. *C. ohridella* has not been detected attacking *Acer* species in Greece.

Key words: *Cameraria ohridella*, *Aesculus hippocastanum*, Greece, spread, pheromone traps, *Acer*-host plant

The horse chestnut leaf miner (*Cameraria ohridella)* was observed for the first time in Europe in 1984 when it was reported attacking horse chestnut trees at Lake Ohrid (Simova-Tosic and Filev 1985). In 1986, the leaf miner was identified by Deschka and Dimic as *Cameraria ohridella*, using the name of the area where it was first discovered. In 1989, the insect was observed in Central Austria, about 1000 km north of the first point of attack (Puchberger 1995). Apparently the spread of *C. ohridella* into Central and Eastern Europe occurred very rapidly (Freise and Heitland 1999); it was reported in Germany (Butin/Führer 1994), Hungary (Szaboky 1997) in Czech Republic (Liska 1997) and Slovakia (Sivicek et al. 1997). The spread of this insect in Greece was very slow, probably because of the limited distribution of *Aesculus hippocastanum* (Skuhravy 1999).

Materials and Methods

Within the framework of the European Community Project named "Controcam," in which Greece participates through the Department of Forestry of the Technological Educational Institute of Kavala, we attempted for the first time to study the spread as well as the bio-ecology of this particular leaf miner in Greece. Prior to the start of the "Controcam" Project, the unique information known about the status of *C. ohridella* in Greece was about the appearance of *C. ohridella* on two *A. hippocastanum* ornamental trees at the mountain Pelion in Central Greece (Longitude: E 23^{o} 04. 459, Latitude: 39^{o} 20. 810, Altitude: 605 ml) in1998 (Skuhravy, 1999). In order to satisfy the needs of the Project mentioned above, we initiated a systematic study of this insect in Greece.

Development-Number of Generations

In order to study the development of *C. ohridella* and to determine the number of generations per year, 10 "Delta" traps were set out during the first ten days of April 2001 at Grevena (Central Greece). Traps were placed in the lower crown of 10 *A. hippocastanum* that were growing along a stream at an altitude of 845 meters (Longitude: E 021^{o} 12. 060, Latitude: 39^{o} 58. 073). The pheromone dispenser was produced at the Institute of Organic Chemistry and Biochemistry, Academy of Sciences of the Czech Republic.

Observations during the first season (2001) started at the beginning of April and finished at the end of September. During this period of observations the dispenser of every trap was changed every fourth week.

Every observation lasted 24 hours. That means that at the beginning of every observation every Delta trap received a new sticky bottom, which was removed the next day, exactly 24 hours after its installation.

In that way the number of the captured moths during the 24-hour observation period provided information about the flight period of the adults as well as the fluctuations of their population intensity.

The dispenser was changed every fourth week and the period of observation lasted for 24 hours. This means that at the beginning of every observation every trap receives a new sticky bottom, which is removed the next day, in exactly 24 hours. Observations took place on the same trees in the same area (Grevena) during 2002.

Spread

The spread of *C. ohridella* in Greece was studied by visiting locations throughout Greece with the assistance of the local Greek Forest Service. Information including photographs and leaf samples were collected from each location for further analysis. This work was conducted in 2001 and in 2002.

Host plants

A number of samples were taken monthly at the area of Grevena and Karitsa (Longitude: E 022^o 45. 971, Latitude: 39^o 48. 785, Altitude: 705 m), in order to search for evidence of infestation among the different *Acer* species. These obseravtions began in 2001 (April-October) and were repeated in 2002.

The search was conducted in areas adjacent to heavily infested horse chestnut trees and included leaf sampling of the following *Acer* species:

1. *Acer obtusatum* (Grevena)
2. *A. monspessulanum* (Grevena)
3. *A. campestre* (Grevena)
4. *A. platanoides* (Grevena)
5. *A. pseudoplatanus* (Karitsa)

Results and Discussion

The pheromone trap data indicate that *C. ohridella* has three generations per year at Grevena (Fig. 1).

This result agrees with published literature which suggests that *C. ohridella* has 3-5 generations per year (Deschka and Dimic 1986, Pschorn-Walcher 1994, Skuhravy 1999). Based on observations during the two years (2001-2002), the periodicity of moth capture was similar during the first generation in early May and the second generation that peaked in early July.

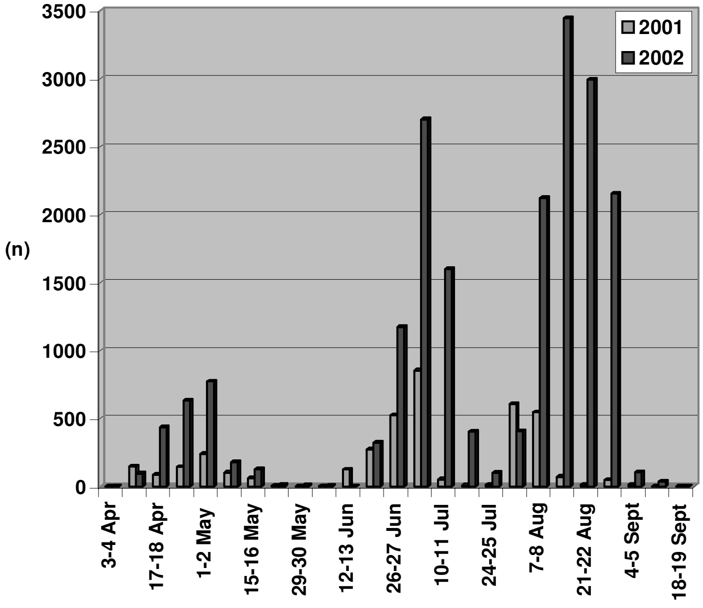


Figure 1.—Total number of captures of *C. ohridella* from ten pheromone traps at Grevena

However the peak flight period for the third generation in 2002 was delayed by approximately two weeks.

The explanation for the approximately five times greater number of insects captured in 2002 (19,828 moths) as compared to 2001 (3,938 moths) may be related either to the weather conditions or to the complex of natural enemies that occurred at the observation sites. Both of these parameters will be investigated in future years at Grevena.

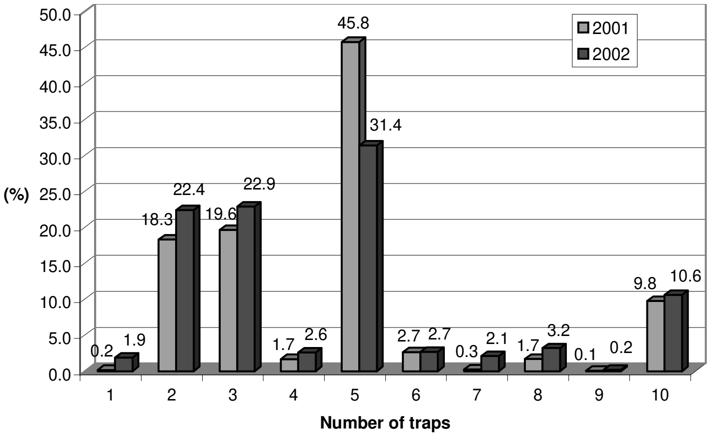


Figure 2.—Captures (%) of *C.ohridella* from ten pheromone traps at Grevena

There was an observed variation in the number of *C. ohridella* that were captured among the 10 trees at Grevena. In both years, significantly more insects were captured on the same four trees (2,3,5,10) even though all trees were growing under the same site conditions on a line of about 1,800 across the stream (Fig. 2). We have no explanation for this, however we will continue to monitor populations in future years.

For the distribution of *C. ohridella* in Greece, results from two years of observations indicate that the insect occurs at 36 locations. Among the 36 locations, 18 consisted of wild trees/stands and 18 were ornamental plantings. The majority of those sites were located across the main mountain region of Greece on a north-south axis as illustrated in Figure 3. All of the sites occurred at an Altitude of 520 to 1370 meters above sea level, at a Longitude from E 020°51 100 to E 023° 10.444, and at a Latitude from N 38° 37 751 till 40° 50 683.

Observations to date indicate that:

1. The insect attacks wild as well as ornamental horse chestnut trees in parks, gardens and along roads.
2. No difference was observed in the intensity of attacks from *C. ohridella* between wild and ornamental trees. The infestation level after the flight of the adults of the second generation may vary from a few mines per compound leave (0-5%) up to almost complete infestation of leaflets with mines (more than 80% of the photosynthetic area per leave).
3. All the wild *A. hippocastanum* trees, wherever they were found in Greece, were attacked by *C. ohridella*.

It has been suggested that second generation moths of *C. ohridella* may occasionally infest species of *Acer* if there is a shortage of healthy *A. hippocastanum* foliage. Other authors reported development of *C. ohridella* on the leaves of *A. platanoides* and *A. pseudoplatanus* (Krehan 1995, Pschorn-Walcher 1997, Skuhravy 1999). However, we did not find any infestation by *C. ohridella* on *Acer* foliage from Grevena and Karitsa even if the infestation level on the adjacent *A. hippocastanum* trees was very high (more than 80% of the total surface of the leaves). Other authors reported development of *C. ohridella* on the leaves of *A. platanoides* and *A. pseudoplatanus* (Krehan 1995, Pschorm-Walcher 1997, Skuhravy 1999).

So far, *C. ohridella* is not a serious problem in Greece because of the limited presence of *A. hippocastanum.* However this situation may change in the future because in recent years, the horse chestnut tree seems to be one of the most popular species for plantings in parks, gardens and along avenues in many areas of Greece. In order to prevent this problem from worsening in the future, use of the most resistant species (e.g. *carnea*) in plantings should be encouraged.

Figure 3.—Localities in Greece where *C. ohridella* was found attacking *A. hippocastanum* as of September, 2002

References Cited

Butin, H. und E. Führer. 1994. Die Kastanien-Miniermotte (*Cameraria ohridella* Deschka & Dimic) an Aesculus hippocastanum. Nachrichtenbl. Deut. Pflanzenschutzd. 46 (5): 89-91.

Deschka, G. and N. Dimic. 1986. *Cameraria ohridella* sp. n. (Lep., Lithocolletidae) aus Mezedonien. Acta Entomol. Jugosl. 22: 11-23.

Freise, J. and W. Heitland. 1999. A brief note on sexual differences in pupae of the horse-chestnut leaf miner, *Cameraria ohridella* Deschka & Dimic (1986) (Lep., Gracillariidae), a new pest in Central Europe on Aesculus hippocastanum. J. Appl. Ent. 123: 191-192.

Krehan, H. 1995. The horsechestnut leafmining moth *Cameraria ohridella* - incidence of attack in Austria. Forstschutz Aktuell No. 16:8-11.

Liska, J. 1997. Verbreitung der Roßkastanienminiermotte in der Tschechischen Republik. Forstschutz-Aktuel, Wien 21: 5.

Pschorn-Walcher, H. 1994. Freiland–Biologie der eingeschleppten Roßkastanienminiermotte *Cameraria ohridella* Deschka et Dimic (Lep., Gracillariidae) im Wienerwald. Linzer biol. Beiträge, 26/2: 633-642.

Pschorn-Walcher, H. 1997. Zur Biology und Populationsentwicklung der eingescleppten Rosskastanien-Miniemotte, *Cameraria ohridella.* Forstschutz Aktuell. No. 21: 7-10.

Puchberger, K.M. 1995. Zur Geschichte der ersten Ausbreitung von *Cameraria ohridella* Deschka & Dimic 1986 in Österreich (Lepidoptera, Gracillariidae). Ent. Nacht. Blatt, Wien, 2 (1): 2-3.

Simova-Tosic, D. und S. Filev. 1985. Prilog poznavanju minera divljeg kestena (Contribution to the Horse chestnut miner). Zastita Bilja (Belgrad) 36: 235-239.

Sivicek, P., P. Hrubik und G. Juhasova. 1997. Verbreitung der Roßkastanienminiermotte in der Slovakei. Forstschutz-Aktuel, Wien 21: 6.

Skuhravy, V. 1999. Zusammenfassende Betrachtung der Kenntnisse über die Roßkastanienminiermotte, *Cameraria ohridella* Deschka & Dimic (Lep., Gracillariidae). Anz. Schädlingskunde, 72: 95-99.

Szaboky, C. 1997. Verbreitung der Roßkastanienminiermotte in Ungarn. Forstschutz-Aktuel, Wien 21: 4.

New Lure for the Larger Pine Shoot Beetle, *Tomicus piniperda* — Attractant/Trap Design Combinations Tested in North America and Europe

D. Czokajlo[1], B. Hrašovec[2], M. Pernek[2], J. Hilszczanski[3], A. Kolk[3], S. Teale[4], J. Wickham[4] and P. Kirsch[1]

[1]IPM Tech, Inc. 4134 N. Vancouver Ave, Suite 105, Portland, OR 97217, USA
[2]University of Zagreb, Zagreb, Croatia
[3]Forest Research Institute, Warsaw, Poland
[4]State University of New York, College of Environmental Science and Forestry, Syracuse, NY 13210, USA

Abstract

An optimized, patented lure for the larger pine shoot beetle, *Tomicus piniperda* has been developed and tested in the United States, Poland, and Croatia. Seven different beetle attractants were tested: α-pinene, α-pinene oxide, ethanol, nonanal, myrtenal, myrtenol, and *trans*-verbenol. α-pinene was tested alone or in combination with two or more of the remaining compounds. Attraction of all candidate lures was compared to attraction of Tomodor, a Polish commercial lure for *T. piniperda*, using the Intercept™ Panel Trap (PT). A lure containing α-pinene, α-pinene oxide, nonanal, myrtenal, myrtenol, and *trans*-verbenol was used to compare trap captures in Intercept PT with 12-unit multi-funnel traps in USA, Theyson trap in Croatia, and IBL-3 trap in Poland. This study demonstrated that at least a quaternary semiochemical combination, including α-pinene, nonanal, *trans*-verbenol, and myrtenol is required to assure maximum trap captures. The best IPM Tech lure was significantly more attractive than Tomodor when tested in Poland and Croatia. Catches of *T. piniperda* in the Intercept PT were significantly higher than in the IBL-3 trap or Theyson trap.

Keywords: larger pine shoot beetle, *Tomicus piniperda*, attractant, Intercept Panel Trap (PT), insect monitoring

Introduction

The larger pine shoot beetle, *Tomicus piniperda,* is native to Europe and Asia. In 1992, *T. piniperda* was discovered in the United States (Haack et al. 1997). Czokajlo et al. (1996) demonstrated that the beetle had been introduced to North America as early as the late 1970s or early 1980s. Since then, *T. piniperda* has spread through 12 USA states and two Canadian provinces (NAPIS 2002). The chemical ecology of *T. piniperda* is not well understood, and consequently, this pest is difficult to monitor and manage. Presently in North America, only α-pinene is used as a commercial lure (Phero Tech, Inc., Delta, BC, Canada). In Europe, Tomodor (Z.D. Chemipan, Poland) and Tomowit (Bio/Technik/Chemie WITASEK, Austria) are the only known commercially available lures, however none of these lures attract a satisfactory number of beetles. Several trap designs are used for monitoring beetle populations. The multi-funnel trap (Phero Tech, Inc., Delta, BC, Canada) has been the most common trap design used in North America. Several other trap designs have been used in Europe and Asia, e.g. Theyson trap, drain-pipe trap, barrier traps, and multi-funnel trap. Forest managers and land owners need an effective *T. piniperda* monitoring system.

IPM Tech has developed an improved lure for the larger pine shoot beetle based on previous research (Czokajlo 1998, Czokajlo and Teale 1999, Teale et al. 2001) and unpublished field results. The main objective of this study was to validate an optimal blend and optimal release rates of semiochemicals, along with field test trap designs in order to determine the most effective system for trapping *T. piniperda* during its reproductive flight in spring.

Figure 1.—Intercept PT (left), Multi-funnel trap (center), IBL-3 trap (top right), Theyson trap (bottom right).

Materials and Methods

Experiments were conducted in the United States, Poland, and Croatia in the spring of 2002. In the United States, the experiment was conducted in an isolated (5 ha), unmanaged, 50-year-old Scots pine stand near Syracuse, NY. In Croatia, the experiment was conducted in a mixed 90% *Pinus sylvestris*, 10% *P. nigra* uneven age (40 to 80-year-old) forest. In Poland, the experiment was conducted in a 65-year-old, even-aged Scots pine forest near Suprasl.

Beetles were caught in Intercept™ Panel Trap (Int PT, IPM Tech, Inc., Portland, OR, USA) and in: 12 unit multi-funnel trap in the United States, IBL-3 funnel trap in Poland, and Theyson trap in Croatia (Fig. 1). Traps were spaced at 15 m or more, with the collection cup or container about 30 cm above the ground. The chemicals used were: α-pinene (Berje, Inc., 98%), α-pinene oxide (Elf-Atochem, 96%), ethanol (Aaper Alcohol and Chemicals, Co., 100%), nonanal (Polarome, 98%), myrtenal (Aldrich, 98%), myrtenol (Aldrich 98%), and *trans*-verbenol (IPM Tech, Inc., 99%). The compounds were released separately and combined into mesh bags for different treatments (Fig 2). Lure combinations, release dispensers and rates of release are provided in Table 1. There were eight treatments in the US experiment and seven treatments in Poland and Croatia. Each treatment was replicated ten times. Beetles were collected weekly.

The field data were subjected to a single factor ANOVA. Trap catches from the United States were log transformed and trap catches from Croatia were square root transformed to satisfy ANOVA assumptions. The HSD test was used to compare means in Poland and LSD test was used to compare means in Croatia and in the United States (Stat Soft, Inc., 1995).

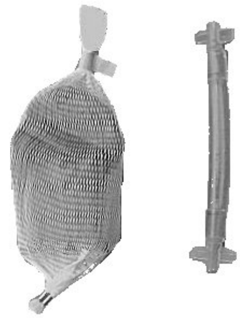


Figure 2.—*Tomicus piniperda* IPM Tech's lure (left) and Tomodor (right).

Table 1.—Candidate semiochemicals for *Tomicus piniperda.*

Common Name	Abbreviation	Release device	Release rate (mg/24h)	Treatment*
α-Pinene	α-P	2 LDPE bulbs	300	A,B,C,D,E,F
α-Pinene Oxide	α-P-ox	2 LDPE vials	4	D,E
Nonanal	N	2 LDPE vials	16	B,C,D,E,F
(-) Myrtenal	M-al	LDPE pouch	12	C,D,E
trans-Verbenol	t-V	LDPE pouch	4	B,C,D,E,F
(-) Myrtenol	M-ol	LDPE pouch	4	B,C,D,E
Ethanol	E	LDPE pouch	70	E
Tomodor				Tomodor

* Treatment D was used to compare captures in Intercept PT, Theyson trap, and Multi-funnel trap.

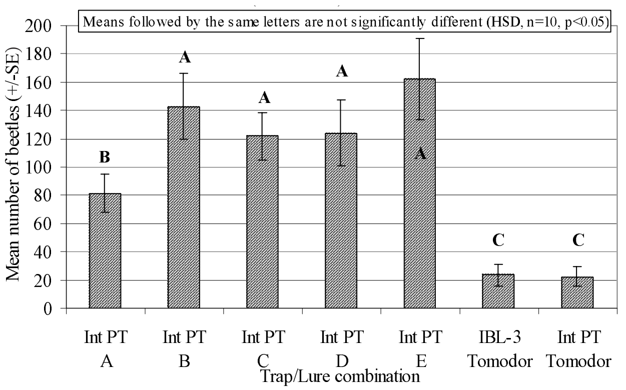


Figure 3.—Captures of *Tomicus piniperda* in Intercept PT and IBL-3 traps baited with various IPM Tech lure combinations and Tomodor (Polish lure) Poland, 2002.

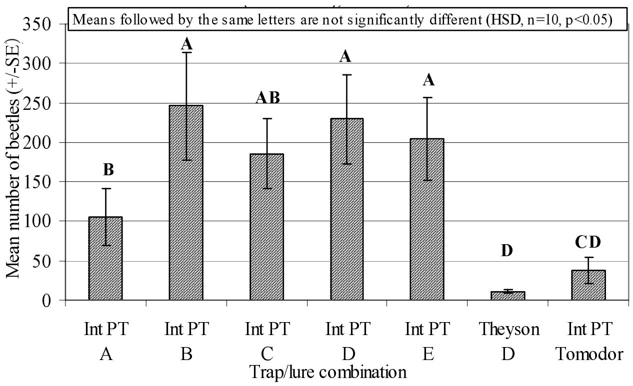


Figure 4.—Trap captures of *Tomicus piniperda* in INT PT and Theyson traps baited with various IPM Tech lures and Tomodor (Polish lure) Croatia, 2002.

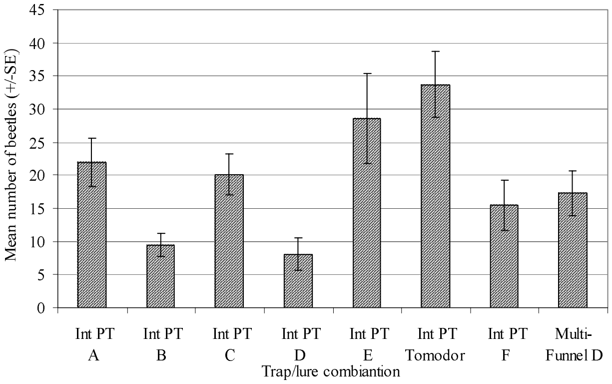


Figure 5.—Trap captures of *Tomicus piniperda* in INT PT and Multi-funnel traps baited with various IPM Tech lures and Tomodor (Polish lure) near Syracuse, NY, USA, 2002.

Results

The best IPM Tech lure was significantly more attractive than Tomodor and α-pinene lures when tested in Poland (Fig. 3) and Croatia (Fig. 4). Data from the United States was inconclusive (Fig. 5). In Poland, IPM Tech's best lure attracted 638% more beetles than Tomodor and 176% more beetles than α-pinene. In Croatia, the best IPM Tech lure attracted 650% more beetles than Tomodor and 233% more beetles than α-pinene. In the United States, captures in traps baited with the best IPM Tech lure, Tomodor, or α-pinene were not different. However, the data collected in the United States was probably inconclusive because in 2002, the reproductive flight of *T. piniperda* occurred unusually late in the spring and was extended over a period of several weeks; in addition, population levels were unusually low. Also, in Poland and Croatia, the Tomodor lure attracted significantly fewer beetles than α-pinene (by 363% and 278%, respectively); however this was not the case in the United States. Captures of *T. piniperda* in Intercept PT in Croatia were significantly higher than in the Theyson trap (by 216%).

Conclusions

The new IPM Tech trap (Intercept PT) and lure for *T. piniperda* proved to be superior to those used commercially in Europe. IPM Tech's lure for *T. piniperda* performs better than commercially available European lures and better than the α-pinene lures used in the United States. Our research indicates that at least a quaternary semiochemical combination, including α-pinene, nonanal, *trans*-verbenol, and myrtenol is required to assure maximum trap captures. Further, IPM Tech's Intercept PT proved to be the best trap compared to any of the European trap designs tested in this study.

References Cited

Czokajlo, D. and S.A. Teale. 1999. Synergistic effect of ethanol to α-pinene in primary attraction of the larger pine shoot beetle, *Tomicus piniperda*. J. Chem. Ecol. 25(5): 1121-1130.

Czokajlo, D. 1998. Semiochemicals for the larger pine shoot beetle, *Tomicus piniperda* L. And its clerid predators. Ph.D. Dissertation. State University of New York, College of Environmental Science and Forestry. 164 pp.

Czokajlo, D., R.A. Wink, J.C. Warren, and S.A. Teale. 1997. Growth reduction of Scots pine, *Pinus sylvestris* L. caused by the larger pine shoot beetle, *Tomicus piniperda* (L.)(Col., Scolytidae) in New York State. Can. J. For. Res. 27, 1394.

Haack, R.A., R.K. Lawrence, D.G. McCullough, and C.S. Sadof. 1997. *Tomicus piniperda* in North America: An integrated response to a new exotic scolytid. In Proceedings: Integrating cultural tactics into the management of bark beetle and reforestation pests, J.C. Grégoire, A.M. Liebhold, F.M. Stephen, K.R. Day, and S.M. Salom, Eds. (USDA For. Ser. Gen. Tech. Rep. NE-236), pp. 62-72.

NAPIS. 2002. Website: www.ceris.purdue.edu/napis/pests/psb Stat Soft, Inc. 1995. Statistica for windows (Computer program manual). Tulsa, Oklahoma.

Teale, S.A., D. Czokajlo, and F.X. Webster. 2001. Pine shoot beetle attractant composition. U.S. Patent # US 6,203,786 B1.

Bark Beetle Management After a Mass Attack — Some Swiss Experiences

B. Forster, F. Meier and R. Gall

Forest Insect and Disease Survey FIDS, Swiss Federal Research Institute WSL CH-8903 Birmensdorf

Abstract

In 1990 and 1999, heavy storms accompanied by the worst gales ever recorded in Switzerland, struck Europe and left millions of cubic metres of windthrown Norway spruce trees; this provided breeding material for the eight-toothed spruce bark beetle (*Ips typographus* L.) and led to mass attacks in subsequent years which resulted in the additional loss of millions of cubic meters of standing spruce trees. In addition to the ecological concerns, many forest owners were faced with a difficult financial situation, resulting in a change in strategy that left some storm and bark beetle damaged areas uncleared. Also, logistical issues made it sometimes impossible to remove all of the timber before a new generation of beetles emerged. This situation forced forest services and land-owners to set priorities. To address questions related to developing a new risk assessment, we initiated observation projects about scolytid behaviour occurring in variously threatened storm areas and regions.

Keywords: storm damage, bark beetles, Scolytidae, *Ips typographus*, forest protection

Mass attacks of bark beetles following storm damage

In the last decade, two heavy storms struck Western and Central Europe; they were the worst gales ever recorded in Switzerland. In 1990 storm "Vivian" caused a loss of 5 million cubic meters of wood, representing a one-year regular cut in Switzerland. Norway spruce stands (*Picea abies* (L.) Karst.) in the central and eastern Alps and Prealps were the most severely damaged. A total of about four million cubic meters of spruce timber was blown down. In the following six years, the eight toothed spruce bark beetle (*Ips typographus* L.) caused mass attacks which resulted in the death of another 2 million cubic meters of standing spruce trees (Fig. 1). This phenomenon was also a record for Swiss forests.

In 1999 storm "Lothar" produced 13 million cubic meters of windthrown wood, which included 8 million cubic metres of spruce. The worst storm damage occurred in the western and central Plateau regions and in the Prealps. In addition to spruce, windthrows occurred also in many mixed and broadleaf stands. The amount of subsequent bark beetle attacks that will follow this storm is not yet known, but will certainly exceed the level of timber infested after "Vivian" (Meier et al. 2002). During a period of 200 years prior to storm "Vivian," no other Swiss bark beetle gradation produced more than 500,000 cubic meters of timber loss.

Experiences from mass attacks abroad have demonstrated that spruce bark beetles are one of the most effective natural factors that can quickly influence forest dynamics by killing large stands of conifers (Nationalparkverwaltung Bayerischer Wald 1996, Wittwer et al. 1998). Bark beetle gradations follow frequently after storm damage or when warm and dry periods occur during the growing season (Weslien and Schröter 1996).

Outbreaks of bark beetles should be contained in order to maintain both forest sustainability and protection against natural hazards. In Switzerland this is accomplished mainly through mechanical forest practices especially by preventive clearing of devastated areas and by evacuating or debarking freshly infested spruces. After the two big storms, the forest services realized that it was impossible to clear all damaged stands in a timely manner and that there would be a high risk of bark beetle outbreaks. Reasons and conditions were analyzed that enforce clearing practices in storm-damaged areas and bark beetle infestation spots, as well as decisions to leave damaged areas uncleared. Priorities had been established and new strategies in bark beetle management and risk assessment were developed.

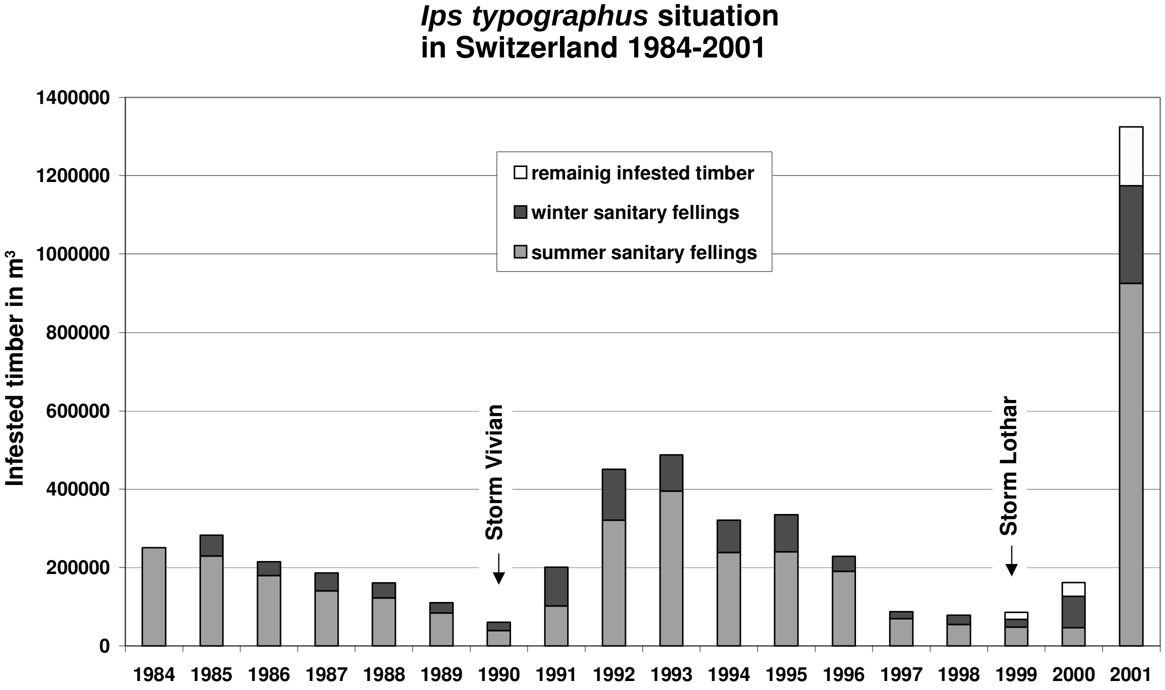


Figure 1.—Yearly infestation and sanitary felling of *Ips typographus* attacked spruce in Switzerland

Knowledge about *Ips typographus*

Ips typographus is the best known forest insect in Central Europe. During the last 200 years, numerous publications have dealt with its biology, epidemiology and management. *Ips typographus* has a strong predilection for mass attacks, consequently after storm events, beetle populations build up rapidly in wind thrown spruce stems and there is a high risk for subsequent attacks in neighbouring spruce forests. There is a strong relationship between storm intensity and subsequent bark beetle attacks (Fig. 2 and Fig. 3). In the first vegetation period after a storm, beetle populations are able to multiply by a factor of more than 10 in only one generation (Wermelinger et al. 1999). In later years, natural enemies help to control excessive propagation, but under favourable weather conditions and if there are still plenty of susceptible host trees, mass attacks will often continue for several years. Emerging bark beetles have dual strategy which allows a portion of the population to stay in suitable infestation spots and allows other to spread to new areas (Duelli et al. 1997). Flight distances can vary considerably. Active flight normally takes place within the first 500 metres however some can get caught by updrafts and then transported over distances of several kilometres. In mountain areas with steep slopes, passive wind transport of beetles seems to be more frequent because the area of turbulence that occurs above tree crowns can easily be reached by horizontal flight.

At lower elevations, two generations of *Ips typographus* can normally be observed per year; above ca 1300 metres asl., only one generation is common. This is one of the reasons why mass attacks peak normally earlier in the Plateau than in the Alps. In 2000, immediately after the storm “Lothar”, breeding conditions for *I. typographus* were very favourable. An abundance of damaged spruce timber was available as suitable breeding material, and very favourable weather conditions occurred, resulting in an explosion of beetle populations (Fig. 1). In warmer areas, two and a half or even three generations of beetles were observed and a second generation was recorded in areas up to about 1600 metres asl.

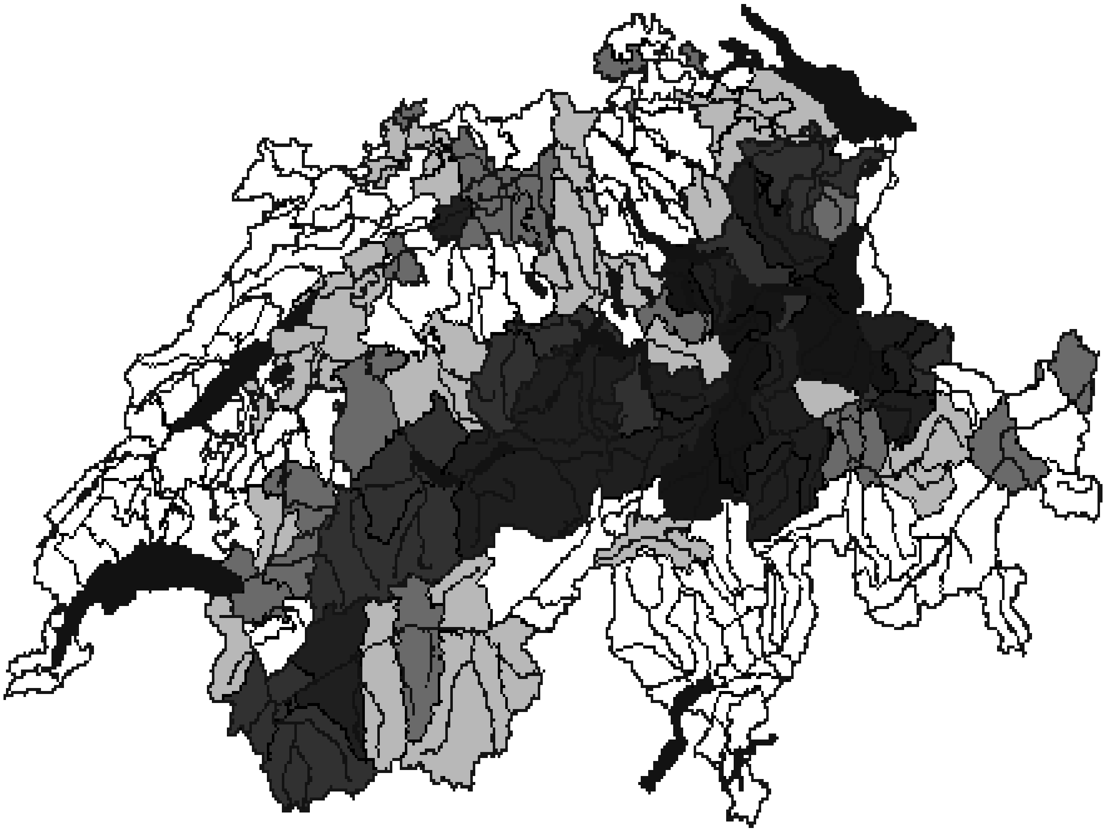


Figure 2.—Density of storm damage by forest district, caused by “Vivian” 1990 (dark colours indicate heavy windthrows)

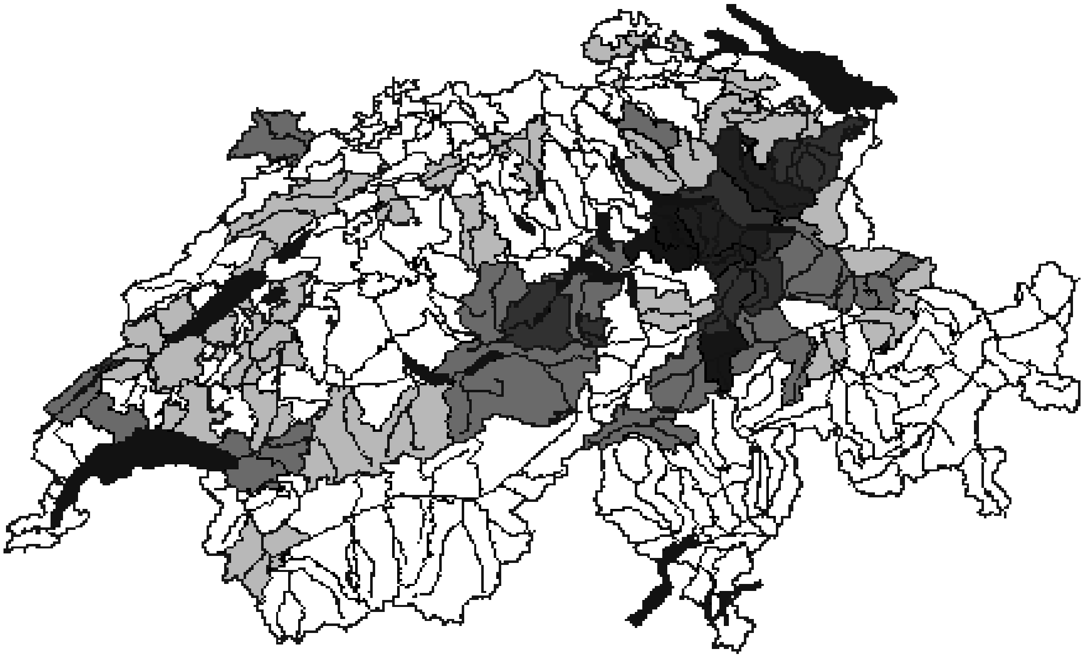


Figure 3.—Density of bark beetle attack by forest district 1992-1996 (dark colours indicate heavy attacks by *Ips typographus*)

Field experiences and new challenges

During the 1990s and after storm "Vivian", there were only a few storm-damaged areas and neighbouring spruce stands where bark beetle control activities were not implemented. In these regions, secondary beetle attack on storm-damaged timber often exceeded 60% on average. In the worst case, new spot infestations spread until almost the entire stand was killed (Forster 2001b); similar phenomena have also been described in Germany (Niemeyer et al. 1995). Within some regions where severe storm damage occurred and where adequate control measures could not be taken in time, the percentage of secondary timber lost due to beetles approached 100%. Examples of this are described from the Toggenburg Valley in the canton St. Gall (Schmidtke and Scherrer 1997) and from the Schwanden region in the canton Glarus (Kantonsforstamt Glarus 1995). Conversely, good experiences with efforts to remove storm damaged timber occurred in the severely devastated eastern Bernese Oberland or in the canton Schwyz, where secondary beetle attacks were recorded on only 20 to 40% of windthrown trees. The removal of damaged trees from storm areas affected by "Vivian" and reduction of subsequent bark beetle attacks was also observed in the canton Wallis (Metral 1995). These examples indicate that, even in a disastrous situation, forest protection measures are effective in lowering subsequent bark beetle damage to about 50% of that which would have occurred without intervention.

Today, the demands of forest owners and the public are changing considerably and more storm and bark beetle damaged areas will remain uncleared. In addition to ecological concerns, the difficult financial situation experienced by many forest owners has caused them to consider changing strategies and leaving some damaged areas uncleared. Many mountain forest owners are unable to cover their harvesting costs because of the decline in timber revenue. Logistical reasons (accessibility) made it sometimes impossible to remove all timber before it was infested and before a new generation of beetles emerged. These facts forced forest services and timber land owners to establish priorities (Forster 1998). To address questions related to assessment of risk, the WSL initiated observation projects of scolytid behavior in different threatened storm areas and regions (Forster 2001a).

As a result of these projects, we propose the following recommendations: an overview of a storm disaster must be established and the regional forest functions must be known. The necessity for clearing damaged stands to satisfy a given forest function needs to be assessed. Then the means (harvest specialists, machinery, time) must be evaluated along with the financial situation and the feasibility of hiring additional manpower. If the means are not insufficient to clear all areas in time, or other objections against clearing exist, priorities must be established. Due to the mobility of the beetles, a common strategy must be considered for entire valleys or landscape compartments encompassing several square kilometres.

In order to reduce infestation levels in strict protection forests, disaster areas should normally be cleared. In some cases, the stems can be debarked and then used in place as paravalanche construction. If such compartments of at least two square kilometres can be cleared to prevent potential attacks or to destroy infected breeding material in time, this will help to lower the risk of secondary bark beetle attack on standing trees. In areas with appropriate forest protection measures, mass attacks peak earlier than in other locations but fewer standing trees will be infested.

If all wind thrown trees cannot be removed or debarked in time, or in less important protection forests, adapted management strategies should be used. The stated goal is to limit secondary damage by bark beetles to such a degree that sustainable forest management can be realized. Because not all windthrown trees on totally damaged areas will be infested before they dry out, we propose to first clear the areas with a high proportion of thrown trees before clearing areas with mainly broken stems. Fallen trees that still have some root contact with the soil and/or that are lying in the shade of standing trees remain suitable for bark beetle colonization for a longer period of time. Therefore, this will reduce the availability of potential breeding material in subsequent years. Despite new recommendations about establishing priorities, a mixture of different management strategies are observed quite often in damaged stands, especially within private forests. This is a result of differences among owners, their means (manpower, finances, machinery) and their individual interpretation of priorities and opportunities. Management conflicts arise along the borders of different ownerships, especially if stands containing storm damage and bark beetle infestations border on managed stands where control practices are being implemented. In these cases buffer zones of some 100 to 1500 metres in width should be established (Niemeyer et al. 1995 and Heurich et al. 2001). However, frequently there is not enough space available for buffer zones and consequently the edges of managed stands will be re-infested. It is almost impossible to determine to what degree infestations in unmanaged stands contribute to new infestations that occur in neighbouring stands.

The actual "state of the art" on what is known about bark beetle behaviour and the effectiveness of control measures was compiled and published a few years after the storm "Vivian" (Jansen and Duelli 1993). Later the Swiss Forest Agency and the WSL compiled a key on windthrow clearing based on our initial experiences with "Vivian" (BUWAL 2000). Recommendations were again published after the storm "Lothar" (Forster et al. 2000, Forster 2001c) and communicated further through training courses and through the internet (www.pbmd.ch).

Conclusions

- There is a strong relationship between the intensity of storms and subsequent bark beetle attacks.

- In cases of disastrous storm damage in Norway spruce stands, subsequent bark beetle outbreaks can not be avoided and secondary damage on standing trees must be accepted.

- If newly attacked standing trees can be detected and processed efficiently, the gradation will generally subside sooner than in stands where the level of intervention is inadequate. Our experiences indicate that even in a disastrous situation, the application of forest protection measures will effectively lower subsequent bark beetle damage to about 50% of that which would occur without intervention measures.

- By establishing priorities, the course of the gradation can be influenced regionally. It is very important that resources should not be spent inefficiently or for punctiform control measures; resources must be committed to the regions most at risk. The same management strategy must be used within landscape compartments, throughout the affected region regardless of ownership.

- In Swiss mountain forests, the annual growth of timber has not been harvested for many years. This practice has provided high stocks of timber which will be more at risk of storm and bark beetle damage in future years. Additionally, bark beetles are likely to play an even more significant role in forest dynamics if projections on climate change will lead to warmer vegetation periods.

References Cited

BUWAL (ed.), 2000. Entscheidungshilfe bei Sturmschäden im Wald. Schriftenreihe Vollzug Umwelt. Bundesamt für Umwelt, Wald Landschaft (BUWAL), Bern. 100 p.

Duelli, P., P. Zaradnik, M. Knizek and B. Kalinova. 1997. Migration in spruce bark beetles (*Ips typographus* L.) and the efficiency of pheromone traps. J. Appl. Ent. 121, 297-303.

Forster, B. 1998. Storm damages and bark beetle management: how to set priorities. In: Methodology of Forest Insect and Disease Survey in Central Europe, Proceedings of the first Workshop of the IUFRO WP 7.03.10 - Ustron-Jaszowiec, Poland, April 1998. Edited by Grodzki, W. et al., IBL Forest Research Institute, Warszawa: 161-165.

Forster, B. 2001a. Bark beetle survey: Can monitoring of *Ips typographus* help to minimise control measures? In: Knizek, M. et al. (eds.), 2001: Methodology of Forest Insect and Disease Survey in

Central Europe. Proceedings of the IUFRO WP 7.03.10 Workshop, Sept. 24-28 2000, Busteni, Romania. Brasov, Forest Research and Management Institute (ICAS), Section of Brasov, 22-25.

Forster, B. 2001b. Chronologie der Borkenkäferentwicklung im Raum Schwanden 1990 bis 1997. In: Sophie und Karl Binding Stiftung (ed.) 2001: Binding Preis für vorbildliche Waldpflege 2001. Vivian als Chance. Gemeinde Schwanden GL. Basel, 115 p. 41-42.

Forster, B. 2001c. Käferholz erkennen und richtig handeln. Wald Holz 82, 8: 72-74.

Forster, B., B. Wermelinger and F. Meier. 2000. Sturmschäden und Borkenkäfer. Die Situation nach "Lothar". Wald Holz 81, 2: 40-42.

Heurich, M., A. Reinelt and L. Fahse. 2001. Die Buchdruckermassenvermehrung im Nationalpark Bayerischer Wald. In: Waldentwicklung im Bergwald nach Windwurf und Borkenkäferbefall. Bayer. Staatsforstverwaltung Wiss. Reihe, Grafenau, Vol. 14, 9-48.

Jansen, E. and P. Duelli. 1993. Borkenkäfer: Was wissen wir, was vermuten wir, was sollten wir wissen? Schweiz. Wald 129,7-8:31-33.

Kantonsforstamt Glarus (ed.) 1995. Sturmschäden im Glarner Wald vom 27./28.2.1990. Schlussbericht. Glarus. 52 p.

Meier, F., R. Engesser, B. Forster and O. Odermatt. 2002. Forstschutz-Überblick 2001. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft. 18 p.

Metral, R. 1995. Bekämpfung des Borkenkäfers im Unterwallis. Der Aufwand hat sich gelohnt. Wald Holz 76,6:20-21.

Nationalparkverwaltung Bayerischer Wald (ed.). 1996. Totholz im Nationalpark Bayerischer Wald, Entwicklung des Anteils abgestorbener Fichten. Grafenau, 36 p.

Niemeyer, H., J. Ackermann and G. Watzek. 1995. Eine ungestörte Massenvermehrung des Buchdruckers (*Ips typographus*) im Hochharz. Forst Holz 50,8:239-243.

Schmidtke, H. and H.-U. Scherrer. 1997. Sturmschäden im Wald. Schlussbericht NFP 31. Zürich, vdf Hochschulverlag. 38 p.

Wermelinger, B., M.K. Obrist, P. Duelli and B. Forster. 1999. Development of the bark beetle (Scolytidae) fauna in windthrow areas in Switzerland. Mitt. Schweiz. Entomol. Ges. 72, 3-4: 209-220.

Weslien, J. and H. Schröter. 1996. Natürliche Dynamik des Borkenkäferbefalls nach Windwurf. Allg. Forst Z./Der Wald 51,19:1052-1055.

Wittwer, D., K. Matthews, K. Zogas, L. Trummer, E. Holsten, B. Schulz, P. Hennon, M. Schultz, J. Riggs and R. Burnside. 1998. Forest Insect and Disease Conditions in Alsaka – 1998. Gen. Tech. Rep. USDA For. Serv. R10-TP-74. 57 p.

Integrated Management of Little Spruce Sawfly (*Pristiphora abietina*): Design Pattern

J. Holusa[1] *and K. Drápela*[2]

[1]Forestry and Game Management Research Institute Jíloviste-Strnady, Office Frýdek-Místek, Nádrazní 2111, CZ-73801 Frýdek-Místek
[2]Mendel University of Agriculture and Forestry, Zemedelská 3, CZ-61300 Brno

Abstract

This paper presents the design of a regulation model of the little spruce sawfly that is based on monitoring of defoliation. This method is based on the assessment of the percentage of defoliation of each whorl from ca. 100+ trees, beginning from the top and using four classes of defoliation. The critical value influencing the height of current increment of trees is six. Consequently 20 yellow sticky boards installed in lines on every other tree could monitor the next spring abundance of sawfly adults. Critical value is about 11 to 19 females per one sticky board (format A5). Impact of low temperature on sawfly populations during swarming is still not clear. Possibilities for using chemical measures for control are discussed.

Several outbreaks of the little spruce sawfly (*Pristiphora abietina* (Christ 1791)), covering thousands of hectares of spruce forests, have occurred in Europe (Pschorn-Walcher 1982). Little spruce sawfly is the most numerous tenthredinid in both young and older spruce stands from an altitude of 250 to 700 m a.s.l. in the eastern part of the Czech Republic (Holusa 1999, 2002). Every year spraying of a portion of this region is necessary (e.g. Pschorn-Walcher 1982, Liska 1999, 2000, Liska et al. 1991), because an integrated pest management (IPM) approach to address this problem is lacking.

In spite of this, the pest status of little spruce sawfly is not clear (Regulation no. 101/1996 Sb. dated March 28th 1996 of Ministry of Agriculture, Czech Republic), because larvae feed only on current year needles and therefore do not cause total defoliation of trees (Pschorn-Walcher 1982). Therefore it suggests that some level of economic threshold should be established, however, we lack appropriate methods to monitor this pest. *Pristiphora abietina* is usually monitored by estimating the density of cocoons in the soil (Bogenschütz 1986, Pschorn-Walcher 1982); however this procedure is time consuming, is not practical on a large scale, and is very unreliable (Janásek 1964). Thus, a new method of evaluation is needed. (Bogenschütz 1986). An assessment of defoliation (i.e. larval feeding) provides an indirect, objective method to determine the intensity of tenthredinid infestations (see Svestka and Holusa 2000, Holusa and Holusa 2002, Holusa and Drápela in press.). In order to work out an approach to develop an IPM system for *P. abietina*, the following questions needed to be answered:

1. What degree of defoliation causes a decrease of height tree increment?

Pristiphora abietina population fluctuations are of the temporary-distractive type, thus causing outbreaks that may last from a few years to several decades (Pschorn-Walcher 1982). Outbreaks of the little spruce sawfly can be only eruptive, because cocoons lying 10 months in the litter can be attacked by predators (in *Neodiprion sertifer* discussed by Larsson et al. 1993) and larvae that drop to the ground to pupate can be attacked by fungi. There is also a possibility that cocoons can overwinter in the soil for more than one year (Pschorn-Walcher 1982), however the first author found that this occurs in less than 1% of overwintering cocoons in the eastern part of the Czech Republic (Holusa 1999).

2. What is the best method to assess the abundance of sawfly adults in the following spring?

1. Impact of defoliation on the height of current increment of trees

Introduction

Nageli (1936) found that *P. abietina* caused a loss of 33-40% height tree increment in 1917-1934 in Switzerland. In Mooswald at Freiburg i.B., loss of height tree increment reached an average above 2 m (Niechziol 1958 in Pschorn-Walcher, H. 1982). In the case of very heavy defoliation, height tree increment declines rapidly and after several years of repeated defoliation, it decreased to zero; the loss is greater in younger forests. In spite of these observations no data exists that defines the relationship between the density of populations and increment loss.

In the past, a method of assessing defoliation caused by Tenthredinids (without discrimination of species) was prescribed but lacked precision (CSN 482718: Ochrana lesa proti pilatkám na smrku. 1958). The loss of needles was classified into four groups (loss of 1/3 of needles, 1/3 - 2/3, more than 2/3, and total defoliation). We have developed a scale of damage on spruce (Svestka and Holusa 2000, Holusa and Holusa 2002, Holusa and Drápela in press) which allows us to provide an objective evaluation of insect defoliation. This method was used to establish the degree of defoliation that can cause the decrease of tree height increment.

Method

About 100 trees in each plot were investigated to assess the percentage of defoliation of each whorl beginning from the top of the tree using four classes of defoliation:
Rare (value 0,1) - very light defoliation of annual shoots – below 10% of shoots were eaten;
light defoliation (value 1) - 10-50% of annual shoots were eaten;
heavy defoliation (value 2) - 50–90% of annual shoots were eaten
total defoliation of annual shoots (value 3) –over 90%.

A damaged tree leader (terminal) is evaluated by 1 (no feeding by 0). The average defoliation of each whorl was calculated per tree and then the results of all whorls were accumulated (this value is named as the degree of defoliation in this work).

We have determined the mean height current increment of young forests. We have measured height current increment of young forests 4-5 m (i.e. 6-12 years old) using a special measuring pole with 1 dm scale. In all places a set of 100 trees was investigated. Forests were separated according to condition of growth. Three types of potential habitats (*Querceto-Fagetum*, *Fagetum*, *Abieto-Fagetum*) were examined. Statistical analyses including correlation and regression analyses of the influence of defoliation on height current tree increment were performed using Statistica 6.0 (a = 0.05).

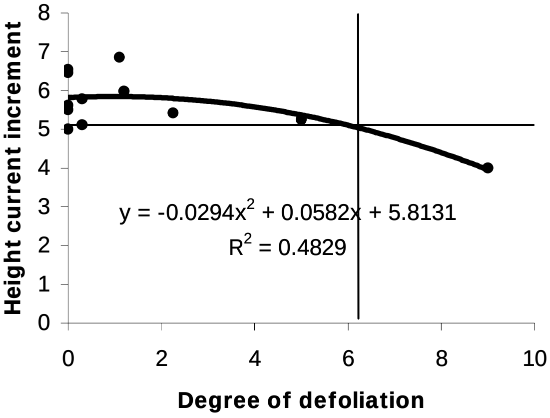


Figure 1.—Correlation between the degree of defoliation and current height tree increment (habitat *Fagetum*)

Results

Defoliation data sets are non-normal, because they are positively skewed and leptokurtic or platykurtic. Because Box-Cox transformation on normality was often not successful, the median value of defoliation distribution is used. The method is easy and fast; on average it is possible to evaluate 100 trees in less than half an hour, which is an important consideration for forestry applications.

The forests of the habitat *Querceto-Fagetum* were very weakly defoliated, therefore no correlation was found between the degree of defoliation and mean of height current increment. In the other two habitats, positive correlations were found however it was necessary to confirm the relation due to other statistical calculation (Figures 1, 2). The parabola was used to characterize the relationship because it corresponds better to the consideration that only more intensive defoliation should negatively influenced the tree height current increment.

No correlation was found between the degree of defoliation and the height tree current increment in the next year.

Based on this result, we can conclude that a degree of defoliation equal to six can negatively influence tree height current increment. There is an exception as e.g. the point in Fig. 2, which is probably caused by drought or fungus (or an unknown factor).

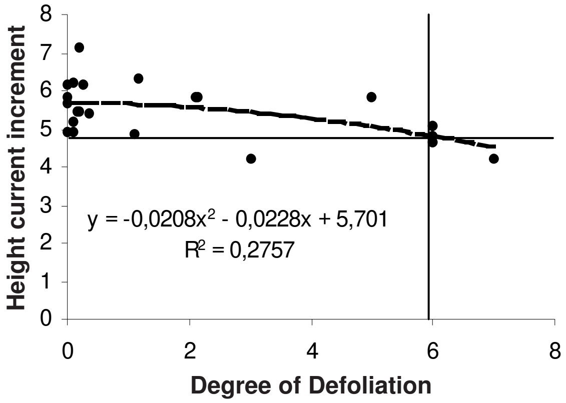


Figure 2.—Correlation between the degree of defoliation and current height tree increment (habitat *Abieto-Fagetum*)

Discussion

The impact of defoliation on the height current increment of trees is the most important factor in assessing the economic injury level though we need to determine also the impacts of treatment on non-wood-producing values of the forest, ecosystems, selection, and on the population dynamics of the pest (contraction of amplitude). The impact of control measures on the ecosystem could be reduced by using insecticides based on ecdysoids (growth regulators), whose impact on ecosystem health is minimal.

In the case of other stresses (mainly fungi in the habitat *Querceto-Fagetum*), the critical degree of defoliation should be decreased. Forest health condition will be a much more important factor than the decrease in height tree increment.

The defoliation of an entire young spruce stand (up to 40 years old) may be evaluated using a modified method. For the entire stand, a scale with four levels was deployed using a critical mean defoliation value of approximately 50% of trees (see Fig. 3). The degree six of critical defoliation corresponds approximately with the total defoliation of forests if three or more of the top whorls are consumed on over one half of the trees. Defoliation can be displayed graphically on a grid map (Central European System) in which the map fields are delimited by parallels of latitude (6 by 6 minutes) and meridians (10 by 10 minutes) with an approximate size of 11.2 x 12.0 km in Central Europe. Circles of different size in the map field can be used to designate the degree of defoliation for an entire forest. The range and intensity of infestation and the change in defoliation from year to year are easily observed (Holusa and Holusa 2002).

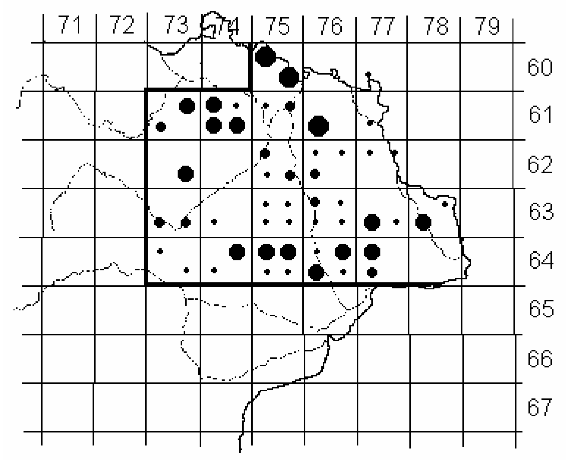


Figure 3.—The infestation caused by tenthredinids to young spruce forests in the eastern part of the Czech Republic in 2000 (marks: point - throughout the stand, only a single shoot on trees is consumed; small circle - half of trees with one or two top whorls consumed; mid-size circle - more than half of the trees with three and more top whorls consumed [this infestation reduces the growth of trees in the following year], circle of one quarter the size of the map field - stunted trees; fat line - margin of studied area) (Holusa and Holusa 2002)

Using the present method and maps in conjunction with GIS, and including information on altitude, total annual precipitation, average annual temperature, moisture, and characteristics of the habitat, pest risk assessment maps can be established.

2. Monitoring adult sawfly abundance

Introduction

Sawfly adults are generally attracted to yellow traps (Murhead-Thompson 1991). For monitoring of spruce web-spinning sawflies (*Cephalcia* spp.), some authors used yellow sticky boards (Jensen 1988, Cescatti and Battisti 1992) and correlated trap captures with the density of prepupae in the soil (Battisti and Rodeghiero 1998). Berger (1992) found that *Pristiphora abietina* adults could also be attracted to yellow traps. The number of adults captured in traps correlated with the density of cocoons in the soil.

In recent years, we have acquired positive results and experience in studies using yellow sticky boards. A statistically significant relationship was found between captures in Malaise traps and those on yellow sticky boards, and a highly significant relationship was found between the number of captured adults (on five sticky boards) and the degree of defoliation in seven localities. To estimate the abundance of adults, it is sufficient to install yellow sticky boards before swarming and then check them after swarming is completed. We did not observe statistically significant difference between samples taken at different intervals (Holusa and Drápela in press).

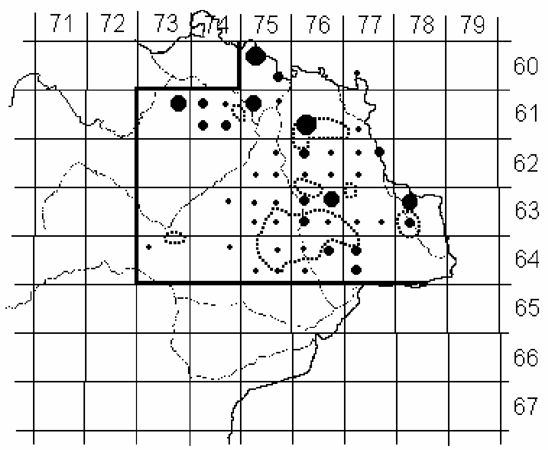


Figure 4.—The infestation caused by Tenthredinids to young spruce forests in the eastern part of the Czech Republic in 2001(dashed line - area of measures) (Holusa and Holusa 2002)

The relationships between catch number and defoliation has yet to be confirmed, however there is another important question that needed to be answered.

3. What number of traps is necessary to ascertain a statistically significant abundance of sawflies?

Method

The traps consisted of yellow plastic boards 14.8 x 21 cm, coated on both sides with entomological glue, that were suspended from the top of trees or from a branch at about 2 m above the ground. They were exposed in lines of 20 boards on the southeastern side of every other tree. All traps were installed in mid April (prior to adult emergence) and kept in place until mid-June (after the end of swarming). The number of localities studied in 2001 and 2002 were 30 and 20 respectively. The localities consisted of young spruce forests in Silesia and eastern Bohemia at an altitude 300 to 500 m a.s.l.

Captured sawfly adults were preserved in 70% alcohol (leg. J. Holusa, coll. VÚLHM Jíloviste-Strnady). Because of the inequality of variance and non-normality (tested using D´Agostino normality test) of the sets in the majority of cases, the Box-Cox transformation on normality was used to represent the mean capture. Correlation and regression analyses were performed with Statistica 6.0 (a = 0.05). The sample size necessary to achieve the desired level of precision in estimating a population mean is given by the following formula (Zar 1984):

$$n = \frac{s^2 t^2_{\alpha(2),(n-1)} F_{\beta(1),(n-1,\nu)}}{d^2}$$

s^2 is the sample variance with n degrees of freedom;
d is the half-width of the desired confidence interval (this accuracy is subjectively chosen until we have used approximately one third of catch mean);
1- α is the confidence level for the confidence interval;
1- β is the assurance that the confidence interval will not be greater than specified;
t- is the two tailed critical value of t-distribution with (n-1) degrees of freedom;
F is the one tailed critical value of F-distribution with (n-1) and n degrees of freedom.

The degree of defoliation was estimated using the same procedures that were deployed in the previous study.

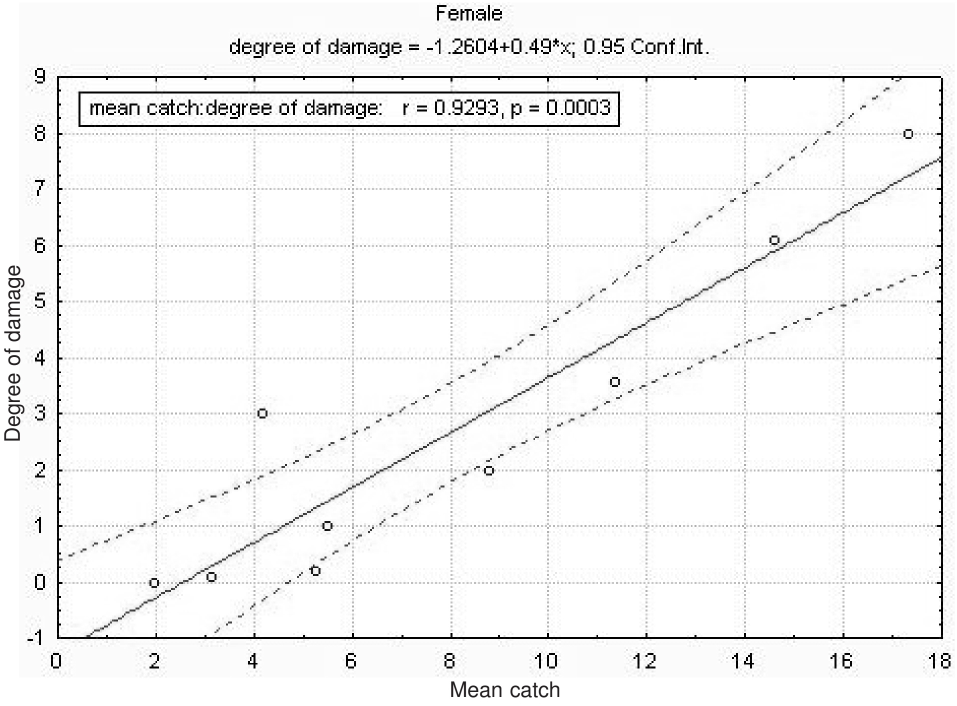


Figure 5.—Relationship between the number of captured *Pristiphora abietina* females and the subsequent defoliation of forest stands (y=-1.2604+0.49x; — confidence interval of model)

Results

We found a highly positive correlation between catch mean of females and subsequent defoliation (Fig. 5) in nine localities in 2002 (The majority of localities were treated chemically therefore they could not be used in the regression). No correlation was found when male sawflies were used.

Based on data on the distribution of females on sticky boards, we have established that from 20 to 40 yellow sticky boards are needed to obtain an accuracy equivalent to one third of the mean. If less efficiency is acceptable, about 20 boards are needed. (Tables 1, 2). In 2001, in the majority of localities, the numbers of females captured were too low for analysis.

Discussion

A positive correlation was found only between the mean catch of females and subsequent defoliation possibly because the distribution of females in forests is more equal, resulting in data sets that are much more homogeneous. This is related to the bionomics and behavior of this species. Female sawflies actively search along the twigs looking for suitable places to oviposit; on the other hand, male sawflies are much more active and vagile and fly around the tops of trees mainly on sunny sites. Therefore the distribution of males is more aggregated. If the defoliation degree of six is critical, about 11 to 19 females would correspond to this value.

Based on the experiments in 2001 and 2002, the number of boards sufficient to obtain an accuracy equivalent to one third of the catch mean varies between 20 and 30. The number varies between 20 and 30 because it depends strongly on the sample variance, which differs from place to place. The use of this number is practical because the time required for the installation of 20 boards is about 30 minutes. Counting the number of captured sawflies depends, of course, on the total number of adults captured and is sometimes time consuming.

Table 1.—Number of yellow sticky boards sufficient for monitoring sawfly abundance in 2001. (A…accuracy, NB…number of boards)

Locality	Longitude; Latitude	Female catch mean ± SD	Transformed female catch mean ± SD	A	NB	A	NB	A	NB
Metylovická hùrka hill	18°21'; 49°37'	4.30±3.05		2	12	1	39		
Paskovský les wood	18°17'; 49°43'	51.20±21.20		35	6	25	9	15	20
Slavíè Mt. Nr. 1	18°35'; 49°34'	6.31±9.74		4	13	3	21		
Slavíè Mt. Nr.2	18°35'; 49°34'	29.00±41.61		15	15	20	29		
Rovná wood	18°41'; 49°38'	64.00±45.57		30	12	20	23	15	38
The village of Pustá Polom Nr. 1	17°58'; 49°51'	21.73±13.55	19.40±12.67	10	10	7	17	5	30
The village of Pustá Polom Nr. 2	18°00'; 49°51'	11.85±21.79	0.60±2.81	10	21	7	40		
Kubalánky place	18°19'; 49°36'	16.11±30.98	0.43±2.27	15	19	12	29	8	60
Stoláøka Mt.	18°19'; 49°36'	3.38±5.15	0.12±0.63	3	14	2.5	20	2	29

Table 2.—Number of yellow sticky boards for monitoring of sawfly abundance in 2002. (A…accuracy, NB…number of boards)

	Longitude; Latitude	Female catch mean ± SD	Transformed female catch mean ± SD	Accuracy - ca 1/3 of mean	NB	A	NB
Kabátice hill	18°16'; 49°39'	3.11±2.7		1.0	21		
Paskovský les wood	18°17'; 49°43'	4.13±4.36	2.83±3.69	1.5	35	2.0	21
Slavíè Mt.	18°35'; 49°34'	3.15±3.53	1.95±2.90	1.2	36	1.7	19
Rovná wood Nr. 1	18°41'; 49°38'	13.16±10.65	10.14±8.34	4.0	30	5.0	20
Rovná wood Nr. 2	18°41'; 49°38'	8.20±5.48		3.0	16		
The village of Pustá Polom Nr. 1	17°58'; 49°51'	12.38±11.80	8.78±8.41	4.0	36	6.0	18
The village of Pustá Polom Nr. 2	18°00'; 49°51'	18.76±15.00	14.61±13.15	6.0	27	8.0	16
The village of Pustá Polom Nr. 3	18°00'; 49°51'	7.14±7.67	5.26±5.86	2.5	37	.5	21
Kubalánky place	18°19'; 49°36'	8.78±9.38	5.51±8.12	3.0	41	4.3	21
Na horách hill	16°09'°; 50°23'	4.15±2.85		1.4	19		
The village of Pøibyslav	16°10'°; 50°22'	25.91±15.76	22.48±13.34	8.0	18		
The village of Brná	16°20'; 50°05'	10.10±8.40	7.63±5.44	3.3	28	4.0	20
The village og Nýdek Nr. 1	18°44'°; 49°39'	17.30±11.24		6.0	16		
The village og Nýdek Nr. 2	18°44'°; 49°40'	1.15±2.43	failed	0.4	145	1.2	19
The village of Nýdek Nr. 3	18°44'°; 49°40'	13.35±11.33	11.33±7.33	4.0	21		

Conclusion

According to these results, we suggest the following model of regulation. Two main criteria are the degree of defoliation and the abundance of adults in the following spring.

Model of regulation

S (step) 1 Monitoring of forest defoliation

> Criterion: If the degree of defoliation exceeds the value 5, go to S2 otherwise continue monitoring of defoliation.

S2 Monitoring of swarming adults next spring

> Criterion: if an average of 15 females or more are caught on yellow sticky boards, go to S3 otherwise continue monitoring of defoliation.

S3 Coincidence of sawfly swarming with spruce budbreak

Cool and rainy weather can directly influence the swarming of adults, or fecundity of females could be decreased by low temperature as reported by Gruppe (1998) for *Cephalcia abietis* (Linnaeus 1758). Both cases resulted in a weaker attack of shoots by larvae. We do not know any exact criterion and the decision is based only on field observations. In the case of high abundance of eggs on shoots, go to S4.

S4 Chemical (biological) measures

There is no effective biological control for *P. abietina* so that only chemical treatments are available. However, there is a possibility of using fungal spores against mature larvae before they fall into the litter (Führer et al. 2001). To eliminate negative impacts on the ecosystem, the following recommendations should be considered:

1. We should prefer using ecdysoid-based insecticides; synthetic pyrethroids should be considered for use only against strong insect infestations. On the foothill of the Moravskoslezske Beskydy Mountains (Czech Republic), three insecticides (Dimilin 48 SC, Mimic 240 LV, Trebon 10 F) were sprayed on 25 ha plots using ULV aerial application. Results from this experiment suggest that ULV aerial applications of both Trebon 10 F and Dimilin 48 SC are effective in protecting stands against sawfly larval feeding (Svestka and Holusa 2000).

2. Chemical treatments should be applied in mid-May when *P. abietina* larvae are in the first to second instars. However, it is very difficult to determine the timing of application. During the period 1997-1999 the forests in the hills (altitudes around 300 m a.s.l.) were sprayed from May 19 to 22 (i .e. the period when the larvae of 1st and 2nd instars are most numerous), stands in the highlands (500 m a.s.l.) about one day later, and stands at an altitude of 700 m a.s.l. until May 26 (Holusa and Svestka 2000) (Fig. 4).

3. Criteria for selecting forests for treatment are as follows:

– Spruce stands should be younger than 40 years, when the impact on height tree increment is most severe. Only very heavily damaged older forest stands should be considered for spraying.

– Prevalence of spruce must be more than 70%, otherwise the percentage of spruce could be eliminated by tending and other planting measures.

– Aerial application should be used to spray only those spruce stands that are larger than 1 ha. However smaller areas must be treated from the ground to prevent the increase and spread of populations to adjacent areas.

In forests situated in broken highlands, it is necessary to use helicopters that can maneuver better under flight speeds of 80 km/hour and therefore provide more precise applications.

Further studies are needed to confirm parameters in the proposed regulation model:

- Confirm the degree of defoliation that influences height current increments of trees.
- Assess the impact of fungal infestation on the incidence of defoliation.
- Confirm the relationship between the number of captured females and defoliation.
- Determine the coincidence of sawfly swarming and budbreak of spruce.
- Determine the impact of low temperatures on female fecundity.
- Establish an economic threshold level (which will be based on a comparison of increment loss and costs of control measures.
- Evaluate the use of fungi for biological control.

References Cited

Battisti, A. and Rodeghiero, M. 1998. Monitoring spruce web-spinning sawflies *Cephalcia* spp.: the correlation between trap catches and soil sampling. Ent. Exp. Appl. 88: 211-217.

Berger, R. 1992. Gelbtafeln: eine Methode zur Kontrolle von Fichtenblattwespen. Mitt. Dtsch. Gesell. allg. angew. ent. 8: 196-200.

Bogenschütz, H. 1986. Monitoring populations of defoliating sawflies in forests of southwest Germany. For. Ecol. Management 15: 23-30.

Cescatti, A. and Battisti, A. 1992. Distribution and ecology of *Lymantria monacha* and *Cephalcia* spp. in non-outbreak areas of Trentino (N-Italy). Anz. Schäd.-Kde Pfl.- Umweltschutz. 65: 92-99.

Führer E., Rosner A., Schmied A. and Wegensteiner R. 2001. Studies on the significance of pathogenic fungi in the population dynamics of the Lesser Spruce Sawfly, *Pristiphora abietina* Christ. (*Hym.*, *Tenthredinidae*). J. Appl. Ent. 125: 235-242.

Gruppe, A. 1998. Influence of genotype and temperature on the fitness of the webspinning sawfly Cephalcia abietis (Hymenoptera: Symphyta, Pamphilidae), pp. 439-440. In: Brunnhofer V. & Soldán T. (eds.): Book of abstracts, VIth Eur. Congr. Ent. Ceské Budejovice, August 23-29, 1998, 760 pp.

Holusa, J. 1999. Bionomie pilatky smrkové (*Hymenoptera:Tenthredinidae*) na severní Morave a ve Slezsku v letech 1998-1999. Zprávy lesnického výzkumu 44: 19-27.

Holusa, J. 2002. Species composition of spruce tenthredinids (*Hymenoptera: Tenthredinidae*) in the eastern part of the Czech Republic. Biologia, Bratislava 57: 213-222.

Holusa, J. and Drápela, K. In press. Yellow sticky boards: a possible way of monitoring the little spruce sawfly (*Pristiphora abietina*) (*Hymenoptera: Tenthredinidae*). J. Appl. Ent.

Holusa, J. and Holusa, O. 2002. Monitoring of sawfly (*Hymenoptera: Tenthredinidae*) infestation on spruce. J. For. Sci. 48: 219-224.

Holusa, J. and Svestka, M. 2000. Pilatka smrková na severovýchodní Morave a ve Slezsku. Výsledky studia bionomie a zkusenosti z obranných zásahu v letech 1997-1999. Lesnická práce 79: 270-272.

Janásek, M. 1964. Ke kontrole pilatky smrkové (*Pristiphora abietina* Christ.). Lesn. Cas. 10: 195-208.

Jensen, T. S. 1988. Phenology and spatial distribution of *Cephalcia* (Hym., Pamphilidae) imagines in a Danish spruce forest. J. Appl. Ent. 106: 402-407.

Larsson S., Björkann, C. and Kidd, N.A. 1993. Outbreak in diprionid sawflies: why some species and not others ? pp. 453-484. In: Wagner M.R. & Raffa K.F. (eds.): Sawfly Life History Adaptations to Woody Plants. Academic Press Inc., San Diego, London, 581 pp.

Liska, J. 1999. Listozravý hmyz, pp. 21-27. In: Kolektiv: Výskyt lesních skodlivých cinitelù v roce 1998 a jejich ocekávaný stav v roce 1999. Zpráv. Ochr. Lesa 1999 (Suppl.): 1-66 pp.

Liska, J. 2000. Listozravý hmyz, pp. 24-31. In: Knízek M. & Kapitola P. (eds.): Výskyt lesních skodlivých cinitelù v roce 1999 a jejich ocekávaný stav v roce 2000. Zpráv. Ochr. Lesa 2000 (Suppl.): 1-45 pp.

Liska, J., Píchová, V., Knízek, M. and Hochmut, R. 1991. Prehled výskytu lesních hmyzích skùdcù v ceských zemích. Lesnický prùvodce 1991 (3): 1-37 pp.

Murhead-Thompson, R.C. 1991. Trap responses of flying insects. The influence of Trap Design on capture Efficiency. Academic press, London, San Diego, New York, Boston, Sydney, Tokyo, Toronto, 288 pp.

Nägeli, W. 1936. Die kleine Fichtenblattwespe. (*Lygaeonematus pini* Retz. = *Nematus abietinus* Christ). Mitt. Schweiz. Anst. forstl. Vers.-Wes 19: 213-381.

Pschorn-Walcher, H. 1982. Unterordnung Symphyta, Pflanzenwespen. In: Schwenke W. (ed.): Die Forstschädlinge Europas 4. Haufflügler und Zweiflügler. Parey, Hamburg, Berlin, 4-234 pp.

Rannert H. and Minneli H. 1961. Uber Zuwachsverluste an Fichten – verursacht durch mehrjahrigen frass der kleinen Fichtenblattwespe (*Pristiphora abietina* Christ) – im Kartner befallsgebiet Wolschartwald. Allg. Forstztg. 72: 167-171.

Svestka, M. and Holusa, J. 2000. Úcinnost letecké aplikace prípravku° Dimilin 48 SC, Mimic 240 LV a Trebon 10 F na housenice pilatky smrkové (*Pristiphora abietina*). Zprávy lesnického výzkumu, 45 (3): 15-29.

Zar J. 1984. Biostatistical analysis. Prentice Hall, New Jersey, 718 pp.

Definition of Spatial Patterns of Bark Beetle *Ips typographus* (L.) Outbreak Spreading in Tatra Mountains (Central Europe), Using GIS

Rastislav Jakuš[1], Wojciech Grodzki[2], Marek Ježík[1], Marcin Jachym[2]

[1]Institute of Forest Ecology, Slovak Academy of Sciences, Zvolen, Slovakia
[2]Forest Research Institute, Kraków, Poland

Abstract

The spread of bark beetle outbreaks in the Tatra Mountains was explored by using both terrestrial and remote sensing techniques. Both approaches have proven to be useful for studying spatial patterns of bark beetle population dynamics. The terrestrial methods were applied on existing forestry databases. Vegetation change analysis (image differentiation), digital elevation model, and stand characteristics have been integrated in the remote sensing part of the study. Results have revealed that the spatial pattern of bark beetle spread depends on the phase of the outbreak and on the insolation (amount of incoming solar radiation) of stands on mountain slopes and, specifically on the bark beetle spots themselves.

Introduction

The Tatra Mountains are located in the Western Carpathians on the border between Slovakia and Poland. The entire area of the Tatra Mountains has been designated as a protected area – comprising two National Parks: Tatrzański Park Narodowy (TPN) in Poland and Tatranský Národný Park (TANAP) in Slovakia.

In 1995-97, a serious outbreak of the spruce bark beetle *Ips typographus* (L.) (Col.: Scolytidae) occurred in the Norway spruce stands of the Tatra Mountains, on both the Polish and Slovak sides of the border (Fig. 1). This insect, recognized as the most serious pest associated with Norway spruce stands, caused dramatic tree mortality in the region of Łysa Polana – Morskie Oko – Tatranská Javorina. On the Polish side, in stands which are under a strict protection regime, mature Norway spruce stands died over large areas; on the Slovak side, where several different forest protection strategies were applied, many entire stands of Norway spruce had to be felled.

Materials and Methods

We used both terrestrial and remote sensing techniques to conduct spatial analyses of the spread of *I. typographus* outbreaks.

Terrestrial Approach

We initiated our research by creating rich databases which contained detailed information about the characteristics of stands and bark beetle populations. Information on site characteristics, stand composition and age, and annual tree mortality during the period 1990-1999 was acquired from the administrative offices of the Tatrzński Park Narodowy (TPN – Poland) and Tatranský Národný Park (TANAP – Slovakia). The smallest units of data that were used in our research consisted of forest sub-compartments. The data concerning tree mortality was transformed into tree mortality indices (TMI) and expressed as the mean volume of infested trees per one hectare in the sub-compartment (m^3/ha). The data were ranked according to a somewhat adjusted scale developed by Capecki (1981), with the following ranges of mortality in m^3/ha: 0.01-0.4 – normal, 0.41-1.2 – premonitory, 1.21-2.4 – intensive, 2.41-10.0 – very intensive, >10.0 – catastrophic.

The digital map with a DTM, covering the research area (Koreň et al. 2002), and the layers concerning tree mortality, were constructed using a vector oriented software ArcView 3.1. The layers on tree mortality (TMI) in successive years were used to produce a visualization of spread of bark

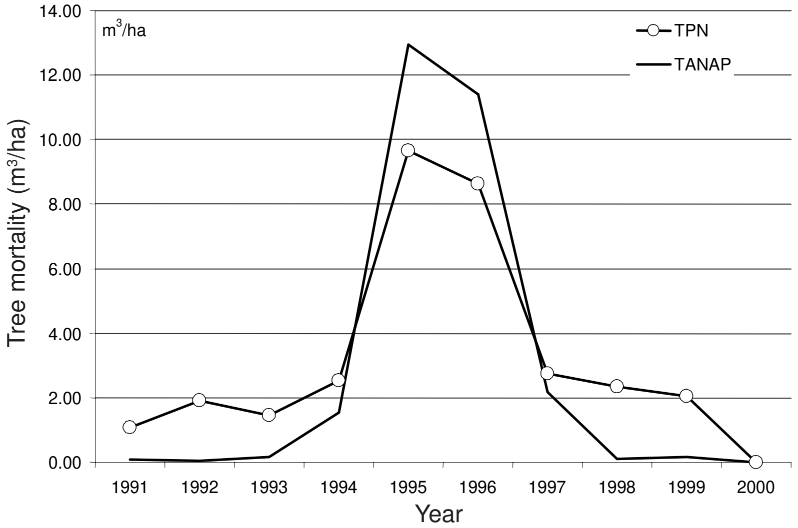


Figure 1.—Intensity of bark beetle outbreaks in the Tatra Mountains expressed through mean tree mortality (m^3/ha) caused by bark beetle attacks in 1991-2000 in Polish (TPN) and Slovak (TANAP) parts of the study area.

beetle outbreaks. The total area of attacked stands, i.e. the area of all sub-compartments with recorded trees attacked by bark beetles in a year, were derived from the database.

Remote Sensing Approach

The time series of LANDSAT images for years 1991, 1993, 1995, 1997, 1999, a digital elevation model, and other GIS data obtained from Koreň et al. (2002), were processed by using by a raster oriented GIS program IDRISI 32.

Identification of Bark Beetle Spots

Based on the summarized data, we prepared a mask of spruce forest cover on the geographical area under study. This mask was used for localization of work to spruce stands. First we tried to identify bark beetle spots on the time series of LANDSAT images with the aid of standard classification methods, however this approach was not successful. Later we used the vegetation change analysis and the method of image differentiation (Eastman et al. 2000). This research was applied during the periods: 1991 - 1993, 1993 - 1995, 1995 - 1997, 1997 - 1999.

The work was intricate, which was caused by the presence of shadows cast within the mountain environment. We tried to resolve this problem by applying an approach which integrated remote sensing and GIS tools. A pilot study comparing areas with cast shadows and areas containing bark beetle spots showed that there was no overlay between these two categories. *I. typographus* did not attack forests that occurred on steep North - oriented slopes (Fig. 3) with cast shadows. This determination allowed us to exclude the areas with cast shadows from our interest in bark beetle spot identification.

The selection of suitable vegetation indices was obtained through our conduct of a special literature review. We selected the following indices: Normalized Difference Vegetation Index, Specific Leaf Area Vegetation Index, Vegetation Condition Index , Greenness Condition Index, and Normalized Ratio Vegetation Index. The change analyses were performed using the maps of all the above vegetation indices. The resultant maps were compared with several forest compartment maps and with the data obtained on bark beetle damage (Fig. 2). Only the Vegetation Condition Index (TM7 / TM4; Jakubauskas, Price 1997) was found to be a usable characteristic. The resultant maps were then compared with aerial infrared photographs of the study area taken by the Research Station of the Tatra National Park in 1999.

Spatial analyses

We used spatial analyses to investigate the processes of spot initiation and spot spreading. Our analyses of vegetation change allowed us to distinguish three phases in the development of bark beetle outbreaks (progradation: 1991 - 1993, 1993 - 1995; culmination: 1995 - 1997; retrogradation 1997 - 1999.)

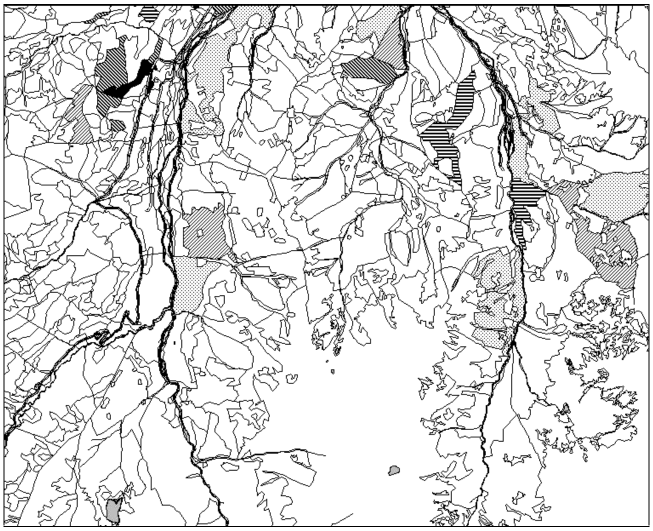
a) Spot initiation: By examining images indicating areas of bark beetle damage, we were able to differentiate between new (initiated in the current year) and old (initiated in any of the previous years) spots, and to calculate the areas of both. We then measured the shortest distances between the new and old spots. The data obtained were transferred into the statistical software STATISTICA for further analyses.

b) Spot spreading: Direction and speed of spreading were calculated for increasing bark beetle spots. The calculations were performed with the use of surface functions (IDRISI) and trigonometry for every pixel of the areas examined. Speed of spreading was measured only on the active (increasing) spots; spots with no expansion were excluded from consideration. Further analyses were performed using raster data at the pixel level, meaning we measured parameters for pixels belonging only to particular spots (one spot could be covered by several pixels). Then the data were subjected to the statistical analyses using STATISTICA software.

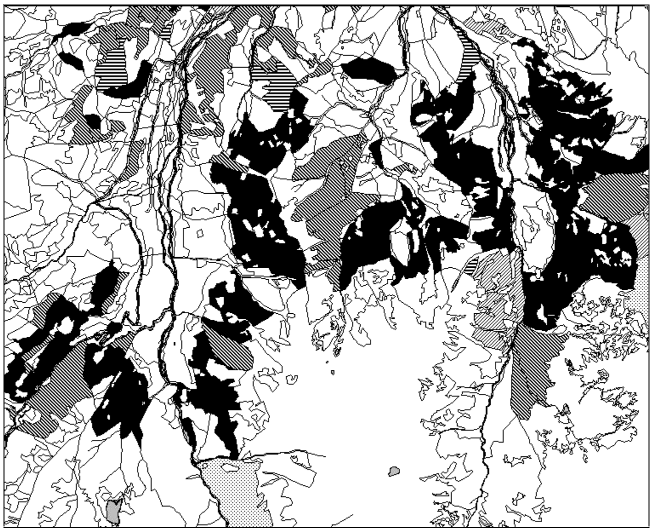
Results

Terrestrial research

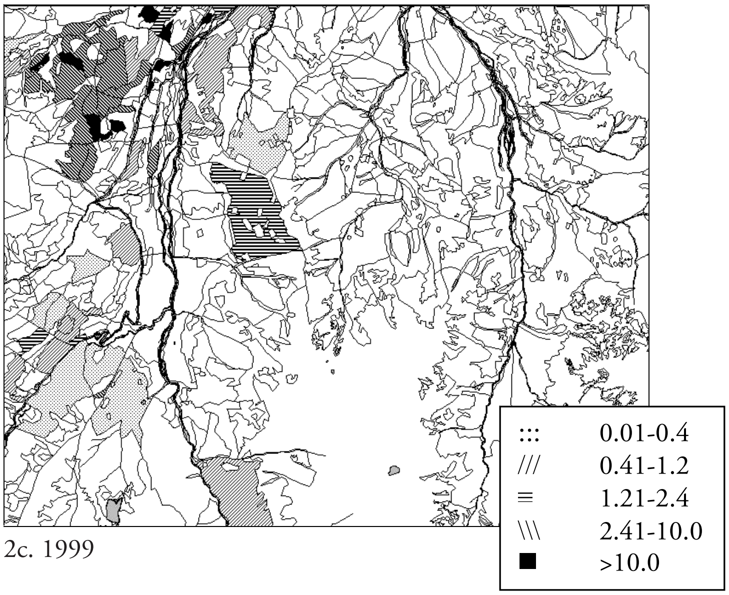
The well-designed and developed database was used for assessing the course of *I. typographus* outbreaks over time on both sides of the state boundary (Table 1). The level of tree mortality remained relatively constant during the entire outbreak period (Spearman's rank correlation r_s=0.91***); however, both the degree of mortality and the area of stands attacked changed more dramatically on the Slovak portion of the area studied, especially during the period 1995-1996 when intensive sanitary cuttings were deployed.



2a. 1991



2b. 1995



2c. 1999

Figure. 2 a-c.—Spatial development of the bark beetle outbreak in the Tatra Mountains in 1991 (a), 1995 (b) and 1999 (c), with the degree of tree mortality (m^3/ha) in the individual forest sub-compartments.

Table 1.—Area (ha) of stands attacked by bark beetles, derived from the database

year	TPN	TANAP
1991	387.92	297.22
1992	544.58	224.30
1993	567.55	364.91
1994	672.80	897.34
1995	712.24	1435.29
1996	816.64	1453.52
1997	727.77	1216.60
1998	768.60	92.02
1999	741.53	306.40

The outbreak began on several sites that were separated geographically and distributed throughout the entire study area (Fig. 2a); during the culmination phase, most of the stands in the entire study area were attacked (Fig. 2b), whereas during the retrogradation phase, attacks receded to certain stands close to the state boundary and to the initial outbreak area (Fig. 2c). The distribution of the most seriously attacked stands based on their exposition is shown in Figure 3. Data on the localization of *I. typographus* spots provided by TPN services and based on terrestrial estimations, and data on the distribution of attacked sub-compartments, had been overlaid on the map with vegetation types. However, the classification of vegetation types currently used in Poland was very simplified as compared to the much more elaborate differentiation of forest vegetation types used in Slovakia. Consequently, use of this classification was possible only in Poland. In the Polish stands attacked by *I. typographus* and belonging to only two forest types (*Abietetum* and *Piceetum tatricum*) occurring in two altitudinal zones (upper and lower mountain zone), we observed no distinct differences in attack intensity related to vegetation type/altitudinal zone.

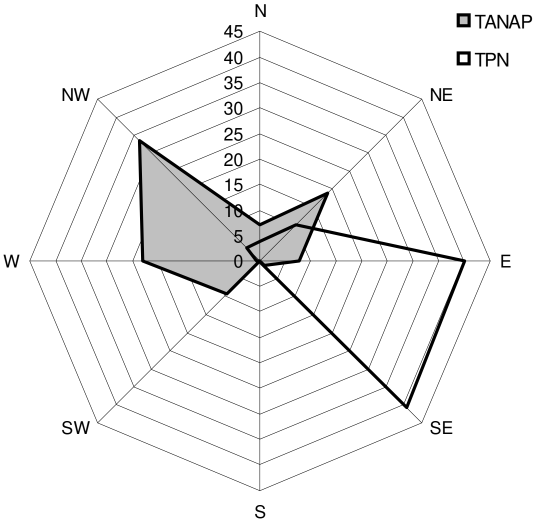


Figure 3.—Distribution of the volume of infested trees (% of total) on mountain slopes in the Slovak (TANAP) and Polish (TPN) parts of the study area.

Remote sensing approach

The map of damage caused by the spread of bark beetle populations is provided in Fig. 4. The comparison between this map and infrared aerial photographs demonstrated that 99% of bark beetle spots visible on the aerial photos had also been identified by vegetation change analysis of the LANDSAT time series. Therefore, the map was used in further analyses.

a) Spot initiation: Spatial analyses have shown that the area of new spots was larger than the area of old spots during the progradation phase (Fig. 5). Incidence of tree mortality was linked mainly with spot initialization. During the culmination and retrogradation phases, the area of new spots was considerably smaller than the area of old spots. In this case, the mortality was caused primarily by the expansion of old spots. The distances between new and old spots decreased during the course of the outbreak (Fig. 6).

b) Spot spreading: The spots were spread in all directions except south (Fig. 7). The speed of active spot spreading increased during the outbreaks (Fig. 8).

Figure 4.—Map of the spread of bark beetle outbreaks based on satellite image analysis

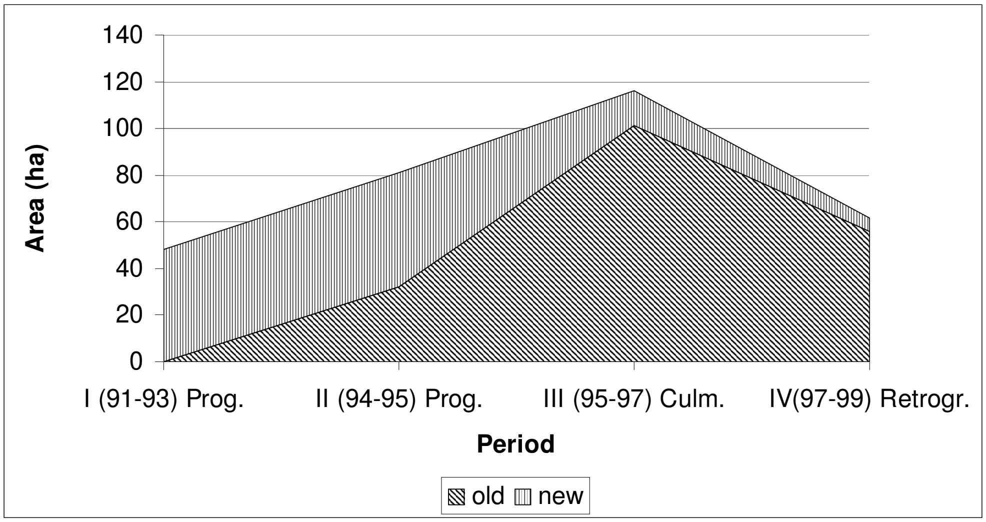


Figure 5.—Area of new and old bark beetle spots in different phases of bark beetle outbreaks

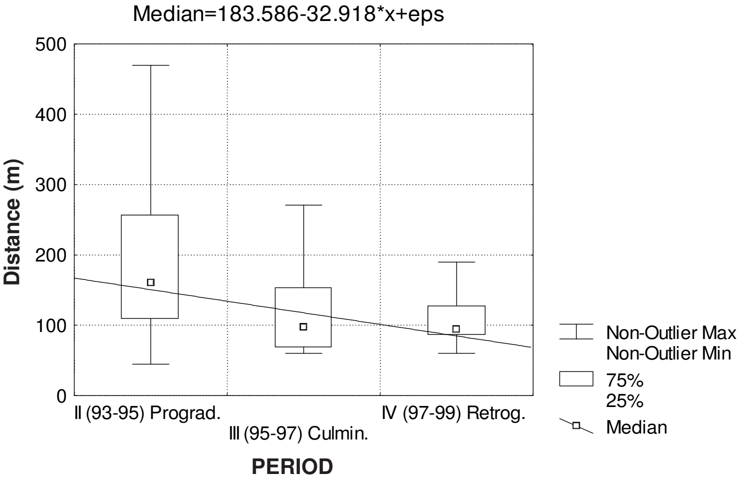
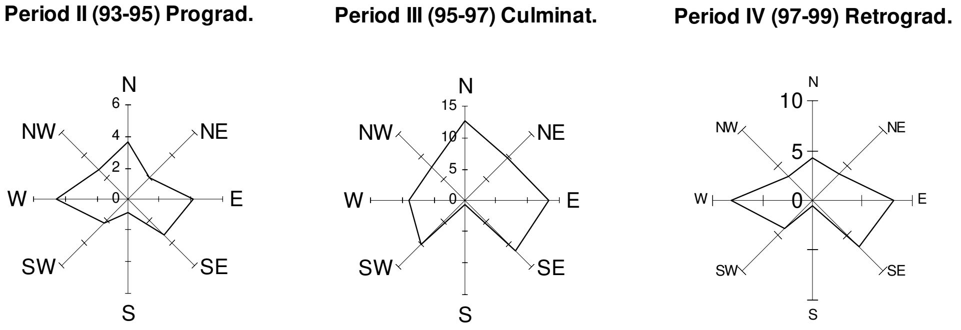


Figure 6.—Minimum distances between new and old spots.


Period II (93-95) Prograd.

Period III (95-97) Culminat.

Period IV (97-99) Retrograd.

Figure 7.—Direction of spread of spots (ha of damaged area).

Discussion

Methodology

Both approaches utilized (terrestrial & remote sensing) have demonstrated their usefulness for studying the spatial dynamics of bark beetle populations. The terrestrial approach can be applied using data acquired through common forestry practices used in both Poland and Slovakia and therefore is relatively inexpensive. Digital maps of forest stands will be made available to foresters in the near future. The main disadvantage of this approach is its low spatial resolution (compartment). The remote sensing approach requires the use of spatial methods for processing satellite images and the availability of digital elevation models and thematic maps. All these technologies are quite expensive, however the remote sensing approach provides a much higher spatial resolution (30 m for LANDSAT images).

A fairly high accuracy in identifying bark beetle spots (about 99%) was achieved by combining information obtained from both LANDSAT images and from the thematic databases. Zemek at al. (1999) achieved 89% accuracy in classifying an area affected by a bark beetle outbreak in the NP Šumava, using classical remote sensing data. We have achieved relatively good results with our method, however it places a higher demand on the quality and quantity of thematic information and time series of LANDSAT images.

The Expansion of Bark Beetle Outbreaks

The general pattern in which *I. typographus* outbreaks spread agrees with descriptions of other authors (Schwerdtfeger 1955, Stolina 1970, Capecki 1978). The distribution of most frequently attacked stands based on their exposure reflects the general distribution of slopes in both parts of the studied area. Nevertheless, attacked stands are distributed more southward and eastward, which agrees with observations of *I. typographus* outbreaks from other mountain areas (Grodzki 1997). Our results have shown that during progradation phase of the outbreak, the spread arises mainly from new bark beetle spots. In the culmination and retrogradation phases, outbreaks spread by further expansion from old spots. Lohberger (1993) revealed that 69% of the spots studied during the period 1988 - 1991 in the NP Bayerischer Wald were spread from old spots while only 6% of spots were attacked only in the first year. Thus, the dominance of continuous growth of spots could be characteristic of *I. typographus* outbreaks and could explain the dominance of old spots that we observed in later outbreak stages in the Tatra Mountains.

We have recorded time-dependence of a decrease in the distances between old and new spots. In the first stage of the outbreak, the beetles migrated over fairly long distances and explored available resources. The area containing stressed trees that were susceptible to being attacked was quite large. In later stages, the available resources were more limited, thus the beetles were more likely to attack only less suitable resources adjacent to old spots. We found that the distances that we measured between old and new attacked spots were similar to those measured by Wichman and Ravn (2001). Otto and Schreiber (2001) recorded almost equal distances between the currently attacked spots and the spots attacked in the preceding years, however, the distances were almost two times further than the

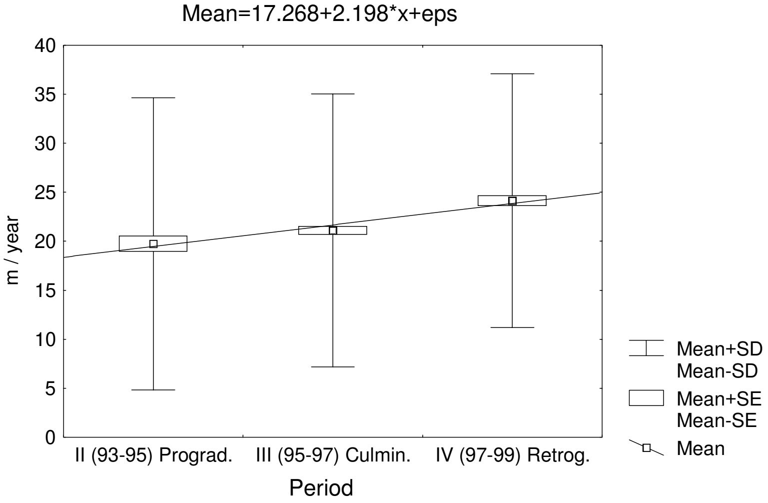


Figure 8.—Speed in which active spots spread.

distances that we measured in the Tatra Mountains Time-dependent differences in distances can be explained by the existence of a lower outbreak intensity, consequently beetles probably had not utilized the majority of the resources available. The aforementioned authors recorded their distances in an outbreak that occurred at lower elevations and under climatic conditions that were optimal for bark beetle development. The outbreak in the Tatra Mountains took place at relatively high elevations and in an area that is not suitable for outbreaks. The smaller distances that we recorded in the Tatra Mountains can be explained by the fact that the outbreak area was characterized by high mountain chains without vegetation that provided a separation between the attacked spots.

The direction in which spots spread was in agreement with Lohberger (1993). Beetles preferred to attack trees at forest edges exposed to solar radiation. According to Schopf and Köhler (1995), the main factor influencing the spread of outbreaks is the stress on trees caused by an abrupt increase in the level of solar radiation. This increase of solar radiation can result from cutting, downing or defoliation of neighboring trees. Trees on forest edges with a northern exposure were not stressed. Thus there were almost no attacks spreading in a southerly direction (that means attacks at forest edges exposed to the North) from initial bark beetle spots.

The increase in the rate of spread of active bark beetle spots during of the course of the outbreak could be explained by the expansion of old spots over time.

Conclusions

1. The spatial pattern of the spread of bark beetle outbreaks is related to the phase of the outbreak, to the insolation (incoming solar radiation) of stands on mountain slopes, and – primarily – the insolation of the individual bark beetle spots.

2. The integration of vegetation change analysis (image differentiation), a digital elevation model, and information about stand characteristics, provides a reliable method that can be used for mapping intensive bark beetle outbreaks in mountainous conditions.

3. These results demonstrate the usefulness of such approaches for conducting research on bark beetle outbreaks in mountain conditions, and for applying forest (nature) protection practices.

Acknowledgments

The research was supported by EU-INCO project: Integrated risk assessment and new pest management technology in ecosystems affected by forest decline and bark beetle outbreaks, and by the Grant Agency for Science of Slovak Academy of Sciences (2/1162/21). The authors wish to thank foresters from both national parks and Eva Lajzová for help with data acquisition and Dr. Kúdelová for correction of the English grammar.

References Cited

Capecki Z. 1978. Badania nad owadami kambio- i ksylofagicznymi rozwijającymi się w górskich lasach świerkowych uszkodzonych przez wiatr i okiść. Prace Inst. Bad. Leśn., 563: 39-117.

Capecki Z. 1981. Zasady prognozowania zagrożenia oraz ochrona górskich lasów świerkowych przed owadami na tle szkód wyrządzanych przez wiatr i okiść. Prace Inst. Bad. Leśn. Nr 584: 3-44.

Eastman, J. R.; McKendry, J. E.; Fulk, M. A. 2000. Change and Time series analysis. (United Nations Institute for Training and Research, Explorations in Geographic Information Systems Technology, Volume 1), Clark University, Worcester, CD.

Grodzki W. 1997. Changes in the occurrence of bark beetles on Norway spruce in a forest decline area in the Sudety Mountains in Poland. Pp 105-11 *in* J.-C. Gregoire, A.M. Liebhold, F.M. Stephen, K.R. Day, and S.M. Salom (Eds.), Proceedings of the IUFRO conference, *Integrating cultural tactics into the management of bark beetles and reforestation pests*, Vallombrosa 1-4 september 1996. USDA, Forest Service General Technical Report NE-236.

Jakubauskas, M. E.; Price, K. P. 1997. Empirical relationship between structural and spectral factors of Yellowstone lodgepole pine forests. Photogrammetric Engineering & Remote Sensing. 63 (12): 1375-1381.

Koreň et al. 2002. Building of a GIS database. In: Integrated risk assessment and new pest management technology in ecosystems affected by forest decline and bark beetle outbreaks. (Final report from INCO-Copernicus European research project).
URL: http://www.vsv.slu.se/schlyter/tatry_pr/tatrypr.htm

Lohberger, E. 1993. Zur Populationsdynamik von *Ips typographus* L. im Nationalpark Bayerischer Wald: Entstehung und Entwicklung von ausgewählten Befallsflächen im Lusengebiet. Diplomarbeit der Forstwissenschaftlichen Fakultät der Ludwig-Maximilians-Universität München. 80 pp.

Otto, L. F.; Schreiber J. 2001. Spatial patterns of the distribution of trees infected by *Ips typographus* (L.) (Coleoptera, Scolytidae) in the National Park „Sächsische Schweiz" from 1996 to 2000. Journal of Forest Science, 47 (Special Issue No. 2): 139 - 142.

Schopf, R.; Köhler, U. 1995. Untersuchungen zur Populationsdynamik der Fichtenborkenkäfer im Nationalpark Bayerischer Wald. In: Biberlriether, H. at al.: 25 Jahre auf dem Weg zum Naturwald. Passavia Druckerei GmbH, Passau, p. 88-109.

Schwerdtfeger, F. 1955. Pathogenese der Borkekäfer-Epidemie 1946 - 1950 in Nordwestdeutschland. Schriftenreihe der Forstlichen Fakultät der Universität Götingen und Mitteilungen der Niedersächsischen Forstlichen Versuchsansstalt. 13/14. 133s.

Stolina, M. 1970. On the problem of indifference of *Ips typographus.* Zborník vedeckých prác Lesníckej fakulty VŠLD vo Zvolene. 12 (3): 61-76. (In Slovak).

Wichmann L., Ravn, H. P. 2001. The spread of *Ips typographus* (L.) (Coleoptera, Scolytidae) attacks following heavy windthrow in Denmark, analysed using GIS. Forest Ecol. Mgmt, 148: 31-39.

Zemek, F., Heřman, M., Klouda, Z. 1999. Bark beetle calamity assessment from remotely sensed data. Silva Gabreta. 3: 191-172.

The Population and Seasonal Dynamics of Weevils Developing in the Soil of Birch Stands

E. Kula

Institute of Forest Ecology, Faculty of Forestry and Wood Technology, Zemědělská 3, 613 00 Brno, Czech Republic, e-mail: kula@mendelu.cz

Abstract

Curculionidae developing in the soil of birch stands in an air-polluted region were classified using the method of soil photoeclectors on the basis of their population dynamics (1986 – 2000) and phenology of their emergence from where they developed. In the course of 15 years we saw two evident culminations in the population density of *Polydrusus undatus,* while the population density of the other species – *Polydrusus (Metallites) impar, Phyllobius arborator, P. argentatus, P. calcaratus, Rhinomias forticornis* and *Strophosoma capitatum* culminated only once*.* We derived the sum of effective temperatures, which characterise the start of activity of a wide range of weevils. Based on the phenology of emerging from where they developed, the dominant species were those weevil species that are active in the spring.

Key words: Curculionidae, weevils, photoeclectors, population and seasonal dynamics, birch stands, *Betula pendula* Roth

Introduction

The Curculionidae, the most abundant family of beetles in the Czech Republic (900), are generally found among the phytophagous fauna of birch stands (*Betula pendula* Roth) (Kula 1990/1991). Their harmful effect in the study region has not yet made itself felt to such an extent as the willow leaf beetle, mottled umber moth and winter moth, miners of the genus *Eriocrania* or the case-bearers (Kula 1988a, 1988b, 1989, 1990a, 1990b, 1995, 1998, 2000; Kula and Vaca 1995). Despite this, they include a number of species whose gradation potential is well known so we cannot exclude the impact of their heavy feeding and clear eating (e.g. of the genus *Phyllobius – P. pyri* L.) on birch trees (Axelsson et al. 1973).

Ioannisiani et al. (1970) indicated that humidity had a dominant effect on the population dynamics of weevils, although the site, stand density, soil quality, degree of coverage of the soil and light conditions are also important factors.

According to Schauermann (1987), the population density of weevils which develop in the soil is generally higher under conditions where moderate acid rain occurs. In heavily polluted localities, birch stands are damaged by *Phyllobius arborator* (Herbst.), *P. calcaratus* (Fabr.) and *P. pyri,* and in the moderately polluted birch stands by *Strophosoma capitatum* (Deg.), which undergoes gradation under these conditions and damages up to 50% of the entire assimilation area (Chlodny 1982, Chlodny and Styfi-Bartkiewicz 1982). These are not, however, the only species that appear as they could be accompanied by other species e.g. *Polydrusus cervinus* L. (Tomkow 1976).

The objective of the present study was to evaluate the population and seasonal dynamics of weevils which develop in the soil of birch stands that occur in the air-polluted regions of the Děčín Sandstone Upland (northern Bohemia). Data were collected in the years 1986 – 2000 using the method of photoeclectors.

Material and Methods

Weevils were collected in six birch stands (*Betula pendula* Roth) in the forest district Sněžník. In 1986 – 2000, we placed seven soil photoeclectors (1 X 1 X 0.3 m) in each of the 5-7 year old stands;

every year in late March they were moved under the projection of crowns of other birch trees. The weevils were collected at seven-day intervals during the entire vegetation period (15 April – 30 October) and were preserved in 75% ethanol.

During the 15 years of our investigations, we used several methods of collection (photoeclectors, ground traps, shaking trees, Moericke's dishes) and collected 41,686 imagoes of 122 species of weevils; using photoeclectors we collected 20,131 weevils of 83 species, of which 16,862 specimens (73 species) were collected in the birch stands. The sum of effective temperatures (SET) applied to evaluate the onset of activity of the weevils was calculated as the sum of positive temperatures from the beginning of the calendar year.

Identification of the weevils was accomplished with the assistance of Dr. O. Majzlan, CSc. from the Faculty of Teaching of Komensky University in Bratislava, Ing. J. Fremuth from Hradec Králové and R. Stejskal from Znojmo.

Description of the Study Area

The forest district Sněžník is a part of the Děčín Sandstone Upland (northern Bohemia, 14°04 E, 50°46 N, number of square of net fauna mapping 5250) which for many years had been exposed to SO_2 concentrations of more than 60 μg/m^3. The region lies in a cold mountain climate (average annual temperature 6°C, average annual precipitation is 800 mm, length of the vegetation period 110 – 120 days, altitude 450 – 700 m), and is currently under a moderate pollutant load. Large areas of spruce stands died in 1979 and were subsequently replaced by stands dominated by birch (*Betula pendula* Roth).

Results

In the study region, the following weevils were the eudominant species: *Polydrusus (Metallites) impar* Des Gozis (10.5%), *P. arborator* (11.7%), *Polydrusus undatus* (Fabr.) (12.7%) and *P. argentatus* (23%). The dominant weevil species were *P. calcaratus* (5.6%), *Rhinomias forticornis* (Boh.) (5.02%) and *S. capitatum* (5.17%). Four species were classified as sub-dominant, i.e. *Barypeithes mollicomus* (Ahrens) (4.79%), *Otiorhynchus (Dorymerus) subdentatus* Bach (3.16%), *Hylobius abietis* (L.) (4.63%) and *Otiorhynchus niger* (Fabr.) (2.39%). The other weevils are recedent (3) and sub-recedent species (111).

Population Density of Weevils in the Soil

The imagos of weevils whose larvae develop in the soil emerge from where they developed during the vegetation period, usually in the spring. The method of soil photoeclectors made it possible to specify the species spectrum of weevils, their abundance, and the population and seasonal dynamics.

In 1986-2000, using the method of photoeclectors placed in the birch stands, we collected 16,862 specimens of 73 species which is 59.8% of all the fauna of the region. Two species of the genus *Phyllobius* (i.e. *P. argentatus* 34.9% and *P. arborator* 15.18%) and the species *P. undatus* (14.81%) were eudominant. Two species, i.e. *P. calcaratus* and *Strophosoma melanogrammum* (Forst.), were dominant (6.71% and 6.48%, respectively). Only two species, i.e. *Otiorhynchus singularis* (L.) (2.61%) and *O. subdentatus* Bach (3.68%), were classified as sub-dominant (Table 1).

Generally 22 weevil species occurred in the soil in the study region. In some places the incidence of some of the sub-recedent species (*B. mollicomus, P. impar, Simo horticornis* Herbst., *Otiorhynchus scaber*) was higher.

P. argentatus was the species most frequently captured in the photoeclectors (5,908). Since 1988, the abundance of individuals leaving emergence sites had increased and culminated in 1993-1996 (21.10 – 32.95 specimens/m^2). After the culmination in 1996, the number of weevils decreased to 1.36 specimens/m^2 and then increased to 7.57 specimens/m^2 in 2000 (Table 1).

Table 1.—Population dynamics of Curculionids in birch stands (1986-2000, photoeclectors, spec/m^2)

Species	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	Sum	%	Avg.
Barypeithes mollicomus (Ahrens, 1812)	0.00	0.00	0.00	0.00	0.07	0.00	0.07	1.40	0.36	0.83	0.55	0.14	0.17	0.07	0.33	168	1.00	0.267
Ceutorhynchus floralis (Paykull, 1792)	0.00	0.00	0.00	0.00	0.07	0.07	2.50	1.05	0.67	0.33	0.02	0.02	0.40	0.00	0.02	217	1.29	0.344
Metallites impar Des Gozis, 1882	0.00	0.00	0.00	0.12	0.02	0.00	0.14	0.24	0.83	0.05	0.36	0.14	0.29	0.12	0.33	111	0.66	0.176
Otiorhynchus niger (Fabricius, 1775)	0.00	0.02	0.07	0.26	0.00	0.62	0.43	0.33	0.19	0.31	0.26	0.00	0.00	0.00	0.02	106	0.63	0.168
Otiorhynchus scaber (Linnaeus, 1758)	0.00	0.00	0.00	0.02	0.02	0.17	0.00	0.45	0.38	0.62	0.33	0.24	0.45	0.60	0.93	177	1.05	0.281
Otiorhynchus singularis (Linnaeus, 1758)	0.00	0.00	0.00	0.00	0.26	0.19	0.40	1.52	0.86	1.26	0.98	0.71	1.81	1.19	1.29	440	2.61	0.698
Otiothynchus subdentatus Bach, 1854	0.02	0.07	0.31	0.60	0.38	1.02	1.36	1.40	1.74	1.40	2.05	1.14	1.31	0.71	1.24	620	3.68	0.984
Phyllobius arborator (Herbst, 1797)	0.05	5.10	1.05	2.26	10.79	5.52	4.67	14.81	8.64	4.17	3.19	0.07	0.10	0.12	0.43	2560	15.18	4.063
Phyllobius argentatus (Linnaeus, 1758)	0,17	1.43	0.00	0.14	0.40	2.76	8.00	21.10	30.79	27.33	32.95	1.36	3.69	2.43	7.57	5885	34.90	9.341
Phyllobius calcaratus (Fabricius, 1792)	0.02	3.19	0.50	2.90	0.12	2.71	4.55	2.17	3.83	1.57	2.10	0.05	0.88	1.00	1.33	1131	6.71	1.795
Polydrusus cervinus (Linnaeus, 1758)	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.10	0.33	1.10	0.95	0.36	0.17	0.10	0.17	140	0.83	0.222
Polydrusus undatus (Fabricius, 1781)	0,00	0.45	1.02	0.62	0.31	1.14	4.48	2.40	7.55	7.52	4.40	0.52	7.43	6.55	15.07	2498	14.81	3.965
Rhinomias forticornis (Boheman, 1843)	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.12	0.17	0.29	0.31	0.02	0.83	0.31	1.12	135	0.80	0.214
Rhynchaenus rusci Herbst, 1795	0.00	0.29	0.57	0.45	0.00	0.00	0.00	0.00	0.50	0.10	0.00	0.02	0.21	0.02	0.29	103	0.61	0.163
Simo hirticornis (Herbst, 1795)	0.00	0.00	0.00	0.07	0.07	0.05	0.02	0.31	1.00	0.93	0.67	0.31	0.79	0.71	0.52	229	1.36	0.363
Strophosoma melanogrammum (Forster, 1771)	0.00	0.02	0.02	0.02	0.00	0.07	0.33	0.71	2.67	2.50	1.14	0.71	1.83	2.88	13.10	1093	6.48	1.735
Tachyerges decoratus Germar, 1827	0.00	0.00	0.00	0.00	0.43	0.24	0.62	0.90	0.00	0.05	0.29	0.00	0.00	0.19	0.00	114	0.68	0.181
Trichapion simile Kirby, 1811	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.19	0.14	0.14	1.69	1.76	1.17	214	1.27	0.34
Total	0.57	11.60	4.21	9.98	13.38	15.14	28.71	50.76	63.55	51.52	54.40	6.48	24.26	20.29	46.62	16862	100	26.77

P. arborator (Herbst) is one of the most abundant species and its population density was very high. The level of abundance increased in 1987 to 5.1 specimens/m^2 and was followed by a decrease; during the three-year interval we saw a culmination of 10.79 specimens/m^2 in 1990 and 14.81 specimens/m^2 in 1993. From 1994 the population density of the weevil in the region decreased to 0.07 – 0.43 specimens/m^2 in 2000 (Table 1).

During the 15 year period, no important culmination levels of *P. calcaratus* (Fabr.) were recorded; the population density ranged between 0.02 and 4.55 specimens.m^{-2}, although it varied irregularly in individual years and its abundance was the highest during the period 1991 – 1994 (2.71 – 4.55 specimens.m^{-2}).

After a balanced and low population density in 1987 – 1991 (0.3 – 1.14 specimens/m^2), *P. undatus* (Rabr.) was the first species to reach the culmination period in 1992 (4.48 specimens/m^2) and in 1994 – 1995 (7.55 specimens/m^2). After a sudden decrease in 1997, we observed a continuous growth to a maximum density of 15.07 specimens.m^{-2} in 2000. This species is a typical representative in birch stands whose population density varies among respective localities.

S. melanogrammum (Forst.) was captured in the photoeclectors only sporadically during the period 1986 – 1991. Its population density was the highest in 1994 – 1995 (2.67 and 2.50 specimens/m^2 respectively) and after two years of recession it culminated at a population density of 13.1 specimens/m^2 (Table 1).

O. singularis (L.) was not captured in the photoeclectors until 1990; in 1993 – 2000 its population density was balanced and ranged between 0.71 and 1.81 specimens/m^2 (Table 1).

O. subdentatus Bach appeared in the study region in each of the 15 years; its population density increased slightly from 1986 to 1996 (0.02 to 2.05 specimens/m^2) and after that its level was balanced (0.71 – 1.31 specimens/m^2) (Table 1).

Seasonal Dynamics of Weevils

In terms of phenology, Schauermann (1973) separated the weevils according to the length of life of the imagos and larval ontogenesis. Based on weevils captured in soil photoeclectors in the Sněžník forest district, we can distinguish species active in the spring with an evident culmination and subsequent disappearance of imagos: *Hylobius abietis* L. (no weevils were reported in the region in the summer due to the limited number of coniferous stands); *Coeliodes rubicundinus* (Herbst.), *Rhynchaenus rusci* (Herbst.), *P. undatus, Anoplus roboris* Suffr., *Tachyerges decoratus* Germ., *Trichapion simile* Kirby, *P. argentatus, P. calcaratus, O. niger* appearing sporadically during the entire vegetation period; weevils active in the summer include *Polydrusus cervinus* (L.), *B. mollicomus, P. impar, P. arborator, Simo hirticornis* Herbst.; weevils active in the autumn (*Acale camelus* Fabr.); and weevils with no evident culmination, but with a changing activity when leaving the soil during the entire vegetation period (*Otiorhynchus singularis* (L.), *O. subdentatus* Bach). In spite of the low population density of *Strophosoma melanogrammum* (Forst.) we can define its appearance in spring and autumn with only a hint of culmination.

Weevils Leaving the Soil Regulated by the Sum of Effective Temperatures

The sum of effective temperatures (SET) differentiates the respective weevil species at the start of their activity on leaving the soil environment. We saw some differentiation also within the framework of genera in species that move up into birch crowns. Ioannisiani et al. (1970) reported that the SET from the egg until the imagoes of *P. arborator* leave the soil was 1929^{o}C but they did not define the individual developmental stages. Based on the results of 15 years of collections using soil photoeclectors, this species can be expected to appear under an average ambient SET temperature of 574^{o}C. *P. argentatus* and *P. calcaratus* began to be active at SET 456^{o}C and 463^{o}C, respectively, and the later activity of *P. clorpus* is expressed as SET 619^{o}C. The population density of *P. pyri* in the soil was not high enough and showed a separate period of activation at SET 255 – 865^{o}C and 1410 –

1981°C. The increased incidence of this species in birch crowns did not correspond with its population density in the soil. Species of the genus *Polydrusus* belong to the early spring species, i.e. *P. undatus* at SET 236°C (109 – 360°C), while a higher SET characterises the species *P. impar* (784°C). A considerably different SET of the species *Acalles camelus* (Fabr.) and *A. commutatus* Dieckmann (480°C and 1832°C) indicated that both hatching and the subsequent activity were disharmonious. Only the spring activity of the species *A. echinatus* (Germar) was derived from the low population density (388°C). Members of the genus *Anoplus* (*A. roboris* Suff. 280°C) and *A. plantaris* Naeyen 293°C) have an identical activity. The imagoes of the species *Barypeithes mollicomus* (Ahrens) have a high SET value (903°C). The early spring species with a low SET value are *Ceutorhynchus floralis* (Paykull) (282°C), *Coeliodinus rubicundus* (Hbst.) (236°C), *Deporaus betulae* (L.) (259°C) and *Otiorhynchus niger* (Fabr.) (296°C).

Discussion

The broad spectrum of weevils that develop in the soil of birch stands no doubt create a potential complex of pests of the root system of plants, but due to the high degree of weed infestation of the stands, they do not present a very grave danger for the root system. However, insect infestation may increase and cause defoliation due to the site conditions, which are particularly favorable for the development of species subsequently moving up into the birch crowns (*Phyllobius, Deporaus, Polydrusus*). Members of the genus *Phyllobius* differed not only in the population density, for instance 23% of the weevil fauna was *P. argentatus*, but also in the start and duration of increased population density in the study region in contrast to *P. arborator* (Kula et al. 2000). With the exception of *P. undatus,* no repeatedly increased population density of weevils appeared in the period 1986 – 2000. In 1997 the incidence of weevils in the soil decreased, and this was confirmed by the limited activity both over the soil surface and in the crown fauna. In Denmark the hatching of the species *Otiorhynchus singularis* takes place from late May to late June (Nielsen 1974), while in Germany the weevils hatch continuously from April to October and their culmination is quite evident in May and June (Grimm 1973). The period of hatching in the investigated area corresponded with the data of Grimm (1973), only the culmination was not so evident. The year-round activity with no culmination from mid-April to mid-September was confirmed when we used ground traps (Kula et al. 2000). Spring activity is associated with a relatively low sum of effective temperatures (338°C). Nielsen (1974) explained the phenology of the incidence of weevils and stated that *P. argentatus* adults made their appearance in late April and early May when the temperature of the soil at a depth of 3 cm is 7-9°C. According to Schauermann (1973) activity does not begin until late May to early July at a soil temperature of 8°C. The defined shift in the appearance of *P. arborator* corresponds with data of Urban (1998). The sum of effective ambient air temperatures defined for the weevil fauna in birch stands (Kula et al. 2000) contributes to their control and to prognoses of their incidence.

Conclusion

The weevil fauna (73 species) developing in the soil of birch stands in the air-polluted region included important phytophagous insects of the genera *Phyllobius, Deporaus and Polydrusus*, which damage the assimilation area of birch trees. The population dynamics (1986 – 2000) indicated that, with the exception of *P. undatus,* the periodicity of increased population density was greater than five years. Based on the sum of effective ambient air temperatures, which characterizes the initiation of weevil activity, we can derive a prognosis of the culmination of weevil incidence in spite of minor differences due to the discordant development of the larvae.

Acknowledgments

This study was supported with the grant research project No. 308/98:434100005 from the Ministry of Education and VaV/830/3/00 funded by Ministry of Environment of the Czech Republic and by the following firms and companies: SCA Packaging ČR s.r.o. in Jílové, Netex and Alcan Děčín Extrusions s.r.o. in Děčín, District Offices in Děčín, Setuza in Ústí nad Labem, CEZ a.s. Prag, Čižkovice Lafarge Cement Works, North-Bohemian Mines in Chomutov, Dieter Bussmann in Ústí nad Labem.

Literature Cited

Axelsson B, Larsson S., Lohm U., Persson T. 1973. Production of larvae of *Phyllobius piri* L. (Col., *Curculionidae*) in an abandoned field. Ent. scand., 4: 21-29.

Chlodný J. 1982. Uwagi o zagrozeniu przez szkodliwe owady drzewostanów i zadrzewien GOP w latach 1976-1980. Sylwan, 5: 19-26.

Chlodny J., Styfi-Bartkiewicz B. 1982. Oddzialywanie skazen przemyslowych na zageszczenie populacji owadów zasiedlajacych mlodniki brzozy brodawkowatej (*Betula verrucosa* Ehrh.). Sylwan, 4: 31-39.

Ioannisiani T.G., Lavrova N.K., Birg A.V., 1970. Ecological peculiarities of some species of the genus *Phyllobius* Germ. (Coleoptera, Curculionidae) from Byelorussia. Ent. Obozrenye, 49 (4): 800-809.

Kula E. 1988a. Hledisko ochrany v náhradních porostech břízy. Les. práce, 8: 362 - 367.

Kula E. 1988b. The willow leaf beetle (*Lochmaea capreae* L.) in birch stands. Acta univ. agric., 1-4: 261-307.

Kula E. 1989. Bázlivec vrbový na bříze. Les. práce, 2: 68 - 71.

Kula E. 1990a. Bedrohung der Birkenbestände mit Gelben Weidenblatkäfer (*Lochmaea capreae* L.). Wissenschaft Theorie und Praxis, Kolloquium Tharandt-Brno „Ökologie von Schlagflächen und ihre Weideraufforstung im Immissionsschadgebiet des Erzgebirges“, Neuhausen, 21.-23.9. 1990, p. 192-199.

Kula E. 1990b. Bázlivec vrbový (*Lochmaea capreae* L.). Folia, řada B, 64 pp.

Kula E. 1990/1991. The weevil beetles (*Curculionidae, Coleopter*a) in birch stands. Acta univ. agric., řada C, No. 1-4: 5-17.

Kula, E. 1995. Notes on bionomy and control of case-bearer (*Coleophora serratella* L.). Mitt. Dtsch. Ges. allg. angew. Ent. 10: 83 - 86.

Kula, E. 1998. Crown fauna of birch stand caterpillars in a pollution area and their population dynamics. In: M.L. McManus and A.M. Liebhold (eds.) Proc. „Population Dynamics Impacts, and Integrated Management of Forest Defoliating Insects. USDA Forest Service General Technicial Report NE-247: 303-310.

Kula, E. 2000. Minovači rodu Eriocrania škůdci břízy s gradačním potenciálem. J. For. Sci. 46 (1): 27-33.

Kula, E., Vaca, D. 1995. Pouzdrovníček stromový (*Coleophora serratella*) v porostech břízy imisní oblasti. Les - Lesnická práce, 10: 12-13.

Schauermann J. 1987. Tiergesellschaften der Wälder im Solling unter dem Einfluss von Luftschadenstoffen und künstlichem Säure- und Düngereintra. Verhandlungen der Gesellschaft für Ökologie (Giessen 1986), Band XVI: 53-62.

Tomkow M.J. 1976. Entomofauna olszy szarej i czarnej (*Alnus incana* Mnch. i *Alnus glutinosa* Gaertn.) na uprawach lesnych zakladanych w ramach przebudowy drzewostanow pozostajacych pod wplywem emisji przemyslowych. Ent. a ochrona srodowiska, (Wisla Uzdrowisko10-12.X.): 53-58.

Spread and Character of *Tomostethus nigritus* F. Outbreaks in Croatia During the Last Decade

Dinka Matošević[1], Boris Hrašovec[2] and Milan Pernek[1]

[1]Forest Research Institute, Jastrebarsko, Croatia
[2]Faculty of Forestry, University of Zagreb, Croatia

Abstract

The larvae of *Tomostethus nigritus* F. (Hym.: Tenthredinidae) began causing severe defoliation on ash along avenues and tree lines in Zagreb, Croatia since 1997. The phenomenon of population outbreaks in periurban and urban environments is known but poorly documented in the literature; the fact that it has not yet been recorded in Croatian forests has spurred authors to investigate further into this natural event. Populations achieved outbreak levels in the second year after defoliation was first recorded. Although only *Fraxinus excelsior* L. was attacked; palatability tests indicate that larvae show no preference among several ash species, larval development *in situ* and their dispersion in the field suggest that phenology of the host tree was the dominant factor in host selection. Based on foliage availability, *F. excelsior* proved to be the most suitable species for females during their oviposition period. Detailed study of all developmental stages, especially the late larval and prepupal stages, confirmed earlier published knowledge on this sawfly but provided also some new facts and practical solutions that can be utilized for monitoring and managing this species. Parasitoid fauna have also been studied and, despite the relatively small impact that was recorded from laboratory rearings, it is assumed that parasitoids and floods are the most important natural controlling factors affecting this species in forests. Based on the spread and intensity of the recent outbreak and its similarity to European outbreaks, we presume that environmental factors, mainly the impact of late fall and early spring floods, are the most important trigger mechanism involved in this phenomenon.

Introduction

In terms of their ecological and economic value, the lowland forests of pedunculate oak (*Quercus robur* L.), narrow leaved ash (*Fraxinus angustifolia* Vahl), and several other hardwood species are the most valuable components of forests in Croatia. Based on the tree species composition and forest structure, these forests are natural or very close to natural as is the fauna that thrives in them. Common ash (*Fraxinus excelsior* L.) grows on drier and higher sites, and along with *F. pennsylvanica* Marshall is commonly planted as an amenity tree. Periodic outbreaks of common forest pests are well monitored in the area so the first dramatic signs of ash defoliating caused by *T. nigritus* aroused interest among forest entomologists who were concerned about the threat it could pose to these valuable tree species.

After the initial taxonomic problem due to absence of adult stages, it was identified as *T. nigritu*s F. (Hym.: Tenthredinidae). It was first detected on *F. excelsior* planted along an avenue in Zagreb, Croatia in 1997 and has not appeared in forest stands as was the case in some European countries (Liška 2000, Holuša pers. comm.). Mrkva (1965) reported that it completely defoliated up to 50 ha of mixed or pure ash stands while Liška (2000) and Liška and Holuša (2001) reported that *T. nigritus* defoliated almost 800 ha of mixed and pure ash stands during the years 1999 and 2000. However, Austara (1991) and Hrašovec and Diminić (2000) documented that this species occurs in urban areas. In a recent faunal review of Croation sawflies Perović and Leiner (1991) include this species in the checklist with available loci occurring in only a part of the country. As noted in some older European works (Escherich 1942, Mrkva 1965) *T. nigritus* is a widely distributed Euroasian species which occurs at very low densities and occasionally reaches higher population levels.

Our research on this species was stimulated by the occurrence of new outbreak loci in urban areas and by some reports that a similar pest was causing serious damage on ash species in forest and periurban stands in northern Italy (Stergulc, pers. comm.) The main goal of our research was to devise monitoring techniques, possibly predict population trends, determine why outbreaks were initiated in urban habitats, and to test available suppression methods in the urban environment.

Material and Methods

The biology and development of the sawfly was studied both in the laboratory and in the field. In order to monitor closely some details of embryonic, larval and prepupal development, freshly laid eggs, larvae and cocooned eonymphs and pronymphs were brought to the laboratory and reared under various ambient conditions.

In the laboratory, palatability tests were conducted whereby young leaves of three ash species, *F. excelsior, F. angustifolia* and *F. pennsylvanica* were offered to young larvae of *T. nigritus* in *petri* dishes (20 larvae/dish); leaves were changed daily. A total of 100 larvae were reared on each tree species. The same trial was conducted in larger insectariums where 100 larvae were reared collectively on foliage of each of the three ash species. *F. angustifolia* was included in this experiment because of the relative importance of this species; *F. pennsylvanica* was chosen because it was obviously not being attacked in the area of massive outbreak, whereas *F. excelsior,* the most severely attacked ash species in the field, served a s a control.

Laboratory and field trials were conducted on various larval stages using applications of four chemical pesticides (two IGR products, a pyrethroid, and neem oil) in order to determine the most appropriate method of suppressing this pest in urban and possibly forest environments.

The incidence of parasitism and species involved were checked in the field and by rearing various developmental stages but mainly the cocooned eonymphs or pronymphs. One hundred earthen cocoons were collected during February 2002 and placed in glass vials. After parasitoids emerged, the rest of the apparently non-parasitized cocoons were dissected to determine the occurrence of other possible mortality causing factors. Also, insect nets were used to capture the massive swarming of parasitoids that occurred in the ash crowns during the peak of larval feeding.

Results

Most of the findings of Mrkva (1965) regarding the biology and development of *T. nigritus* were verified by our research. There are expected differences regarding phenology since in our climate, the adults started swarming much earlier and larval feeding peaked and was completed by the beginning of May throughout our period of monitoring. This is approximately one month earlier than what was reported in central Europe. In Croatia we consider that *T. nigritus* is a monophagous species because *F. excelsior* is the only species of ash with which it is synchronous phenologically; the perfectly conditioned leaves of *F. excelsior* are attractive to the swarm of *T. nigritus* and to the females which oviposit on the margins of newly emerged foliage. Both visual and chemical clues could be involved in the selection of oviposition sites by female sawflies.

We made observations on larval development and conducted morphmetric studies to determine the number of larval instars. Color of the larva changes through its development. First instar larva, whitish or almost hyaline, during eclosion emerges from the swollen chamber on the leaf margin, and molts soon after into the second larval instar which has a greenish cast as the gut fills with leaf chloroplasts. Later instars become more light green with even light coloured ventral parts. The most conspicuous change happens after the last larval molt when larva changes to an olive green color just before descending from the tree and prior to spinning its cocoon. Dynamics of defoliation is typical and quite dramatic as the developing larvae consume proportionately more foliage; what appears initially as a moderate episode of defoliation becomes total defoliation over a period of several days. Under these conditions, a large number of larvae are often unable to complete their development and die due to starvation. It is interesting to note that even under these conditions, larvae would not disperse and feed upon the foliage of nearby *F. pennsylvanica*.

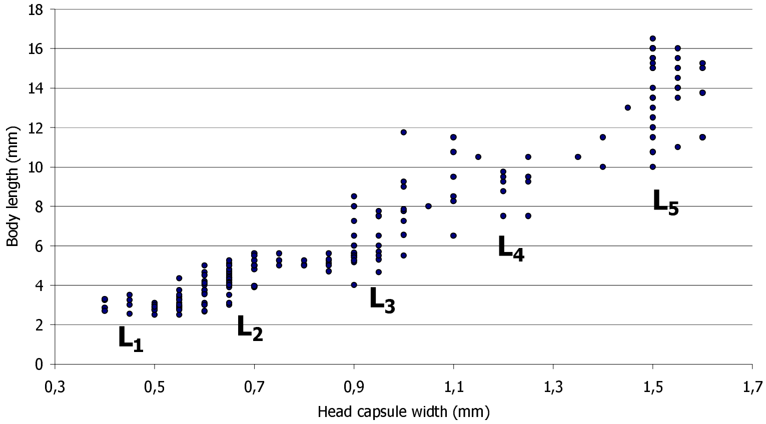


Figure 1.—Body length and head capsule width of 199 selected *T. nigritus* larvae.

A plot of the measurements of head capsule width and larval length indicate that there are five distinctive larval instars (Fig. 1). In this research we did not distinguish between male and female developing larvae as Mrkva did (1965), nor are we certain that he included the measurement of the last descending instar in his study. The head capsule widths for the 5th larval instar in Mrkva (1965) vary between 1.87 and 2.06 mm which is clearly larger than our results for the last feeding instar, therefore there is a need for additional measurements in order to clarify the description of larval instars.

The last larval instar observed (in this study it was referred to as the 5th larval instar), olive green in colour, stops feeding, descends the trunk and enters the soil. Larvae don't go too deep into the soil which, in our study site was a compacted managed grassland. As described by Mrkva (1965), they concentrate in the vicinity of the root collar and form shiny, black parchment-like cocoons covered on the outside with earth. They transform into enonymphs and most of them later become pronymphs. Pupae were found by mid March and adult emergence began in late March and early April. The period of massive swarming varied from year to year but usually peaked in mid April.

Palatability tests indicated that there were no preferences among the three ash species tested and that all larvae reared in both series of tests devoured the foliage and completed their development successfully. It should be noted however that because of difficulties in obtaining the first instar larva, only second and partially third larval instars were collected and fed. Mortality of reared larvae could not be observed.

Beginning in 1998, laboratory and field trials were conducted in order to determine the best possible way of suppressing *T. nigritus* populations with chemical pesticides. All tests conduced under laboratory conditions gave satisfactory results and results differed only in the time lag between the application of the products and first symptoms of larval intoxication. Four commercially available chemicals were tested: NOMOLT SC (a.s.teflubenzuron 150 g/l), BONUS SC (a.s.alphacypermethrin/teflubenzuron 40/120 g/l), SOxJA (neem oil) and FASTAC SC (a.s.alphacypermethrin 100g/l) which was used as the control. Based on operational success, market availability, and legislative restrictions on the use of chemical treatments in urban areas, we selected NOMOLT SC for field use and since 1998 it has been applied annually. The success of the applications has varied. It was influenced by the efficiency of the equipment, in terms of good crown coverage and droplet distribution, and correct timing of application. In the context of this research the applications are considered as additional impact factors which obscured the otherwise more natural dynamics of the population.

On February 21, 2002, 100 cocoons were collected in the field and placed individually into glass vials. After a period of three month, they were dissected and provided the following results: 57 cocoons were empty of filled with earth, 19 cocoons were parasitized, 8 contained live enonymphs or pronymphs and 16 contained dead and dried enonymphs (due to fungi and other unidentified causes). The parasitism rate, calculated on the basis of 43 cocoons bearing either dead or live sawfly or parasitoids was 44%. All emerged parasitoids belong to the Ichneumonoidea and are not yet identified. Taxonomic identification of the parasitoids collected in earlier years (netted during swarming in the crowns) is still in the progress, however preliminary results revealed that two ichneumonids, *Synoecetes* sp. Főrster and *Ctenopelma* sp. Holmgren were most numerous; less numerous were other ichneumonids belonging to the subfamily Ctenopelmatinae and three species of braconids.

Discussion

Information on the biology of *T. nigritus* combined with the results of the palatability tests so far, support our suggestion that this sawfly can be regarded as a monophagous pest of *F. excelsior* in Croatia. For this research, it was important to determine if *T. nigritus* larvae feed equally well on *F. angustifolia*. Narrow leaved ash is an important tree species in valuable lowland forests in Croatia and the threat of defoliation by *T. nigritus* could pose a serious threat. Though larvae reared in the laboratory fed well on all three ash species the situation was markedly different in the field. The most important determining factor based on our observations was the synchrony in phenology of the insect with that of its candidate host plant. Successful oviposition was critically dependant on the availability of emerging foliage. At the time of adult eclosion and later swarming, only the *F. excelsior* trees provided foliage at the required development stage. Even within the same tree species, there was a significant variation in individual phenology which resulted in variation in the oviposition rates and subsequent defoliation. It is suggested that the pronounced variation in tree phenology within the same ash species is caused by the induced effect of the prior years defolition. We observed that trees which were totally defoliated in previous years leafed later in the following year. Other ash trees that occurred in proximity to the attacked *F. excelsior* trees were left almost untouched. Although we are not sure of the different scenarios that may exist in other locations, in the area where the outbreak took place during the past 6 years, only *F. excelsior* was affected. It is still possible that *T. nigritus* could successfully thrive on *F. angustiflia* at other locations but in that case some other suppressive factors might be involved in keeping the insect population at low levels.

Regarding the spatial and temporal distribution of larval stages and postembryonic development, it is of practical interest to note that it is quite common to have almost all larval instars present at the same locality at the same time. This is due to the intraspecies diversity in tree phenology. This complicates the timing of application of suppression tactics and is the most important factor that contributes to inconsistent results of the treatments. Early appearance of the egg laying females and insufficient leaf area available for spray deposits also contribute to application problems. Among the chemicals tested, both IGR compounds appeared to be effective however the treatments had little impact on the ongoing outbreak and complicated interpretation of the research data. Investigation of the parasitoid community was expected to reveal some clues into the regulation of *T. nigritus* specifically what causes the decline in populations. However the parasitism rates were not as high as was reported by Mrkva (1965). He reported parasitism rates as high as 80% and stated that even a 20% rate was considered as adequate to cause the population decline and eliminate the need for spraying. The parasitism rate obtained in our monitored population was less than 50% and this level did not seem to have any effect on sawfly populations. It's very possible that repetitive chemical treatments had detrimental effects on the parasitoid community. At the same time, ineffective treatments only partially reduced *T. nigritus* populations which might have contributed to the continuation of the outbreak itself (Speight and Wainhouse 1989).

Although flooding was not a regulating factor in our study site, it has been documented to be an important factor by other authors (Mrkva 1965, Liška 2000, Liška and Holuša 2001). In all described cases of *T. nigritus* outbreaks occurring in forests, one thing was common-they were al semi-natural or natural forest types located in riparian zones. In the undisturbed and periodically flooded forests of this type, it is normal to have at least two flood seasons-late fall to winter and in the spring. Species of *Fraxinus* are naturally accustomed to this excessive surface water and thrive well in these conditions. It is also known that the floods can have a negative impact on some populations of forest arthropods that occur in the soil or litter including some serious forest pests (Schowalter 2000). Excessive moisture in the soil during a portion of the year could heighten the impact of pathogenic fungi thus enhancing the mortality of arthropod populations. Presumably, the high levels of flood water during adult emergence in spring could also serve as a source of mortality; all of these parameters might have a significant role in regulating some other pest populations in these forests (Hrašovec 1993). Competitive adaptation is a mechanism that enables insect populations to escape the niche during the flood period through its adaptive biology (as is the case with another tenthredinid sawfly, *Apethymus filiformis* Klug). Absence of floods in these habitats might alter the existing equilibrium and, in the case of *T. nigritus* populations, could be the triggering mechanism for outbreaks.

In conclusion we emphasize that we lack considerable knowledge about population dynamics of this sawfly, especially the role of natural enemies. The fact that it rarely (if ever) occurs in Croatian forest habitats and thrives obscurely at low population levels, hinders the pace of research. Additional studies of the dynamics of the natural populations will be needed in order for us to assess the potential threat of this sawfly on Croatian forests.

Acknowledgments

We would like to thank Franjo Perović, Croatian Natural History Museum in Zagreb, for his help during taxonomic validation of the *T. nigritus*, Csaba Thuroczy, Systematic Parasitoid Laboratory in Koszeg, for his help in parasitoid identification, Jaroslav Holuša, Forestry and Game Management Research Institute in Jíloviště-Strnady, on supplying the valuable literature references, and Suzana Videc, for her valued contribution in the field and laboratory work.

References Cited

Austara, O. 1991. Severe outbreaks of the ash sawfly *Tomostethus nigritus* F. (Hymenoptera, Tenthredinidae) on ornamental trees in Oslo. Anzeiger für Schadlingskunde, Pflanzenschutz und Umweltschutz 64 (4): 70-72.

Escherich, K. 1942. Die Forstinsekten Mitteleuropas. Bd. 5, Paul Parey Verlag, Berlin.

Hrašovec, B. 1993. Prilog poznavanju bioekologije insekata iz roda *Balaninus* Germ., štetnikažira hrasta lužnjaka (*Quercus robur* L.). Glasnik za šumske pokuse 29: 1-38.

Hrašovec, B. and D. Diminić. 2000. Pests and diseases of trees in continental urban areas in Croatia – current status and future trends. In: International Symposium on Plant Health in Urban Horticulture; Braunschweig, Germany, May 22-May 25 2000, Mitteilungen aus der Biologischen Bundesanstalt für Land- und Forstwirtschaft, Heft 370: 63-68.

Liška, J. 2000. Listožravý hmyz, pp.24-31. In M. Knížek and P. Kapitola [eds.], Výskyt lesních škodlivých činitelů v České republice v roce 1999 a jejich oekávaný stav v roce 2000. Zpravodaj ochrany lesa 2000 (suplementum): 1-62.

Liška, J. and J. Holuša. 2001. Listožravý hmyz, pp.28-38. In P. Kapitola and M. Kní•ek [eds.], Výskyt lesních škodlivých činitelo v České republice v roce 2000 a jejich očekávaný stav v roce 2001. Zpravodaj ochrany lesa 2000 (suplementum): 1-74.

Mrkva, R. 1965. Prispevek k morfologii, bionomii a poznani parazitu pilatky jasanove (*Tomostethus nigritus* F.). Prace vyzkumnych ustavu lesnickych, ČSSR, svazek 30, Zbraslav-Strnady: 35-64.

Perovič, F. and S. Leiner. 1996. Index of the Sawflies Sensu lato (Hymenoptera, Symphyta) of Croatia. Natura Croatica 5(4): 359-381.

Schowalter, T. D. 2000. Insect Ecology – an Ecosystem Approach. Academic Press. San Diego.

Speight, M. R. and D. Wainhouse. 1989. Ecology and Management of Forest Insects. Clarendon Press, Oxford.

Microsporidian Pathogens in European Gypsy Moth Populations

Michael L. McManus[1]*and Leellen Solter*[2]

[1]United States Department of Agriculture, Forest Service, Northeastern Center for Forest Health Research, 51 Mill Pond Rd., Hamden, CT USA

[2]Center for Economic Entomology, Illinois Natural History Survey, 607 E. Peabody Dr., Champaign, IL USA

Abstract

The significance of microsporidian pathogens as mortality agents of gypsy moth (*Lymantria dispar* L.) in Europe frequently is overlooked. Collections of isolates from 10 different countries suggest that three genera and several biotypes are extant. It is important that the taxonomic placement and phylogeny of currently described genera and species be clarified and that regulatory issues be addressed before exotic entomopathogens are introduced into North America to regulate *L. dispar* populations.

Introduction

Microsporidia are a diverse group of obligate intracellular parasites that use most animals and humans as hosts. They are among the oldest eukaryotes and have many primitive yet uncommon and complex characteristics. At the molecular level, they possess a ribosomal RNA structure that is thought to be more prokaryotic than eukaryotic. Microsporidia have no mitochondria and undergo a primitive nuclear division (Vossbrinck et al. 1987), though sequence analysis of several microsporidian genes suggest that they are fungi (Weiss et al. 1999; Van de Peer et al. 2000).

Microsporidia were elevated to the phylum Microspora by Sprague (1977) and amended to the Phylum Microsporidia by Sprague and Becnel (1999). According to Larsson (1999), about 1,300 species have been described but a substantial number of identified genera and species have not been studied or named. The genus *Microsporidium* was introduced by Sprague (1977) as a temporary designation for species that have been excluded from other genera and are awaiting proper taxonomic classification based on new information.

The taxonomy of microsporidia—specifically, their identification in field collections—has been hampered by their size (typically 2-10m) and because few species have been described adequately and placed in appropriate genera (Larsson 1999). It is estimated that about half of microsporidian genera contain only a single species. The advent of electron microscopy and recent advances in molecular technology have improved the systematics of microsporidia but also raised questions about the taxonomic placement and phylogeny of currently described genera and species.

According to Maddox et al. (1999), six species of microsporidia have been described from gypsy moth populations in Europe, and several isolates that have not been described or identified are recorded in the literature. Despite a rich microsporidian complex in European gypsy moth populations, microsporidia have not been reported from gypsy moth populations in North America (McManus et al. 1989). Table 1 is an updated version of the information provided initially by Maddox et al. (1999).

Of the listed species, probably only *N. lymantriae* (Weiser 1957) and *N. serbica* (Weiser 1964, Pilarska and Vavra 1991) satisfy the diagnostic criteria defined by the International Code of Zoological Nomenclature (1985) for describing a new taxon. With respect to the identification of the other species, it should be noted that ultrastructural and molecular information was not available to the authors at the time these microsporidia were described as new species

Table 1.—Microsporidia Described or Reported from European Gypsy Moths[a]

Microsporidian species	Location	Reference
Nosema lymantriae	Czechoslovakia	Weiser (1957)[b]
Nosema muscularis	Czechoslovakia	Weiser (1957)[b]
Nosema muscularis	Spain	Romanyk (1966)
Nosema muscularis	USSR, Ukraine	Zelinskaya (1980)
Nosema serbica	Yugoslavia	Weiser (1964)
Nosema serbica	USSR, Ukraine	Zelinskaya (1981)
Nosema serbica	Bulgaria	Pilarska and Vavra (1991)
Thelohania disparis	Russia	Timofejeva (1956)
Thelohania similis	Czechoslovakia	Weiser (1957)[b]
Nosema portugal	Portugal	Maddox et al. (1999)[b]
Nosema sp.	Portugal	Cabral (1977)
Nosema sp.	Yugoslavia	Sidor (1979)
Nosema sp.	Romania	Saftoiu et al. (1978
Endoreticulatus	Portugal, Bulgaria, Hungary	Solter et al. 1997

[a] Modified from Maddox et al. (1999).
[b] Species descriptions.

Importance of Microsporidia in Gypsy Moth Population Dynamics

In Central Europe, the gypsy moth is considered a periodic pest, with outbreaks occurring every 7-10 years. Further south in the Mediterranean and Balkan regions, where the climate is more conducive to gypsy moth development and survival, outbreaks are reported every 3-4 years (Weiser 1987).

In Europe, several entomopathogens have been reported from *L. dispar* populations particularly during outbreak years (Weiser 1987). These include the baculoviruses (nuclearpolyhedrosis virus (NPV) and granulosis virus (GV), cytoplasmic polyhedrosis virus (CPV), microsporidia, fungi, bacteria, and nematodes. In North America, where the gypsy moth was introduced in 1869, NPV is the dominant pathogen causing outbreak populations to collapse. Bacteria, nematodes, and CPV are recovered only occasionally; microsporidia have not been recovered. In 1989, the fungus *Entomophaga maimaiga*, which was introduced in 1910-11 from Japan but never reported as established, was found simultaneously in several locations in the northeastern United States and subsequently caused a regional epizootic in U.S. gypsy moth populations (Hajek et al. 1995). Since then, *E. maimaiga* has been the most dominant mortality factor in preoutbreak populations and acts in a density-independent manner, which is atypical of most entomopathogens.

Among the pathogens in European gypsy moth populations, NPV is primarily responsible for the termination of *L. dispar* outbreaks whereas microsporidia are prevalent during the gradation period prior to outbreaks and then persist at low levels among gypsy moth populations in the years between outbreaks. Whereas the NPV causes acute disease and results in dramatic epizootics among mid-and late-instar larvae, microsporidia usually produce a chronic disease state that results in the death of some larvae and pupae and prolongs the developmental period of larvae, possibly lengthening the window of opportunity for early-instar parasitoids such as *Cotesia melanoscela* and *Glyptapanteles sp.* Weiser and Novotny (1987) reported that hymenopteran parasitization of the gypsy moth was 58% higher in plots treated with *N. lymantriae* than in control plots.

Different microsporidian species that infect the gypsy moth target different tissues within their host, including the silk glands, midgut epithelium and associated muscle tissue, fat body, Malpighian tubules, nerve tissue, and reproductive organs. Species in the genus *Nosema* infect the gonads and ovarioles, reducing fecundity and killing overwintering embryos. Zelinskaya (1980) reported that the mortality of overwintering eggs laid by severely infected females was 58.5% compared to 34.2% in healthy females. Survival rates for neonates that emerged from infected egg masses also were reduced significantly.

According to Weiser (1987), microsporidian infections become more prevalent in the progradation period prior to a gypsy moth outbreak and may infect 15-30% of the population during an outbreak's peak period. As soon as the NPV appears in the population, microsporidian prevalences decline. However, many researchers suggest that microsporidia might have a more significant role in the population dynamics of *L. dispar.* Purrini and Skatulla (1978) reported that the prevalence of *N. lymantriae* in Sardinia reached 60% in1977. Sidor and Jodal (1983) studied the prevalence of a microsporidia identified as *N. serbica*, and NPV in the Acacia Forest "Bagremara" during a gypsy moth outbreak in 1978-81. The average larval mortality attributed to *N. serbica* exceeded that caused by NPV in each of the 4 years of the investigation and reached a maximum of 72% in 1978 when the estimated density of *L. dispar* was 16,000 egg masses/ha. Zelinskaya (1980) concluded that a complex of four microsporidian species was the major cause of a decrease in the population of I-III instar gypsy moth larvae in forest plantings along the lower Dnepr River in the Ukraine during 1976-77, and that 26-60% of egg-laying moths were infected during the outbreak phase. Sierpinska (2000) reported a prevalence of infection of 91% among late-stage *L. dispar* larvae that were sampled from the Biebrza National Park in Poland. Larvae were infected by a *Nosema*-like microsporidium.

Strong evidence that microsporidia are significant mortality factors in the dynamics of gypsy moth populations in Central Europe was the motivating factor behind a foreign exploration program that was initiated in 1985. The long range objective was to explore the feasibility of introducing candidate microsporidia from Europe as classical biocontrol agents to enhance the natural control of gypsy moth in North America.

Published Description of Species

In 1986, the USDA Forest Service supported a foreign exploration trip to Europe by J. Maddox and M. Jeffords (Illinois Natural History Survey) to search for microsporidian isolates from gypsy moth populations (McManus et al. 1989). Isolates were recovered from Portugal and the Czech Republic; a description of the microsporidium recovered from Portugal was published (Maddox et al. 1999). Included was a tabular listing for six species of microsporidia that were described or reported from European gypsy moth population at that time (Table 1).

The original description of these microsporidia contained few ultrastructural details and little data on life cycles. This lack of information led to confusion in identifying microsporidia isolated from Lepidoptera because some species are dimorphic (Maddox and Sprenkel 1978), i.e., they produce two different types of spores. Unfortunately, the microsporidia from the gypsy moth in Europe were described before dimorphism was recognized. Consequently, species reported in the literature as mixed infections of *Thelohania* sp. and *Nosema* sp. probably represent a single dimorphic species in the genus *Vairimorpha*. According to Sprague et al. (1992), the formation of uninucleate spores in an octosporous sporulation cycle is characteristic of *Vairimorpha*. Figure 1 shows the probable relationships among the described species of gypsy moth microsporidia.

> *Nosema lymantriae*: Probably a valid species as described by Weiser (1957). Mention in the literature of mixed infections of *Nosema* and octosporous *Thelohania*, though probably refers to a different species in genus *Vairimorpha*.
>
> *Thelohania similis*: Probably not a valid species and always was reported as mixed with diplokaryotic spores (*Nosema* type) spores, suggesting a *Vairimorpha sp*. No *Thelohania* sp. has been recovered in our surveys of microsporidia in European gypsy moth populations.
>
> *Thelohania disparis*: Close examination of the description in Timofejeva (1956) leads us to believe that this is a *Vairimorpha* sp.

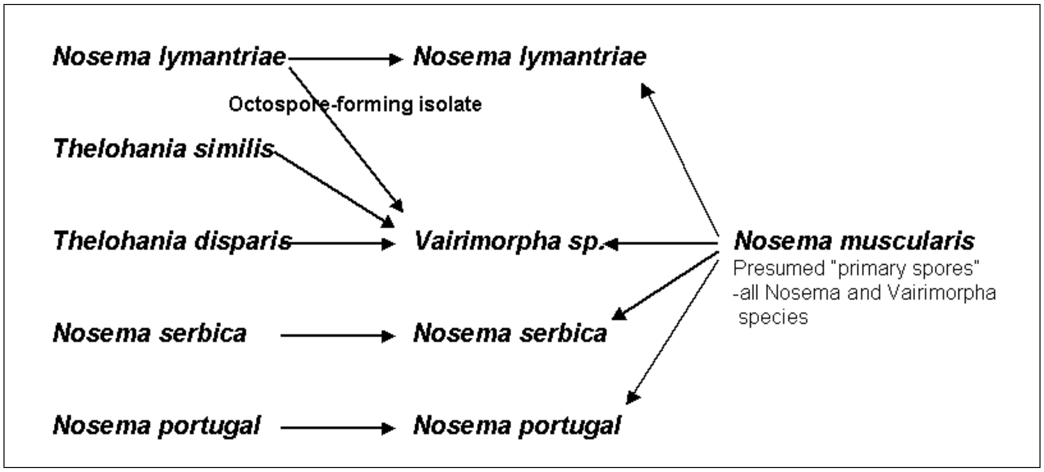


Figure 1.—Relationships of gypsy moth microsporidia.

Nosema muscularis: Its description matches the characteristics of "primary spores," an autoinfective stage that apparently occurs in all lepidopteran *Nosema* and *Vairimorpha* species as well as in other microsporidia genera (Solter and Maddox 1998a).

Endoreticulatus sp: The status of this species and its synonomy with *Pleistophora schubergi*, which was described from *Euproctis chrysorrhoea* (L.), is being investigated. The isolate from Portugal was first referred to as *Vavraia* sp. (McManus et al. 1989), but later was called *Endoreticulatus* sp. (Solter et al. 1997). It has since been recovered from *L. dispar* populations in Bulgaria and Hungary.

Nosema serbica: It is not known whether this species is similar to or conspecific with *N. Lymantriae*; unfortunately, neither isolates nor stained slides are available for analysis. Pilarska and Vavra (1991) discussed the similarities and differences between *N. serbica* and *N. lymantriae.* Attempts are being made to isolate this microsporidia from gypsy moth populations in the Balkans from where it was described originally.

Nosema portugal: First reported by Cabral (1977) and later isolated and described in detail by Maddox et. al. (1999) this species is closely related to other *Nosemas* isolated from gypsy moth populations. However, on the basis of molecular data, it may stand as a distinct species.

Ultra structural and molecular studies have been completed on isolates of *Vairimorpha sp.* recovered from gypsy moth populations in Bulgaria. A report is being prepared that describe this species and clarifies the taxonomy of the species listed in Table 1.

Foreign Exploration in Search of Microsporidian Isolates

As mentioned earlier, a foreign exploration program was initiated by the Forest Service in 1993 with support provided by the USDA Foreign Agricultural Service, International Cooperation and Development Research and Scientific Exchange Division, to search for microsporidia among gypsy moth populations in several countries in Europe, to compare these isolates with previously described species, and to evaluate isolates that might be candidates for introduction as classical biological control agents against *L. dispar* populations in North America. Although gypsy moth populations were at low densities throughout most of Europe during the period of exploration, we recovered microsporidian isolates representing three genera from more than 20 locations in seven countries. All of the isolates are stored in liquid nitrogen at the Illinois Natural History Survey laboratory of the junior author.

Since 1994, an ad hoc team of 10 scientists from six countries has conducted research on various aspects of several of the isolates that we recovered: ultrastructure and life cycle, modes of transmission, effects of infection on the gypsy moth host, impacts on nontarget Lepidoptera, and molecular sequencing of small subunit rDNA. A synthesis workshop was held in Prague in October 1997 and attended by 12 scientists from the United States and Europe to report results of individual studies, exchange relevant data, and identify laboratory and field research that is needed to realize accomplishments in a reasonable period of time. Much of the progress that is documented here resulted from the combined efforts of workshop participants.

Related Research

Since the stated goal of the research program was to evaluate the feasibility of introducing microsporidia into U.S. gypsy moth populations as a classical biological control agent, a basic knowledge about their host specificity is fundamental in resolving safety and regulatory issues (Maddox et al. 1992). A series of laboratory bioassays was initiated in 1994 that elucidated the host range of five of the biotypes listed in Table 1 by testing larvae of 49 lepidopteran species that are indigenous to North America and sympatric with gypsy moth larval populations (Solter et al. 1997). The microsporidia produced a variety of responses in the nontarget hosts such that the latter were placed in one of three categories: (1) no infection (refractory); (2) a typical infection in which few or no typical environmental spores were produced and horizontal transmission is unlikely; (3) heavy "host-like" infections in which mature environmental spores are formed that may be infective to conspecific individuals. On the basis of the response of nontarget species to the five microsporidian biotypes, Solter et al. (1997) concluded that *N. portugal* was the least infectious to nontarget Lepidoptera, and that *Endoreticulatus sp*. was most infectious, producing a "host-like" infection in 15 different species. The other isolates, *Nosema*-like isolates from Slovakia and Romania and *N. lymantriae*, were intermediate in infectivity to lepidopteran larvae, but host ranges and responses of hosts to infection were closer to those of *N. portugal* than to *Endoreticulatus sp*. The infectivity of *Endoreticulatus sp*. is not surprising. Although it has been recovered from gypsy moth populations in Portugal, Hungary, and Bulgaria, *Endorecticulatus sp*. is considered a generalist; its taxonomic placement is under study.

Solter and Maddox (1998b) conducted studies to determine the usefulness of laboratory studies in predicting ecological host specificity by feeding microsporidia isolated from other Lepidoptera to *L. dispar* larvae and then comparing the horizontal transmission between infected and uninfected *L. dispar* larvae to that which occurs among individuals of the natural hosts. Although nine microsporidian species infected *L. dispar* larvae, only one was transmitted to uninfected *L. dispar* larvae. This supports the concept that there is a much higher level of ecological host specificity among Lepidoptera microsporidia than laboratory host-range studies might predict.

Although laboratory bioassays provided a method to assess the host range of microsporidia in sympatric populations of Lepidoptera, there was a need to accumulate supporting data on the presence and prevalence of *L. dispar* and other microsporidia from natural populations of Lepidoptera in the field. Long-term monitoring of *L. dispar* populations in several sites in central and western regions of Bulgaria revealed that three species were present (*Endoreticulatus sp., Nosema sp., Vairimorpha sp.*) and that the same species were recovered repeatedly from the same site (Solter et al. 2000). Eleven microsporidia isolates from the same three genera were recovered from 1494 insect larvae representing 12 families of Lepidoptera. However with one possible exception, none of these isolates produced a typical host-like infection when fed to *L. dispar* larvae. The infective isolate was genetically different from the local endemic microsporidium. That no *L. dispar* microsporidia were found in Lepidopteran larvae feeding sympatrically with gypsy moth larvae on the same host-tree species supports predictions from laboratory studies that the ecological host specificity of *L. dispar* microsporidia is much narrower than physiological (laboratory) host specificity.

More definitive studies being conducted in Slovakia to evaluate the infectivity of *N. portugal* and *Vairimorpha* sp. against nontarget Lepidoptera when the isolates are applied to control gypsy moth larval populations. In this multiyear study, suspensions of each isolate are applied via ULV spray in replicated 500-m^2 plots to which gypsy moth larvae had been introduced previously. There were intensive collections of all larval Lepidoptera 7 and 14 days after spraying. Preliminary results suggest that the *Vairimorpha* isolate is more infectious to nontarget Lepidoptera, particularly certain genera of noctuids, than *N. portugal.* These results corroborate the results of laboratory studies of Solter et al. (1997), though additional field studies will be conducted in subsequent years to better clarify the impacts of these two isolates.

As mentioned earlier, a recurring dilemma concerning microsporidia, including the gypsy moth isolates, is related to their taxonomic placement. Many of the morphological and life-cycle characters that traditionally were used in microsporidian systematics are not holding up to molecular scrutiny, and other new techniques are elucidating characters such as multiple spore types in some species that understandably confused early taxonomists. Nevertheless, pathogens identification is a necessary component of a classical biological control program where exotic organisms are being considered for release into the environment. From analyses of ribosomal DNA sequences we know that the gypsy moth *Vairimorpha* and *Nosema* species are taxonomically distinct from the type species (*Nosema bombycis* from silk moth and *Vairimorpha necatrix* from the true army worm), and that gypsy moth *Nosema* and *Vairimorpha* isolates are more closely related to each other than to other members of the genera to which they are assigned. While there are sufficient differences between the gypsy moth *Nosema* and *Vairimorpha* isolates to designate them as good species groups, the *Nosema* group continues to be difficult to analyze. The rDNA sequences (both large and small) are nearly identical between isolates but most differ by one base pair. The rDNA sequence may be too conservative to analyze differences in closely related species or distinguish differences between populations. The problem is twofold: to which of the previously described species are they most closely related (or are they synonymous), and do they represent one variable species or several species?

We will need to rely on the extant records (the literature and Giemsa-stained specimen slides) to determine whether our isolates are synonymous with previously described species. However, to evaluate relative differences between our viable isolates, we are experimenting with PCR-RAPDs. In preliminary studies we have been able to distinguish definitive differences between *Vairimorpha* sp. and *Nosema* spp. as well as certain differences between the *Nosema* isolates. We are not yet certain that this method will yield the information we seek and will consider using AFLP or protein analysis in future studies. Overcoming the taxonomic difficulties within these groups will allow us to take more positive steps toward satisfying the regulatory issues that must be addressed before an exotic entomopathogen is introduced into North America to control gypsy moth populations.

References Cited

Cabral, M.T.E.C. 1977. Papel das doencas na limitacao natural das populacoes de *Lymantria dispar* L. (Lepidoptera: Lymantriidae). Ann. Inst. Super. de Agron. Univ. Tec. de Lisboa. 37: 153-177.

Hajek, A.E., R.A. Humber, and J.S. Elkinton. 1995. Mysterious origin of *Entomophaga maimaiga* in North America. Am. Entomol. 41: 31-42.

International Commission on Zoological Nomenclature. 1985. International Code of Zoological Nomenclature. 3rd ed. 338pp. Int. Comm. Zool. Nomencl., London.

Larsson, J.I. Ronny. 1999. Identification of microsporidia. Acta Protozool. 38: 161-197.

Maddox, J. and R.K. Sprenkel. 1978. Some enigmatic species of the genus *Nosema.* Misc. Publ. Entomol. Soc. Am. 11: 65-84.

Maddox, J.V., M.L. McManus, M.R. Jeffords, and R.E. Webb. 1992. Exotic insect pathogens as classical biological control agents with an emphasis on regulatory considerations. *In* Selection criteria and ecological consequences of importing natural enemies (W.C. Kauffman and J.E. Nechols, eds.) Entomology: Proc. Entomol. Soc. Am.: 27-39.

Maddox J.V., M.D. Baker, M.R. Jeffords, M. Kuras, A. Linde, L.F. Solter, M.L. McManus, J. Vavra, and C.R. Vossbrinck. 1999. *Nosema Portugal,* NSP., isolated from gypsy moths (*Lymantria dispar* L.) collected in Portugal. J. Invert. Pathol. 73: 1-14.

McManus, M.L., J.V. Maddox, M.R. Jeffords, and R.E. Webb. 1989. Evaluation and selection of candidate European microsporidia for introduction into U.S. gypsy moth populations. *In* Proceedings Lymantriidae: a comparison of features of New and Old World tussock Moths (W.E. Wallner and K.A. McManus tech. Coords.) USDA For. Serv. Gen. Tech. Rep. NE-123. pp. 455-468.

Pilarska, D. and J. Vávra. 1991. Morphology and development of *Nosema serbica* Weiser, 1963 (Microspora, Nosematidae), parasite of the gypsy moth *Lymantria dispar* (Lepidoptera, Lymantriidae). Folia Parasitol. 38: 115-121.

Purrini, Von. K. and U. Skatulla. 1978. On the natural diseases of the gypsy moth, *Lymantria dispar* L. in Sardinia, Italy. Anz. Schaedlingskd., Pflanzenschutz Umweltschutz 51: 9-11.

Romanyk, N. 1966. Enemigos naturals de la *Lymantria dispar* L. en Espana. Bol. Serv. Plagas For. 9(18): 157-163.

Saftoiu, A. and M. Caloianu-Iordachel. 1978. New ultrastructural data on the development of the protozoan *Nosema Lymantriae* (Weiser)(Microsporidia) intracellular parasite on *Lymantria dispar L.* (Lepidoptera). Trans. Museum. Nat. Hist.. Bucuresti 19: 83-87.

Sidor, C. 1979. The role of insect pathogenic microorganisms in the protection of the environment. Mikrobiologija 16: 173-186.

Sidor C. and I. Jodal. 1983. Results of investigations of health conditions of gypsy moth(*Porthetria dispar* L.) in Acacia Forest Bagr´mara. Zast. Bilja. 34: 445-455.

Sierpinska. A. 2000. Preliminary results on the occurrence of microsporidia of gypsy moth (*Lymantria dispar* L).from different forest habitats of Poland. IOBC wprs Bull. 23: 291-295.

Solter, L.F. and Maddox, J.V. 1998a. Timing of an early sporulation sequence of microsporidia in the genus *Vairimorpha* (Microsporidia Burenllidae). J. Invertebr. Pathol. 71: 207-216.

Solter, L.F. and Maddox, J.V. 1998b. Physiological host specificity of microsporidia as an indicator of ecological host specificity. J. Invertebr. Pathol. 71: 207-216.

Solter, L.F., J.V. Maddox, and M.L. McManus. 1997. Host specificity of microsporidia (Protista: Microspora) from European populations of *Lymantria dispar* (Lepidoptera: Lymantriidae) to indigenous North American Lepidoptera. J. Invertebr. Pathol. 69: 135-150.

Solter, L.F., D.K. Pilarska, and C.F. Vossbrinck. 2000. Host specificity of microsporidia pathogenic to forest Lepidoptera. Biol. Cont. 19: 48-56.

Sprague, V. 1977. Systematics of the microsporidia. *In* Comparative pathobiology, vol. 2. (L.A. Bulla, Jr. and T. C. Cheng, eds.) Vol. 2. Plenum Press, New York.

Sprague, V., and J.J. Becnel. 1999. Appendix: checklist of available generic names for microsporidia with type species and type hosts. *In* Microsporidia and microsporidiosis. (M. Wittner and M.L. Weiss, eds.) ASM Press, Washington, D.C. pp. 531-539.

Sprague, V., J.J. Becnel, and E.I. Hazard. 1992. Taxonomy of phylum Microspora. Crit. Rev. Microbiol. 18: 285-395.

Timofejeva, E.R. 1956. Nozematoz neparnogo shelkoprjada. Infekt.i Protoz. Bol. Pol.i vred, nasekoych [Serbo-croatian] 210-219.[cited from Weiser (1957)]

Van de Peer, Y., B.A. Abdelghani, and A. Meyer. 2000. Microsporidia: accumulating molecular evidence that a group of amitochondriate and suspectedly primitive eukaryontes are just curious fungi. Gene 246: 1-8.

Vossbrinck, C.R., J.V. Maddox, S. Friedman, B.A. Debrunner-Vossbrinck, and C.R. Woese. 1987. Ribosomal RNA sequence suggests microsporidia are extremely ancient eukaryotes. Nature 326: 411-414.

Weiser, J. 1957. Mikrosporidien des Schwammspinners und Gold-afters. Z. Angew. Entomol. 40: 509-527.

Weiser, J. 1964. Protozoan diseases of the gypsy moth. Proc. Int. Congr. Protozool. 1: 497-499.

Weiser, J. 1987. Patterns over place and time. *In* Epizootiology of insect diseases. (J.R. Fuxa and Y. Tanada, eds.). John Wiley & Sons, New York. pp. 215-244.

Weiser J. and J. Novotny. 1987. Field application of *Nosema lymantria* against the gypsy moth, *Lymantria dispar* L. J. Appl. Entomol. 104: 58-62

Weiss, L.M., T.D. Edlind, C.R. Vossbrinck, and T. Hashimoto. 1999. Microsporidian molecular phylogeny: the fungal connection. J. Eukaryot. Microbiol. 46: 17S-18S.

Zelinskaya, L.M. 1980. Role of microsporidia in the abundance dynamics of the gypsy moth, *Porthetria dispar*, in forest plantings along the Lower Dnepr River (Ukranian Republic, USSR) Vestn. Zool.1: 57-62.

Zelinskaya, L.M. 1981. Using the index of imago infection by spores of microsporidia for predicting the reproduction of *Lymantria dispar.* Lesn. Khoz.4: 58-60.

Dependency of Outbreaks Distribution from Insects-defoliators' Seasonal Development

Valentina Meshkova

Ukrainian Research Institute of Forestry & Forest Melioration, meshkova@u-fri.kharkiv.com

Abstract

Analysis of data on the population dynamics of foliage browsing insects in time and space was conducted in the Ukraine. For each of the main species, correlation indices were calculated between outbreak characteristics (mean and specific foci area, outbreak probability), weather elements (air temperature, precipitation), indices (hydrothermal coefficient, winter severity) and the dates of air temperature transition over and below different limits (0, 5, 10, and 15°C).

The population dynamics of insects with different types of seasonal development depends on peculiarities in insect seasonal development and in particular, on weather conditions of the region. For insect species which hibernate in the egg stage (*Tortrix viridana*, *Neodiprion sertifer*, *Lymantria dispar*), the initiation of outbreaks occurs more often in years when larval feeding begins early.

Outbreaks of insect species that hibernate in the larval stage (*Dendrolimus pini*, *Euproctis chrysorrhoea*) often follow years when dry and hot weather occurs during the period when young larvae are feeding at the end of the summer.

Outbreaks of insect species that hibernate in the pupal stage begin in years following after the occurrence of an early spring (*Panolis flammea*) or a dry and hot June (*Bupalus piniarius*) and are associated with conditions that promote the rapid development of young larvae.

The occurrence of outbreaks of insect species whose feeding takes place at the end of the season are also associated with warm and dry weather during the feeding period which promotes synchrony in the completion of their seasonal development with completion of the period of vegetation by the host tree.

Introduction

Analysis of many years of data suggests that not all foliage browsing insects cause outbreaks of mass propagation (Meshkova 2002a) and that the dynamics of different geographical and ecological populations is not the same (Meshkova 1999, 2001b, 2001e).

Differences in the spread of geographical population foci indicate that it depends on certain indices which are rather stable for separate regions (Meshkova 1999). In our opinion, such indices are not only air temperature, precipitation and hydrothermal indices, but also the dates and rates of the annual course of air temperature (Meshkova 2001c; 2001d).

Our observations on the foci of different foliage browsing insects show that occurrence of an early spring is favorable for survival of the spring complex of larvae (Meshkova 2002b; 2002c).

According to phenological theory (Meshkova 2002a), the most frequent and intensive outbreaks of foliage browsing insects in the South are associated with an early production of host-tree vegetation in the Spring and acceleration of insect development due to temperature. In conditions of a more continental climate (that is evaluated as the difference in air temperature between July and January) east of the Ukraine, air temperature increases rather fast in the spring however soil temperature increases rather slowly. Hatching of larvae is dependent on air temperature but bud break begins only after the soil thaws and translocation of water in the stems begin. Therefore in the East, larval hatch coincides with the occurrence of the youngest leaves which have a high nitrogen content and almost no protective substances (phenols, tannins). In the West, larval hatch coincides with more developed foliage that has accumulated protective substances, due in part to high availability of water in stands in these regions.

Differences in the intensity and frequency of outbreaks of different insect species were supposedly dependent on peculiarities in their seasonal development. The main foliage browsing insect species were classified into four groups (Meshkova, 2001a) that differ mainly by their overwintering stage: group 1 – egg (larvae feeding in spring), group 2 – larvae (feeding in spring and at the end of vegetation (autumn)), for example *Dendrolimus pini* L., *Euproctis chrysorrhoea* L.), group 3 – pupae (feeding in spring or in summer-autumn), and group 4 – eonymph (feeding in summer-autumn, for example, *Diprion pini* L.). Subgroups differ by the terms of diapause: subgroup 1a – development from egg to egg without diapause, summer diapause of eggs transits to winter diapause (*Tortrix viridana* L.); subgroup 1b – summer diapause of pupae or eonymph, swarming in autumn, winter diapause of eggs (*Operophthera brumata* L., *Neodiprion sertifer* Geoffr.); subgroup 3a – summer diapause of pupae transits to winter diapause (*Panolis flammea*); subgroup 3b – winter diapause of pupae transits to summer diapause (*Bupalus piniarius* L.).

The objectives of this study were to analyze the history and geography of insect outbreaks in the Ukraine and to determine what combinations of weather conditions are most favorable for different insect species.

Methods

We assumed that if weather conditions that are favorable for certain insect populations can occur in some years in one point, then there are regions where such situations occur more often.

We calculated the correlation coefficients between climatic indices including air temperature, precipitation, hydrothermal coefficients for different months, indices of winter severity, dates of late spring and early autumn frosts, dates of stable transition of air temperature over and below different limits (0, 5, 10, and 15°C) and indices that characterize foliage browsing insects outbreaks, the probability of outbreaks, mean annual foci area, and specific annual foci area (Meshkova 1999, 2002c).

Such correlation indices were calculated on the one hand for mean data for many years on weather elements and on insect outbreaks for 25 points within the Ukraine, and on the other hand for a single point, Kharkiv for the period 1894 –2001.

Data on the history and geography of insect outbreaks were obtained from the literature, archives of the Ministry of Forest Management (later – State Committee of Forest Management of Ukraine), the laboratory of forest protection of Ukrainian Research Institute of Forestry & Forest Melioration, and from our own investigations. Meteorological indices were obtained from respective electronic data bases. Data for 1894–1999 were obtained from the Kharkiv regional meteorological Center.

Statistics were calculated with the help of standard computer programs (Microsoft Excel 5.0. and Statistica 4.3 for Windows). The reliability of coincidence for insect outbreak years and certain weather elements was estimated using c^2 criteria (Rokitskij 1973).

Results

The foci area for *Tortrix viridana* L. covers more than half of the area that contains foci from all leaf-browsing insects. There is a significant correlation in the probability of its outbreaks with latitude (r=-0.41; P=0.05), longitude (r=-0.67; P=0.01), continentality (r=-0.57; P=0.05), suggesting that outbreaks occur more often in regions with higher air temperature and lower precipitation during the vegetation period. There is also a high correlation with indices that characterize the integral influence of temperature and precipitation (r=-0.75; P=0.01).

The probability of *T. viridana* outbreaks is higher in regions where the dates of the last spring frost occur earlier (r = -0.49; P=0.05) and there is a stable transition of air temperature over 10° (r = -0.58; P=0.05) with a shorter interval between the dates of stable transition of air temperature over 0° and 15° (r = -0.51; P=0.05), 5° and 10° (r = -0.54; P=0.05); This means that outbreaks are more frequent in the regions that experience more early springs and shorter periods of larval feeding.

When we take into account data over many years at one point (Kharkiv, 1894–2000), we often see the coincidence of years with earlier larval hatching and years of high larval density (r=-0.53; 0.01<P<0.05) as well as an increase in foci area (r=-0.42; P=0.05). This means that the early hatch of larvae is favorable for *T. viridana* populations.

For *Lymantria dispar* L. there is a negative relationship between latitude and foci area (r= -0.64; P=0.05), latitude and outbreak probability (r= -0.63; P=0.05). Dependence of outbreak probability is reliable for longitude (r=0.54; P=0.05) and the continentality index (r=0.52; P=0.05). This means that the more favorable conditions for gypsy moth populations occur in the East and South of Ukraine.

There is a positive correlation between gypsy moth foci area and air temperature in January (r=0.62; P=0.05) and in Autumn – in September (r=0.44), October (r=0.56; P=0.05), November (r=0.57; P=0.05), December (r=0.59; P=0.05). This suggests that the most favorable conditions for gypsy moth populations occur in those regions with a warm autumn. These conditions are favorable for eggs to complete their embryonation and to enter diapause.

The most high and reliable (P=0.01) correlation of gypsy moth outbreaks probability is related to the months from May to September (r=0.7; r=0.8; r=0.82; r=0.8; r=0.72), and then becomes lower for October (r=0.54; P=0.05). Negative dependence of outbreak probability with latitude agrees with its positive dependence on temperature. This means that warm conditions in the south are favorable for gypsy moth populations.

There is an explanation for the positive correlation of specific foci area with the sum of negative temperatures for the period with negative air temperature (r=0.52; P=0.05). The natural selection of a specimen, that enters a deep diapause earlier is more intensive in regions with colder winters.

The negative correlation of mean (r= -0.49; P=0.05) and specific (r= -0.62; P=0.05) foci areas with precipitation for periods with negative air temperature and a positive correlation with index of winter severity (r=0.46 and r=0.4 respectively) can be associated with a weakening of host plants that occurs in frosty dry winters.

There are negative correlations between annual precipitation, for periods with positive temperature and monthly temperature over 10°C and gypsy moth specific foci area (r=-0.62; r=-0.50 and r=-0.55 respectively) and with probability of outbreaks (r=-0.68; r=-0.67 and r=-0.7 respectively). This suggests that conditions are more favorable for gypsy moth outbreaks in regions with less precipitation.

There is a negative correlation between gypsy moth foci area and precipitation in almost all months except December and January, but the correlation is highest in August (r= -0.53). The correlation coefficient between specific areas and monthly precipitation are highest for July (r = -0.7) and August (r = -0.67) but they are also reliable at P=0.05 for April (r = -0.64), May (r = -0.6), June (r = -0.6), and September (r= -0.53). The most significant (P=0.01) correlation coefficients between precipitation and probability of gypsy moth outbreaks occur for the months of July (r= -0.8), August (r= -0.8) and September (r= -0.78), but they are rather high also for April (r= -0.63), May (r= -0.6), June and October (r= -0.56). The high correlation between air temperature and precipitation in July-August and indices characterizing gypsy moth foci is probably related to the influence of weather conditions during the period of oviposition and embryonation.

It is clear that integral indices which characterize periods of drought are also correlated negatively with the spread of gypsy moth foci (correlation indices for mean, specific foci area and outbreak probability with hydrothermal coefficient of vegetation period are r = -0.4; r = -0.62 and r = -0.79 respectively).

A negative correlation was found between the probability of gypsy moth outbreaks and the date air temperature over 10° stabilizes in the spring (r=-0.62; P=0.05). This means that occurrence of an early spring is favorable for development of gypsy moth outbreaks.

For *Neodiprion sertifer* Geoffr., a reliable but moderate positive correlation was found between specific area and air temperature during the vegetation period (r=0.55–0.58; P=0.01). The correlation of mean, specific foci area and outbreak probability with precipitation is negative. The correlations are negative between mean area and April precipitation (P=0.05; r = -0.47), and highly significant (P=0.01) between specific area with precipitation in April (r = -0.64) and July (r = -0.59). The correlation between mean area and precipitation in other months is reliable at P=0.05. Negative correlation coefficients were calculated between *Neodiprion sertifer* mean and specific foci area and precipitation for the year and vegetative season, and for the hydrothermal coefficient.

The negative correlation calculated between specific foci area and outbreak probability with the dates when stable air temperatures over 5° occurs in spring (r=-0.61 and r=-0.47) and 10° (r = -0.56 and r = -0.58) suggests, conditions are favorable for *N. sertifer* survival in regions where spring begins earlier.

The correlation is positive between the date when the transition of air temperature below 15° in autumn is stable with both specific area (r=0.58; P=0.05) and outbreak probability (r=0.58; P=0.05). This means that conditions are more favorable for outbreaks of *N. sertifer* in areas where the transition of air temperature below 15° occurs late in the autumn. The correlation between outbreak probability and intervals between the transition of stable air temperature in autumn below 15° and 10° (r = -0.64; P=0.05), 15° and 5°C (r = -0.66; P=0.05) is higher. This suggests that shorter intervals are better for *Neodiprion sertifer* populations. It is during this time that the pronymphs change into pupae, and when adults swarm and lays eggs.

Outbreaks of *N. sertifer* in the Kharkiv region coincide with those years when the date of stable transition of air temperature over 10°C is earlier than 23.IV (χ^2=10.6; P<0.01). The reliability is even higher when this occurs earlier than 16 April (χ^2=11.3; P<0.01).

The probability of *Euproctis chrysorrhoea* L. outbreaks is higher in the south (r=-0.53 with latitude). A positive dependence with longitude is calculated for specific foci area (r=0.64) and outbreak probability (r=0.67; P=0.05); this means that outbreaks of this pest occur more often and with greater intensity in the East of Ukraine. The same dependence is determined for continentality index which increases from the West to East (r=0.74 and r=0.58 for specific foci area and outbreak probability respectively).

The probability of *E. chrysorrhoea* outbreaks correlates reliably with air temperature in May (r=0.67; P=0.05), June (r=0.76; P=0.01), July (r=0.80; P=0.01), August (r=0.77; P=0.01) and September (r=0.6; P=0.05). Influence of air temperature on *E. chrysorrhoea* outbreak probability increases from spring to summer, and is maximal during the period of moth flight and when neonate larvae appear. This can be explained by the fact that survival of neonate larvae is essential in the life cycle of this species, which appear almost simultaneously in different points of area (Meshkova 2001). Rapid development of eggs within a short time period promotes species survival. At locations with higher July temperatures, insect development accelerates and therefore from a geographical perspective, we see such changes of correlation coefficients by months. The beginning of larval feeding (that coincides with initiation of spring) and completion of larval feeding (that coincides with completion of the vegetation period) varies strongly in different regions. Therefore the correlation of air temperature with *E. chrysorrhoea* outbreak probability is less for the early spring or autumn months.

A negative essential correlation is determined between *E. chrysorrhoea* outbreak probability and precipitation for the vegetation period (P=0.01). Correlation indices for July, August and September (r = -0.71; r= -0.8; r = -0.8) indicate that conditions are more favorable for the development of young larvae in locations where there is less precipitation during this period.

The correlation index for *E. chrysorrhoea* outbreak probability and hydrothermal coefficient for vegetation season is -0.79 (P=0.01). This supports the notion that the growth of outbreak probability occurs under dry conditions. The negative influence of winter severity coefficient on outbreak area (r=-0.51) suggests that *E. chrysorrhoea* foci spread more in regions with low winter precipitation and low temperature, that is in the regions characterized with low host plant resistance.

The probability of *E. chrysorrhoea* outbreaks is higher in the regions where the date of air temperature transition below 15° (r=0.64) occurs later.

Analysis of many years of data for Kharkiv (1894–2000) shows that the mean hydrothermal index for July is equal to 0.1±0.006. It is equal to 0.09±0.01 in the years of outbreaks and to 0.07±0.01 in previous years. Coincidence of *E. chrysorrhoea* outbreaks with the years following after years when the hydrothermal index for July is less than 0.09 is significant with a probability of 99.9% (χ^2=10.3).

For *Dendrolimus pini* L, there is a positive correlation with foci area and April air temperature (r=0.71; P=0.05) (this is the period when larvae begin feeding after hibernation) as well as with air temperature during August–October (r – 0.65–0.68), which is the period of young larval feeding. We found a high correlation of specific foci area with annual year temperature (r=0.69).

There is a negative correlation of specific foci area with precipitation for most months (March – -0.72; April – -0.68; June – -0.65; July – -0.67; August – -0.68; October – -0.71; November – -0.7; December – -0.69). There is also a negative correlation of specific foci area with the hydrothermal coefficient (r=-0.69). This suggests that localities with low precipitation are more favorable for *D. pini*.

The reliable correlation of winter precipitation with *D. pini* foci specific area (r=0.67) can be explained by the fact that high water content in the litter during thaws causes the spread of infection by fungi among larvae. On the other hand, when the snow layer is dense, thaws occur slowly and larvae begin feeding later.

We determined that there is a negative correlation of indices that characterize *D. pini* outbreaks with the date of the last spring frost (r = -0.63; P=0.05) and a positive correlation (r=0.64) with the date of the first autumn frost. There is also a positive correlation (r=0.69) between mean and specific foci area with the number of days with air temperature over 5°C. This suggests that weather conditions are more favorable to *D. pini* survival in those regions that are characterized by an early beginning and late completion of warm weather. These conditions promote the rapid development of older larvae after winter and neonates at the end of the season.

A high correlation index was estimated for the interval between dates of air temperature transition over 5° and 10°C with *D. pini* mean (r=0.63; P=0.05) and specific (r=0.71; P=0.05) foci area. It is during this period that larvae initiate feeding after hibernation. The correlation between specific foci area and the interval between the dates of air temperature stable transition below 5° and 0°C in autumn is also reliable (r=0.68; P=0.05). This is during the period when winter diapause of *D. pini* caterpillars begins.

The correlation of indices that characterize dates and rates of spring development in the Kharkiv region (1894–1999) with the dynamics of *D. pini* populations in the Kharkiv region indicates that 85.7% of outbreaks begin in the years when the stable transition of air temperature over 0°C occurs before 21. (χ^2=4.0; P>0.1), and 92.9% of outbreaks occur in the years when stable transition of air temperature over 5°C occurs before 10.IV ($\chi^2=3.7$; $P>0.1$). This means that 78.6% of outbreaks occur in the years when the interval between stable air temperature transition over 0 and 5°C is not less than 16 days ($\chi^2=3.7$; $P>0.1$); 71.4% of outbreaks occur in the years when the interval between stable air temperature transition over 5 and 10°C is not less than 18 days ($\chi^2=6.5$; $P=0.04$). This means that an early spring with slow development and uniform soil thawing and initiation of pine vegetation in the stand promotes high quality forage for caterpillars and is favorable for survival of *D. pini* populations.

Years with higher air temperature are favorable for *D. pini* populations because a greater portion of larvae will begin hibernation in later instars. During 1894–2001 in the Kharkiv region, 92.9% of *D. pini* outbreaks began in years when the sum of positive air temperatures during July-September was over 1664°C ($\chi^2=11.9$; $P<0.01$), and 71.4% outbreaks began in years when the July temperature was over 20.7°C ($\chi^2=4.2$; $P>0.1$).

For *Panolis flammea* L., there is a positive correlation of mean foci area with the date of stable air temperature transition over 0°C ($r=0.58$) and a negative correlation with the date of such transition in autumn. The correlation is higher for mean foci area and when the interval between dates of air temperature stable transition is over 0° and 5°C ($r=-0.81$), and between dates of air temperature stable transition over 0° and 10°C ($r= -0.77$. This suggests that a rapid increase of air temperature in the spring is favorable for swarming, mating, egg laying and their development.

It was stated that 77.8% of *P. flammea* outbreaks in the Kharkiv region between 1894–2001 occur in cases when air temperature transition over 0°C in the previous year occurred not later than 17. ($\chi^2=5.5$; $P>0.05$). Thus 88.9% of outbreaks begin when stable air temperature transition over 5°C in the previous year occurs before 5.IV ($\chi^2=6.9$; $P=0.03$), and transition over 10°C occurs before 23.IV ($\chi^2=8$; $P>0.02$).

The influence of high temperatures on caterpillar development and their survival is confirmed by the fact that 88.9% of *P. flammea* outbreaks in the Kharkiv region occur after years when the mean air temperature in May is over 15°C ($\chi^2=4.5$; $P>0.1$) and 55.6% of outbreaks began in the years following those years when the hydrothermal coefficient for June was less than 0.05 ($\chi^2=6.3$; $P<0.05$).

The length of *P. flammea* larval development varied from 26 to 44 days in different years. In 1998 (before the last outbreak), it was 30 days, while in 1999 it was 32 days. In 2000, development required 36 days because of relatively cold temperatures in May; the mean air temperature was approximately 13°C. The larval feeding period did not exceed 34 days in years when outbreaks were initiated ($x^2=4.6$; $P=0.01$).

For *Bupalus piniarius* L., there is a reliable correlation (P-0.01) of specific foci area with precipitation in the winter months of December, January and February ($r=0.89$; $r=0.98$; $r=0.76$). This can be explained by the beneficial effect of additional snow cover on the survival of pupae. There is a moderate correlation ($P=0.05$) between the probability of *B. piniarius* outbreaks and precipitation of other months ($r=-0.51$ – $r=-0.74$). This is indicative of the preference by this species for mesophytic conditions. *B. piniarius* outbreaks occur more often in areas with more humid conditions unlike most other foliage browsing insects; in the Ukraine, outbreaks occur in the background of other species i.e. pine sawflies and are of short duration.

The correlation between *B. piniarius* specific foci area with the date of air temperature transition over 0° is positive ($r=0.73$; $P<0.05$). This suggests that conditions are more favorable for *B. piniarius* outbreaks in regions where spring begins later. This may be related to the requirement by larvae for a certain soil humidity that is optimal for their survival.

An analysis of the change in autumn temperatures in different regions indicates that a later decline in temperature is favorable for *B. piniarius* populations ($r=-0.82$).

The absence of a significant correlation between *B. piniarius* outbreaks and the change in spring temperature for many years observations in the Kharkiv region ($\chi^2<1$) can be explained. Larvae of *B. piniarius* browse the previous year's foliage which is suitable for feeding long before the swarming of moths occurs. Therefore a shift in the date of swarming does not have an effect on the conditions required for larval feeding.

A positive correlation (P=0.05) of *Diprion pini* L. was found between specific foci area and air temperature in March and April (r=0.51 and r=0.53 respectively); this may be related to the influence of spring conditions affecting the termination of diapuse and on the emergence of imagos.

There is good correlation (r=0.59; P=0.05) between specific foci area with air temperature during the vegetation season (period with air temperature over 10°C); this is explained by the occurrence of two *D. pini* generations per year in the south, while there is only one generation in the north. A negative correlation was found between specific foci area with the date of air temperature stable transition over 5° (r=-0.63) reflecting the beneficial effect of an early spring for *D. pini*.

There was a significant positive correlation between the probability of *D. pini* outbreaks with precipitation in January (r=0.6; P<0.01); this may be related to the fact, that snow cover is favorable to the survival of cocoons the litter. There is a negative correlation between specified foci area with the hydrothermal coefficient for the vegetation period (r = -0.48) suggesting that there is an increase in *D. pini* populations in regions with less humidity.

In the Kharkiv region, 76.5% of *D. pini* outbreaks occur in those years when the transition of stable air temperatures over 10°C occurs before 23.IV (χ^2=8.2; P=0.015); 100% of outbreaks occur in those years when the transition occurs before 30.IV (χ^2=5.1; P>0.05), and 88.2% of *D. pini* outbreaks occur in the years when the transition is before 20.V (χ^2=12.8; P<0.01).

The initiation of outbreaks occurs when air temperature in May and June (16.3°C and 20°C respectively) exceeds the mean data for many years (15.4°C and 19°C respectively). For the period of 1984–2001 in Kharkiv, 94.1% of *D. pini* outbreaks began in years when the air temperature in May exceeded 14°C (χ^2=3.7; P>0.1), and 82.4% of outbreaks began in years when the air temperature in May exceeded 18°C (χ^2=2.3; P>0.1).

In the years when outbreaks began, first generation of cocoons of *D. pini* were formed before 17.VI in 88.2% cases (χ^2=12.2; P<0.01). The majority of first generation larvae complete feeding before the solstice (when photoperiodic reaction begins to have a dominant influence on developmental temps). The larvae that do not complete their development before this date often continue development after the monovoltine type. The occurrence of a larval diapause in summer allows larvae to complete their development in September simultaneously with larvae from the summer generation.

We did not find a reliable correlation between outbreaks and hydrothermal indices for the summer generation feeding period. However in 70.6% of the years when *D. pini* outbreaks occurred, the hydrothermal index in August did not exceed 0.08 (χ^2=2.0; P>0.1).

All *D. pini* outbreaks in the Kharkiv region occurred in years when the stable transition of air temperature below 5°C occurred after 20 October (χ^2=5.9; P=0.05).

Discussion

A reliable correlation was found between the beginning of outbreaks caused by foliage browsing insects and terms and temperature during the seasonal development of these species.

For species that hibernate in the egg stage (1st group – *Tortrix viridana*, *Lymantria dispar*, *Neodiprion sertifer*), the beginning of outbreaks coincide with the time when larval feeding begins.

For the 2nd group (hibernate as larvae), the initiation of *Dendrolimus pini* outbreaks coincides with high air temperature in June-September of the current year, while for *Euproctis chrysorrhoea,* it coincides with low hydrothermal coefficient in July of the previous and current years.

Panolis flammea outbreaks (the 3rd group, which hibernate as pupae) occur in years following after those years with an early transition of air temperature over 0, 5 and 10°C. High air temperature in May (over 15°C) of the current year and low hydrothermal coefficient in June (below 0.1) of the previous year are less coincident with outbreaks of *Panolis flammea*. Outbreak of *Bupalus piniarius* coincide with high air temperature in July of the previous year and to a lesser degree with high air temperature in September of the current year.

The beginning of *Diprion pini* outbreaks (the 4th group, hibernate as enonymphs) reliably coincide well with years when an early transition of air temperature over 10°C occurs.

Estimated correlation of dates and rates of the course of annual temperature with the dissemination of foliage browsing insects in different regions of the Ukraine allows us to obtain data to support a suggested phenological theory of population dynamics (Meshkova 2002a). The dates and rates of the development of all foliage browsing species that feed during first part of the vegetation period (before the solstice) depend on the course of temperatures. Dates and rates of the development of those foliage browsing insects that feed during the last part of the vegetation depend on the photoperiodic reaction of organisms which complete their seasonal development coincident with completion of the vegetation period of their host.

Foliage browsing insect outbreaks occur more often and are intensive in the South because:
–insects develop more rapidly at higher temperature
–tree resistance (general, and to insects) declines at low humidity
–at the absence or insignificant soil chilling to the date when larval feeding begins, the sap of host plants begins to move earlier in spring; therefore the needles of the previous year become more suitable for larvae of *Neodiprion sertifer* and *Dendrolimus pini*, while the development of current needles (for *Panolis flammea*) and budbreak of deciduous trees (for leaf-feeding larvae of the spring complex) is accelerated.

Outbreaks of foliage browsing insects occur more often and are more intensive in the East because:
–stands are more resistant in the East regions that have high precipitation, which causes slowing of larval development and a decline in their survival
–in the East regions with high continentality index, the occurrence of colder winters and hotter summers (as compared to West regions) cause a rapid increase in air temperature in the spring which results in acceleration of larval development. This is favorable for insect populations
–in the East regions there is optimal difference in the rates of air and soil heating, which allows larvae to consume the most suitable foliage immediately after hatching.

References cited

Meshkova V. 1999. Forest pests outbreaks prognosis on the base of climatic factors analysis, pp.74–79. In Beat Forster, Milos Knizek, Woiciech Grodzki [eds.], proceedings, Methodology of Forest Insect and Disease Survey in Central Europe (Second Workshop of the IUFRO Working Party 7.03.10. April 20–23, 1999, Sion-Chateauneuf, Switzerland). Swiss Federal Institute for Forest, Snow and Landscape Research, Birmensdorf, Switzerland.

Meshkova V. 2001a. Classification of forest pests-defoliators in ukraine by the types of their seasonal development. Biology & Valeology: Scientific papers. Kharkiv: Kharkiv State Pedagogical University. 4: 81–87 [In Ukrainian].

Meshkova V. 2001b. Global and local factors in the forest insect defoliators eruptions in Ukraine, pp.72–77. In Methodology of Forest Insect and Disease Survey in Central Europe: Proc. Third Workshop of the IUFRO WP 7.03.10. Romania.

Meshkova V. 2001c. Phenological prognosis of *Neodiprion sertifer* Geoffr. for different zones of Ukraine. Problems of forest ecology and forest use in Polissya of Ukraine. Zhitomir: Volin 2 (8): 125–130 [In Ukrainian].

Meshkova V. 2001d. Prediction of the seasonal development of the gold-tail moth *Euproctis chrysorrhoea* L. Proceedings of National Agrarian University. 46: 164–171 [In Ukrainian].

Meshkova V. 2001e. Spatial dynamics of forest insects-defoliators in Ukraine. Third Balkan Scientific Conference «Study, Conservation and Utilisation of Forest Resources»: Proceedings (2–6 October 2001, Sofia).– Sofia. –V.III: 78–85.

Meshkova V. 2002a. History and geography of foliage browsing insect pest outbreaks. Kharkiv: Majdan. – 244 p [In Ukrainian].

Meshkova V. 2002b. Spring development dates and *Tortrix viridana* L. population dynamics. Proceedings of Kharkiv National Agrarian University («Entomology & Phytopathology») 3: 133–140 [In Ukrainian].

Meshkova V. 2002c. The role of spring beginning dates in pest-defoliators outbreaks development. Forestry & Forest Melioration 101: 15–19 [In Ukrainian].

Rokitskij P.F. 1973. Biological statistics. Visheisha Shkola, Minsk.– 320 p.

Dynamics of Foci of Forest Pest Insects in Russia over the Last Decade

E. G. Mozolevskaya[1], *I. A. Utkina*[2*]*and L. S. Matusevich*[3]

[1]Department on Ecology and Forest Protection of the Moscow State University of Forest
[2]The Institute for Forest Science of the Russian Academy of Sciences
[3]Department for Forest Fund Protection of the Administration of Conservation, Protection and Reproduction of Forest Fund, Ministry for Natural Resources of the Russian Federation

---

Abstract

Procedures for obtaining data about the sanitary state of forests in Russia are discussed briefly. The single parameter of official statistical accounts is the area of forests that have been killed or that serve as foci for pest and disease outbreaks. However, this scant information allows us to observe the variation over time of forested areas that have been killed by several unfavorable factors: insects, wild fauna (ungulates and rodents), diseases, weather, and human activity. The dynamics of outbreaks of the most important needle- and leaf-eating insects in the Russian territory from 1990-2001 are discussed.

Materials and Methods

Forms of Compulsory Statistical Accounts Related to Forest Pathology

The composition of generalized data about disturbances in the state of Russian forests is determined by the form of statistical accounts approved by the State Statistical Committee of Russia. All subjects of the Russian Federation (RF) are obliged to provide information on the use of forest protection, the areas of forests that have been killed in total and by individual causal agents, along with the data on areas of foci of forest pests and diseases. This form, "the dynamics of areas of killed stands and foci of pests and diseases (ha) in the territory of the Russian Federation," designated as "Form No. 12" (within the list of all affirmed forms of statistical accounts) must be utilized by all forestry enterprises.

These data are published annually in the "Protection of Environment" issued by the State Statistical Committee of Russia, in the State Reports about the Condition of Environment of Russia and its Regions, issued by the Ministry of Natural Resources, and are also presented periodically on the web site of the Ministry.

This information is the only official source available and is absolutely necessary for one to understand the general ecological situation in Russian forests and to document areas of distribution of all disturbances caused by biotic, abiotic and anthropogenic factors. The value of these data can be enhanced further by adding data about monitoring the impact of forest pathogens; these data will be collected in the future.

Table 1 is a shortened version of the compound table containing statistical data on areas of stands killed by different factors of unfavorable impact (FUI) and areas of foci of pests and diseases over last 12 years (1990-2001). Data about forest protection measures (*lines 01-11)*, and some other lines which contain no useful information (for example, *line 20,* area of foci of pests + diseases, *line 35,* the total area of foci of certain pests including such different species as wood-eating pests, chafers, bark bugs, and others) have been eliminated.

Some explanation about the rules for filling out Form No. 12 is necessary in order to interpret that data that are presented. *Line 12,* the total area of stands killed, also includes the area of killed forest plantations, the area of dead stands to be felled in the course of a clear sanitary cutting, and stands destroyed by forest fires and other FUI; (*lines 13-19*) the main causes of dieback in stands; *line 16* includes the area of stands killed by unfavorable weather conditions (drought, frosts, changing the water-table level, wind throw, snow breakage); in the last case instead of " wind throw, snow

Table 1.—The area of stands killed and the area of pest and disease foci, by years (10^3 ha)*

Parameters	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
12. All dead stands, including those killed by	**158.5**	**419.3**	**492.1**	**171.2**	**274.5**	**162.1**	**515.1**	**254.3**	**279.2**	**299.5**	**699.8**	**486.4**
13. … pest insects	2.4	8.9	19.2	13.2	25.4	78.4	194.5	3.0	3.1	3.6	20.3	15.5
14. … wild animals.	13.3	9.3	9.3	3.9	5.3	4.5	1.0	1.5	1.1	0.2	1.2	0.7
15. … diseases	0.7	1.9	1.4	0.8	1.1	1.9	3.5	2.2	5.1	6.0	5.5	11.3
16. … weather conditions	45.0	184.7	86.9	19.6	15.9	22.9	24.2	18.6	15.3	20.1	33.6	11.0
17. … forest fires	95.4	213.4	313.1	131.6	225.3	53.1	291.0	227.8	245.9	268.4	637.4	127.1
18. … anthropogenic factors	1.6	1.2	62.2	2.2	1.4	1.5	0.8	1.1	8.7	1.2	1.9	161.4
19. …including industrial pollution	0.6	0.3	61.8	1.1	0.3	0.6	0.2	0.1	0.1	0.1	0.1	159.5
The area of foci of pests and diseases												
20. Needle-eating insects, including	**292.7**	**868.4**	**342.3**	**198.5**	**458.5**	**892.1**	**449.8**	**333.0**	**358.7**	**373.6**	**6518.4**	**10181.5**
21. …Dendrolimus sibiricus	4.2	84.6	140.9	12.2	145.1	574.8	245.6	81.7	120.8	152.3	6257.6	6858.5
23. … *Dendrolimus pini*	5.2	12.0	7.0	6.3	11.4	11.0	8.4	10.4	8.7	9.3	23.8	3.2
24. … *Lymantria monacha*	59.7	23.5	53.0	37.7	27.6	24.4	24.3	41.2	49.6	61.9	73.7	36.9
25. … *Bupalus piniarius*	11.7	12.0	11.0	16.7	149.9	36.2	5.3	21.1	17.7	5.6	4.6	140.1
26. … *Panolis flammea*	0.6	0.3	0.4	0.3	0.2	0.6	0.3	3.3	11.2	3.0	31.0	45.1
27. … *Diprion pini*	18.0	9.0	22.3	22.3	18.9	34.9	21.4	24.2	10.8	14.7	11.9	9.6
28. … *Neodiprion sertifer*	105.3	55.4	40.6	53.9	35.8	67.5	29.5	85.4	56.6	50.2	39.4	51.4
29. … *Acantholyda stellata*							27.3	32.8	32.4	35.9	42.5	8.1
… *Boarmia bistortata*							67.8	4.0	0	0	0	0
30. Leaf-eating insects, including	**1021.4**	**1832.5**	**716.0**	**1045.5**	**1351.9**	**1070.4**	**1624.8**	**1671.2**	**1084.1**	**974.1**	**623.2**	**1217.9**
31. … *Lymantria dispar*	479.7	1379.6	265.9	421.3	1078.7	855.2	1427.1	1310.8	755.8	571.5	238.6	985.4
32. … *Euproctis chrysorrhoea*	27.9	7.8	6.2	4.9	1.3	0.8	5.7	12.3	1.2	1.6	1.5	6.4
33. … *Tortrix viridana* and other leaf rollers	475.7	416.2	375.2	545.9	220.9	184.9	121.3	123.7	98.9	78.6	84.0	123.9
36. Wood-eating insects	**36.1**	**39.8**	**48.4**	**50.0**	**33.7**	**19.3**	**34.8**	**58.2**	**278.6**	**191.7**	**201.7**	**183.4**
37. *Melolontha* and other chafers	**107.7**	**106.9**	**105.7**	**107.5**	**101.5**	**99.9**	**93.4**	**83.4**	**77.5**	**76.2**	**79.0**	**76.3**
38. *Aradus cinnamomeus*	**20.6**	**19.3**	**19.7**	**17.2**	**16.8**	**15.5**	**12.7**	**10.2**	**9.7**	**9.0**	**7.7**	**5.5**
39. Rodents	**5.3**	**3.2**	**2.2**	**3.7**	**5.5**	**59.6**	**3.5**	**2.7**	**5.7**	**3.4**	**2.5**	**2.4**
41. Diseases, including	**79.2**	**163.4**	**207.8**	**239.1**	**1467.0**	**273.6**	**943.5**	**808.7**	**852.8**	**954.1**	**966.3**	**1081.1**
42. … root rot	44.0	49.7	72.0	87.9	99.4	115.1	136.1	136.7	134.8	138.9	145.4	160.8

*All data in the Form No. 12 must be given in ha, here they are presented in thousands ha to be more convenient for consideration

Table 2.—Areas of Russian forests killed by groups of factors (10^3 ha / percentage)

Year	Factors of unfavorable impact					
	insects	wild animals	diseases	weather	Fires	anthrop.
1990	2.4 / 1.5	13.3 / 8.4	0.7 / 0.4	45.0 / 28.4	95.4 / 60.2	1.6 / 1.0
1991	8.9 / 2.1	9.2 / 2.2	1.9 / 0.4	184.7/ 44.0	213.4 / 50.9	1.2 / 0.3
1992	19.2 / 3.9	9.3 / 1.9	1.4 / 0.3	86.9 / 17.7	313.1 / 63.6	62.2 / 12.6
1993	13.2 / 7.7	3.9 / 2.3	0.8 / 0.5	19.6 / 11.4	131.6 / 76.9	2.2 / 1.3
1994	25.4 / 9.3	5.3 /1.9	1.1 / 0.4	15.9 / 5.8	225.3 / 82.1	1.4 / 0.5
1995	78.4 / 48.3	4.5 / 2.8	1.9 / 1.2	22.9 / 14.1	53.1 / 32.8	1.5 / 0.9
1996	194.5 / 37.8	1.0 / 0.2	3.5 / 0.7	24.2 / 4.7	291.0 / 56.5	0,8 / 0,2
1997	3.0 / 1.2	1.5 / 0.6	2.2 / 0.9	18.6 / 7.3	227.8 / 89.6	1.1 / 0.4
1998	3.1 / 1.1	1.1 / 0.4	5.1 / 1.8	15.3 / 5.5	245.9 / 88.1	8.7 / 3.1
1999	3.6 / 1.2	0.2 / 0.1	6.0 / 2.0	20.1 / 6.7	268.4 / 89.6	1.2 / 0.4
2000	20.3 / 2.9	1.2 / 0.2	5.5 / 0.8	33.6 / 4.8	637.4 / 91.1	1.9 / 0.3
2001	15.5 / 3.2	0.7 / 0.1	11.3 / 2.3	11.0 / 2.3	127.1 / 26.1	161.4 / 33.2

breakage" which is the consequence of the impact it would be more correctly to say "the impact of wind and snow"; *line 20* includes data about needle-eating pests, and *line 30* includes data about leaf-eating insects. The sum of columns attributed to certain pest species can be less than the figures provided in *lines 20* and *30,* because the total areas can include damage by other species that are not listed; the instructions allows us to add new lines with data about the foci of pests that are important in certain years for certain regions, for example, the data provided for *Boarmia bistortata*.

Line 41 contains data about forest diseases in addition to the root rot mentioned in *line 42*: these include *Armillaria mellea* root rot, the canker (pathogen *Peridermium pini*), the Dutch elm disease (pathogen *Ceratocystis ulmi*), the oak wilt (pathogen *C. roboris*) which affect predominantly adults stands of various species, the pine shoot rust (pathogen *Melampsora pinitorqua*), disease of pine underwood and young plants in nurseries and plantations.

If stands, forest plantations, and nurseries are infected by several species of pests or diseases, it is recommended to mention the area infected by the dominant species.

Another supplementary form, Form No. 22 for forest-pathology information and accounting is prepared in November for forest management administration. It is then used for planning forest protection activities for the coming year. This form presents information about the area of foci at the beginning of the year, the area that is newly infested, the area of foci that was abolished including that which was eliminated by natural factors, the area of foci at the end of year, and what portion of it "needs to be treated". However, these kinds of data are not adequate for use for scientific purposes.

Table 2 presents data transformed from Table 1 followed by the contribution (in percent) of each group of factors that cause the death of forests. These data suggest that forest fire is the most dominating factor and that their impact is catastrophic: 51 to 91% of forests were killed between 1990—2001; the proportion killed by fire was less than 50% only in 1995 and 2001.

The contribution of insects in the death of forests seems to be insignificant as compared to fire and caused less than 10% mortality during the period of this report. The exception occurred in 1995-1996 after an outbreak of *Dendrolimus sibiricus* in Siberia, which caused 38-48% mortality of trees. It is likely that in current and succeeding years, the area of forests killed may increase significantly as a result of recent outbreaks of *D. sibiricus* and other needle-eating insects in the Asian part of Russia.

These two forms, No. 12 and No. 22, are prepared for forests of all subjects of the RF and separately for certain especially preserved territories. The territory of Russian forests are divided into 12 regions (Lesnoi Fond Rossii, 1999): Pribaltiiskii (the Baltic region), Severnyi (the Northern region), Severo-Zapadnyi (the North-Western region), Tsentral'nyi (the Central region), Volgo-Vyatskii (the Volga-Vyatka interfluve region), Tsentral'no-Chernozyomnyi (the Central Black Soil region), Povolzhskii (the Volga region), Severo-Kavkazskii (the Northern Caucasus region), Uralskii (the Ural region), Zapadno-Sibirskii (the Western Siberia region), Vostochno-Sibirskii (the Eastern Siberia region), and Dal'nevostochnyi (the Far East region). The classification of separate subjects of the RF to these regions is made in the above-mentioned reference rather conventionally, but it insight about the distribution of certain disturbances within different regions of Russian forests.

Dynamics of foci of insect defoliators

Table 1 presents data about areas of outbreak foci of the most important needle- and leaf-eating insects included in the form of compulsory statistical accounts. The remaining tables provide information about the distribution of foci of defoliators by regions. Only data for infested areas exceeding 100 ha are included.

Table 3.—Dynamics of foci of *Dendrolimus sibiricus* by region, 10^3 ha

Year	Regions			
	Ural	West Siberia	East Siberia	Far East
1990	0.0	2.6	0.8	0.8
1991	0.9	27.1	45.4	11.2
1992	0.9	76.8	62.0	1.2
1993	0.0	6.8	5.4	0.0
1994	0.0	13.7	131.4	0.0
1995	0.0	5.1	569.7	0.0
1996	0.0	7.7	107.3	130.6
1997	0.0	10.8	70.0	0.9
1998	0.0	34.6	85.8	0.4
1999	0.0	54.3	76.2	21.7
2000	0.7	238.6	77.7	5940.7

Table 4.—Dynamics of foci of *Dendrolimus pini* by region, 10^3 ha

Year	Regions					
	Black Soils	Volga	Northern Caucasus	Ural	West Siberia	East Siberia
1990	0.0	0.1	1.1	4.0	0	0.0
1991	9.0	0.1	2.8	0.1	0	0.0
1992	2.9	0.1	3.9	0.1	0	0.0
1993	3.1	0.1	3.0	0.1	0	0.0
1994	2.4	3.7	5.2	0.1	0	0.0
1995	0.2	3.5	7.2	0.1	0	0.0
1996	1.8	1.3	5.2	0.1	0	0.0
1997	0.6	0.6	8.9	0.0	0	0.0
1998	1.2	0.5	6.8	1.1	0	0.0
1999	1.1	0.2	3.8	1.3	0	3.0
2000	0.8	0.2	0.9	1.3	18.7	2.0

Table 5.—Dynamics of foci of *Bupalus piniarius* by region, 10^3 ha

Year	Regions					
	Northwestern	Volga	Northern Caucasus	Ural	West Siberia	East Siberia
1990						
1991	0	0	0.4	3.4	0.1	0
1992	0	0	0.4	4.8	0.1	0
1993	0	0.1	1.4	2.6	12.5	0
1994	0.2	0	1.4	2.6	16.3	0.4
1995	1.6	0	1.4	1.2	1.1	0
1996	2.2	1.8	1.4	24.0	0	0
1997	2.2	1.8	3.0	113.6	0	0
1998	2.2	1.8	2.2	3.6	3.0	0
1999	0.2	1.8	2.1	2.3	3.0	1.2
2000	0	1.8	3.3	3.8	3.0	0
2001	0	1.8	0.8	6.0	3.0	0

Table 6.—Dynamics of foci of *Panolis flammea* by region, 10^3 ha

Year	Regions				
	Centr.	Black Soil	Volga	Northern Caucasus	Ural
1990	0.0	0.0	0.0	0.0	0.4
1991	0.0	0.0	0.0	0.0	0.4
1992	0.0	0.0	0.0	0.0	0.4
1993	0.0	0.0	0.0	0.0	0.3
1994	0.0	0.0	0.0	0.0	0.2
1995	0.4	0.0	0.0	0.0	0.2
1996	0.1	0.0	0.0	0.0	0.2
1997	0	0.0	0.0	3.2	0.1
1998		0.0	0.7	10.4	0.0
1999		1.3	0.7	1.1	0.0
2000		6.2	6.1	18.7	0.0

Table 7.—Dynamics of foci of *Neodiprion sertifer* by region, 10^3 ha

Year	Regions							
	North	Central	Black-Soils	Volga	Volga-Vyatka	Northern Caucasus	Ural	West Siberia
1990	0.0	1.7	10.1	15.8	2.0	9.1	8.3	59.9
1991	6.7	1.6	4.8	11.4	0.7	2.1	14.8	13.3
1992	5.5	0.0	1.4	13.4	0.0	6.7	10.5	3.1
1993	5.4	0.0	2.4	20.7	0.0	10.2	9.5	5.7
1994	0	0.0	4.1	12.2	0.0	7.6	3.5	8.3
1995	0.1	0.0	2.6	7.5	0.0	7.4	1.3	48.8
1996	0.1	0.0	2.4	16.2	0.0	9.3	0.8	0.7
1997	0.1	0.0	20.3	29.8	0.0	23.8	0.6	10.8
1998	0.0	0.0	11.6	24.8	0.0	12.8	1.9	5.3
1999	0.0	0.0	8.2	16.4	0.0	17.7	2.1	5.7
2000	0.0	0.0	6.9	13.3	0.0	8.9	6.5	3.9

Table 8.—Dynamics of foci of *Lymantria dispar* by region, 10^3 ha

Year	Regions							
	Baltic	Central	Volga	Northern Caucasus	Ural	West Siberia	East Siberia	Far East
1990	0.0	0.0	40.9	248.2	12.2	0.0	9.9	0.0
1991	0.0	0.0	25.9	64.9	10.6	0.0	1205.6	0.0
1992	0.1	0.0	9.9	77.5	128.5	3.3	0.0	0.1
1993	0.6	0.0	3.7	100.1	77.0	13.4	0.0	0.2
1994	0.2	0.0	4.1	192.8	304.6	67.1	0.0	0.1
1995	1.6	0.0	5.3	180.8	295.7	122.9	0.4	0.0
1996	1.4	0.0	24.9	327.1	588.0	52.9	128.1	0.0
1997	0.2	48.8	22.6	283.0	80.5	197.8	322.4	0.0
1998	0.0	118.0	19.6	176.5	40.0	170.5	84.6	0.2
1999	0.0	63.7	0.3	165.2	94.5	172.9	0.0	0.2
2000	0.0	8.3	0.2	41.1	46.0	104.7	2.5	0.2

Forest pathology monitoring (FPM) in the Russian Federation

In the document "The Concept of Forest Protection and the Basis for the Organizing Structure of the Service for Forest Protection in the Russian Federation," developed by Russian specialists in entomology and phytopathology by order of the Russian Federal Service for Forest Management, it was mentioned as early as 1993 that the structure, content, and reliability of official statistical data about the condition of Russian forests both totally and by regions are inadequate for preparing analytical reviews and forecasts, and consequently for providing opportunities for effective forest management. Data on tree mortality in forests caused by pests and diseases were considered by authors as the least reliable. The situation will be improved only by implementing the specialized system for assimilating data on FPM that has been developed by workers from the Russian Center on Forest Protection in recent years. Since the beginning, this process requires a more detailed interpretation of data on the influence of pests, diseases and other FUI on the condition and death of forests from the statistical accountings.

The system of FPM in Russia has developed rapidly in recent years. The Statement on FPM in Russian forests (1997) proclaims as its goal the development of a system for an operative and permanent survey on the condition of forests, disturbance of their stability caused by pest organisms and other natural and anthropogenic factors over time, so that timely information can be provided about the condition of stands and the need for planning and applying forest protective measures.

The National Center for the forest pathology monitoring established in 1990 by the All-Union Scientific Center for Forest Resources, issued regular reports on the sanitary condition of Russian forests in 1991, 1992, and 1993. In 1994 the report was issued by the Moscow specialized enterprise for forest pathology. After a brief interruption caused by the re-organization of the Service on Forest Protection, the reports of the sanitary condition of Russian forests have been issued by the Russian Center for Forest Protection in 1999—2001.

The Service of Forest Protection has recently received "Guidance for the Organization and Execution of Forest Pathology Monitoring" (2002), which will promote further its development and improvement.

References Cited

Guidance for organization and execution of forest pathology monitoring in Russian forests. Ministry for Natural Resources, the RF, Department for Utilization and Regeneration of the Forest Fund. 2000, 86 p. [in Russian]

The Protection of Environment. The statistical collection. M. Goskomstat. 1998. 202 p. [in Russian]

Review of the Sanitary State of Russian Forests in 1990, 1991, 1992. The National Center for Forest Pathology Monitoring. M., 1990 (33p.), 1992 (41 p.), 1993 (62 p.) [in Russian]

Review of the Sanitary State of Russian Forests in 1993. Moscow Special Enterprise for Forest Pathology Survey. M., 1994. 126 p. [in Russian]

Review of the Sanitary State of Russian Forests in 1998, 1999, 2000. The Russian Center for Forest Protection. Pushkino: 1999 (33 p.), 2000 (34 p.), 2001 (46 p.) [in Russian]

The Sanitary Rules in Forests of the RF. (1998). The Forest Legislation of the Russian Federation. M., 1999. P. 310-329. [in Russian]

Host-plant Relationships and Comparative Ecology of Conifer-feeding Budworms (*Choristoneura* spp.)

V.G. Nealis

Natural Resources Canada-Canadian Forest Service, Pacific Forestry Centre,
506 W. Burnside Rd. Victoria, British Columbia, Canada, V8Z 1M5
vnealis@pfc.forestry.ca

Abstract

North American budworms are eruptive insect species that form intimate ecological relationships with their host trees. Population data for the eastern spruce budworm and jack pine budworm implicate natural enemies as primary determinants of population collapses. Yet the dynamics of these two species display markedly different temporal and spatial characteristics. One possible explanation for these differences is variation in the strength of the density-dependent relationship between the budworms and their host trees via the effects of defoliation on the adequacy of the host tree. The proposed density-dependent relationship operates through the concept of risk of dispersal. In the jack pine budworm, previous defoliation reduces subsequent production of pollen cones by the host tree. These pollen cones are critical to survival of early stages of the jack pine budworm so that defoliation has an immediate negative feedback on survival of future generations of budworm. In contrast, the eastern spruce budworm is less reliant on pollen cones for early-season survival because of their capability of mining old needles. However, defoliation over several years creates non-host gaps in the forest and may also increase early-season mortality resulting from dispersal of small larvae. Thus host-plant relationships may be density-dependent sources of mortality in these life systems via their effect on the risk of mortality resulting from dispersal. Variation in the strength of this density-dependent interaction contributes to differences in the dynamical behavior of the different budworm species.

The eastern spruce budworm, *Choristoneura fumiferana* (Clemens), and the jack pine budworm, *C. pinus pinus* Freeman, are eruptive species that periodically cause severe defoliation of their respective host trees throughout northern conifer forests east of the Rocky Mountains in North America. These species share a near-identical geographic range, life cycle and seasonal ecology. Eggs are laid in masses on the needles of the host trees in mid-summer. Eclosion occurs within two weeks. Neonates do not feed but settle in sheltered niches on the tree where they pass the winter. Larvae emerge in early spring, typically before the current-year buds have flushed. This precocious emergence forces the budworms to feed temporarily on alternative food sources. Both species readily utilize pollen cones (male strobili) of the host tree which typically develop in advance of vegetative shoots. Eastern spruce budworm may also mine old needles (McGugan 1954). Jack pine budworm, however, appears unable to mine the needles of its host (Nealis 1995). In all cases, extensive movement may be associated with this foraging and budworms are frequently observed ballooning on silken threads between trees at this time of year (Sanders 1991). As current-year buds expand and flush, budworms web together the needles, feed for the remainder of their larval period with relatively little further movement, and pupate near these feeding sites. During these later feeding and pupal stages budworms are attacked by a variety of natural enemies (Sanders 1991, Nealis 1991,1995).

Most losses to budworm populations occur during the early larval stages before they establish feeding sites. This paper examines the ecological relationship between the host-plant and mortality of budworms early in the season. The hypothesis presented is that defoliation of the host plant by high population densities of budworms increases the risk of mortality to subsequent budworm generations by increasing the likelihood of early-season dispersal and/or the relative rate of mortality that results from this dispersal, i.e. by increasing the risk of dispersal. Thus, early-season dispersal losses can be viewed as a lagged, density-dependent mortality factor in the budworm system. Variation in the strength of the host-plant relationship and dispersal losses result in differences in the observed dynamics of these budworms.

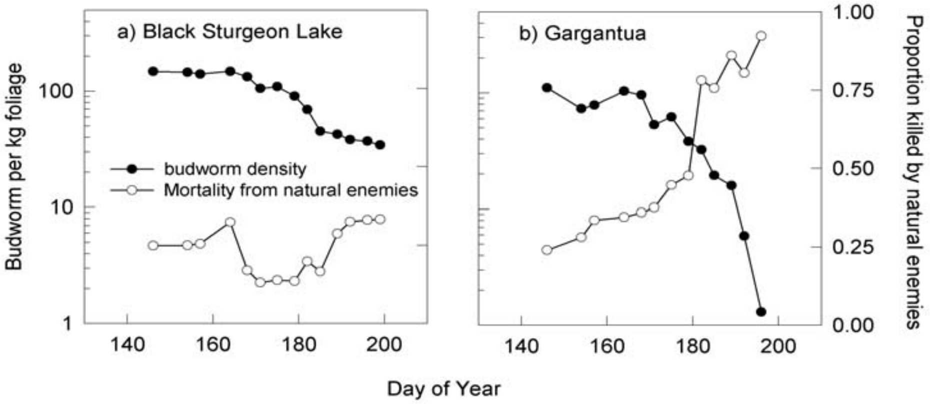


Figure 1.—Changes in density of eastern spruce budworm (solid circles) and mortality resulting from natural enemies (open circles) in a) a continuing outbreak at Black Sturgeon Lake; and b) a collapsing outbreak at Gargantua, Ontario, Canada in 1985.

Population Dynamics

Royama (1984) concluded that the primary fluctuation in populations of the eastern spruce budworm, the 35-year regular oscillation in density, is caused by lagged, density-dependent mortality occurring in the late-larval and pupal stages. The most probable agents responsible for this mortality are generalist predators, parasitoids, and possibly pathogens. This interpretation is consistent with theoretical models which view cyclic population behavior as the result of lagged, numerical responses of predators to changes in prey density (Royama 1992). Further support for this view comes from the apparent lack of the effect of major host-trees, balsam fir (*Abies balsamea*) and spruces (*Picea* spp.), on the primary fluctuation in eastern spruce budworm populations. When budworm kills all of the trees in a stand, populations necessarily collapse. But populations also collapse in forests where mortality of host trees is not complete (Royama 1984, Nealis and Régnière 2003). Experimental work by Lawrence et al. (1997) showed that plant quality does play an important role in the ecological relationship between the budworm and its host tree but it is a seasonal dynamic interaction not clearly related to temporal patterns in the density of eastern spruce budworm populations.

Overall, then, eastern spruce budworm population dynamics are viewed as “top-down” with regulation of populations imposed by “higher” trophic levels. Examples that illustrate these density and mortality patterns from outbreaks in northern Ontario, Canada, in 1985 are provided in Fig. 1. Continuing outbreaks such as Black Sturgeon Lake have little mortality caused by natural enemies and their densities do not change greatly over the generation (Fig. 1a) whereas collapsing populations such as observed at Gargantua display dramatic reductions in density associated with a sharp increase in mortality from natural enemies at the end of the feeding period (Fig. 1b). A similar pattern of increased parasitism in the late-larval stages during collapses of outbreaks of the jack pine budworm was documented by Nealis (1991). Further, the same species of generalist natural enemies in the same rank order of relative abundance were implicated in both the eastern spruce budworm and jack pine budworm systems (Nealis 1991, 1995).

Despite their similar life cycle and ecology, the population dynamics of the eastern spruce budworm and jack pine budworm differ in an important aspect. Whereas eastern spruce budworm populations display long-term cyclicity with outbreaks synchronized over hundreds of thousands of ha (Royama 1984), jack pine budworm outbreaks are short-lived and more sporadic (McCullough 2000). Where cyclical behavior in jack pine budworm populations has been detected, it is associated more with abiotic conditions such as fire history, weather, and soils than with natural enemies (Volney and McCullough 1994, McCullough 2000). Moreover, outbreaks of the jack pine budworm show no particular synchrony with eastern spruce budworm outbreaks despite the fact that both species share an identical guild of natural enemies and geographic sympatry.

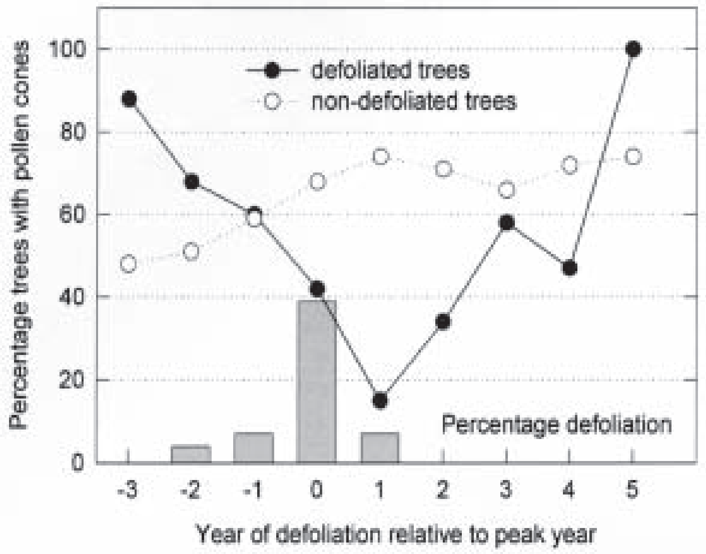


Figure 2.—Percentage of jack pine trees producing pollen cones in non-defoliated stands (open circles) and in stands defoliated by the jack pine budworm (closed circles). Histogram illustrates mean percentage defoliation in defoliated stands standardized by year of peak defoliation (i.e. year of peak defoliation = 0). Data derived from 180 sample plots in Ontario, Canada. Modified from Nealis et al. (2003).

An explanation for the the short-term nature of jack pine budworm outbreaks relative to those of the eastern spruce budworm may lie in the obligatory relationship between the jack pine budworm and the pollen cones of its host tree, jack pine (*Pinus banksiana*). The preference of early-stage jack pine budworm to feed on pollen cones of its host tree was first recognized by Graham (1935). Jack pine is a prolific producer of pollen cones under most forest conditions and outbreaks of jack pine budworm often follow periods of particularly heavy pollen cone production in open stands of mature trees (McCullough 2000, Nealis et al. 2003). Nealis and Lomic (1994) demonstrated that survival of early-instar jack pine budworm is related directly to the local abundance of pollen cones in a stand; when pollen cones are sparse, mortality increases because budworms disperse from host trees and often fail to find a suitable feeding site.

Defoliation by high-density populations of the jack pine budworm, however, causes a dramatic reduction in the propensity of the host tree to produce pollen cones the following year. Comparison of pollen cone production of several thousand trees in a series of defoliated and non-defoliated sites in Ontario, Canada, over a 7-year time series revealed that the probability of a jack pine tree producing pollen cones was reduced by 85% in the year immediately following peak defoliation (Fig. 2). Thus as high-density populations of jack pine budworm cause severe defoliation, they reduce the availability of the necessary resource for future generations. The greater the severity of the defoliation, the greater the reduction in future propensity to produce pollen cones (Nealis et al. 2003). This sets up a negative feedback with a lag in the system analogous to a predator/prey cycle except in this case the jack pine budworm is the predator and the pollen cones serve as the prey.

The feedback between the effects of defoliation and subsequent survival is less evident in the eastern spruce budworm system. First, although eastern spruce budworm is similar to jack pine budworm in that it feeds preferentially on the pollen cones of its host (Blais 1952), it is far less reliant on these structures since early stage larvae also readily mine old needles (McGugan 1954) and are adapted to maximizing the nutritional value of this suboptimal food source (Trier and Mattson 1997).

There is, nonetheless, evidence of a density-related effect in the host-plant relationship that may influence dynamics of the eastern spruce budworm. Figure 3 illustrates a time series of log survival of early-stage eastern spruce budworm (log density of budworms in their first feeding site minus the log density of eggs) from Black Sturgeon Lake, Ontario, Canada. The outbreak lasted 15 years and thus provides us with an unusually long time series. Here, we see something quite different from the pattern described by Royama (1984); survival in these early stages decreases steadily throughout the time series. This trend is very gradual at first and would have been less convincing, or perhaps not

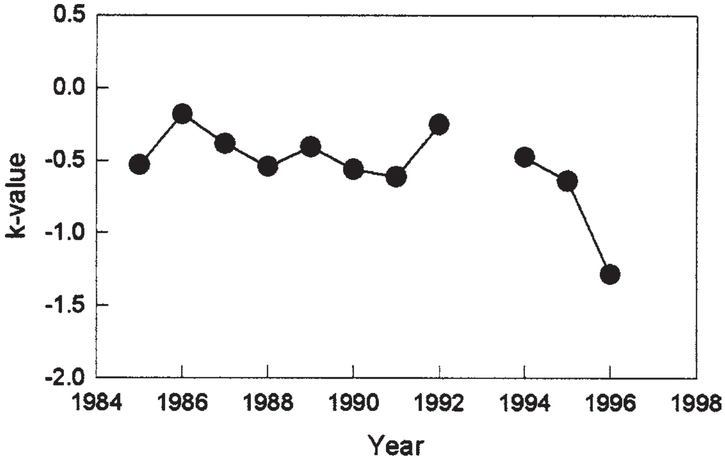


Figure 3.—Annual log difference (k-value) between density of eastern spruce budworm at the egg and early-larval stages throughout a prolonged outbreak at Black Sturgeon Lake, Ontario, Canada. An accurate estimate of egg density in 1993 is not available.

even apparent in the shorter time series that was available to Royama (1984). Note the abrupt downturn in rate of survival after approximately 10 years of defoliation in Fig. 3.

An hypothesis to explain this trend is that increasing early-season losses in the eastern spruce budworm are also the result of previous defoliation in the stand as was the case with the jack pine budworm. In the eastern spruce budworm however, the effect of defoliation becomes a factor only after repeated annual defoliation causes whole-tree mortality of host species with consequent development of canopy gaps (Kneeshaw and Bergeron 1998). Even if the rate of dispersal does not change, mortality resulting from this dispersal would increase because of the lower likelihood of dispersing larvae landing on a suitable host plant. A relative increase in the loss of early-stage budworm has been reported when stands are thinned for management purposes (Jennings et al. 1983). In the case of Black Sturgeon Lake (Fig. 3), significant tree mortality began around 1990 and accelerated throughout the remainder of the outbreak (Nealis and Régnière 2003). Population regulation thus occurs at a larger spatial scale with the eastern spruce budworm because it is through large-scale changes in stand composition that dispersal losses are mediated, rather than through small-scale changes in tree characteristics as occurs with the jack pine budworm.

Comparative dynamics

The interpretation of dynamics presented here is based on the concept of risk of dispersal. Risk of dispersal is the product of the propensity of an early-stage larva to disperse or forage for a feeding site and the likelihood of that movement resulting in mortality. It is density-dependent variation in the risk of dispersal, variation that is both intrinsic to the specific insect-tree interaction as well as within a system over time, that is key to this interpretation.

Most mortality in the life cycles of both eastern spruce and jack pine budworm occurs before the insects establish feeding sites. Because these species emerge in the spring before current-year foliage of their hosts is available, losses associated with foraging in an inadequate environment are common. Both budworm species benefit from the presence of pollen cones as these structures are available early in the season and therefore enhance survival of early larval stages. For jack pine budworm, the importance of these pollen cones is critical since feeding on previous-season foliage is not an option and the risk of mortality from dispersing in a relatively open forest situation is high. Thus, the depression of pollen cone production resulting from previous defoliation is a strong, density-dependent effect that increases the propensity of jack pine budworm to move and thereby increases its risk of dispersal. This results in a tight, fast-acting feedback between defoliation, or jack pine budworm density, and survival in subsequent generations. Outbreaks are short-lived and tree mortality is confined to suppressed and intermediate tree classes (McCullough 2000). Retention of susceptible, dominant trees in the stand and recovery of pollen cone production to pre-defoliation levels within a few years (Nealis et al. 2003) results in the potential for recurrence of outbreaks within a relatively short time-frame.

Defoliation by the eastern spruce budworm also reduces pollen cone production in balsam fir (Ghent 1958). The effect of this reduction in availability of pollen cones on eastern spruce budworm populations, however, is not apparent because of the capability of the budworm to mine needles as an alternative food source (McGugan 1954). Moreover, defoliation actually induces production of epicormic shoots in balsam fir and white spruce (Nealis and Régnière 2003) further buffering the negative effects of defoliation on survival of subsequent budworm generations. Consequently the negative feedback between herbivory-induced changes to the tree condition and survival of eastern spruce budworm is very weak; in fact, it simply functions on a longer time scale. Unlike jack pine budworm, where tree mortality tends to be restricted to suppressed trees, persistent defoliation by the eastern spruce budworm usually results in at least some mortality of dominant trees and the development of gaps within the stand (Kneeshaw and Bergeron 1998, Nealis and Régnière 2003). Thus, even if the propensity for early-stage eastern spruce budworm to disperse does not change greatly over the course of an outbreak, the likelihood of mortality resulting from that dispersal will certainly increase as more of the landbase becomes occupied by non-hosts (Jennings et al. 1983). Either way, the risk of dispersal increases slowly over time.

Conclusion

Theoretical population dynamics models tell us that when lagged, density-dependent processes operate within a persistent system, cyclical population behaviour can be expected (Royama 1992). If conifer-feeding budworm systems all have lagged, density-dependent host-plant relationships, are these sufficient to explain the eruptive nature of their populations? Are natural enemies merely following, not driving, population cycles?

A definitive answer to these questions will require a more comprehensive modelling of population dynamics. This modelling will rely on obtaining better estimates of parameters relating the host-plant interactions to changes in population densities and with sufficient estimates of the influence of natural enemies. A useful working model should reconcile the existing weight of both theoretical and empirical evidence associating population cycles with the action of natural enemies and the emergence of new data and hypotheses gained from the comparative approach provided in this paper.

If the collapse of budworm populations is caused ultimately by a *per capita* increase in the rate of mortality due to natural enemies and these same natural enemies are ubiquitous in forests inhabited by both eastern spruce and jack pine budworms, then it is necessary to add another element that explains why these different budworm species exhibit different dynamics in terms of the frequency and duration of outbreaks. The evidence of the comparative approach is that differences in the strength of the feedback between defoliation and changes in the host-tree that render the host less suitable for early-stage budworm may be that missing element. This aspect of the insect-host relationship requires more explicit inclusion in general models of budworm population dynamics. Structurally, inclusion of the insect-host relationship would result in a model with at least two density-dependent processes affecting budworm density at two distinct stages in the life cycle. The first, the insect-plant feedback outlined here, varies systematically between systems as outlined in this paper. The second density-dependent process, the impact of natural enemies, is stochastic in that many other intractable factors, such as the relative abundance of alternative hosts for generalists natural enemies, influence the numerical response of these natural enemies. The important concept here is that the likelihood of natural enemies impacting significantly generation survival of the budworm is conditioned by what happens earlier in the life stage; i.e. by the first density-dependent process. This is because an increase in apparent mortality from generalist natural enemies can be brought about by either a numerical increase in those natural enemies, or by a decrease in the abundance of budworms entering the susceptible stages.

The need to include more explicitly the insect-host interactions in budworm population dynamics has been recognized before, especially for the western spruce budworm and the jack pine budworm (Campbell 1993). Process-oriented research, however, has focused on possible changes in the quality of foliage following defoliation. One technical problem that exists is that it is not clear what constitutes meaningful measures of quality or how these may be applied to interpretation of population patterns. In contrast, measurement of quantitative or topographical changes in the host-tree at either the individual or stand level is straightforward. Combining these with sufficient measures of budworm density at the critical stages (egg mass and early-feeding stages) should prove revealing.

References Cited

Campbell, R.W. 1993. Population dynamics of the major North America needle-eating budworms. USDA Forest Service, Research Paper PNW-RP-463. 222 pp.

Blais, J.R. 1952. The relationship of the spruce budworm (*Choristoneura fumiferana* Clem.) to the flowering condition of balsam fir (*Abies balsamea* [L.] Mill.). Can. J. Zool. 30: 1-19.

Ghent, A.W. 1958. Mortality of overstory trembling aspen in relation to outbreaks of the forest tent caterpillar and spruce budworm. Ecology 39: 222-232.

Graham, S.A. 1935. The spruce budworm on Michigan pine. Bull. No. 6, School of Forestry and Conservation, University of Michigan, Ann Arbor.

Jennings, D.T., Houseweart, M.W. and J. B. Dimond. 1983. Dispersal losses of early-instar spruce budworm (Lepidoptera: Tortricidae) larvae in strip and clearcut and dense spruce-fir forests of Maine. Environ. Entomol. 12: 1787-1792.

Kneeshaw, D.D. and Y. Bergeron. 1998. Canopy gap characteristics and tree replacement in the southeastern boreal forest. Ecology 79: 783-794.

Lawrence, R.K., Mattson, W.J. and R.A. Haack. 1997. White spruce and the spruce budworm: defining the phenological window of susceptibility. Can. Entomol. 129: 291-318.

McCullough, D.G. 2000. A review of factors affecting the population dynamics of jack pine budworm (*Choristoneura pinus pinus* Freeman). Popul. Ecol. 42: 243-256.

McGugan, B.M. 1954. Needle-mining habits and larval instars of the spruce budworm. Can. Entomol. 86: 439-454.

Nealis, V. 1991. Parasitism in sustained and collapsing populations of the jack pine budworm, *Choristoneura pinus pinus* Free. (Lepidoptera: Tortricidae), in Ontario, 1985-1987. Can. Entomol.123: 1065-1075.

Nealis, V.G. 1995. Population biology of the jack pine budworm. In: Volney, W.J.A., Nealis, V.G., Howse, G.M., Westwood, A.R., McCullough, D.G. and B.L.Laishley (eds.). Jack Pine Budworm Biology and Management. Nat. Res. Canada. Inf. Rep. NOR-X-342. Pp. 55-71.

Nealis, V.G. and P.V. Lomic. 1994. Host-plant influence on the population ecology of the jack pine budworm, *Choristoneura pinus* (Lepidoptera: Tortricidae). Ecol. Entomol.19: 367-373.

Nealis, V.G. and J. Régnière. 2003. Insect-plant relationships influencing disturbance by the eastern spruce budworm, *Choristoneura fumiferana* (Clem.) (submitted).

Nealis, V.G., Magnussen, S. and A.A. Hopkin. 2003. A lagged density-dependent relationship between jack pine budworm *Choristoneura pinus pinus* and its host tree *Pinus banksiana*. Ecol. Entomol. 28: 183-192.

Royama, T. 1984. Population dynamics of the spruce budworm, *Choristoneura fumiferana.* Ecol. Monog. 54: 429-462.

Royama, T. 1992. Analytical Population Dynamics. Chapman and Hall, London.

Sanders, C.J. 1991. Biology of North American spruce budworms. In L.P.S. van der Geest and H.H. Evenhuis (eds.) Tortricid Pests, Their Biology, Natural Enemies and Control. Pp. 579-620. Elsevier Science Publishers, Amsterdam.

Trier, T.M. and W.J. Mattson. 1997. Needle mining by the spruce budworm provides sustenance in the midst of privation. Oikos 79: 241-246.

Volney, W.J.A. and D.G. McCullough. 1994. Jack pine budworm population behaviour in northwestern Wisconsin. Can. J. For. Res. 24: 502-510.

Monitoring and Risk Assessment of the Spruce Bark Beetle, *Ips typographus*

S. Netherer, J. Pennerstorfer, P. Baier, E. Führer and A. Schopf

Institute of Forest Entomology, Forest Pathology & Forest Protection, BOKU -
University of Natural Resources and Applied Life Sciences, Vienna, Austria

Abstract

A model describing development of the spruce bark beetle, *Ips typographus*, combines topo-climatic aspects of the terrain with eco-physiological aspects of the bark beetle. By correlating air temperature and solar irradiation measured at a reference station, along with topographic data and microclimatic conditions of terrain plots, topo-climatic models of a given research area are established. Within the scope of modeling, GIS is used for data processing and visualization. The model allows a monitoring, retrospective analysis and prognosis of brood development at any site and thus facilitates decision-making in forest management and the identification of hazardous zones.

Introduction

Populations of *Ips typographus,* the most severe forest pest in Central Europe, have expanded and intensified due to favorable climate change and more frequently occurring extreme weather conditions, and may increase in severity in the future. The situation has been aggravated by the fact that, after the Second World War, most of the forest stands in Central Europe were planted mainly with spruce. The total area of such plantations in Austria alone amounts to 1 million hectares. These stands are now approaching a critical age where they are attacked readily by the beetle, therefore an abundance of appropriate brood material is available to support devastating outbreaks of this bark beetle species. Control of *Ips typographus* is hindered by the fact that its outbreaks are not only restricted to secondary planted spruce forests of lowlands. As evidenced in the National Park "Bayerischer Wald" in Germany, where *Ips* infestations killed more than 75% of the spruce trees in an area of about 3,500 ha, considerable damage may occur also in the highland at altitudes from 1100 to 1400 m (Bayerische Landesanstalt für Wald und Forstwirtschaft 1999).

Materials and Methods

We developed a model which provides forest organizations the capability to monitor and forecast outbreaks of *Ips typographus* and which is comprised of the following components:

Aspects related to topo-climatology:

- topographic features such as elevation, slope, and aspect
- intensity of potential and effective solar irradiation
- temperature measurements of the air, phloem of trees (and soil)
- stand structural features such as tree species composition, canopy closure, etc.

Eco-physiological aspects of beetle development including:

- time of swarming and brood initiation
- thermal characteristics of developmental stages, i.e. effective thermal sums needed to complete development of specific instars
- voltinism including the factors inducing and terminating diapause

These parameters constitute the input data-set of a database-management system. Information is stored in the form of separate tables and the relationships needed for the model are analyzed and validated by a linked statistical package via multiple regression analyses. Developmental modeling allows us to assess times of brood initiation and actual stages of brood development at each single

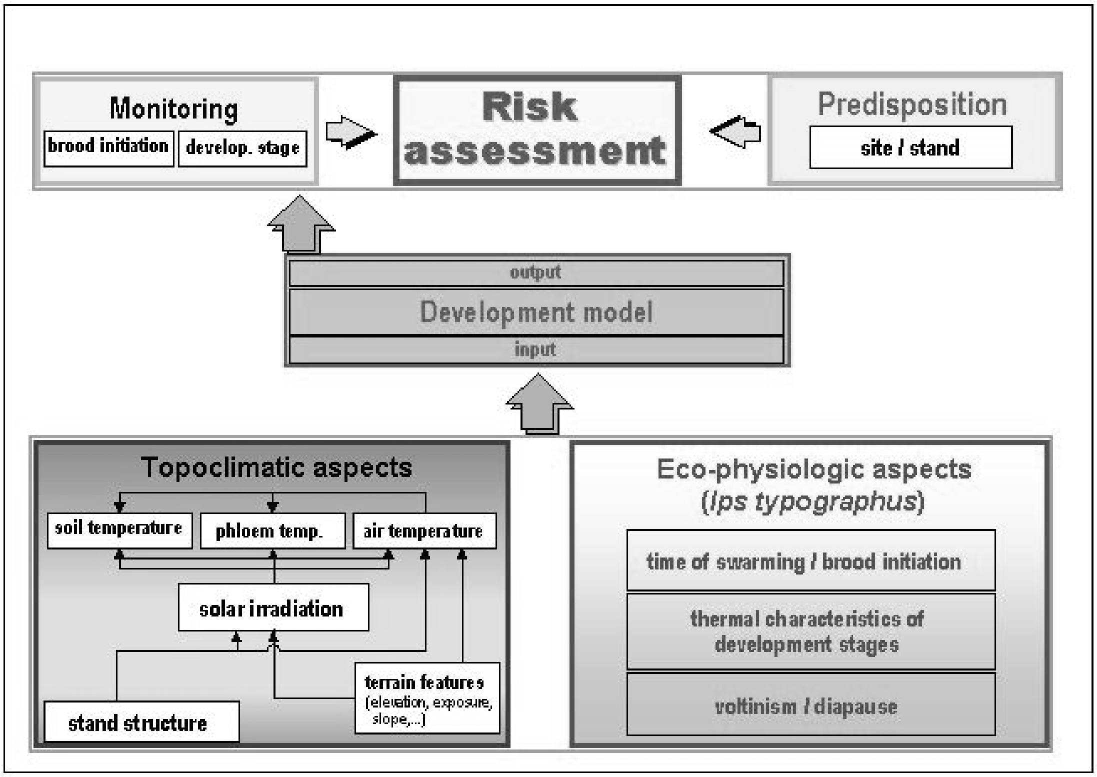


Figure 1.—Components of a model to monitor bark beetle development and to assess the risk of an outbreak.

point of the study terrain and for each time of the season. When combined with data concerning the predisposition of forest stands to bark beetle attack, this model provides managers with a comprehensive tool for risk assessment (Fig.1).

Requirement for the topo-climatic model include the following:

1. Installation of a base station (or reference station) to measure air temperature and solar irradiation
2. Installation of gauging-stations to measure air temperature at various locations in the terrain
3. Deduction of the topographic parameters (elevation, exposure, and slope) from a digital elevation model
4. Multivariate regression analysis of the data recorded at the base station, the gauging-stations, and topographic parameters

By means of resulting correlations, "close to ground" air temperature can be extrapolated for any location of the terrain (without the aspect of vegetation), based on data from the reference station.

A realistic estimation of bark beetle development requires the assessment of microclimatic conditions for the bark beetle, i.e. calculation of mean daily phloem temperatures at various aspects of felled trees and density conditions of the stand. Consequently, relations between phloem temperatures of a spruce tree, air temperature and solar irradiation were deduced (comp. Pennerstorfer 2000) from data at the gauging-stations that were established at an experimental site and by different indices of canopy closure (Fig. 2).

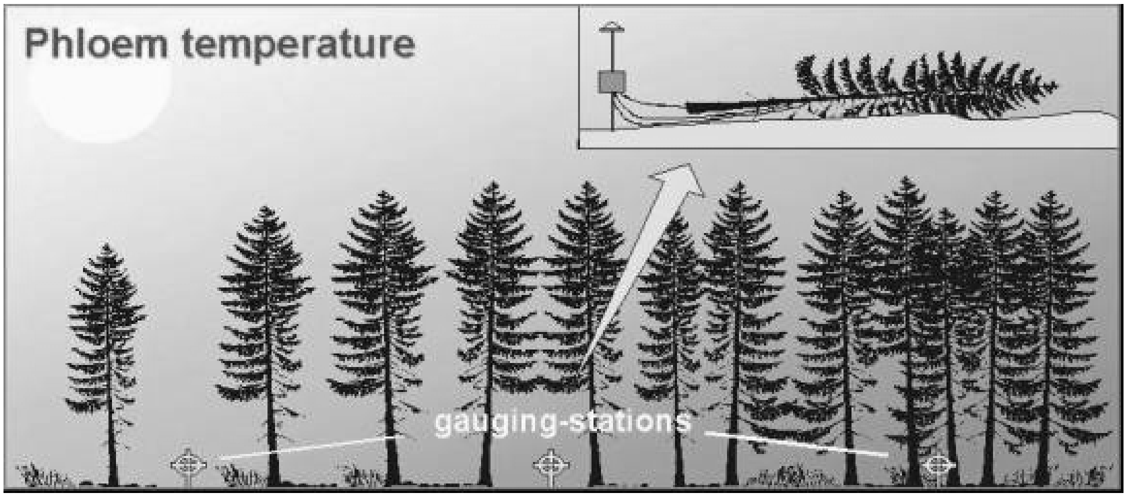


Fig.2.—Experimental design for deducing the correlation of phloem temperature at various positions on felled spruce trees and air temperature as well as solar irradiation (modified by the degree of canopy closure).

Results and Discussion

The terms resulting from the regression analyses allow us to extrapolate the phloem temperature of trees from air temperature and solar irradiation measured at the reference station, and from indices of canopy closure at the stand level. As expected, phloem temperature of the sun-exposed side of a tree is much higher than the air temperature in an open stand, while in a closed stand, the exposure of the log has no influence on cambial temperature (Fig. 3a-b).

Microclimatic conditions may differ significantly at short distances within a stand; this was shown by recordings at forest sites in the High Tatras National Park (Tanap, Slovakia) in 2001 (Netherer et al. 2002). Beetles developing in a sun-exposed tree situated at the forest edge at an elevation of 1000 m were able to complete two generations successfully, with offspring emerging up until August. Nearby in a shaded tree, offspring reached only the larval stage of the second generation within the same period of time.

Thus an estimation of the developmental progress of bark beetles within a tree must be related to “effective phloem temperature sums,” which is the heat sum above the lower developmental threshold needed for stage completion. The instar specific thresholds were determined in laboratory experiments by using the “sandwich” technique (comp. Coeln et al. 1996, Wermelinger & Seifert 1998). Based on times and rates of larval development at different temperatures, lower threshold values were derived for each stage by extrapolation and the corresponding thermal sum in day degrees was calculated.

A realistic monitoring system for the development of *Ips typographus* requires further knowledge about the following:

- Determination of voltinism, i.e. the proportion of uni-voltine and multi-voltine individuals within a population
- number of sister broods and times of brood establishment by the parental beetles
- factors regulating induction and termination of diapause
- frost resistance of hibernating stages
- thermal thresholds that induce spring flight

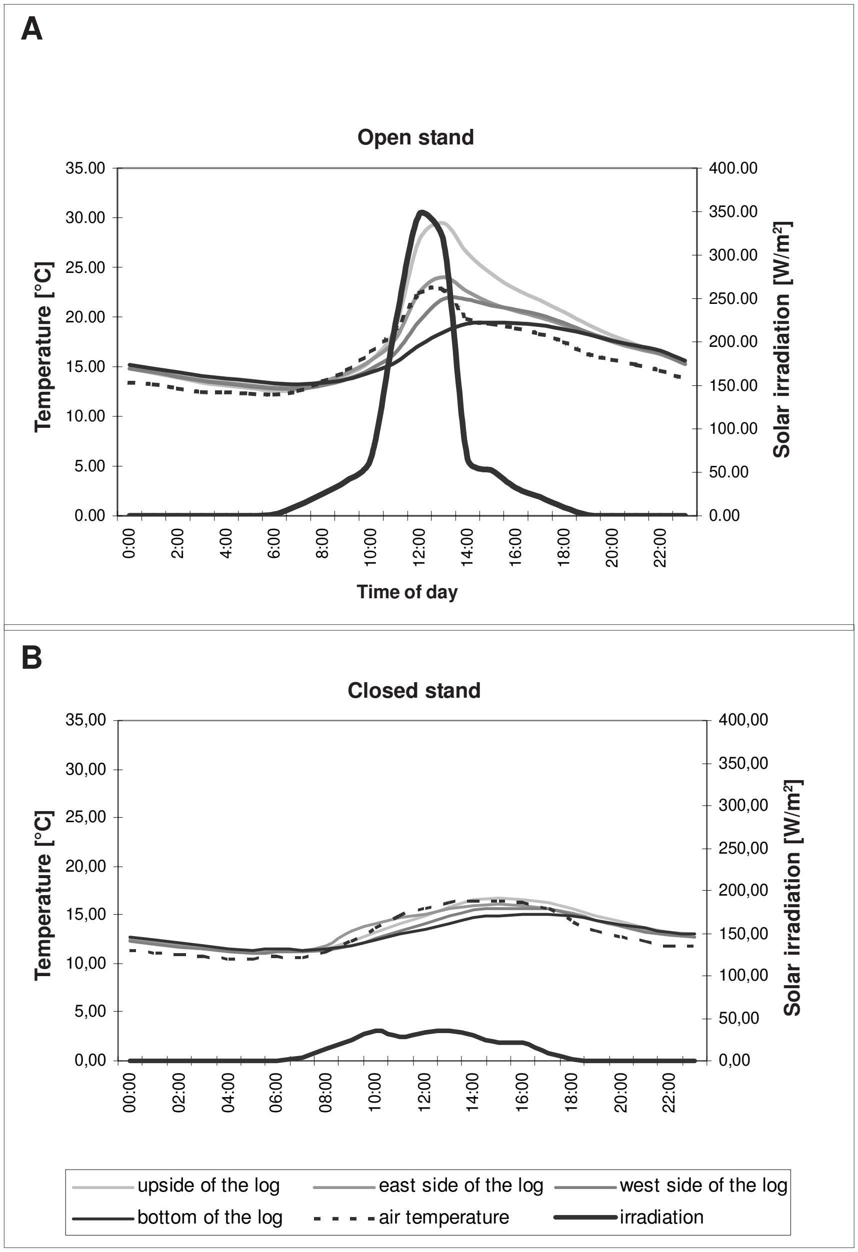
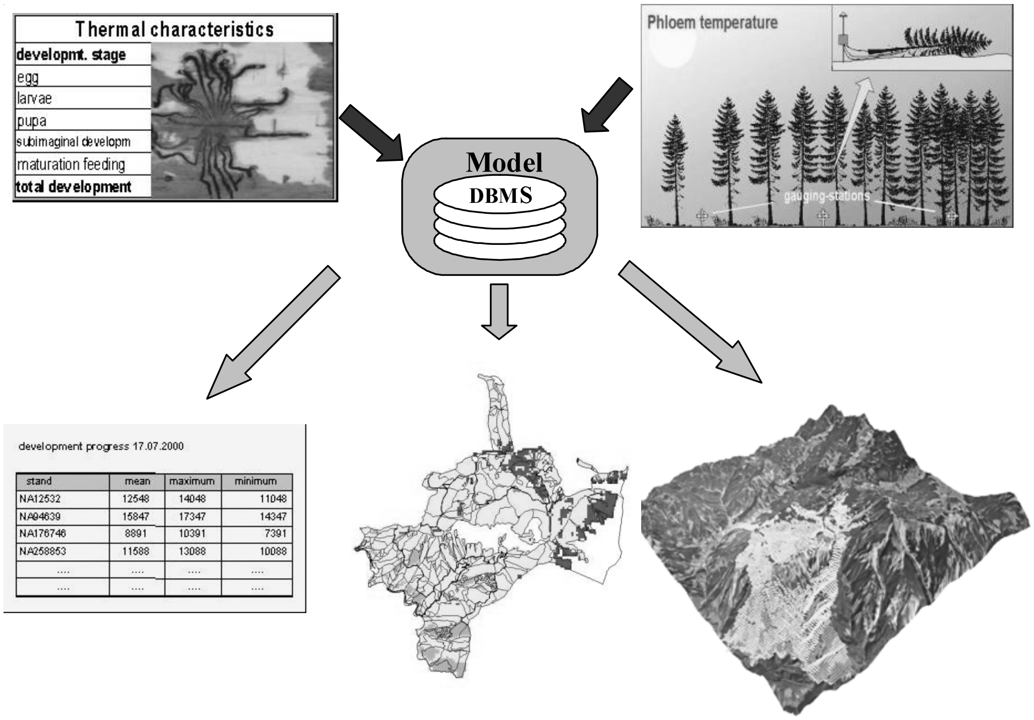


Figure 3a – b.—Phloem temperature measured on felled logs in open (A) and closed (B) stands.

The thermal values ascertained in the lab studies combined with the microclimatic conditions of studied terrain allows us to evaluate and visualize the progress of a population's development at any time of the season and for any site within the research area. The mode of representation is variable and may be realized in the form of tables, maps, or GIS supported 3-dimensional figures (Fig. 4).

The model may be implemented for various purposes which may include:

- Monitoring of insect development in general
- Modeling of scenarios to forecast insect development and to support decision-making regarding modifications and adaptations of forest management in view of climate change
- Indicating the delineation of zones of risk in forest reservations and national parks.
- Retrospective analysis of population dynamics of insects that may provide new insights in population ecology



development progress 17.07.2000

stand	mean	maximum	minimum
NA12532	12548	14048	11048
NA94639	15847	17347	14347
NA176746	8891	10391	7391
NA258853	11588	13088	10088
....	....	....	....
....	....	....	....

Figure 4.—Data input and examples of outputs.

References Cited

Bayerische Landesanstalt für Wald und Forstwirtschaft. 1999. Zur Waldentwicklung im Nationalpark Bayerischer Wald 1999. Buchdrucker-Massenvermehrung und Totholzflächen im Rachel-Lusen-Gebiet. http://www.lwf.uni-muenchen.de/veroef/veroef2000/baywa2000/index.htm

Coeln, M., Y. Niu, and E. Führer. 1996. Entwicklung von Borkenkäfern in Abhängigkeit von thermischen Bedingungen verschiedener montaner Waldstufen (Coleoptera, Scolytidae). Entomologia Generalis 21(1): 37-54.

Netherer S., J. Pennerstorfer, A. Schopf. 2002. Developmental modelling and a hazard-rating system in order to assess long-term predisposition of sites and stands to infestations by *Ips typographus*. "Tatry" final report individual partners report. http://www.vsv.slu.se/schlyter/tatry/fin_rapp/FR43BOKU.htm

Pennerstorfer J. 2000. Forstentomologisches Monitoring im Quellschutzgebiet der Stadt Wien. [Monitoring of bark beetle development in a spring protection area]. http://ifff.boku.ac.at/thermomod/

Wermelinger B, and M. Seifert. 1998. Analysis of temperature dependent development of the spruce bark beetle Ips typographus (L.) (Col. Scol.). J. Appl. Ent. 122: 185-191.

Sterile Insect Technique as a Tool for Increasing the Efficacy of Gypsy Moth Biocontrol

Július Novotný and Milan Zúbrik

Forest Research Institute Zvolen, Research Station Banska Štiavnica, Lesnicka 11, 969 23
Banská Štiavnica, Slovak Republic

Abstract

Characteristics such as the duration of the larval stage and attraction of larvae to oviposition by an endoparasitic wasp were evaluated between groups of irradiated and non irradiated gypsy moth larvae. Untreated larvae required a shorter time to reach the adult stage (both male and female). The mortality of larvae was highest at the highest irradiation dose. Pupae that developed from larvae or eggs irradiated at 110 Gy possessed a high degree of morphological abnormalities (93.18%) whereas in the control group, only 3% were affected. Larval mortality caused by *G. liparidis* reached 17% in the control group and 6 % in the irradiated treatment. The natural population density of gypsy moth at the study plot was low during the experiment and corresponded to a period of latency. Of 750 larvae collected at all sites in 2001, 21.3% were killed by parasitoids and 54.4%. by pathogens and unknown causes. There was a significant difference in the mortality of gypsy moth larvae between selected treatments under field conditions. The parasitic fly *Compsilura concinnata* was the most important parasitoid species present in the sites.

Key words: gypsy moth, *Glyptapanteles liparidis*, gamma radiation, larvae developmental time, SIT, parasitoids.

Introduction

The use of the sterile insect technique for suppressing pest populations was proposed initially by Knipling (1955). Since that time the effectiveness of using the sterile insect technique (SIT) has been demonstrated by various models and has been applied operationally and successfully against many insect species. This technique is based on overflooding the feral population with a large numbers of sterile individuals (mostly males). When there is a high over flooding ratio of sterile: feral individuals in the field, and the sterile individuals are fully competitive, the probability of mating of females by fertile males declines. The sterile insect technique is well suited for population management of the gypsy moth (*Lymantria dispar* L.) because it has one generation per year, and though males may mate several times, females mate only once and produce an egg mass which may contain from 200-1600 eggs (Reardon and Mastro 1993).

Mastro and Schwalbe (1988) summarized various methods and strategies for using SIT against the gypsy moth. Three different application techniques have been used: (1) deployment of totally sterile male pupae; (2) deployment of male pupae treated with a substerilizing dose of radiation; and (3) broadcasting F1 sterile eggs. Our objective was to evaluate a fourth method – the introduction of larvae irradiated as eggs into the field to evaluate the effect of irradiation on larval behavior and to determine if the introduction of larvae irradiated as eggs during the latency period would enhance the activity of parasitoids and predators and thus facilitate biological control of the gypsy moth. Reardon et al. (1987), reported that the release of F1 gypsy moth eggs in Maryland significantly increased parasitism by *Compsilura concinnata*. It is suggested that SIT alone or in combination with low doses of pesticides, could be used as an integrated approach to manage gypsy moth populations.

Material and Methods

For all laboratory experiments we used a laboratory strain (NJ) of the gypsy moth supplied by the USDA – APHIS Methods Development Center in Otis, MA (U.S.A.). In the field tests, field collected gypsy moth egg were received through the cooperation of the Forest Research Institute Bucharest, and Forest District Oradea, Romania.

Development of Irradiated and Non-irradiated Larvae

Gypsy moth eggs were irradiated at 10, 20, 30, 40, 50, 60, 80, or 110 Gy respectively a few days before hatching and larvae were tested for differences in their development by comparison with non-irradiated controls (Gamacel 300 of the Entomology Unit of the IAEA´s Seibersdorf Laboratory in Seibersdorf, Austria was used).

Larvae were reared initially (5 per a cup) on an artificial diet (Bell et al. 1981); from the third instar, larvae were reared separately and were checked daily. The duration of each larval stage was determined by the time of molting. Dead larvae were removed from rearing cups and recorded. Pupae that developed successfully were stored in boxes (60 cm x 60 cm x 100 cm high). The condition and health of the pupae was determined two days after pupation at which time they were weighed. The number of adults that emerged successfully was recorded.

Attraction of Sterile Gypsy Moth Larvae to Oviposition by the Endoparasitic Wasp *Glyptapanteles liparidis* L.

Gypsy moth eggs were irradiated at 50 Gy using a source of cobalt radiation located at the Roosevelt Hospital in the city of Banska Bystrica. The larvae were reared on artificial diet until they reached the fourth larval stage.

We used laboratory strains of the endoparasitic wasp *Glyptapanteles liparidis* L., which was provided by the Department of Entomology, Phytopathology and Forest Protection in the University BOKU of Vienna (Austria).

To investigate the preference of *G. liparidis*, four replicates of 25 fourth instar larvae from irradiated eggs and 25 non-irradiated fourth instars were placed in a rearing box along with five males and five females of *G. liparidis.* The non-irradiated larvae were marked with dots of yellow paint; all larvae were exposed for 24 hours. In order to create a more natural condition, a cage (50 x 50 x 75 cm, covered with monofil) containing oak twigs and arborvitae branches was placed on a table in the lab. The windows in the lab were darkened and artificial light was provided on all four sides. After the period of exposure to the wasps, the larvae were removed and placed individually in 30 ml plastic cup. Larvae were reared on artificial diet until parasitoids emerged, pupation occurred, or larvae died.

The Natural Enemy Complex of *L. dispar* on Experimental Plots

Field collected gypsy moth eggs were subjected to 25 Gy or 50 Gy respectively in early May, a few days before hatching occurred. Three study plots were established in three young (10-15 years) oak stands in the forest of Parovske Haje located near Nitra in southeast Slovakia; *Quercus cerris* and *Q. petraea* were the main tree species. The distance of the study plots from each other was about 100 m. Gypsy moth population density at the experimental sites was estimated by counting the number of egg masses per tree in one plot located about 100 m from the study plots following the method of Turcek (1956). Because of the low density of natural gypsy moth populations on the experimental plots, we supplemented the populations so that an adequate number of larvae were available for subsequent sampling. Therefore 600-1500 g of field collected, non irradiated, *L. dispar* eggs were placed in the first site in the Spring and at the same time, an equal number of irradiated *L. dispar* eggs were released in the second plot (25 Gy) and in the third plot (50 Gy). To determine levels of parasitism, *L. dispar* larvae were collected from experimental plots at different stages of larval development. We collected approximately 100 each of first and second instars (L1+L2), third and fourth instars (L3+L4), and fifth and sixth instars (L5+L6) respectively. Early instars were collected from twigs of the lower crown, stems of trees, understory vegetation, and litter. We used burlap bands to collect late instar larvae.

Table 1.—Mean development (mean ± SE) of L1-L5 gypsy moth larvae exposed as eggs to cobalt irradiation and reared on artificial diet under laboratory condition.

Treatment	Instar of larvae					SUM
	L1[a]	L2[b]	L3[c]	L4[d]	L5[e]	
10 Gy eggs	10.70 ± 1.31de	5.39 ± 1.13ab	5.38 ± 1.00d	4.58 ± 0.77e	8.42 ± 2.10b	34.49
20 Gy eggs	10.68 ± 1.18de	4.56 ± 1.00d	5.56 ± 0.58cd	5.36 ± 0.81c	6.44 ± 2.08b	32.60
30 Gy eggs	10.89 ± 1.09cd	5.24 ± 1.51abc	6.18 ± 1.46ab	4.89 ± 0.89dd	8.36 ± 2.21b	35.58
40 Gy eggs	11.08 ± 0.98c	5.28 ± 1.55abc	5.85 ± 1.14bc	5.22 ± 0.71c	8.36 ± 2.17b	35.80
50 Gy eggs	10.55 ± 0.58e	5.32 ± 0.60abc	4.82 ± 0.65e	6.75 ± 1.31a	9.43 ± 3.12a	36.87
60 Gy eggs	11.50 ± 0.56b	5.52 ± 1.26ab	5.93 ± 1.01bc	5.85 ± 1.25b	8.87 ± 3.16a	37.68
80 Gy eggs	11.42 ± 0.57b	5.10 ± 0.41bc	6.54 ± 1.24a	6.16 ± 1.00b	9.55 ± 4.05a	38.77
110 Gy eggs	12.24 ± 0.91a	5.56 ± 0.57a	6.42 ± 0.70a	5.52 ± 0.81c	9.59 ± 4.26a	39.33
Control 2002	9.45 ± 0.84f	4.95 ± 1.06cd	5.69 ± 0.93cd	4.43 ± 0.74e	8.27 ± 2.48b	32.80

Means followed by different letters (within a columns) are significantly different at P ≤0.05 by Tukey HSD. [a] *F = 49.08; df = 8. 723; P ≤ 0.01;* [b] *F = 5.95; df = 8. 716; P ≤ 0.01;* [c] *F = 14.53; df = 8. 697; P ≤ 0.01;* [d] *F = 42.85; df = 8. 679; P ≤ 0.01;* [e] *F = 3.32; df = 8. 668; P = 0.010.*

Field collected larvae were reared in groups of 20 or 30 larvae in glass cages on oak foliage under room conditions (23 -25°C). Larvae were checked daily and dead larvae as well as larvae from which parasitoids had emerged were removed. Adult parasitoids that emerged were identified and Tachinid larvae that emerged were identified as pupae (Zubrik 1998). Giemsa stained smears were prepared from dead larvae from which no parasitoid had emerged and viewed under light microscopy to determine the presence of pathogens.

Data Analyses

Analyses of variance (ANOVA) was performed on larval duration and pupal weight to determine the effects of irradiation dose (unequal number of replicates, Tukey HSD test) using SAS. The same method was used in case of *G. liparidis* weight of cocoons and weight of male and female adults. We used analyses of variance (ANOVA, equal number of replicates, LSD test) for evaluation the impact of irradiation dose on the hatching ability of eggs (SAS). Significant differences were tested at $P<0.05$.

Results and Discussion

Development of Irradiated and Non-irradiated Larvae

The duration of development of gypsy moth larvae subjected to doses of radiation (10-110 Gy) is provided in Table 1. The duration of development of all larval instars subjected to irradiation differed significantly from the controls. The control group developed 20 % faster than larvae exposed to the 110 Gy dose. Similar data were obtained by Mastro and Schwalbe (1988), who found that the developmental time of F_1 larvae from irradiated eggs varied from ca 30 days (20 Gy) to 34 days (100 Gy).

Differences in the condition of larvae and pupae were also recognized. Table 2 shows that the mortality of larvae was highest when the higher irradiation doses were used. In the control group, the mortality reached 5 % as compared to 20 % in the 60 Gy treatment. Pupae that developed from irradiated eggs showed a high degree of morphological abnormalities (93.18% at 110 Gy) as compared to 3% in the control group. The thoracic segments of the pupae were undeveloped and the antennae were also abnormal. These abnormalities affected the emergence of adults, which was very

Table 2.—Mortality of larvae, condition, and weight of pupae from irradiated and control groups of *L. dispar* fed on artificial diet in laboratory conditions (N= total No. of larvae per treatment).

Treatment	N	Larval mortality		No. of pupae	Deformed pupae		Unhatched pupae		Weight of pupae (g)	
		No	%		No.	%	No	%	Male^a	Female^b
10 Gy eggs	100	4	4.0	96	8	8.33	18	18.75	0.5739 ± 0.045a	1.6622 ± 0.163a
20 Gy eggs	100	7	7.0	93	21	22.58	26	27.95	0.4708 ± 0.088b	1.4133 ± 0.218bc
30 Gy eggs	100	12	12.0	88	20	22.72	28	31.81	0.4738 ± 0.072b	1.3571 ± 0.147c
40 Gy eggs	100	16	16.0	84	22	26.19	38	45.23	0.4631 ± 0.031b	1.2400 ± 0.110d
50 Gy eggs	50	6	12	44	8	18,18	12	27.27	0.5726 ± 0.102a	1.5149 ± 0.164b
60 Gy eggs	100	20	20.0	80	29	36.25	53	66.25	0.4605 ± 0.054b	1.2190 ± 0.181d
80 Gy eggs	50	4	8	46	24	52.17	36	78.26	0.4407 ± 0.066b	1.0568 ± 0.277e
110 Gy eggs	50	6	12	44	41	93.18	39	88.63	0.3631 ± 0.038c	0.8984 ± 0.113f
Control 2002	100	5	5.0	95	3	3.15	7	7.36	0.5574 ± 0.030a	1.8625 ± 0.940b

Means followed by different letters (within a columns) are significantly different at P ≤ 0.05 by Tukey HSD. ^{a} *F = 45.83; df = 8. 419; P ≤ 0.01;* ^{b} *F = 43.09; df = 8. 232; P ≤ 0.01*

low in all treated groups. In the control group these symptoms were not recognized. Somatic abnormalities are relatively common in the production of F1 larvae (Reardon et al. 1987).

We also evaluated how irradiation dose influenced the hatching of eggs. In the control group, the number of unhatched eggs was 9.66% whereas the number of unhatched eggs varied from 28.89-71.93% at doses over 60 Gy. This is quite important if irradiated eggs or larvae are destined for use in field augmentation (Table 3).

Attraction of Sterile Gypsy Moth Larvae for Oviposition by the Endoparasitic Wasp *Glyptapanteles liparidis* L.

Larval mortality caused by *G. liparidis* was 17% (17 of 100) in the control group as compared to 6% (6 of 100) in the irradiated groups. There was recognized differences between the total number of larvae killed by pathogens in the irradiated group as compared to the control group (48% vs. 10%).

Table 3.—Impact of irradiation dose on the hatching ability of eggs (N= number of egg masses).

Treatments	N	Average no. of eggs X ±S.D.	No. of unhatched eggs X ±S.D.	% of unhatched eggs X ±S.D.
10 Gy eggs	10	363.9 ± 87.2	41.6 ± 9.9	11.43 ± 0.52a
20 Gy eggs	10	416.6 ± 118.0	51.8 ± 15.5	12.39 ± 0.42ab
30 Gy eggs	10	436. 3 ± 88.7	61.6 ± 12.1	14.14 ± 0.56bc
40 Gy eggs	10	396.6 ± 91.1	61.8 ± 15.1	15.53 ± 0.62c
50 Gy eggs	-	- - -		
60 Gy eggs	10	411.8 ± 134.5	116.0 ± 35.6	29.18 ± 2.58d
80 Gy eggs	10	520.8 ± 159.5	249.5 ± 71.1	48.47 ± 4.36e
110 Gy eggs	10	452.1 ± 105.3	325.2 ± 66.8	72.31 ± 11.41f
Control	10	412.8 ± 110.7	39.9 ± 13.2	9.58 ± 1.47a
Statistical differences	-	-	-	SD

Means followed by different letters (within a columns) are significantly different at P ≤ 0.05 by LSD. SD= significantly different at P ≤ 0.05 by LSD. *F = 839.94; df = 7. 72; P ≤ 0.01*

Table 4.—Mortality induced by parasitoids, pathogens and total mortality in each treatment of eggs irradiated at 50 Gy.

Replication	50 Gy						Control					
	Pathogen		Parasitoids		Together		Pathogen		Parasitoids		Together	
	No.	%	No	%	No	%	No.	%	No	%	No	%
1	12	48.0	2	8.0	14	56.0	2	8.0	4	16.0	6	24.0
2	10	40.0	3	12.0	13	52.0	3	12.0	6	24.0	9	36.0
3	9	36.0	0	0.0	9	36.0	0	0.0	4	16.0	4	16.0
4	17	68.0	1	4.0	18	72.0	5	20.0	3	12.0	8	32.0
Σ	48	48.0	6	6.0	54	54.0	10	10.0	17	17.0	27	27.0

Unfortunately, females of *G. liparidis* exhibited low activity in searching for host larvae and therefore the parasitism rate was lower than expected (Table 4). We also conclude that the high mortality caused by pathogens in the irradiated group probably was responsible for the low rate of parasitism in that group. Larvae killed by pathogens died before parasitoids were able to complete their development.

There were no statistically significant differences between irradiated and control groups in the development of *G. liparidis* larvae and duration of the cocoon and adult stages (Fig. 1).

We observed some differences in the characteristics of cocoons and adults of *G. liparidis* that developed from irradiated and non-irradiated larvae. The numbers of fresh cocoons and total cocoons produced from the non-irradiated (control) groups of larvae was higher than the numbers produced from irradiated larvae. The mortality of cocoons was quite similar in both treatments. Cocoons from non-irradiated larvae produced hatched larger adults, but these differences were not statistically significant (Table 5).

Host selection experiments can be influenced by other factors, (Hoch et al. 1999). Consequently we conducted additional tests to investigate the effect of microsporidian infection in the host on parasitoid performance.

Natural Enemy Complex of *L. dispar* in Field Experimental Plots

The population density of *L. dispar* in the study plot was low during the experiment, which corresponds to the early progradation period of the pest. Of 750 larvae collected at all sites in 2001,

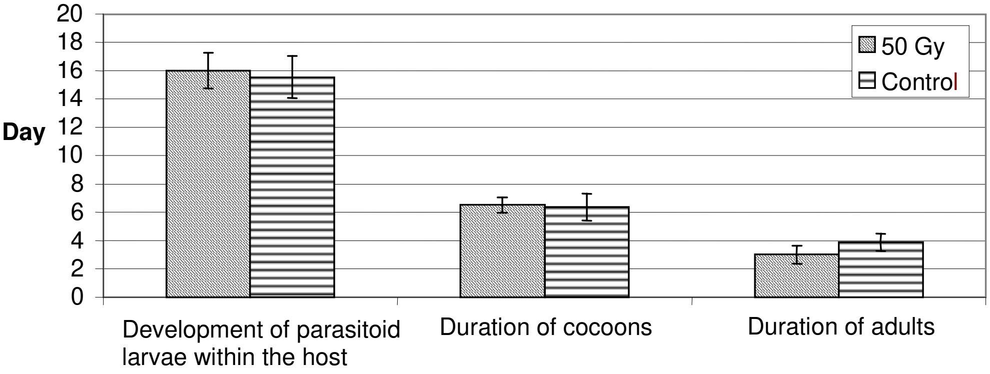


Figure 1.—Mean developmental time (means ± S.D.) of parasitoid larvae within the host, duration of cocoons, and duration of adult *G. liparidis*

Table 5.—*G. liparidis* - weight of cocoons, number and weight of male and female adults, and mortality of the cocoons for each treatment separately. Significant at P<0.05

	Weight of the fresh cocoons (g)	No. of cocoons		No of adults		Adult Weight(g)		Mortality during the cocoon stage (%)
		X	Total	M	F	M	F	
50 Gy	0.002600	29.17	175	130	14	0.000292	0.000371	17.71
Control	0.002940	33.81	541	388	63	0.000294	0.000376	16.63
Statistical differences	NS	NS	-	-	-	NS	NS	-

NS= not significantly different at P ≤ 0.05 by Tukey HSD.

Table 6.—Causes of mortality (pathogens, parasitoids and unknown) in irradiated and non-irradiated gypsy moth larvae.

Cause of mortality	Irradiated (25 Gy + 50 Gy)		Control		Irradiated and control together		Rank
	No. of larvae	%	No. of larvae	%	No. of larvae	%	
G. liparidis	5	1.0	1	0.4	6	0.8	4
C. melanoscela	10	2.0	5	1.6	15	2.0	3
G. porthetriae	6	1.2	2	0.8	8	1.0	5
Meteorus sp.			1	0.4	1	0.1	
Compsilura concinnata	16	3.2	16	6.1	32	4.2	2
Drino incospicua	1	0.2	1	0.4	2	0.2	
Blepharipa pratensis	1	0.2	1	0.4	2	0.2	
Carcelia gnava	1	0.2			1	0.1	
Zenilia libatrix			1	0.4	1	0.1	
Ichneumonidae	63	12.8	29	11.1	92	12.2	1
Total parasitoids	103	21.0	57	21.9	160	21.3	
Path + unknown	322	65.7	86	33.1	408	54.4	
Total larvae	490	100	260	100	750	100	

21.3% (160 of 750) were killed by parasitoids; the larval mortality caused by pathogens and unknown causes was 54.4% (408 of 750).

The irradiated larvae showed a very high sensitivity to the field conditions that resulted in very high mortality. Pathogens and unknown agents caused high mortality of the youngest larvae (L1+L2) and almost 100 % mortality in older larvae (L3-L5). Mortality caused by pathogens and unknown causes was much less among the control larvae (Table 6).

Parasitoids were very important as mortality agents in all experimental groups. We identified nine species of parasitoids belonging to the families Braconidae and Tachinidae. The parasitic fly *Compsilura concinnata* was the most prevalent parasitoid species. *C. concinnata* parasitizes mostly L3-L4 instars. We did not determine significant differences among species nor between the rate of parasitism between irradiated and non-irradiated larvae. The rate of parasitism was extremely similar in medium age larvae and varied from 21.7% to 26.7%. We recognized the highest diversity of parasitoids (nine species) in the control group of older larvae (L5+L6).

Acknowledgments

This study was supported by IAEA (grant 10849). We thank Dr. A. Robinson (Entomology Unit, Seibersdorf, Austria) and Dr. A. Rakytska (Roosevelt Hospital, B. Bystrica, Slovakia) for allowing us to use their irradiation source and Mr. Ilkanič for technical assistance. We also thank Dr. M. McManus for his assistance in the English language and useful comments.

References Cited

Bell, R. A., Owens, C. D., Shapiro, M., and Tardif, J. R. 1981. Development of mass rearing technology. In: Doane, C. C. and McManus, M. L. (Eds.): The Gypsy Moth: Research Toward Integrated Pest Management. U.S. Dep. Agr. Tech. Bull. 1584. 599-633.

Hoch G., Schopf, A., Maddox, J.V. 2000. Interaction between an entomopathogenic Microsporidium and the endoparasitoid *Glyptapanteles liparidis* within their host, the gyspy moth larva. J. of Invert. Pathol. 75: 59-68.

Knipling, E. F. 1955. Possibilities of insect control or eradication through the use of sexually sterile males. J. Econ. Entomol. 48: 459 – 462.

Mastro, V. C., Schwalbe, C. P. 1988. Modern insect control: nuclear techniques and biotechnology. In: Proceedings of an international symposium on modern insect control, IAEA, Vienna, p. 15-40

Reardon, R. C., Mastro, V. C. 1993. Development and status of the sterile insect technique for managing gypsy moth. USDA, NA-TP-13-93. 17 p.

Reardon, R. C., McManus, M., Kolodny-Hirsch, D., Tichenor, R., Raupp, M., Schwalbe, C., Webb, R., Meckley, P. 1987. Development and implementation of a gypsy moth integrated pest management program. J. Arbor. 13: 209-216.

Turcek, J. F. 1956. Mniska velkohlava. SVPL, Bratislava. 57pp.

Zúbrik, M. 1998. Contribution to the morphology of pupae of Tachinid (Diptera: Tachinidae) parasites of gypsy moth *Lymantria dispar* (Lepidoptera: Lymantriidae) in Slovakia [Ger.]. Forestry Journal. 44 (4): 275-285.

Beetle Fauna Captured in Traps Baited with *Tomicus piniperda* Pheromone Blends in a Pine Stand in Central Croatia

Milan Pernek[1]*, Boris Hrašovec*[2] *and Miljenko Županič*[1]

[1]Forest Research Institute, Jastrebarsko, Croatia
[2]Faculty of Forestry, University of Zagreb, Croatia

Abstract

During field evaluations of pheromone blends used for monitoring *Tomicus piniperda* beetles, many non-target beetles were captured and identified. Five pheromone blends, plus commercially available TOMODOR were used in two different traps: the IPM Tech Intercept PTBB and the THEYSOHN intercept barrier trap. In addition to *Tomicus* bark beetles we trapped 3,469 other Coleoptera in three of the 10 replications that represented 53 species distributed among 27 families. Most numerous were representatives of Staphyllinidae, Elateridae, Cleridae and Rhizophagidae. Temporal distribution of the most important predatory species as well as their responsiveness to pheromone blends is presented. The results are discussed in terms of interspecies chemical communication and few practical aspects relevant for the potential use in *Tomicus* monitoring or suppression activities.

Introduction

Recent developments in research on *Tomicus piniperda* pheromone communication (Csokajlo 1998, Kolk 2000) and small scale outbreaks of this pest in some parts of Croatia, served as a basis for a three-country (USA, Poland, Croatia) collaborative field test of new trap designs and pheromone blends. In Croatia, a mixed *Pinus sylvestris* and *P. nigra* forest culture of 16 ha was chosen in the continental part of the country (44° 44' N, 15° 39' E of Greenich). During the last three years a heavy attack of several bark beetle species occurred in this area. The most important pests were: *T. piniperda*, *T. minor*, *Ips sexdentatus* and *I. acuminatus*.

The research was initiated in 2001 but due to a late deployment of traps, the number of beetles (target as well as non target) recovered was too low for us to make reasonable comparisons; the data presented were recorded in 2002.

Materials and Methods

Six candidate semiochemicals, with or without the addition of ETOH, were tested in a completely randomized block design with 10 repetitions. Each block consisted of 6 IPM Tech Intercept PTBB traps and one THEYSOHN type intercept barrier trap equipped with odour blends with the following characteristics and combinations:

Semiochemicals

α-pinene (AP), nonanal (N), (-)-trans-verbenol (TV), (-)-myrtenol (MOL), (-)-myrtenal (MAL), (±)- α-pinene oxide (APOX), Ethanol (ETOH) and TOMODOR released at rates of 300, 6.0, 5.0, 5.0, 5.0, 2.5, and 20 mg/24 h at 24 °C, respectively (release rate and blend of TOMODOR was not known).

Blends

1. Blend #1 (AP) with IPM Tech Intercept PTBB
2. Blend #2 (AP + N + TV + MOL) with IPM Tech Intercept PTBB
3. Blend #3 (AP + N + TV + MOL + MAL) with IPM Tech Intercept PTBB
4. Blend #4 (AP + N + TV + MOL + MAL + APOX) with IPM Tech Intercept PTBB
5. Blend #4 (AP + N + TV + MOL + MAL + APOX) with THEYSOHN trap
6. Blend #5 (AP + N + TV + MOL + MAL + APOX + ETOH) with IPM Tech Intercept PTBB
7. Tomodor with IPM Tech Intercept PTBB

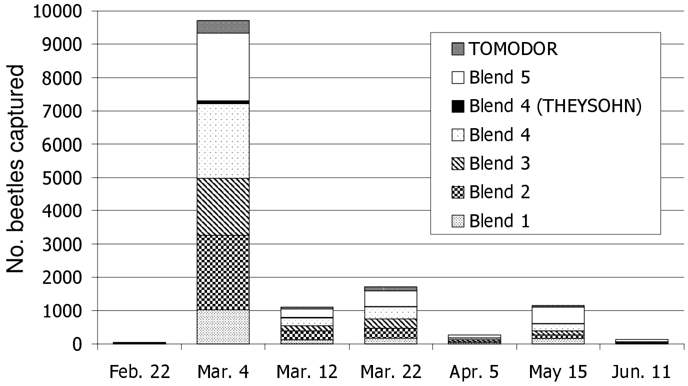


Figure 1.—Response of *T. piniperda* to offered blends.

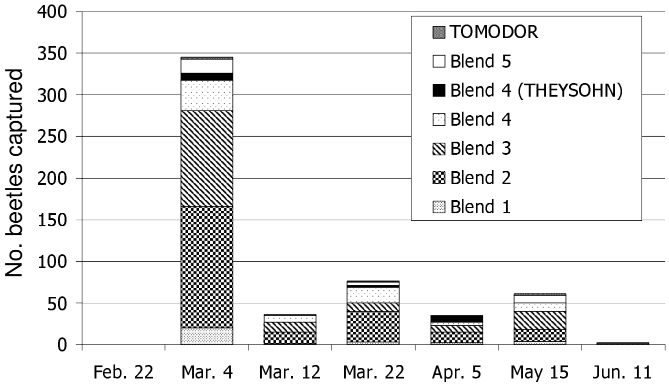


Figure 2.—Response of *T. minor* to offered blends.

Traps were positioned in each block 15 meters apart and close to the ground so both THEYSOHN and IPM Tech Intercept PTBB collecting cups were about 20 cm above ground. Trapped beetles were collected weekly or biweekly (later in the season), dried in the laboratory and identified.

Results

During the trapping period in 2002 (February – June), a total of 34,735 *Tomicus* beetles were trapped: 33,488 *T. piniperda* and 1,241 *T. minor*. These numbers refer to a total number of 60 IPM Tech Intercept PTBB traps and 10 THEYSOHN traps set up in the field trial. Blends #4 and #5 performed best based upon response by *T. piniperda* and the IPM Tech Intercept PTBB trap outperformed by far the THEYSOHN trap in the capture of *Tomicus* and the predatory beetles. (Figs. 1-3). An obvious time lag between the maximum flight period of the *Tomicus* and *Thanasimus* offers the possibility to reduce the predatory catches by removing the traps (attractants) after the initial flight of pine shoot beetles. Gradual decline of the *Thanasimus* catches later in the season might be related to the appearance and boring activity of other bark beetle populations in the area (*I. sexdentatus*, *I. acuminatus*)). It is unclear whether the clerid beetles could differentiate between their scolytid prey on the basis of some specific compounds released during the initial phase of bark beetle attack.

Non-target beetles that responded to the offered compounds belong to several guilds of wood inhabiting insects, whether as xylophages, saproxyllic or predators. The most common were: *Paromalus parallelepipedus*, *Necrophorus humator*, *N. vespilloides*, *Agathidium* sp., *Anisotoma* sp., *Liodopria* sp., *Scaphisoma* sp., *Melolontha melolontha*, *Aphodius* sp., *Athous* sp., *Ampedus ferrugineus*, *Melanotus* sp., *Megatoma undata*, *Thanasimus formicarius*, *Pityophagus ferrugineus*, *Ipidia quadrimaculata*, *Rhizophagus ferrugineus*, *R. depresus*, *Uleiota planata*, *Cerylon evanescens*, *Lathridius* sp., *Corticarina* sp., *Corticaria* sp., *Enicmus* sp., *Ditoma crenata*, *Mycetophagus quadripustulatus*, *Ptinus* sp., *Vincenzellus ruficollis*, *Acanthocinus aedilis*, *Asemum striatum*, *Rhagium inquisitor*, *Anastrangalia sanguinolenta*, *Cortodera* sp., *Pogonocherus* sp., *Anthribus albinus*, *Rhyncolus* sp., *Hylobius abietis*, *Pissodes nottatus*, *Hylastes* sp., *Hylurgus ligniperda*, *Hylastes cunicularius*, *Xyloterus lineatus*, *Ips sexdentatus*, *Orthotomicus* sp.

Different responses of four non-target beetles depicted in Figure 4 may illustrate various colonizing strategies regarding the state and physical condition of the attacked pine trees (reflected by different amounts of chemical compounds released in time).

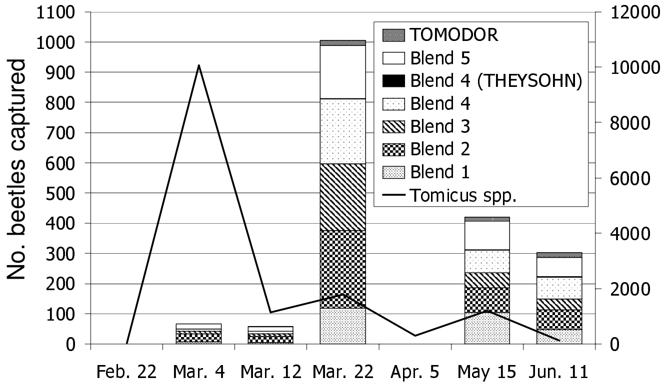


Figure 3.—*T. formicarius* response on tested blends and comparison with the total *Tomicus* catches (left axis *Thanasimus*, right axis *Tomicus* beetles.

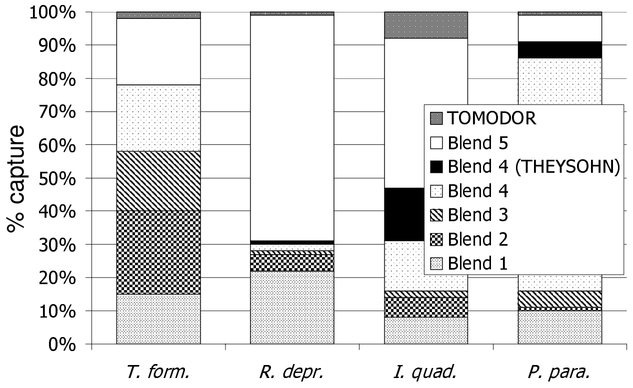


Figure 4.—Different response types for four non-target species: *T. formicarius*, *R. depressus*, *I. quadrimaculata* and *P. parallelepipedus*.

References Cited

Czokajlo, D. 1998. Semiochemicals for the Larger Pine Shoot Beetle (*Tomicus piniperda* L.) and its Clerid Predators. Dissertation, State University of New York, College of Environmental Science and Forestry, Syracuse, New York, 165 pp.

Kolk, A. 2000. Feromony i kairomony wybranych owadów fitofagicznych sosny pospolitej (*Pinus sylvestris* L.) oraz możliwości ich wykorzystania w ochronie lasu. Instytut Badawczy Leśnictwa, Warszawa, 129 pp.

Puchegger, F. 1987. Entwicklung einer Zuchttechnik für den Ameisenbundkäfer *Thanasimus formicarius*. Diploma thesis, Institut für Forstschutz und Forstentomologie, Universität für Bodenkultur, Wien.

Yüksel, B., G. Tozlu and M. Şentürk. 1999. The Serious Harmful Bark Beetles at Sarıkamış Scotch Pine Forests and Their Precautions, Doğu Anadolu Ormancılık Araştırma Müdürlüğü, Teknik Bulten Yayını No: 3, Erzurum, 71pp.

Interrelations of Green Oak Leaf Roller Population and Common Oak: Results of 30-year Monitoring and Mathematical Modeling

V.V. Rubtsov and I.A. Utkina

Institute of Forest Science, Russian Academy of Sciences, Uspenskoe, Moscow region, 143030 Russia

Abstract

Long-term monitoring followed by mathematical modelling was used to describe the population dynamics of the green oak leaf roller *Tortrix viridana* L. over a period of 30 years and to study reactions of oak stands to different levels of defoliation. The mathematical model allows us to forecast the population dynamics of the green oak leaf roller and main characteristics of its development: survival, fecundity, and propagation coefficient. The model demonstrated that oak stands in various sites differ in their response to severe defoliation. The responses of absorbing roots of damaged trees are most intense after the first year of damage and decrease gradually if subsequent defoliation occurs. The analysis of weather characteristics over 50 years revealed that the hydro-thermic coefficient of growing seasons increased 1.7 times during the last 30 years; this may be favorable for oak stands growing in the observed region.

Introduction

The green oak leaf roller *Tortrix viridana* L. is a widely distributed leaf-eating monophagous species in oak stands that is well-adapted to its host tree specie, *Quercus robur var. praecox* Czern. It also damages other oak species both deciduous (*Q. petraea*, *Q. cerris*, *Q. suber*, *Q. rubra*) and evergreen (*Q. ilicifolia*). The green oak leaf roller is distributed throughout the European part of Russia and in many European countries, though it prefers conditions that occur in the steppe and forest-steppe zones. Outbreaks of mass propagations of the green oak roller are durable and larvae and egg masses are very tolerant to unfavourable biotic and abiotic factors. Larvae hatch over a period of 7 to 12 days. The lack of synchrony between hatching and oak budbreak or injury to young leaves caused by spring frosts can cause reinforced migrations of larvae looking for food and therefore impact significantly on their numbers. Larvae of both older and younger ages are not very mobile and move within a crown only if food is absent. Nearly 90% of larvae often die because of this discrepancy and are killed by predators and entomophages. A significant portion of the larval population is killed by diseases caused by entomopathogens, however the magnitude of this mortality is usually not catastrophic for the population. Males pupate before females (2-3 days) so when over-population occurs, mortality of male pupae is less than what is incurred by female pupae. The total number of pupae is an index of the state of the population and of the stage of an outbreak and depends on food quality, weather conditions and population density. The total number of female pupae of the green oak leaf roller depends directly on the level of crown defoliation.

The development of *T. virdiana* outbreaks depends significantly on survival in the larval and pupal stages and consequently on weather conditions, the condition of the host tree, and biotic factors. A delay in the development of larvae and pupae due to unfavorable conditions causes their increased mortality and therefore is an important factor in the population dynamics of this species.

Materials and Methods

This study of *T. viridana* populations was conducted on permanent trees in the Tellerman oak grove (the southern part of the forest-steppe zone, Voronezh oblast the Central Black Soil region of Russia), an area characterized by a dry continental climate. Observations were initiated in 1969 by N.N. Rubtsova and have been continued since 1975 by the authors.

Observations of the condition of trees and their crowns are made every year on 26 permanent plots located over the area of the Tellerman Forest Experimental Station, Institute of Forest Science, to reveal the locations of mass outbreaks of phyllophagous insects and to evaluate the status of crown defoliation.

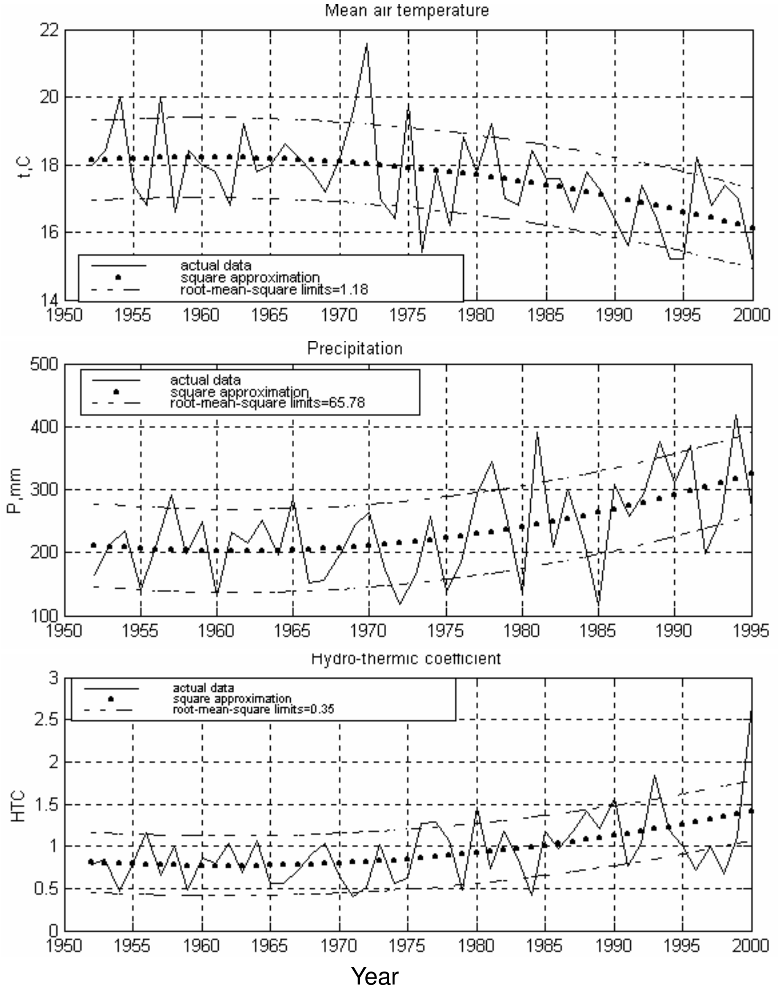


Figure 1.—Some weather characteristics over a growing season (May-September)

The most detailed study was conducted mainly in two types of forest: a) the floodplain lily-of-the-valley / dewberry oak stand (site index II, relative density 0.6-0.8, aged 85 years); b) the upland solonets oak stand (site index IV-V, relative density 0.6-0.8, aged 80-95 years).

Counts of larvae and pupae were made individually on marked trees, by cutting sample branches from the upper and lower parts of the crown. Butterflies and entomophages were raised in glass containers in the laboratory. Counts of egg masses of *T. viridana* L. in the forest were made twice a year, in October and March. In order to determine the mortality of eggs, larvae were allowed to hatch from eggs that were sampled at different periods during their development (Rubtsov et al. 1989b).

Before discussing some features of the population dynamics of *T.viridana* and other phyllophages and their impact on the condition of oak stands, we offer some discussion about the changing weather conditions over the last 30 years. This is meaningful for understanding the potential impact of climate and its relation to phyllophages and their host trees.

It is known that significant changes in weather and climate are occurring. We have analyzed various weather parameters recorded in the vicinity of our investigations for last 50 years in order to reveal some trends. Fig. 1 shows changes in three parameters selected for a growing season (from May to September): mean air temperature, precipitation and hydro-thermal coefficient (the sum of precipitation in mm divided by sum of air temperatures above 10°C multiplied by 0.1). It is evident that mean air temperature has decreased by 2°C during the last 30 years, whereas precipitation over the same period has increased by 110 mm. Consequently, the average hydro-thermic coefficient of a growing season has increased by a factor of 1.7. Since the southern forest-steppe zone is a region with

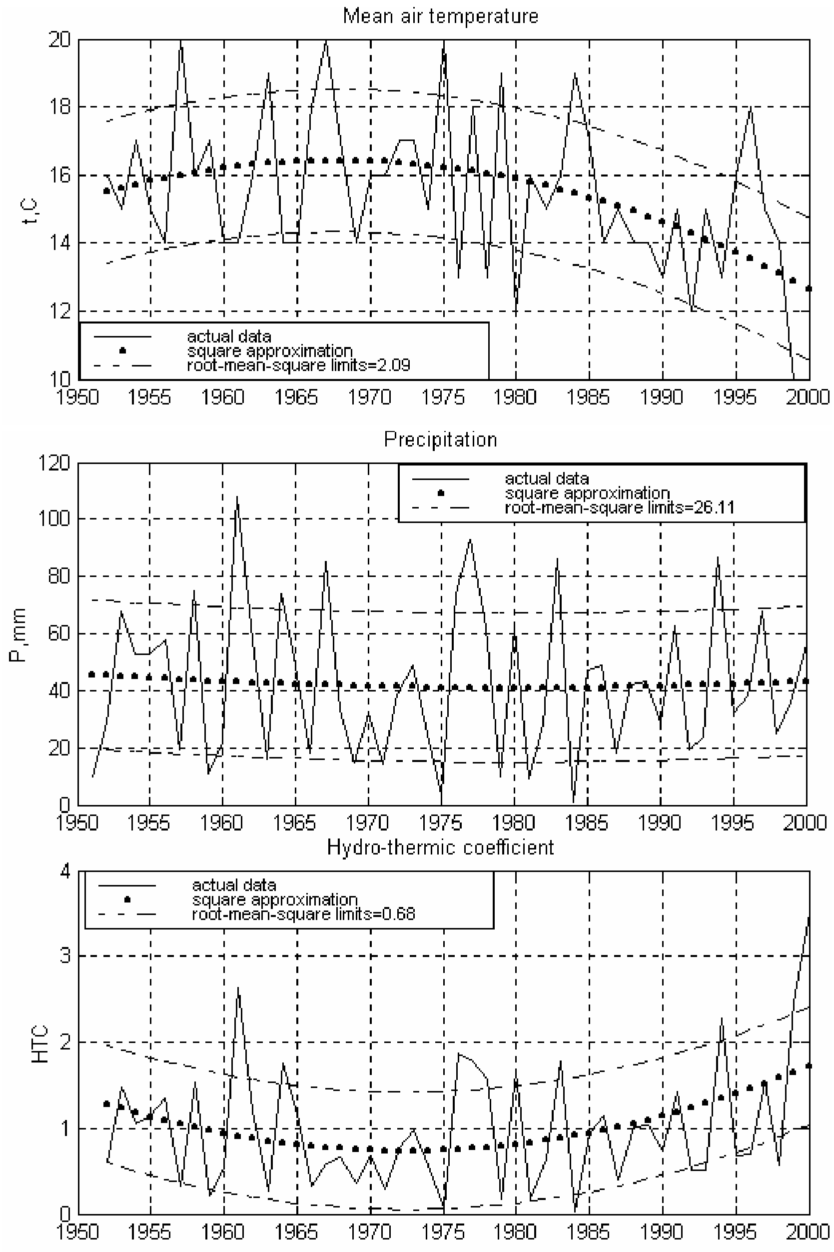


Figure 2.—Some weather characteristics in May

deficient moisture, the changing hydro-thermic regime during the growing season may be considered favorable for vegetation. The consequences of these climatic changes have also influenced the state and productivity of oak stands. Figure 2 illustrates the trend in the same three parameters for the month of May. It is obvious that the mean air temperature and the hydro-thermic Coefficient has declined by a factor of 2.4. Because May is the period when intensive feeding by larvae of *T. viridana* and other early-spring phyllophagous insects occurs, these changing weather conditions should clearly influence the relationship between phyllophagous insects and their host trees.

Results and Discussion

A mathematical model of the development of *T. viridana* populations was developed on the basis of data obtained from the literature and from studies conducted by one of the authors (Rubtsov 1983, 1990). It interprets the mechanism of outbreak development in accordance with the synthetic theory (Victorov 1965, Schwerdtfeger 1968). The model is non-linear, non-stationary, has alternating structure and dimensions, and reflects the results of a series of complex interactions within the modeled system. The mathematical model can be used to describe the dynamics of *T. viridana*

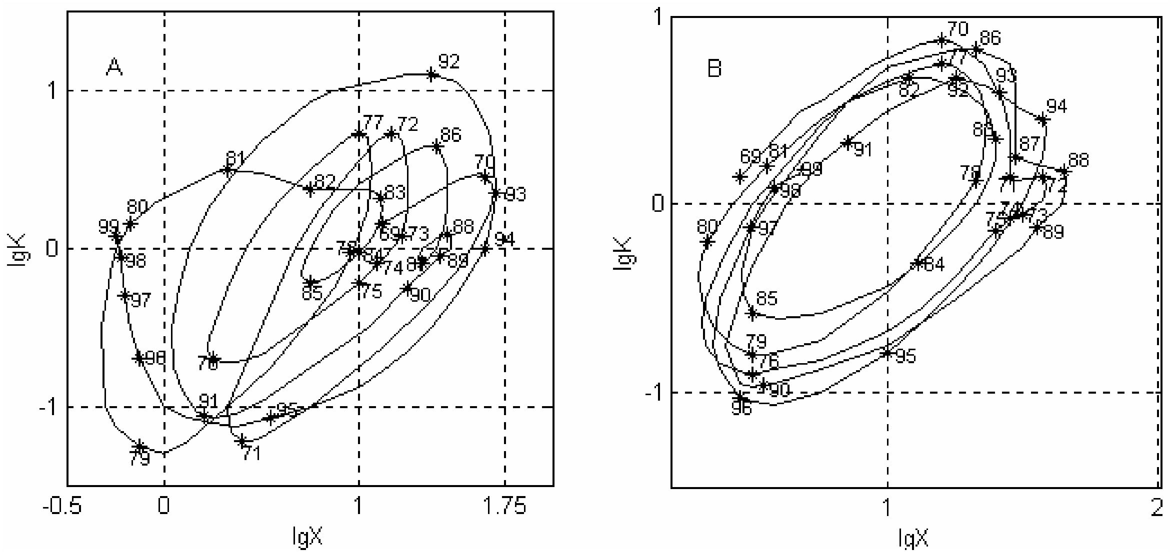


Figure 3.—Phase trajectories of green leaf roller's population in floodplain oak stand (A) and solonets oak stand (B). X – population density, K – propagation coefficient.

populations and can be used to estimate the following parameters: the density, survival, fecundity, and propagation coefficient of the population in each generation; defoliation and refoliation of crowns in a stand; value and loss of stem increment, and some other parameters. The model demonstrates that weather has a relative impact on the development of larvae and that the level of crown defoliation decreases at higher population densities; if the population continues to increase, i.e. a significant over-population occurs, the importance of weather factors again increases. Results of the modeling demonstrate also that when severe over-population occurs, discrepancy (lack of synchrony) between bud break and larval hatching can be favorable for survival of *T. viridana* populations because it reduces the over-population; the extended period of hatching provides for the successful development and survival of the remainder of the population. The results of our modeling indicate that there is the possibility of large amplitudes of fluctuations in *T. virdana* population density under certain conditions not only in the period of its mass propagation, but also when populations are at low densities.

The main factors that are responsible for modifying and regulating populations of *T. viridana* were considered in detail in earlier publications.(Rubtsov 1990, Rubtsov and Utkina 2001, and others). Here we discuss only the importance of larval and pupal entomophages in regulating populations of the green oak leaf roller. The species composition of these organisms in the Tellerman oak grove is very rich. This can be explained in part by the complex composition of stands, their many-tiered stratification, and the presence of many glades with flowering plants including cruciferous species. The most abundant entomophagous species are as follows: *Phaeogenes invisor* Thunb., *Itoplectis alternans* Grav., *Apectis resinator* Thunb., *Apectis rufata* Gm., *Trichomma enecatur* Rossi., *Lissonota* sp., *Meniscus bilineator* Grav., *Elodia tragica* Mg., *Bessa fugas* Rd., *Dibrachys cavus* Waiker., *Habrocytus* sp., *Brachyimeria intermedia* Nees., *Monodontomerus minor* Ratz., *Apanteles* sp. aff *albipennis* Nees., *Apanteles* sp., *Microgaster laevisenta* Thans.(Rubtsov and Rubtsova 1984).

The regulation of the population density of phyllophages can often be well described by means of mathematical modelling. However, it is very difficult to forecast changes in population density due to their stochastic and non-stationary nature. This decreases significantly the accuracy of forecasting. After analyzing the features of fluctuating population numbers, we conclude that the green oak leaf roller can be described as an eruptive species in accordance with Isaev et al. (1984). Figure 3 shows the phase trajectories of *T.viridana* populations in the floodplain oak stand (A) and in the upland solonets oak stand (B). The development of outbreaks in an eruptive pattern was observed in 1968-1976, 1979-1987 in the floodplain stand. In the latter case, *T.viridana* was affected by a modifying

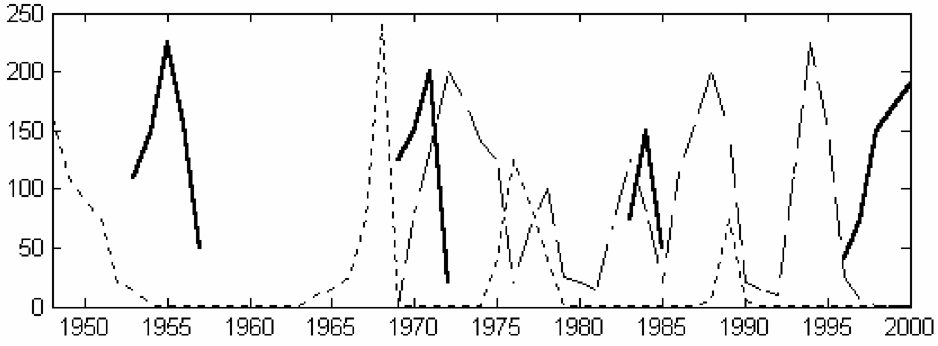


Figure 4.—Population dynamics of some phyllophagous insects in the Tellerman oak grove,

……………*Lymantria dispar L.* : number of egg-masses per 50 trees
___ ___ ___*Tortrix viridana L.* : number of egg-masses per 5m of branch length
__________*Operophthera brumata L.* : number of imago females per 1 tree

factor, a significant drought which occurred in 1979; the population expanded rapidly after this occurrence.

However, the population did not reach its maximum due to the significant impact of another modifying factor, severe winter frosts that occurred in 1984/1985 and affected populations of both *T. viridana* and the entomophages that normally regulate its numbers. This is represented by the formation of a loop in the phase portrait (Fig. 3A, 1984-1985). When studying phase portraits, a conclusion can be made about the permanent character of outbreaks of the green oak leaf roller since the population does not usually stabilize its numbers when the gradation cycle is over and a new outbreak begins. Attention is drawn to the relative stability of population density and propagation coefficients at similar stages of different gradation cycles in the solonets oak stand (Fig. 3B). The highest population density is 20-32 and the lowest is 2-3.5 egg-masses per 1 m of a sample branch; the maximum propagation coefficient is 5-7 and the minimum is 0.1-0.25. These features suggest that the solonets oak stand is representative of a stable ecological regime and simplifies forecasting the population development.

Before proceeding to the influence of phyllophagous insects on oaks, we should note that other leaf-eating insects, such as the gypsy moth and the winter moth occur also in stands of the Tellerman oak grove. Their population dynamics are presented in Figure 4. Four outbreaks of both the gypsy moth and the winter moth were recognized after the Second World War (Rubtsov et al. 1989a); permanent monitoring of *T.viridana* populations began in 1969. The impact of *T.viridana* on the state and growth of oak trees in a floodplain oak stand is shown in Figure 5. Values of stem increment and percentage loss of increment averaged for a stand are plotted along with data on the population density of *T. viridana* and defoliation estimates on individual trees. Figure 6 shows the results of modeling the loss of increment of oaks as a function of a single and cumulative defoliation index in four different stands by means of statistical regression analysis.

The most loss occurred in the upland and solonets stands: 40% after a single defoliation and 60% after two consecutive defoliations. The cumulative defoliation, equal to 250-270% over three years, caused nearly 100% loss of increment and significant mortality of trees. The least loss of increment occurred in oaks of the floodplain stand, which can be explained by their tolerance of frequent and significant insect defoliations and their increased ability to refoliate (Utkina and Rubtsov 1994).

The impact of crown defoliations on the seasonal growth activity of absorbing roots in oaks has been studied during the past five year in collaboration with V.V. Mamaev (Mamaev et al. 2001, 2002). Figure 7 shows the relation between the growth of absorbing roots of defoliated and non-defoliated oak trees in 1998 in the floodplain stand. The defoliated trees incurred up to 90% defoliation while

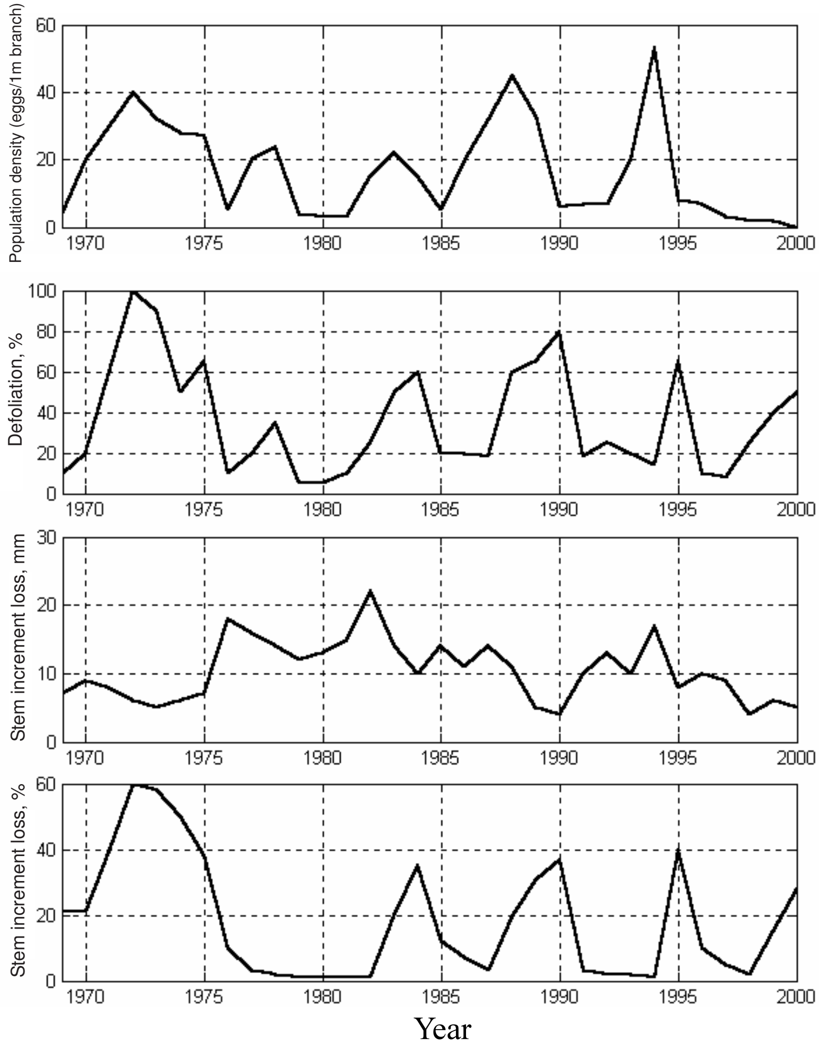


Figure 5.—Population dynamics of *Tortrix viridana L.* and its impact on defoliation and stem increment in the floodplain oak stand.

the control trees were practically undamaged. The winter moth was the dominant leaf-eating insect species responsible for the defoliation. Active regrowth of foliage began on May 28 and occurred very rapidly. By June 18 the new foliage was very abundant and denser as compared to the foliage on the undamaged trees. New leaves were not damaged by insects and mildew, appeared to be rather fresh and were slightly different color as compared to spring foliage. The root system of the damaged trees responded immediately to defoliation by producing intensive mycorhizae. However, as refoliation occurred in early June, the rate of growth declined. The least amount of root growth occurred during the period of most intense refoliation. The control trees experienced peak root activity during the same period. Additionally, the amount of newly generated mycorhizae per 1 unit of soil volume was more comparable to that which occurred on the control trees over the entire growing season. The least difference between damaged and control trees was evident only in autumn.

The principal conclusions from this study suggest that the growth of new absorbing oak roots is closely related to the condition of the crown and responds keenly to a loss of foliage, however, the intensity of the response varies in trees that suffer single or repeated defoliations. In the first year of severe defoliation, the root systems of trees respond by rapidly producing a mass of new mycorhizae roots, however after repeated defoliations, there was no increase in this root growth activity. When an abundance of oak mycorrhizae with well formed mycelia occurs in soil, this results in a significant increase in the volume of absorbing root surface. This suggests on one hand that the weakening of

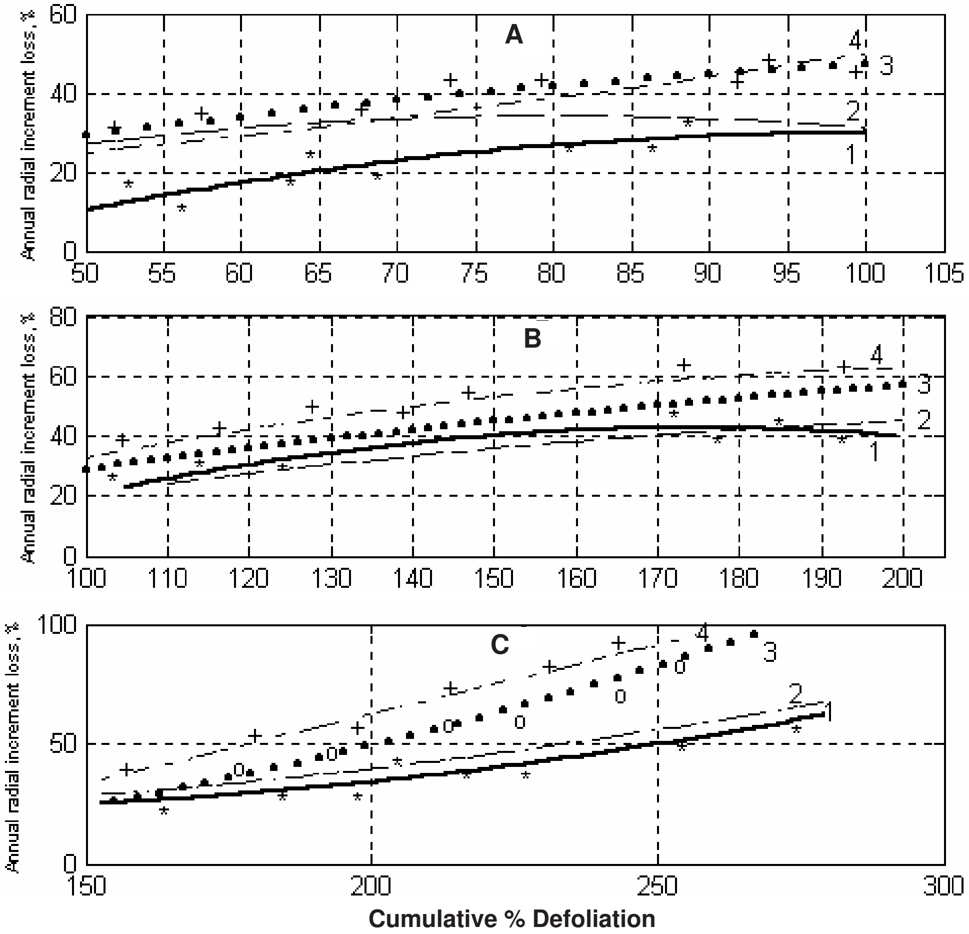


Figure 6.—Loss of radial increment in different oak stands in response to various level of defoliation: A - single defoliation; B - repeated defoliation during two successive years; C - repeated defoliation in three successive years. Numbers and different symbols indicate stand type: 1- floodplain; 2 - riverbank; 3 - solonetz; 4 - upland.

trees and reduction assimilates and reserves occurs and, on the other hand, that oak trees respond to the stress of repeated severe defoliations by engaging defensive mechanisms. It should be noted that healthy trees have the highest growth activity of roots after defoliation occurs, whereas growth activity of roots is less in weakened and suppressed trees and nearly absent in dying trees. The close relationship between the development of new absorbing roots and the condition of crowns is one of the ways by which trees survive under conditions of stress. During the last five years, oaks in the floodplain and solonets stands suffered severe defoliation caused by the winter moth. These defoliations combined with summer droughts in 2001 and especially in 2002, caused severe weakening of oak trees and produced a micro-focus of decline. We are forecasting that these foci of decline will expand next year since in the current year, the refoliation of trees and accumulation of energy reserves in damaged trees was poor.

Acknowledgments

The study is supported by the Russian Fund for Basic Research (project 01-04-48276).

References Cited

Isaev, A.S., R.G. Khlebopros, L.V. Nedoresov, V.V. Kiselev, Yu.P. Kondakov. 1984. Population Dynamics of Forest Insects. Nauka, Novosibirsk. [In Russian]

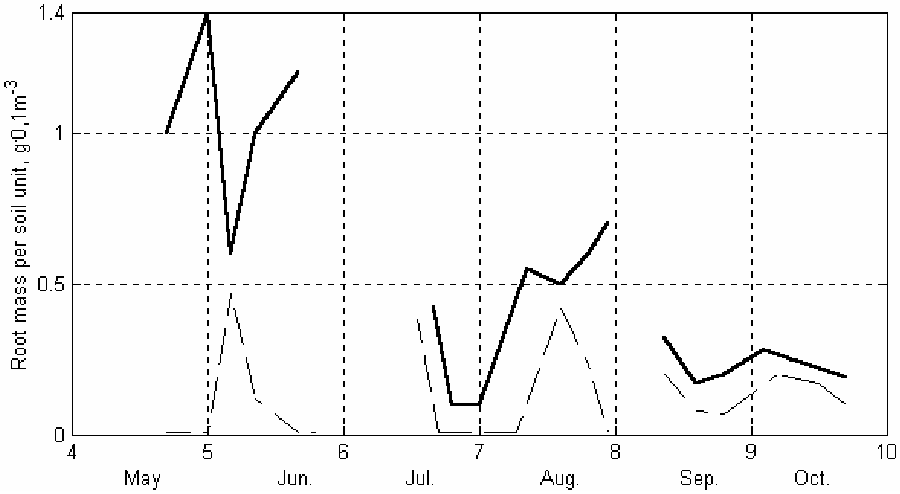


Figure 7.—Dynamics of new growth of young absorbing oak roots in the floodplain oak stand after insect defoliation in 1998

— — — — trees without defoliation (control)

———— trees with 90 % defoliation

Mamaev, V.V., V.V. Rubtsov, I.A. Utkina. 2001. Impact of oak crown defoliation on growth activity of absorptive roots. Lesovedenie ‡5: 43-49. [In Russian]

Mamaev, V.V., V.V. Rubtsov, I.A. Utkina. 2002. Seasonal dynamics of oak absorbing roots after repeated defoliation in floodplain stands. Lesovedenie ‡5: 48-53. [In Russian]

Rubtsov, V.V. 1983. Mathematical model for development of leaf-eating insects (oak leaf roller taken as an example). Ecological Modelling 18: 269-289.

Rubtsov, V.V. 1990. Some results of the study of the green oak leaf roller population in relation with the modelling of its population dynamics, pp.210-225. In: S.E. Vompersky [ed.]. An experiment and mathematical modeling for the study of forest and swamp biogeocenoses. Nauka, Moscow. [In Russian]

Rubtsov, V.V. 1996. Influence of repeated defoliations by insects on wood increment in common oak (*Quercus robur* L.). Ann. Sci. For. 53: 407-412.

Rubtsov, V.V., and N.N. Rubtsova. 1984. The analysis of interaction of leaf-eating insects and oak. Nauka, Moscow [In Russian]

Rubtsov V.V., N.N. Rubtsova, I.A. Utkina. 1989a. The dynamics of some leaf-eating insects and oak forests defoliation, pp. 97-116. In: V.V. Osipov [ed.]. The state of oak forests in the forest-steppe zone. Nauka, Moscow [In Russian]

Rubtsov V.V., N.N Rubtsova, I.A. Utkina. 1989b. Population dynamics of the green oak leaf roller in the Tellerman oak grove. Lesovedenie ! 3: 46-54. [In Russian]

Schwerdtfeger F. 1968. Ökologie der Tiere. Z. Demökologie. Parey, Hamburg.

Utkina, I.A. and V.V. Rubtsov. 1994. Refoliation of common oak after insect damage. Lesovedenie No.3: 23-31. [in Russian]

Victorov, G.A. 1965. Variations of insect population dynamics as regulated process. Zhurnal Obshchei Biologii (Journal of General Biology) 24: 43-55. [in Russian]

Host-tree Preferences of the Pine Moth (Lepidoptera: Lasiocampidae) and Pine Beauty Moth (Lepidopera: Noctuidae) Larvae in Relation to Needle Quality

Lidia Sukovata,[1] Andrzej Kolk,[1] Jadwiga Jaroszynska,[2] Urszula Krajewska,[2]
Agnieszka Purzynska and Valerii Isidorov[2]

[1]Forest Protection Department, Forest Research Institute, Sekocin Las, 05-090 Raszyn, Poland,
e-mail: L.Soukovata@ibles.waw.pl
[2]Institute of Chemistry, University in Bialystok, 11/4 J. Pilsudski Ave., 15-443 Bialystok, Poland

Abstract

The larvae of *Dendrolimus pini* L. and *Panolis flammea* (Den. et Schiff.) usually occur in high numbers on different trees within a stand. Studies that focused on the host tree-preference of these two species were conducted in the Wymiarki Forest District (Poland) in 2001. Sixteen Scots pine trees were selected to estimate the larval abundance of both species using 1x1 m collectors. In June the trees were cut down, the larvae in crown were counted and the samples of needles for chemical analysis were taken from the lower, middle and upper parts of the crowns. Natural radiation was measured under each tree using the methods developed by dowsers (radiesthets). There were no significant differences in the concentrations of any terpene or phenolic acid in different parts of crowns. The abundance of pine moth larvae was related significantly with 7 monoterpenes, 6 sesquiterpenes and 5 phenolic acids, while the abundance of the pine beauty moth was related with 5 monoterpenes, 6 sesquiterpenes and 1 phenolic acid. There were 6 compounds which had significant impact on the abundance of both species: â-pinene was in positive relationship with *D. pini* and inverse with *P. flammea*, while the compound with a retention index of 1430, ã-muurolene, â-vetivenene, á-cadinene and protocatechuic acid were in inverse relationships with *D. pini* and positive with *P. flammea*. These differences may explain why these insect species are rarely observed in high numbers on the same trees. Natural radiation is possibly one of the causes of variation of secondary metabolites in Scots pine needles. It was in significant relationships with 9 monoterpenes, 3 sesquiterpenes and 1 phenolic acid. The results of studies suggest that â-pinene and sesquiterpene with a retention index of 1430 are the only links between natural radiation and abundance of both *D. pini* and *P. flammea*.

Key words: *Dendrolimus pini*, *Panolis flammea*, host preference, secondary metabolites, terpenes, phenolics, natural radiation

The pine moth, *Dendrolimus pini* L., and pine beauty moth, *Panolis flammea* (Den. et Schiff.), belong to a group of the most harmful defoliators of Scots pine, *Pinus sylvestris* L., in Poland. Both species have a one-year life cycle however their biologies are different.

The pine moth females lay eggs in July-August. Young larvae feed before late-October or early-November, overwinter in forest litter, and resume feeding in early spring on old needles. After all of the old needles are consumed, the larvae start to feed on young needles. The larvae pupate in June through August (Vorontsov 1982, Kolk and Starzyk 1996).

The pine beauty moth overwinters as a pupa. Adults emerge in April-May, mate, and females deposit egg masses. The young larvae emerge and begin feeding in late-May on buds, needles and bark of fresh shoots. The older larvae feed on old needles and pupate in late June-July.

Both species prefer 20-80 year old pine monocultures, however their outbreaks usually occur in different stands; if both species occur within a stand, high numbers of their larvae are observed on different trees. This observation led us to hypothesize that needle quality (concentration of secondary metabolites) could be of a great importance in the host tree preference of the pine moth and pine beauty moth larvae.

On the other hand, the terpene components of coniferous resin systems are under strong genetic control and are valuable indicators of population diversity. Moreover, they interact with other components of the ecosystem and are thus of great value as adaptive markers (Forrest et al. 2000). All components of ecosystems are also under the impact of cosmic radiation, and geomagnetic, electric, electromagnetic and gravitational fields of the earth. Concentrations of minerals, underground streams of water, geological downcasts et al. cause the anomalies in these fields (Krolicki 1998), which may have an impact on the distribution of living organisms and their condition, biodiversity of ecosystems, and variability within a population.

Several studies on the impacts of different fields of the earth on some insect species were conducted in Austria and some other countries in the late 60s – early 80s of the last century (Schneider 1960, Robert 1963, Becker 1964, 1971, Schimitschek 1972, Jahn and Nessler 1971). Some studies by Jahn (1973, 1975, 1977) focused on the impact of natural radiation on nun moth survival and fecundity. Natural radiation was considered to be an electromagnetic radiation of very low frequency. The mortality of young nun moth larvae inside the zone of high radiation was significantly lower than in the normal zone. The mortality of young larvae reared on plants from the zone of high radiation was significantly lower and the fecundity of females was significantly higher than from those plants reared from the normal zone. These results suggest that there might be some direct relationships between the natural radiation of the earth and the occurrence of the defoliators or indirect through the impact of the radiation on the insect host trees. This hypothesis was also tested in our studies.

Material and Methods

Study Site

The studies were conducted in the Wymiarki Forest District of Regional Directorate of State Forests, located in the south western part of Poland. Scots pine stands (38-44 years of age) of similar quality and growing on similar site conditions, occur on an area of about 1500 ha. The threat of these stands from the pine moth and pine beauty moth in 2001 was assessed to be high, and therefore chitin synthesis inhibitors were applied on May 17 to prevent heavy defoliation of trees. The threat assessment revealed also that the pine moth was more abundant in some stands than in others while the pine beauty moth was more numerous in the stands where the abundance of pine moth was low. Insect abundance was estimated on 16 trees and samples of needles from each of the trees were taken for chemical analysis.

Estimation of Insect Abundance on Sampled Trees

One meter square collectors were placed beneath each of the selected trees at the time that the spray was applied so that dying insects fell into the collectors. One month later, on June 17, 2001, the trees were felled onto cotton sheets and the larvae of all species found in the crowns and on the sheet were counted.

Chemical Analysis of Needles

Chemical analysis was conducted to estimate the concentration of essential oils (monoterpenes and sesquiterpenes) and phenolics in the needles of the selected Scots pine trees. The samples of previous year needles were taken on June 17, 2001, from lower, middle and upper parts of crown of each tree in order to check the possible differences in the concentration of secondary metabolites among them. Analysis of the composition and concentration of monoterpenes and sesquiterpenes was conducted using GC/SPME and GC/MS methods. The concentration of phenolics was analyzed using the GC method. The analyses were conducted using HP 4890D chromatograph with FID detector (on DB-5 column, 30 m x 0,25 mm ID). The temperature program for analyzing phenolics was from 50 to

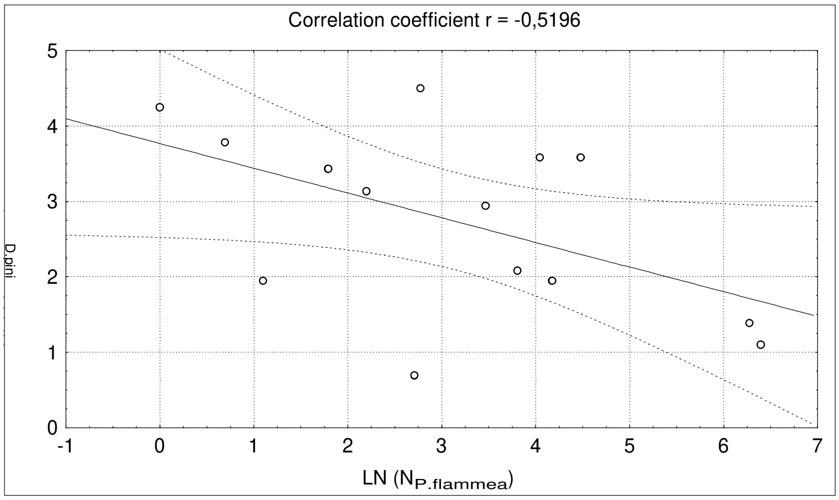


Figure 1.—The relationship between the ln-transformed abundances of the pine moth and pine beauty moth larvae on 16 selected Scots pine trees in the Wymiarki Forest District in 2001

300°C with a rate increase of 3°C/min. For essential oils, the program was from 40°C to 200° with a rate increase of 3°C/min followed by a rate increase of 10°C/min up to 300°C.

Measuring Natural Radiation

To determine the natural radiation, we used the method of Jahn (1974, 1977), which is known as the radiesthetical (dowsing) method. It is based on using a pendulum and scale specially developed by the radiesthets. In this case the natural radiation was measured in °SRW (Swaczyna 1991).

Statistical Analysis

Relationships between the concentration of each chemical compound and the number of specimens of each insect species, and the relationship between the natural radiation and the concentration of each chemical compound were analyzed with regression analysis using the statistical package Statistica 5.1/98 (StatSoft Poland). To decrease the variation of variables and to achieve a normal and homoscedastic distribution of points around the regression line, either or both variables were submitted to a logarithmic transformation.

Results

Insect Abundance

The number of the pine moth larvae on the trees varied from 0 to 90 specimens ($\overline{N}$ =24,6±25,93), while the number of the pine beauty moth varied from 0 to 598 specimens ($\overline{N}$ =94,4±185,18). There was an inverse relationship between the abundances of these two species on the selected trees (Fig. 1).

Secondary Metabolites

There were 28 monoterpenes, 29 sesquiterpenes and 18 phenolics in the needles sampled from 16 selected trees. The most common compounds which were used for the statistical analysis, are presented in Table 1. There were no significant difference among the concentrations of any compound measured in different parts of the crown, thus we used measurements from the middle of the crown in the data analysis.

Table 1.—Composition of the most common secondary metabolites in the needles sampled from 16 selected Scots pine trees in the Wymiarki Forest District, Poland, in June 2001.

Monoterpenes	Sesquiterpenes	Phenolics
3-hexene-1-ol	longicyclene	Vanillic
tricyclene	RI 1386	Homovanillic
RI 925*	β-longipinene	Protocatechuic
α-pinene	(E)-caryophyllene	Homogentisic
camphene	RI 1430	m-coumaric
sabinene	RI 1441	p-coumaric
β-pinene	(E)-β-farnesene	o-coumaric
myrcene	RI 1475	Gallic
3-carene	γ-muurolene	Phenol
α-terpinene	RI 1483	
limonene	β-selinene	
RI 1037	RI 1494	
(E)-β-ocimene	RI 1502	
γ-terpinene	(Z)-γ-bisabolene	
terpinolene	Â-vetivenene	
m-cymene	α-cadinene	
Bornyl acetate	RI 1581	
trans-sabinyl-acetate	Conipferyl alcohol	
RI 1340		
α-terpinyl-acetate		

*- undetermined compound with a retention index (RI)

Insect Abundance on Trees and Secondary Metabolites in Needles

Monoterpenes. Regression analysis of the concentrations of monoterpenes in needles and the abundance of the pine moth revealed that 7 monoterpenes were related to the number of the pine moth larvae per tree (Table 2).

One of them, β-pinene, was related positively with the abundance of pine moth larvae, while all of the others were related inversely. The strongest correlation between the variables was observed for camphene (r=-0.72), β-pinene (r=0.85) and trans-sabinyl-acetate (r=-0.80).

The abundance of the pine beauty moth larvae on trees was significantly and positively related to the concentrations of sabinene, RI 1037 and RI 1340 and inversely related with β-pinene and (E)-β-ocimene (Table 3).

Sesquiterpenes. Significant relationships were found between 6 sesquiterpenes and the number of pine moth larvae (Table 4), and 6 sesquiterpenes and the number of the pine beauty moth larvae on trees (Table 5). For the former species, all sesquiterpenes were inversely related with larval abundance and for the latter species, they were positively related with larval abundance.

Phenolics. Regression analysis revealed that the number of pine moth larvae on trees was significantly inversely-related with the concentrations of 4 phenolics extracted from the needles while positively related with gallic acid (Table 6). In case of the pine beauty moth, the only phenolic that was related to the abundance of larvae was protocatechuic acid and this relationship was positive [ln*N* = 0.67 x ln (*protocatechuic acid*), r=0.71, R^2=0.46].

Table 2.—Regression models of the number of *Dendrolimus pini* larvae and monoterpenes in the needles of Scots pine trees (with p<0.05)

Monoterpene	Correlation coefficient	Regression model	Determination coefficient
camphene	-0.72	$\ln N = 4.7 - 0.87 \times \textit{camphene}$	0.52
β-pinene	0.85	$\ln N = 1.51 \times \ln(\beta\textit{-pinene})$	0.69
α-terpinene	-0.59	$\ln N = 4.2 - 11.79 \times \alpha\textit{-terpinene}$	0.35
γ-terpinene	-0.60	$\ln N = 4.6 - 6.49 \times \gamma\textit{-terpinene}$	0.35
terpinolene	-0.59	$\ln N = 4.3 - 15.48 \times \textit{terpinolene}$	0.35
m-cymene	-0.60	$\ln N = 4.3 - 0.64 \times \textit{m-cymene}$	0.35
trans-sabinyl-acetate	-0.80	$\ln N = -1.21 \times \ln(\textit{trans-sabinyl-acetate})$	0.59

Table 3.—Regression models of the number of *Panolis flammea* larvae and monoterpenes in the needles of Scots pine trees (with p<0.05)

Monoterpene	Correlation coefficient	Regression model	Determination coefficient
sabinene	0.71	$\ln N = 6.75 \times \textit{sabinene}$	0.46
β-pinene	-0.69	$\ln N = 5.51 - 1.64 \times \ln(\beta\textit{-pinene})$	0.48
(E)-β-ocimene	-0.68	$\ln N = 3.3 - 1.8 \times \ln(\textit{(E)-}\beta\textit{-ocimene})$	0.46
RI 1037	0.73	$\ln N = 46.56 \times \textit{RI 1037}$	0.49
RI 1340	0.75	$\ln N = 0.35 + 12.26 \times \textit{RI 1340}$	0.53

Table 4.—Regression models of the number of *Dendrolimus pini* larvae and sesquiterpenes in the needles of Scots pine trees (with p<0.05)

Sesquiterpene	Correlation coefficient	Regression model	Determination coefficient
RI 1430	-0.78	$\ln N = 4.65 - 12.26 \times \textit{RI 1430}$	0.56
γ-muurolene	-0.66	$\ln N = 4.4 - 2.48 \times \gamma\textit{-muurolene}$	0.39
RI 1494	-0.78	$\ln N = -1.76 \times \ln(\textit{RI 1494})$	0.57
RI 1502	-0.85	$\ln N = 2.9 - 0.81 \times \ln(\textit{RI 1502})$	0.70
β-vetivenene	-0.79	$\ln N = 5 - 0.57 \times \beta\textit{-vetivenene}$	0.58
α-cadinene	-0.84	$\ln N = 5.2 - 18.5 \times \alpha\textit{-cadinene}$	0.67

Table 5.—Regression models of the number of *Panolis flammea* larvae and sesquiterpenes in the needles of Scots pine trees (with p<0.05)

Sesquiterpene	Correlation coefficient	Regression model	Determination coefficient
RI 1386	0.77	$\ln N = 6.85 + 1.58 \times \ln(\textit{RI 1386})$	0.55
RI 1430	0.87	$\ln N = 27.71 \times \textit{RI 1430}$	0.74
γ-muurolene	0.76	$\ln N = 7.27 \times \gamma\textit{-muurolene}$	0.53
(Z)-γ-bisabolene	0.65	$\ln N = 1.45 \times \textit{(Z)-}\gamma\textit{-bisabolene}$	0.38
β-vetivenene	0.80	$\ln N = 1.55 \times \beta\textit{-vetivenene}$	0.60
α-cadinene	0.85	$\ln N = 28.08 \times \alpha\textit{-cadinene}$	0.69

Table 6.—Regression models of the number of *Dendrolimus pini* larvae and phenolics in the needles of Scots pine trees (with $p<0.05$)

Sesquiterpene	Correlation coefficient	Regression model	Determination coefficient
Homovanillic	-0.74	$\ln N$ = 4.30 - 0.82 x ln (*homovanillic*)	0.55
Protocatechuic	-0.69	$\ln N$ = 4.96 - 0.42 x ln (*protocatechuic*)	0.47
o-coumaric	-0.76	$\ln N$ = 6.48 - 1.02 x ln (*o-coumaric*)	0.57
Phenol	-0.78	$\ln Nl$ = 7.46 - 1.49 x ln (*phenol*)	0.41
Gallic acid	0.70	$\ln N$ = 0.67 x ln (*gallic*)	0.61

Table 7.—Coefficients of correlation between the number of *Panolis flammea* and *Dendrolimus pini* larvae and chemical compounds related to both insect species

Type of chemicals	Compound	Correlation coefficient for	
		Dendrolimus pini	*Panolis flammea*
monoterpene	β-pinene	0.97	-0.69
sesquiterpene	RI 1430	-0.78	0.87
	γ-muurolene	-0.66	0.76
	β-vetivenene	-0.79	0.80
	α-cadinene	-0.84	0.85
phenolic acid	protocatechuic	-0.69	0.71

Among the compounds analyzed, 1 monoterpene, 4 sesquiterpenes and 1 phenolic acid were related to the abundance of larvae of both the pine moth and pine beauty moth (Table 7).

When the coefficients of correlation among these compounds and both insect species were compared, it was revealed that there was a difference in preferences of needles by larvae of the pine moth and pine beauty moth (Table 7). The abundance of pine moth larvae was positively related to â-pinene and inversely related to all other common compounds, while the pine beauty moth larvae preferred needles with a lower concentration of β-pinene and higher concentrations of other compounds.

Natural Radiation and Secondary Metabolites

Natural radiation measured under selected trees varied from 40 to 2100 °SRW ($\overline{R}$ =898,75832,16). There was a significant relationship between natural radiation and the concentration of some monoterpenes (Table 8), sesquiterpenes and 1 phenolic acid (Table 9) in the needles of selected Scots pine trees. These relationships were inverse for most monoterpenes, while positive for 3-hexene-1-ol, RI 1037 and (E)-β-ocimene, all 3 sesquiterpenes and homovanillic acid.

Discussion

The only studies on the relationship between monoterpenes and the pine moth larvae were conducted by Smeljanec (1969), and Rudnew and Smeljanez (1969). They revealed that camphene, â-pinene and borneol had positive effects on larval development while α-pinene, α-terpineol, limonene and bornyl acetate had negative effects. Our results are somehow contradictory as camphene was inversely related with the number of the larvae per tree, while the relationships with α-pinene, limonene and bornyl acetate were not significant. Only one compound, β-pinene, was positively related with the larvae of the pine moth in both studies.

Table 8.—Regression models of natural radiation and monoterpenes in the needles of Scots pine trees (with p<0.05)

Monoterpene	Correlation coefficient	Regression model	Determination coefficient
3-hexene-1-ol	0.77	$\text{3-hexene-1-ol} = 0.042 \times \ln(\mathit{rad})$	0.55
RI 925	-0.65	$\mathit{RI\ 925} = 0{,}34 - 0.036 \times \ln(\mathit{rad})$	0.37
β-pinene	-0.69	$\ln(\beta\text{-}\mathit{pinene}) = 3.48 - 0.38 \times \ln(\mathit{rad})$	0.47
3-carene	-0.70	$\mathit{3\text{-}carene} = 57.8 - 6.42 \times \ln(\mathit{rad})$	0.49
α-terpinene	-0.66	$\alpha\text{-}\mathit{terpinene} = 0.24 - 0.022 \times \ln(\mathit{rad})$	0.43
RI 1037	0.82	$\mathit{RI\ 1037} = -0.14 + 0.03 \times \ln(\mathit{rad})$	0.66
(E)-β-ocimene	0.74	$\ln((E)\text{-}\beta\text{-}\mathit{ocimene}) = -2.63 + 0.43 \times \ln(\mathit{rad})$	0.54
terpinolene	-0.73	$\mathit{terpinolene} = 0.26 - 0.03 \times \ln(\mathit{rad})$	0.53
m-cymene	-0.63	$\mathit{m\text{-}cymene} = 4.04 - 0.34 \times \ln(\mathit{rad})$	0.40

Table 9.—Regression models of natural radiation and sesquiterpenes and phenolics in the needles of Scots pine trees (with p<0.05)

Compound	Correlation coefficient	Regression model	Determination coefficient
		Sesquiterpenes	
RI 1386	0.72	$\ln(\mathit{RI\ 1386}) = -4.13 + 0.4 \times \ln(\mathit{rad})$	0.47
RI 1430	0.82	$\mathit{RI\ 1430} = -0.17 + 0.047 \times \ln(\mathit{rad})$	0.64
RI 1494	0.74	$\ln(\mathit{RI\ 1494}) = -4.35 + 0.29 \times \ln(\mathit{rad})$	0.50
		Phenolic acid	
homovanillic	0.70	$\ln(\mathit{homovanillic}) = 0.614 \times \ln(\mathit{rad})$	0.44

Studies on the effect of monoterpenes in Scots pine needles on the pine beauty moth were conducted by Leather (1987), however it concerned the oviposition preference by the female moths. The results of these studies suggest that eggs are laid more often on the needles of Scots pines which contained a high ratio β:α-pinene. This leads to an assumption that pine beauty females prefer to lay eggs on those trees which are most favorable for larvae of the next generation. Our results suggest that the needles of preferable trees should contain low amount of β-pinene and thus the ratio β:α-pinene should be low since there was no significant relationship between α-pinene and the number of the pine beauty moth larvae per tree.

The differences between the host tree preferences of *D. pini* and *P. flammea* larvae haven't been studied before. Six chemical compounds were identified that were significantly but oppositely related with the larval abundance of both insect species: β-pinene was related positively with *D. pini* but inversely with *P. flammea*, while the compound with a retention index of 1430, γ-muurolene, β-vetivenene, α-cadinene and protocatechuic acid were related inversely with *D. pini* and positively with *P. flammea*. These differences may help to explain why these two species are rarely observed in high numbers on the same trees.

The possible impact of natural radiation, though measured using a subjective method, on the chemical composition of the Scots pine needles and indirectly on insect occurrence was also investigated for the first time. A significant relationship was found for natural radiation and 9 monoterpenes, 3 sesquiterpenes and 1 phenolic acid. When natural radiation is included in a plant-insect system, the interactions are getting more simple. The sesquiterpene with a retention time of 1430 and β-pinene seem to be the only links between natural radiation and abundance of both *D. pini* and *P. flammea*. Both compounds were inversely dependent on natural radiation, while they had different effects on the larval abundance of these species. These results suggest that natural radiation can have some impact on host plants and the larvae that feed upon them.

Further studies should focus on sampling more trees for analyses to confirm the results obtained so far and on using subjective and available objective methods to explore the relationships with natural radiation.

Acknowledgments

We thank Tomasz Jablonski and Slawomir Lipinski from Forest Research Institute in Warsaw, and the staff from the Wymiarki Forest District for technical assistance. This research was supported by Polish State Forests, project BLP-211.

References Cited

Becker, G. 1964. Reaktion von Insekten auf Magnetfelder, elektrische Felder und Atmospherics. Z. ang. Ent. 54: 55-58.

Becker, G. 1971. Magnetfeld-Einfluβ auf die Galeriebau-Richtung bei Termiten. Naturwiss. 56: 60.

Forrest, I., K. Burg, R. Klumpp, W.L. Mason, R. Alia, A.F.M. Olsthoorn, and K. Sjoberg. 2000. Genetic markers: tools for identifying and characterizing Scots pine populations. Proceedings of the final meeting of a Concerted Action (FAIR CT-95-1447) funded by the European Union under the Fourth Framework Programme, CENEAN-Valsain, Spain, June 1999. Investigacion Agraria, Sistemas y Recursos Forestales. Fuera de Serie 1: 67-88.

Jahn, E. 1973. Hinweise zur Auswirkung biophysikalischer Umweltverhältnisse auf forstschädliche Insekten, untersucht insbesondere an *Lymantria monacha* L. Anz. Schädlingskde., Pflanzenschutz, Umweltschutz 46: 37-43.

Jahn, E. 1975. Ergebnisse weiterer Untersuchungen zur Natur biophysikalischer Umweltverhältnisse und ihrer Wirksamkeit auf Lebensprozesse von *Lymantria monacha* L. (Lep., Lymantriidae). Anz. Schädlingskde., Pflanzenschutz, Umweltschutz 48: 136-139.

Jahn, E. 1977. Über Einflüsse biophysikalischer und elektrischer Felder auf *Lymantria monacha* L. Raupenwanderung, Faraday-Versuche, physikalische Meβmethoden. Anz. Schädlingskde., Pflanzenschutz, Umweltschutz 50: 101-104, 113-115.

Jahn, E., and N. Nessler. 1971. Auswirkungen von Bestrahlungen mit langen, sehr langen und insbesondere ultralangen Radiowellen auf Mortalität, weiter auf Fruchtbarkeit und Entwicklung der Nonne, *Lymantria monacha* L. Anz. Schädlingskde., Pflanzenschutz, Umweltschutz 44: 113-119.

Kolk, A., and J. Starzyk. 1996. Atlas szkodliwych owadów leśnych. Multico, Warsaw.

Krolicki, Z. 1998. Radiestezja stosowana. Ravi, Lodz.

Leather, S.R. 1987. Pine monoterpenes stimulate oviposition in the pine beauty moth, Panolis flammea. Ent. Exp. et Appl. 43:295-303.

Robert, P. 1963. Les migrations orientées du Haneton commun *Melolontha melolontha* L. Ergebn. Biol. 26: 135-146.

Rudnew, D.F., and V.P. Smeljanez. 1969. Ursachen der Massenvermehrung einiger Forstschädlingsarten. Anz. Schädlingskde. u. Pflanzenschutz 42: 177-184.

Schimitschek, E. 1972. Strahlungseinflüsse und Biophysikalische Effekte. Anz. Schadlingkde. u. Pflanzenschutz 44: 161-165.

Schneider, F. 1960. Der experimentelle Nachweis einer magnetischen und elektrischen Orientierung des Maikäfers. Verh. Schweiz. Naturforsch. Ges., Aarau: 132-134.

Smeljanez, W.P. 1969. The role of terpenoids in the tree resistance to insect pests. Anz. Schädlingskde. u. Pflanzenschutz 42: 33-37.

Swaczyna, M. 1991. Radiestezja a przyroda. PWRiL, Warsaw.

Vorontsov, A.I. 1982. Lesnaja entomologia. Vysshaja shkola, Moscow.

Radial Growth Rate and Susceptibility of *Picea rubens* Sarg. to *Tetropium fuscum* (Fabr.)

K. O'Leary[1], J.E. Hurley[2], W. Mackay[2] and J. Sweeney[2,3]

[1]Faculty of Forestry and Environmental Management, University of New Brunswick,
Fredericton, NB, Canada
[2]Natural Resources Canada, Canadian Forest Service-Atlantic Forestry Centre,
PO Box 4000, Fredericton, NB, Canada, E3B 5P7
[3]Presenter

Abstract

The brown spruce longhorn beetle, *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae) recently became established in Halifax, Nova Scotia, Canada, where it is infesting and killing apparently healthy red spruce, *Picea rubens* Sarg. In its native range, *T. fuscum* is a secondary pest of Norway spruce, *Picea abies* L., breeding in recently felled trees or trees weakened by root rots, lightning or other factors. To test the relationship between tree vigor and susceptibility to infestation by *T. fuscum,* we felled 18 pairs of infested and uninfested red spruce in the winter of 2001 in Point Pleasant Park, Halifax, and measured radial growth rates as a correlate of vigor. Mean 5-year radial increment peaked in 1956-1960 and declined steadily thereafter for all red spruce. However, radial growth was significantly lower in attacked trees than in unattacked trees in seven of nine 5-year periods between 1956 and 2000. Our data indicate that red spruce with reduced growth rates and low vigor were more susceptible to infestation by *T. fuscum* than faster growing, more vigorous trees.

In March of 2000, it was determined that the brown spruce longhorn beetle, *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae), had established in Point Pleasant Park, Halifax, Nova Scotia (Smith and Hurley 2000), and was infesting and killing apparently healthy red spruce, *Picea rubens* Sarg. The park is 75 ha in size, most of which is forested, with red spruce being the most common conifer species. The year of introduction is unknown, but recent examination of *Tetropium* specimens from the Nova Scotia Museum of Natural History revealed that 17 specimens of *T. fuscum* (misidentified as the native *T. cinnamopterum* Kirby) had been collected in a naturalist's bark beetle survey of Point Pleasant Park in 1990. Route of entry is uncertain but *T. fuscum* adults likely emerged from softwood packing material from shipping containers in the Halifax port facility located directly adjacent to Point Pleasant Park. *Tetropium fuscum* has been found in solid wood packing material at the ports of Montreal and Vancouver (Smith and Humble 2000, Humble and Allen 2001) and it is possible that the Halifax population is the result of more than one introduction. The chronology of the beetle's discovery in Halifax is described in Sweeney et al. (2001) and at the following website: http://www.atl.cfs.nrcan.gc.ca/BSLB/chronology-e.htm#july1998. A large scale survey and eradication program began in 2000 under the lead of the Canadian Food Inspection Agency.

Tetropium fuscum is native to coniferous forests in northern and central Europe, and western Siberia. Its main host is Norway spruce, *Picea abies* (L.) Karst., but it has also been found on *P. sitchensis* (Bong.) (Francke-Grosman 1954) Carr., *P. pungens* Engelm. (Juutinen 1953), *Pinus sylvestris* L. (Reineck 1919),–*Abies alba* L. and *Larix* spp. (Schaufuss 1916). In Halifax, *T. fuscum* is infesting red spruce, white spruce (*P. glauca* (Moench) Voss), black spruce (*P. mariana* (Mill.) B.S.P.), and Norway spruce. Larvae feed in the phloem and cambium, producing an extensive network of irregular galleries that eventually girdle the stem. It is univoltine, overwintering as a larva in most of its range, but may require 2 years to complete its life cycle in cooler climates or when the nutritional quality of the host is poor (Schimitschek 1929). Trees are often reinfested annually until desiccation and death (Juutinen 1955).

Tree Health and Susceptibility to *T. fuscum* Infestation

In its native range, the brown spruce longhorn beetle, *T. fuscum* is a secondary pest, breeding in recently felled trees or live trees weakened or stressed by biotic or abiotic factors such as root rots (Juutinen 1955) or lightning (Kula and Z′becki 1997). In Halifax, however, investigations in 1999 and 2000 in Point Pleasant Park found little evidence for a direct association between root disease and *T. fuscum* attack. Although both *Armillaria ostoyae* (Romagnesi) Herink and *Inonotus tomentosus* (Fr.:Fr.) S. Teng. were present at many scattered locations in the park, examination of the stumps of *T. fuscum*-attacked and non-attacked trees for wood stain and decay at ground line did not reveal any consistent pattern (G. Warren and Ken Harrison, pers. comm.). However, it is possible that the many root disease centers within the park created a reservoir of stressed, susceptible hosts that allowed the *T. fuscum* population to build to levels at which both stressed and non-stressed hosts became infested (Gary Warren, pers. comm.). A wood stain fungus, *Ophiostoma tetropii* Mathiesen, has been found associated with *T. fuscum* infestation in Halifax (Jacobs et al. 2003); it appears to be only weakly pathogenic but its biology is poorly known and currently under investigation (Doug Strongman and Ken Harrison, pers. comm.).

Juutinen (1955)[1] rated the health or "desiccation" status of 39 Norway spruce trees recently infested with *T. fuscum* in northern Finland as follows:

Health rating	**Description**	**Distribution of *T. fuscum*-attacked trees (%)**
I	Completely healthy trees.	0
II	Onset of desiccation. Desiccation factors are sparse and do not appreciably affect the condition of the tree as a whole. Crown completely without discoloration and the tree— except for possible traces of activity by woodpeckers and slight resin flow— by and large resembles a healthy tree externally.	4.1
III	Desiccation further advanced. Desiccation factors are more prominent, but are not yet able to cause desiccation of the tree. Symptoms of desiccation are already discernible externally, the crown is thinned and already partly dried up.	74.3
IV	Desiccation factors already present to such an extent that rapid desiccation of the tree appears certain. Crown only partly green.	21.6
V	Desiccation just completed. Crown completely dry, but still some fresh parts here and there in the bark.	0
VI	Completely withered trees. Crown and bark dried up throughout.	0

Juutinen (1955) found that most *T. fuscum*-infested Norway spruce had "thinned…and partly dried up" crowns (category III); only 4% of infested trees appeared green and healthy (II) with "slight resin flow." It is worth noting that Juutinen considered most of these trees (in categories II and III) as sub-lethally weakened, i.e., "not yet able to cause desiccation of the tree," prior to *T. fuscum* infestation.

---

[1] English translation available from NRCAN-CFS, Atlantic Forestry Centre

Table 1.—Crown condition and infestation by *Tetropium fuscum* of red spruce, *Picea rubens* in Point Pleasant Park, Halifax, NS, 3 May 2000 (Hurley and MacKay 2000)

Crown class	Crown description	No. red spruce (% of total)	No. with *T. fuscum* signs (% within class)
1	no defoliation	4 (3.5)	1 (25.0)
2	< 25% defol. current foliage only	0 (0)	0 (0)
3	< 25% defol. all foliage	73 (63.5)	35 (47.9)
4	25-50% defoliation	5 (4.3)	4 (80.0)
5	51-75% defoliation	4 (3.5)	0 (0)
6	76-90% defoliation	0 (0)	0 (0)
7	> 90% defoliation	0 (0)	0 (0)
8	recent dead	0 (0)	0 (0)
9	old dead	29 (25.2)	24 (82.7)

He states: "Especially after outbreaks of caterpillars, the spruce longhorn beetles attacked trees which could have undoubtedly recovered and they therefore caused considerable economic damage." (Juutinen 1955). So even in its native range, it appears that *T. fuscum* does not infest only dying trees but also attacks trees undergoing temporary periods of stress or low vigor. Once infested by *T. fuscum,* however, eventual girdling of the stem increases the tree's susceptibility to other pests, and results in death within 1 to 5 years of infestation (Juutinen 1955).

In contrast, the majority of *T. fuscum*-infested red spruce in Halifax appear green and healthy with copious resin flow down the stem. Hurley and MacKay (2000) assessed the crown condition and the presence or absence of signs of *T. fuscum* infestation on 115 red spruce (selected by prism point samples) in Point Pleasant Park on 3 May 2000. Crown condition was visually rated using standardized Canadian Forest Service forest health survey methods (D'Eon et al. 1994) on a scale from 1 to 9, where 1 = no defoliation and 9 = dead for more than a year. Most of the trees surveyed were classified as either green and healthy (67%) or dead for more than a year (25%). Less than 10% of live trees exhibited more than 25% defoliation (Table 1). Signs of *T. fuscum* infestation, i.e., resin flow on the stem and exit holes, were present on almost 50% of the trees with healthy crowns (classes 1–3) and on more than 80% of dead trees. It is difficult to directly compare the two methods of tree health classification, but we suggest that most of the infested trees in our park survey would correspond to Juutinen's health rating of II, i.e., "Crown completely without discoloration … By and large resembles a healthy tree externally." For whatever reason, red spruce infested by *T. fuscum* in Halifax appeared healthier than *T. fuscum*-infested Norway spruce in Finland.

A green and full crown is not always indicative of tree health or vigor, e.g., completely girdled trees may remain green for several months until the roots begin to weaken and die due to lack of photosynthates. Radial growth rate is related to vigor in red spruce; average 10-year radial increments of 2.3 and 0.75 cm are rated as superior and inferior vigor, respectively (Blum 1990). To investigate the relationship between tree vigor and susceptibility to infestation by *T. fuscum,* we compared the radial growth rates of infested and uninfested red spruce in Point Pleasant Park, NS. If *T. fuscum* was infesting red spruce regardless of health status or vigor, then the radial growth rate preceding infestation should be similar in infested and uninfested trees.

Methods

Twenty pairs of spruce trees were selected and tagged in Point Pleasant Park, Halifax, NS, in the fall of 2000. Each pair consisted of a tree with external signs of *T. fuscum* infestation, e.g., resinosis and exit holes, and a tree without such signs, hereafter referred to as attacked and unattacked, respectively.

Within pairs, trees were selected to have the same (± 2 cm) diameter at breast height (dbh) and were growing within 1–15 m of each other. For each tree, the crown condition and canopy position were rated and the north-facing side of the bole was marked. Trees were felled in January 2001 and length of live crown, total height, and live crown ratio were measured. After felling, we learned that one tree in each of two pairs was white spruce instead of red spruce. Therefore, only 18 pairs of red spruce were included in this analysis. A line was marked along the north (or nearest to it) face of the length of the bole and 4–5 cm thick disks were sampled from the center of every 4th discernible internode, and every 0.5 m thereafter. Wood disks were stored at -10ºC until radial increments were measured.

Two measures of radial increment (on both radii along the north–south line marked on the bole) were recorded for each year of growth per disk using a stereomicroscope and a Holman Digi-mic (Holman Electronic Controls Ltd., Fredericton, NB). Ring widths were subsequently checked and re-measured using a high resolution scanner and the "WinDENDRO ™ 2001a" software package (Regent Instruments Inc., www.regentinstruments.com), which also allowed us to save an electronic image of each tree disk. Although increments were measured along the north–south radii, the entire disk surface was examined under the stereomicroscope to check for discontinuous or incomplete rings. Rings that discontinued along a north or south radius were given an radial increment of zero.

For the purpose of this analysis, we assumed there were no completely missing rings and dated the rings using the outermost ring (assumed as year 2000) as a reference. However, missing rings are not uncommon, especially near the base of older, slow-growing trees (Glock 1937). If some of the trees did have missing rings, then the actual year of growth will have been assigned incorrectly, and we will have overestimated some of the 5-year periodic increments for those trees. For example, what we estimated as a 5-year increment may really have represented 6 or 7 years of growth. However, the possibility of missing rings does not seriously affect the main (null) hypothesis tested in this paper, i.e., that attacked and unattacked trees have similar growth rates or vigor. If attacked and unattacked trees are of similar age and vigor, then the probability of having missing rings will be the same. If attacked trees are truly older and less vigorous than unattacked trees, the probability of missing rings (and of overestimating growth and underestimating age) is greater in the attacked trees, resulting in a more conservative test of the our null hypothesis. We plan to use cross-referencing to accurately date rings and conduct a complete stem analysis of these trees in a subsequent paper.

To check the accuracy of our designation of attacked and unattacked trees, we collected one or two 35-cm bolts from each of 11 attacked trees and seven unattacked trees. Bolts were stored at -10ºC and subsequently incubated at 21°C in a containment facility and the emergence of adult *T. fuscum* recorded daily.

In the present analysis, we calculated the mean radial increment per 5-year period, e.g., 1996-2000, from the breast height disk of each tree. Live crown ratio, age (estimated from the bottom-most disk), crown condition, dbh, and height, were compared between attacked and unattacked trees, using paired t-tests. Periodic radial increment (PRI) for each of 19 5-year periods, from 2000 back to 1906, were compared between attacked and unattacked trees using ANOVA, with tree-pair locations as blocks. Residuals were checked for normality using the Shapiro-Wilk test (Zar 1984, SAS 1999-2001). The periodic annual increment of red spruce normally peaks at about age 45 (Meyer 1929). To account for a negative correlation between tree age and radial growth rate, we included age as a covariate and compared the PRI of attacked and unattacked trees for each 5-year period between 1960 and 2000, when most trees were more than 45 years old.

Results and Discussion

Adult *T. fuscum* emerged from bolts from seven of 11 attacked trees; bolts from the four attacked trees that did not produce adult *T. fuscum* had been stored at -10°C for more than 6 months and it is possible that prolonged exposure to cold caused some mortality. No *T. fuscum* emerged from the bolts sampled from the seven unattacked trees. Because *T. fuscum* may reinfest the same host tree year after year, it is possible that some of the attacked trees had been infested before 1999. However, as trees

Table 2.—Mean (± S.E.) size, age, and crown condition of 18 pair of red spruce trees in Point Pleasant Park, Halifax, NS, with signs of *Tetropium fuscum* infestation (attacked) and without such signs (unattacked)

Variable	Attacked		Unattacked		*P* value (paired t-test)
dbh (cm)	27.5	(1.4)	27.3	(1.4)	0.49
height (m)	17.8	(0.5)	17.2	(0.6)	0.31
age (at breast height)	88.2	(4.3)	79.1	(6.3)	0.06
live crown ratio	0.48	(0.03)	0.51	(0.03)	0.59
crown class[1]	3.8	(0.4)	2.9	(0.1)	0.04

[1] crown class assigned using the system described in Table 1.

usually die within 1 to 5 years after first becoming infested (Juutinen 1955), it is unlikely any of the sample trees were infested before 1996.

By design, trees within pairs did not differ in dbh, but attacked trees were on average 9 years older, and had slightly worse crown condition than unattacked trees (Table 2). The overall mean 10-year radial increment at breast height for the period from 1960-2000 was 1.5 cm, which for red spruce corresponds to a vigor class between acceptable (1.2 cm) and good (1.65 cm) (Blum 1990). The mean age at peak PRI did not differ between attacked (43 years) and unattacked trees (40 years) and was similar to that reported for second-growth red spruce (Meyer 1929). Mean PRI peaked in 1956-1960 and declined steadily afterwards for both attacked and unattacked red spruce (Fig. 1). A similar decline in growth rate was observed for red spruce across the Adirondack and northern Appalachian Mountains (Johnson and Siccama 1983; Hornbeck and Smith 1985). Cook and Zedacker (1992) concluded that neither stand dynamics nor climate change, alone or in combination, could be accepted as the cause of the regional decline in red spruce. Johnson et al. (1992) suggest that air pollution has played a significant role in the decline of red spruce in eastern North America, by increasing the sensitivity to winter injury, aluminum mobilization and cation loss. The soil in Point Pleasant Park is a podzol derived from Precambrian slate with pH ranging from 3.5 to 3.9 (Jotcham et al 1991), which is lower than optimal for red spruce (4.0–5.5, Blum 1990). Whatever the mechanism(s) may be, a regional decline in red spruce growth rate and vigor increases the probability of infestation by *T. fuscum* and other species known to exploit weakened or stressed hosts.

Mean PRI was significantly lower in attacked trees than in unattacked trees in seven of nine 5-year periods between 1956 and 2000 (Fig. 1a). This trend persisted when tree age was held constant using covariance analysis, except that differences were significant in only four of eight 5-year periods (Fig. 1b). The mean 5-year PRIs of unattacked trees ranged from 0.6 to 1.07 cm in the last 40 years, which corresponds to good (0.82 cm) or acceptable (0.58 cm) vigor classes for second-growth red spruce (Blum 1990). In contrast, the 5-year PRIs of attacked trees fell below those associated with acceptable vigor for the period of 1991–1995, and below those associated with inferior vigor (0.38 cm) from 1996–2000 (Fig. 1). Thus it appears that *T. fuscum* infestation occurred in red spruce that, on average, were of inferior vigor.

Reasons for the difference in growth rates between attacked and unattacked trees are unknown. Differences due to site, e.g., soil, exposure, etc., were minimized by the close proximity and size of trees within pairs. Feeding damage by *T. fuscum* likely accounts for some of the difference from 1996–2000, but infestation before 1996 is unlikely. Trees attacked by *T. fuscum* sometime within the last 1–5 years, were on average 9 years older and had been growing more slowly than unattacked trees for the last four decades. Age accounted for some but not all of the difference in growth rates. Other factors possibly responsible for differences in growth rate are genotype and root disease at a stage where infection was not discernible on cut stumps.

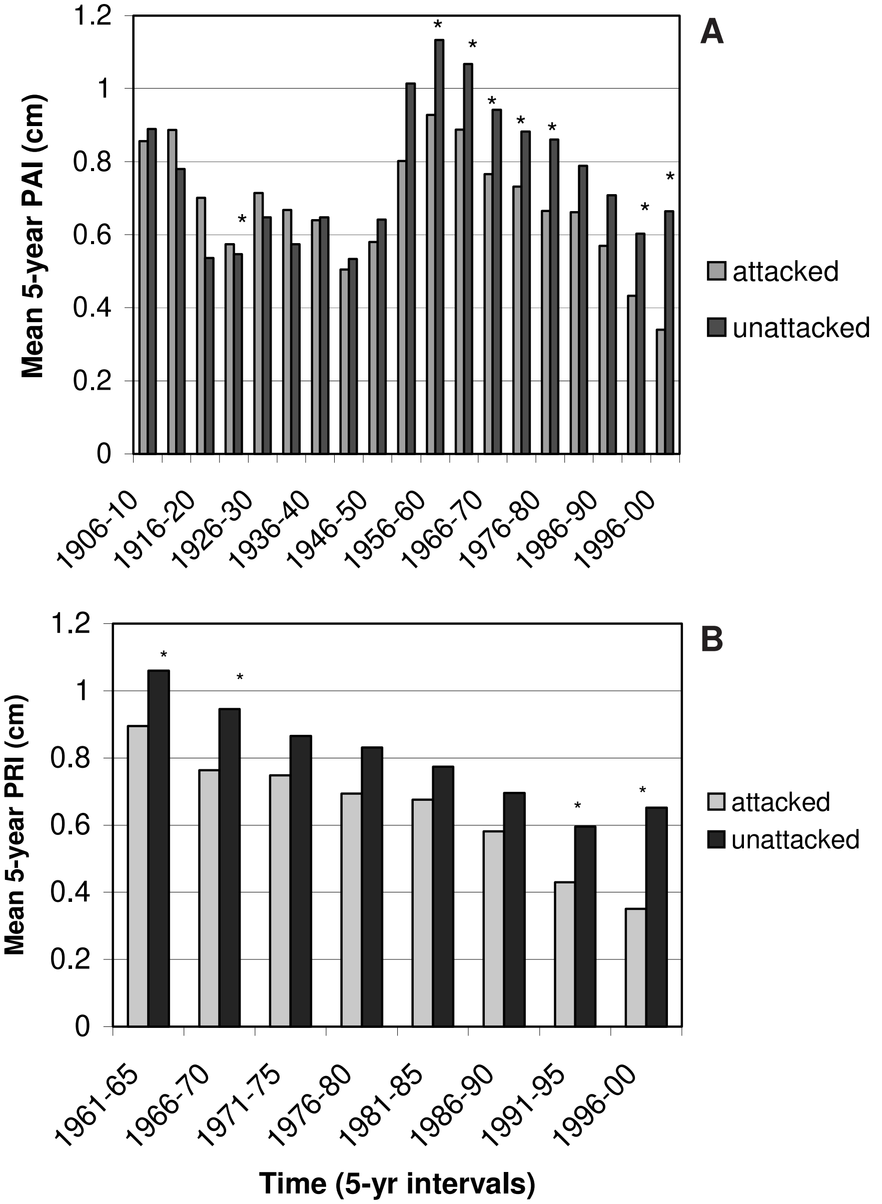


Figure 1.—Mean periodic radial increment per 5-year period (PAI) at breast height of 18 pair of red spruce, *Picea rubens* Sarg., growing in Point Pleasant Park, Halifax, NS, that either had signs of attack by *Tetropium fuscum* in 2000, or did not. A. Raw means for 19 intervals between 1906 and 2000. B. Least square means from covariance analysis where tree age was held constant. Asterisks denote significant differences in PAI between attacked and unattacked trees (ANOVA and COANOVA, P=0.05).

In conclusion, our data indicate that red spruce with reduced growth rates and low vigor were more susceptible to infestation by *T. fuscum* than faster growing, more vigorous trees. However, our data do not suggest these trees were weakened to the point that death was imminent before attack by *T. fuscum.* Red spruce is a long-lived, shade-tolerant species that can survive more than 100 years of suppressed growth and still respond to release (Blum 1990). Indeed, the PRI of unattacked trees increased slightly in the period from 1996–2000, possibly in response to openings in the canopy due to *T. fuscum*-related tree mortality (O'Leary 2002). *Tetropium fuscum* remains a threat to red spruce and other *Picea* spp. in North America, because it can infest and kill trees that may be undergoing periods of stress and suppressed growth due to drought, defoliator outbreaks, or a complex of factors.

Acknowledgments

We thank the Halifax Regional Municipality and staff of Point Pleasant Park and the following individuals: S. Bishop, D. Brown, G. Cunningham, A. Doane, S. Farrell, G. Gesner, K. Harrison, S. King, L. Leger, T. Mahendrappa, J. Price, D. Rogers, A. Sampson, J. Simmons, G. Smith, D. Strongman, T. Walsh, G. Warren, and R. Yerxa. We also thank G. Thurston, H. Piene, and C. Simpson for comments on an earlier version of the manuscript. Funding for this project was provided by the Canadian Food Inspection Agency. This work formed part of Karen O'Leary's undergraduate thesis in the Faculty of Forestry and Environmental Management, University of New Brunswick.

References Cited

Blum, B.M. 1990. *Picea rubens* Sarg. Red Spruce. *In:* Burns, R.M. and B.H. Honkala (eds.) Silvics of North America Volume 1. Conifers. USDA Forest Service Agriculture Handbook 654: 250-259.

Cook, E.R. and S.M. Zedacker. 1992. The dendroecology of red spruce decline. *In:* Eagar, C. and M.B. Adams (Eds.) Ecology and Decline of Red Spruce in the Eastern United States. Springer-Verlag, New York: 192-231.

D'Eon, S.P., L.P. Magasi, D. Lachance and P. Desrochers. 1994. ARNEWS, Canada's National Forest Health Plot Network, Manual on Plot Establishment and Monitoring. (Revised). Natural Resources Canada, Canadian Forest Service, Petawawa National Forestry Institute, Chalk River, Ont. Inf. Rep. PI-X-91. 119 p.

Franke-Grosman, H. 1954. Feinde und Krankheiten der Sitkafichte auf norddeutschen Centralbl. 67: 38-48.

Glock, W.S. 1937. Principles and Methods of Tree-Ring Analysis. Carnegie Institute of Washington, Washington, D.C. 100 pp.

Hornbeck, J.W. and R.B. Smith. 1985. Documentation of red spruce growth decline. Can. J. For. Res. 15: 1199-1201.

Humble, L.M. and E.A. Allen. 2001. Implications of non-indigenous insect introductions in forest ecosystems. *In*: Liebhold, A.M., McManus, M.L., Otvos, I.S., Fosbroke, S.L.C., eds. Proceedings: Integrated management and dynamics of forest defoliating insects. 15-19 August 1999; Victoria, BC: USDA Forest Service, Northeastern Research Station, Gen. Tech. Rep. NE-277: 45-55.

Hurley, J.E. and W. MacKay. 2000. Point Pleasant Park crown condition 2000. Unpublished Report. Natural Resources Canada, Canadian Forest Service, Atlantic Forestry Centre.

Jacobs, K., K.A. Seifert, K.J. Harrison and T. Kirisits. 2003. Identity and phylogenetic relationships of ophiostomatoid fungi associated with invasive and native *Tetropium* spp. (Coleoptera: Cerambycidae) in Atlantic Canada. Can. J. Bot. (in press).

Johnson, A.H. , S.B. McLaughlin, M.B. Adams, E.R. Cook, D.H. DeHayes, C. Eagar, I.J. Fernandez, D.W. Johnson, R.J. Kohut, V.A. Mohnen, N.S. Nicholas, D.R. Peart, G.A. Schier, and P.S. White. 1992. *In:* Eagar, C. and M.B. Adams (Eds.) Ecology and Decline of Red Spruce in the Eastern United States. Springer-Verlag, New York: 385-411.

Johnson, A.H. and T.G. Siccama. 1983. Acid deposition and forest decline. Environ. Sci. Tech. 17: 294A-305A.

Jotcham, J.R., K.W. Strong and T.K. Marvin. 1991. An Ecological Survey of Point Pleasant Park. Marbicon Inc. and Maritime Testing Limited.

Juutinen, P. 1953. Ukkoniluri (*Dendroctonus micans* Kug.) (Col., Scolytidae) okakuusessa (*Picea pungens* Engelm.) (Summary: *Dendroctonus micans* on *Picea pungens.*) Ebenda 19: 35.

Juutinen, P. 1955. Zur biologie und forstlichen Bedeutung der Ficchtenböcke (*Tetropium* Kirby) in Finnland. Acta Entomol. Fenn. 11: 1-112.

Kula, E. and W. Ząbecki. 1997. Lightning-stroken areas as the centres of bark-beetle-infested patches within spruce stands. Sylwan 8: 89-97. (in Polish with English summary).

Meyer, W.H. 1929. Yields of second-growth spruce and fir in the Northeast. USDA, Washington, D.C. Technical Bulletin No. 142.

O'Leary, K.L. 2002. Radial growth rate of *Picea rubens* (Sarg.) and susceptibility to infestation by *Tetropium fuscum* (Fabr.) (Coleoptera: Cerambycidae). BScF. Thesis. University of New Brunswick, Fredericton, NB. 39 pp.

Reineck, G. 1919. Die Insekten der Mark Brandenburg. Coleoptera. Cerambycidae. Deutsche Ent. Zschr. [German Entomological Journal], Supplement.

SAS 1999-2001. SAS Institute Inc., Cary, N.C.

Schaufuss, C. 1916. Calwer's Käferbuch. II. Stuttgart.

Schimitschek, E. 1929. *Tetropium gabrieli* Weise und *Tetropium fuscum* F. Ein beitrag zu ihrer Lebensgeschichte und Lebensgeneinsamschaft. Zeitschrift für angewandte Entomologie 15: 229-334.

Smith, G.A. and L.M. Humble. 2000. The brown spruce longhorn beetle. Exotic Forest Pest Advisory 5. Natural Resources Canada, Canadian Forest Service. 4 pp.

Smith, G.A. and J.E. Hurley. 2000. First North American record of the palearctic species *Tetropium fuscum* (Fabricius) (Coleoptera: Cerambycidae). The Coleopterists Bulletin 54: 540.

Sweeney, J., G. Smith, J.E. Hurley, K. Harrison, P. de Groot, L. Humble and E. Allen. 2001. The brown spruce longhorn beetle in Halifax: Pest status and preliminary results of research. *In:* Fosbroke, S.L.C.; Gottschalk, K.W., eds. Proceedings, U.S. Department of Agriculture interagency research forum on gypsy moth and other invasive species 2001; January 16-19 2001; Annapolis MD. Newtown Square, PA: U.S. Department of Agriculture, Forest Service. Northeastern Research Station. Gen. Tech. Rep. NE-285: 6-10.

Zar, J.H. 1984. Biostatistical Analysis, 2nd Ed. Prentice-Hall, Englewood Cliffs, N.J. p. 95.

Preliminary Results on Predation of Gypsy Moth Egg Masses in Slovakia

Marek Turčáni[1], Andrew Liebhold[2], Michael McManus[3] and Július Novotný[1]

[1]FRI Zvolen, RS Banská Štiavnica, Lesnícka 11, 96923 Banská Štiavnica, e-mail: turcani@lvu.sk
[2]USDA Forest Service, Northeastern Research Station, 180 Canfield St., Morgantown, WV 26505, e-mail: aliebhold@fs.fed.us
[3]USDA Forest Service, Northeastern Research Station, 51 Mill Pond Rd Hamden, CT 06514-1703, e-mail: mlmcmanus@fs.fed.us

Abstract

Predation of gypsy moth egg masses was studied in Slovakia from 1999 –2002. Predation on naturally laid egg masses was recorded and linear regression was used to test the hypothesis that predation follows a type II vs. type III functional response. We also investigated the role of egg mass predation in gypsy moth population dynamics. The relative contribution of invertebrates vs. vertebrates as agents of predation on egg masses was estimated using exclosures. During the study, population densities remained very low and stable. Generally, invertebrata caused 38% and vertebrata 62% of total predation. K-values varied from 0.03 to 0.70 and plots of abundance vs. k-values suggested that total predation is inversely density dependent, characteristic of a "type II" functional response. The ultimate role of predation on gypsy moth egg masses remains unclear, however there are some indications that egg mass predation plays a significant role in the dynamics of gypsy moth populations in Slovakia.

Introduction

The gypsy moth (*Lymantria dispar*) is the most serious pest of broadleaved stands (oak stands mainly) in Slovakia. Outbreaks are repeated in cycles of 6 to 12 years. During the last outbreak of 1992 - 1994, gypsy moth severely damaged more than 18,000 ha of forest land. In stands exhibiting patterns of long-term oak decline, defoliation can cause increased tree mortality in subsequent years and therefore, infested stands are often treated with biopesticides, mainly *Bacillus thuringiensis*. The key biotic factors influencing population dynamics during the latency phase are not well known in Slovakia. Conversely, the bioregulation complex of gypsy moth is better understood in the U.S.A. (Doane and McManus 1981, Elkinton, Liebhold 1990). The goal of this paper is to present results on a study of gypsy moth egg mass predation during the latency phase. The objectives of this study were to: Determine the relationship between predation and gypsy moth densities (i.g. identify the type of functional response); evaluate the role of egg mass predation in gypsy moth population dynamics; and quantify the relative levels of predation caused by vertebrates vs. invertebrates.

Material and Methods

Survey of Population Density

A series of 12 study plots was established across the outbreak area of gypsy moth in southern Slovakia (Fig. 1). Surveys of population density were conducted using the Modified Turcek method (MTM) (Turcani 1998). MTM consists of counting the number of egg masses on 4 points (every point consists of 30 trees) in the study area. If the average number was over 1.00 egg mass per tree, the survey was terminated. If it was below 1.00 egg mass per tree, counting continued on another 4 points (together 240 trees). If the population density was below 0.3 egg masses, another 8 points were taken. The total arrangement consisted of 480 trees. Egg masses were found on trunks from ground level to the 5 – 8 m.

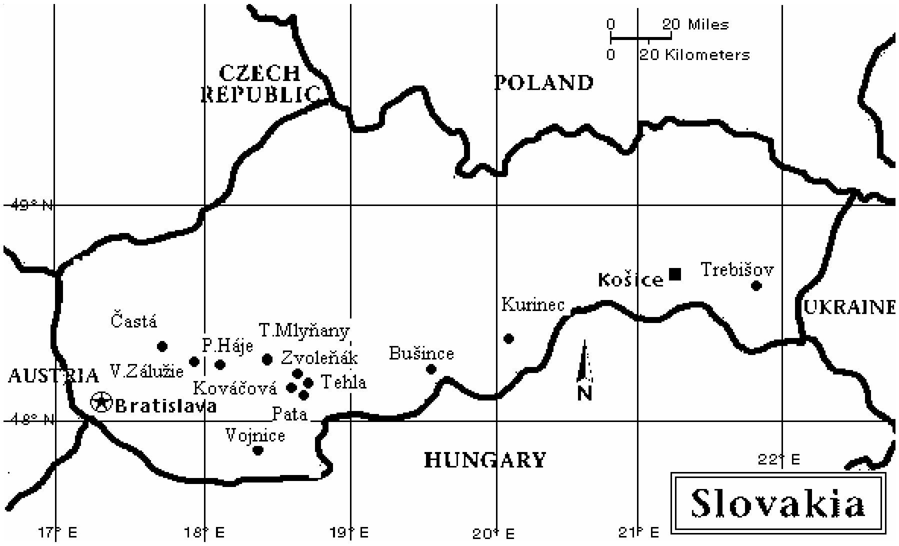


Figure 1.—Placement of study plots (•) in the Slovak Republic

Egg mass predation

Predation on naturally laid egg masses was recorded by inspection of each egg mass found during the annual survey described above. These inspections were conducted at the end of November (around the time of first snowfall) and at the beginning of April (when all snow has melted). At the time of original survey and at each check, the size (length and width) and condition of each egg mass was recorded (we recorded the proportion of each egg mass that was missing).

The effect of density on predation levels was studied by comparing predation levels at different sites in different years. Predation was expressed as k-values at each site in each year. Density dependence was tested by regressing predation vs. log egg mass density. Linear regression was used to test the hypothesis that predation follows a type II vs. type III functional response (Holling 1965).

The impact of egg mass predation on population growth was evaluated by plotting R (N_{t+1}/N_t) vs. k-values from the same year during the entire study period.

The relative contribution of invertebrates vs. vertebrates as agents of predation on egg masses was estimated using exclosures (Grushecky et al. 1998). These experiments were conducted at Zvolenak and Pata during the winters of 2000/2001 and 2001/2002. At each site, 150 laboratory reared egg masses were placed on the stem of individual trees.

Exclosures were placed around 75 of these egg masses. Exclosures consisted of a ~1.5 cm steel mesh (“hardware cloth”) cage stapled to the bark surface around each egg mass. The proportion of each mass was recorded in November (around the 1st snowfall) and in the middle of April (prior to the approximate time of egg hatch). We assumed that the exclosure excluded all vertebrate predators but did not impede invertebrates and the relative contribution of invertebrate predators will thus be estimated by the k-values computed from predation of egg masses inside exclosures. K-values for predation by vertebrates was estimated as the difference between k-values computed from predation of egg masses without exclosured and k-values computed from predation of egg masses inside exclosures (Grushecky et al. 1998).

Results

Population Density Survey

Relatively little change in population density occured during the period of 1999 – 2001. The range of population density varied from 0 to 0.056 egg masses per tree (0 to 28 egg masses/ha). The values indicate a period of latency on all of the plots. Examples of changes in abundance are provided in Figures 2, 3 and 4.

Table 1.—Predation of naturally laid eggs in study period.

Site	Abund 1999	k-values 1999/2000	Abundance 2000	k-values 2000/2001	Abundance 2001	k-values 2001/2002
Trebišov	1	0.699	0	No egg masses	0	No egg masses
Kurinec	4	0.143	1	0.699	1	0.022
Bušince	2	0.046	0	No egg masses	4	0.097
Pata	6	0.125	26	0.076	1	0.046
Tehla	12	0.131	3	0.456	0	No egg masses
Kováčová	29	0.046	14	0.469	3	0.036
Zvoleňák	13	0.046	19	0.051	0	No egg masses
Vojnice	0	No egg masses	1	0.097	0	No egg masses
T.Mlyňany	12	0.119	4	0.046	0	No egg masses
P. Háje	6	0.097	16	0.056	4	0.027
V. Zalužie	1	0.284	4	0.276	2	0.081
Castá	3	0.187	24	0.081	27	0.051

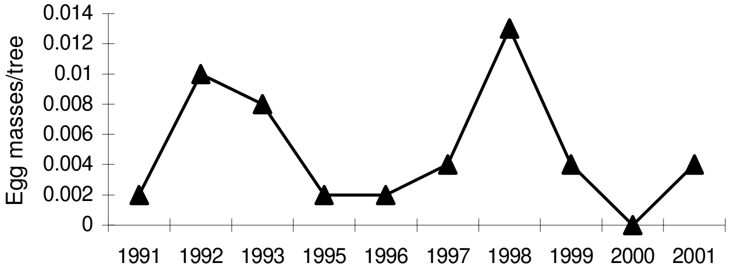


Figure 2.—Trend of egg masses at Bušince.

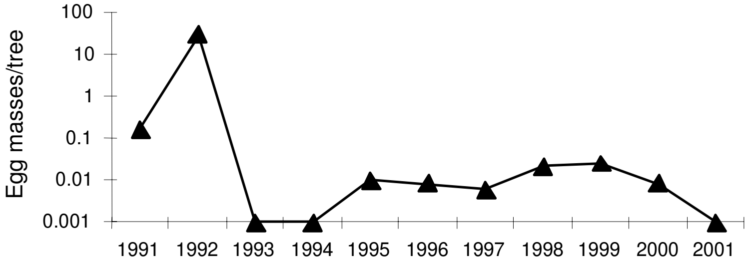


Figure 3.—Trend of egg masses at T. Mlyňany

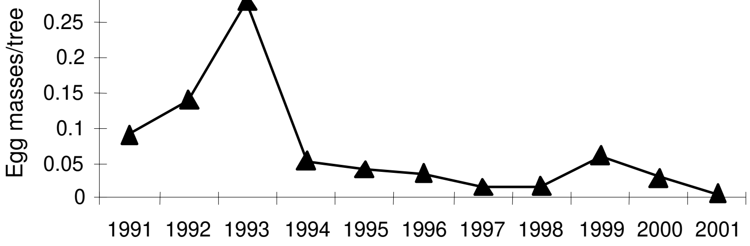


Figure 4.—Trend of egg masses at Kováčová

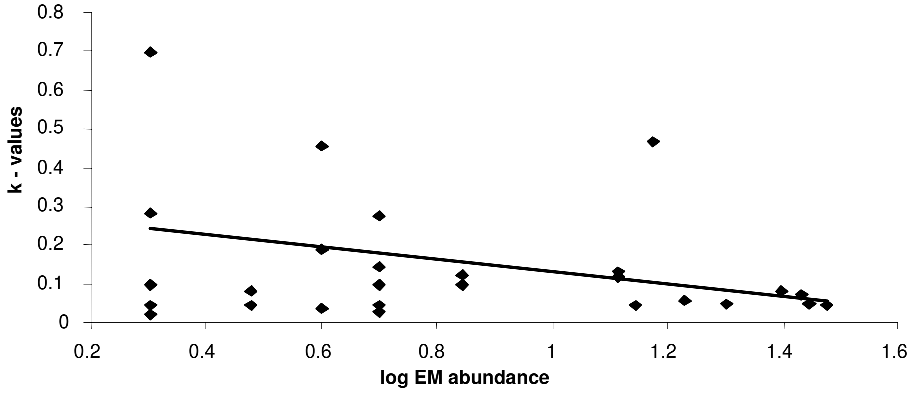


Figure 5.—Comparison of log EM abundance and k-values at the same year (n=28, Cc= -0.34).

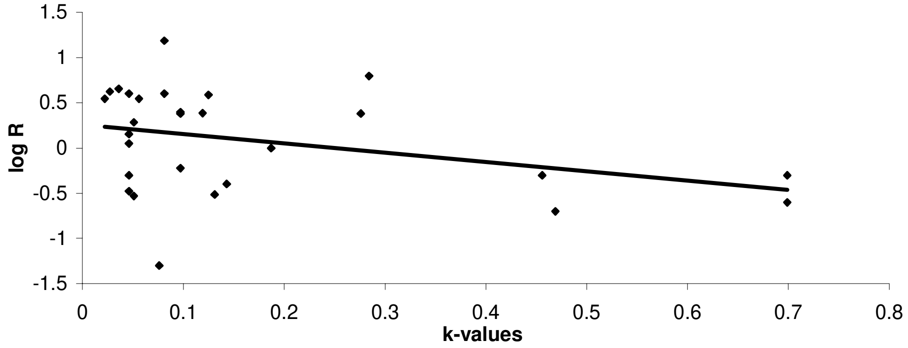


Figure 6.—Relationship between log R (Nt+1/Nt) and k-values (N=28, Cc= -0.35).

Predation of Naturally Laid Egg Masses

Egg mass predation was generally low and was variable among different sites (Table 1).

Dependence of predation was estimated based on the relationship between k-values and abundance in the same year. Though there was an apparent negative correlation, this was not statistically significant (Fig. 5). Neverthérless these data suggest that total predation is inversely density dependent - "type II" functional response (Holling 1965).

We also found an inverse, but insignificant correlation between predation (K) and change in population density. These results suggest that predation on egg masses explains some of the variation in change of population density (Fig. 6).

Determination of the Relative Levels of Predation Caused by Vertebrates vs Invertebrates

Predation in experiments with artificially deployed egg masses was slightly higher than in the case of naturally laid egg masses. This may have been caused by our deployment of egg masses on transects, where the abundance of egg masses is higher than normal, and which might attract predatory birds. Vertebrates caused almost two-thirds of the predation. It is possible, that in several cases, predation by vertebrates could have occurred in exclosures (by birds with long beaks like *Sitta europaea).* In that case, predation caused by vertebrates may have been underestimated in this study.

Discussion

During the length of the study, the quantity of direct damage was low on all sites; k-values only rarely exceeded 0.4. Until now, the importance of damage on egg masses was not well described. Capek et al. (1999) published data on the predation of masses during outbreaks when totally damaged egg masses were found quite often. These data vary from the results of our experiments, in which the occurrence of totally damaged masses was rare. Randík (1967) also mentioned additional information about egg mass predation, but no relationship was found between abundance and

Table 2.—Relative levels of predation in two winters.

Locality	Total K	%	Invertebrata K	%	Vertebrata K	%
Pata 2000/2001	0.102	100	0.046	45	0.057	55
Zvolenak 2000/2001	0.046	100	0.027	59	0.019	41
Pata 2001/2002	0.050	100	0.021	42	0.029	58
Zvolenak 2001/2002	0.132	100	0.030	23	0.102	77
TOTAL	0.330	100	0.124	38	0.206	62

predation. Only frequency of egg mass damage and not the proportion of predation was measured in these experiments.

Turček (1949) observed the following bird species as feeding on gypsy moth egg masses: *Certhia familiaris*, *Sitta europaea*, *Parus major*, *Parus caeruleus*, *Parus major* and *Aegithalos caudatus*. During our experiments, we did not make direct observations of the bird species that were active in the study area.

Various aspects of egg mass predation (e.g., dependence between size of masses and predation; location of masses on trees; and predation and dependence between abundance and predation) were studied by Higasiura (1989). Abundance during his experiments varied between 27 to 230 masses per ha (0.05 to 0.5 EM/T). Percentage of predation varied with abundance and among years. Predation of masses by birds was not usually closely related with abundance. However, when the range of abundances was high, he found a significant inverse correlation dependence between abundance and predation. Higasiura (1980) reported that when abundance varied from 6 to 231 masses per 1 ha (0.01 to 0.5 masses per 1 tree), the predation by birds was almost density independent, but an inverse density dependent trend was observed in 1 year. As a whole, the correlation between egg mass density and percent predation was not apparent. Comparison of abundance and k-values during our experiment suggested an inversely density dependent relationship, but this correlation was not significant.

These results indicate that bird populations are not tightly linked ecologically to populations of gypsy moth and feeding on egg masses is mostly accidental. Predation during individual years may depend on the availability of alternate sources of food to birds and not on the abundance of gypsy moths. An important fact during our experiments was that we used naturally laid eggs except in the vertebrates-invertebrates experiments. In this case it was possible to exclude effect of bird concentrations on areas containing higher egg mass densities.

However, it may be that predation of egg masses is not insignificant in the population dynamics of gypsy moth in Slovakia during the latency phase. Despite the fact that the correlation between log R and k-values was not significant, it is still possible that predation on egg masses plays a relatively important role in gypsy moth population dynamics in Slovakia. The narrow range of egg mass densities encountered along with the sampling methods that were utilized in this study may have limited our ability to detect these relationships.

Conclusions

- Population densities were very low and relatively stable during the study period.
- K-values varied from 0.03 to 0.70 and total predation was slightly inversely density dependent - “type II” of functional response.
- The ultimate role of predation on gypsy moth egg masses is not clear, however there are some indications that predation of egg masses plays some role in the dynamics of gypsy moth populations in Slovakia.
- These experiments indicate that invertebrates caused 38% and vertebrates 62% of egg mass predation.

References Cited

Capek, M., Kristin, A., Novotny, J., Findo, S., Hesko, J., Patocka, J. 1999. Feinde der Eichenschadlinge. In: Patocka, J., Kristin, A., Kulfan, J., Zach, P. (Eds.) Die Eichenschadlinge und ihre Feinde. p. 277-347.

Doane, C. C., McManus, M. L. (eds.) 1981. The gypsy moth: Research toward integrated pest management. USDA For. Serv. Sci. Educ. Ag. Technical Bull. 1584, Washington, D. C. 1981, 757 pp.

Grushecky, S.T., Liebhold, A.M., Greer, R., Smith, R.L. 1998. Does forest thinning affect predation on gypsy moth (Lepidoptera: Lymantriidae) larvae and pupae? Environ. Entomolo. 27:268-276.

Holling, C.S. 1965. The functional response of predators to prey density and its role in mimicry and population regulaton. Mem. Entomol. Soc. Ca. 45:1-60.

Higasiura, Y. 1980. Analysis of factors affecting bird predation on gypsy moth egg masses by using Holling´s disc-equation. Res. Popul. Ecol. 22: 147-162

Higasiura, Y. 1989. Survival of eggs in the gypsy moth *Lymantria dispar*. L. predation by birds. Jour. Animal Ecol. 58: 403-412.

Elkinton, J.S. and Liebhold, A.M. 1990. Population dynamics of gypsy moth in North America. Ann. Rev. Entomol. 35: 571-596

Randik, A. 1967. [Contribution to conservation of birds in areas of occurence of gypsy moth (*Lymantria dispar* L.) in the southern Slovakia]. In:Prace a studie ceskoslovenskej ochrany prirody, Bratislava. 1(2): 1-89.

Turcani, M. 1998. [Estimation of gypsy moth (*Lymantria dispar* L.) abundance changes in different parts of outbreak area in Slovakia during the period 1990 - 1997 by using modified Turcek method]. Vedecke prace LVU Zvolen n. 42, Priroda, p. 129 - 155.

Turcek, J. F. 1949. [About bird populations in deciduous forests during outbreak of gypsy moth]. Zpravy Statnich vyzkumnich ustavu lesnickych CSR. p. 108 – 131.

The Role of Selected Soil Fauna as Predators of *Apethymus abdominalis* Lep. (Hymenoptera, Tenthredinidae) in Oak Forests in the District Căiuţi, Romania

C. Ciornei[1], N. Popa[2], L. Ciucă[3] and C. Rang[4]

[1]Forest Reasearch Station Hemeiuşi – Bacău, Romania, e-mail: icasbc@mic.ro
[2]Forest Direction Bacău, Romania
[3]Natural Sciences Museum of Bacău, Romania
[4]University of Bacău, Romania

Introduction

The present study was initiated in 2001 in the oak forests from Trotuș valley (Forest District Căiucți – Bacău, Romania) which were heavily infested by oak sawflies *Apethymus abdominalis* Lep. (Hymenoptera: Tenthredinidae), in order to understand better the role of soil-inhabitating predators in population regulation of this pest.

A serious outbreak of this defoliator was recorded during the years 1999-2000 and thus a series of treatments with the chitin inhibitors Dimilin and Rimon were applied against larval populations in those forests. Subsequently, after the year 2000, we observed an increase in populations of its natural enemies, from egg-larval parasitoids to eonimphal predators, which gradually subdued the outbreak.

A series of soil inhabitating predators, namely from the families Carabidae (genera *Abax*, *Carabus*, *Harpalus*, *Pterostichus* etc.) and Staphilinidae (*Staphilinius*, *Optionus, Philontus* etc.), as well as red mites (Stigmotrombidiidae) and forest red ants were recorded.

Materials and Methods

Soil fauna was collected using a series of Barber traps. Each series consisted in 12 traps (consisting of a 10 cm diameter, 250ml cup). Nine series of traps were placed in three plots within the Forest District Căiucți-Bacău: Păltinata Forest (3), Heltiu Forest (5) and Cornățel Forest (1). During 2001, contents of the Barber traps were collected monthly beginning on the 15th of April and continuing until the 19th of October (six collecting periods).

The level of defoliation of oak trees in the forests under study was estimated by sampling branches and by estimating the number of eonimphae in the soil around trees. We also recorded the number of other defoliators that are found characteristically in oak forests.

Results

In the spring of 2000 the level of defoliation of oaks by larvae of *Apethymus abdominalis* in the study areas was estimated to be 97% in the Heltiu Forest, 15% in the Păltinata Forest and 5% in the Cornățel Forest. The numbers of eonimphae in the soil was estimated to be 4 specimens/m^2 in Păltinata and 20 specimens/m^2 in Heltiu. Minor defoliation by other forest pests including *Tortrix viridana, Operophtera brumata, Erannis delfoliaria*, O*rthosia* sp.of caterpillars was also noted in all areas, but especially in the Cornățel Forest.

As a consequence of the treatments applied in 1999-2000, the larval populations in the spring of 2001 were at extremely low levels (1-2%), meanwhile the number of eonimphae in the soil was high (maximum 40 specimens/m^2 in Heltiu Forest). However, the caterpillar complex caused an estimated defoliation of 50% in the Cornățel Forest.

The abundance of available larvae, especially those in the latest instar (L_6), and sawfly econimphae induced an abundance of select invertebrate predators in the soil. The most numerous were over 30 species, of carabids such as *Abax ater*, *Carabus coriaceus*, *C. granulatus*, *Harpalus pubescens*, *Pterostichus oblongopunctatus*, and over 10 species of staphilinids such as *Staphilinius olens*, *Philontus chalceus, Quedius* sp.). In the forests Păltinata and Heltiu, there was an abundance of red mites (Acarina) from the genus *Eutrombidium* (Stigmotrombidiidae) during the spring of 2001.

In the Cornățel Forest we observed intensive activity of forest red ants (*Formica ruffa)* (1751 specimens/series of 12 traps) followed by carabids (only *Harpalus pubescens* registered 195 specimens/series, other carabid larvae (698 specimens/series) and staphilinids (46 specimens/series). Most predator species were active during the months of April-May; however an omnivorous forest red ant was active during all vegetation periods.

The most heavily infested area was the Heltiu Forest, where two successive treatments were applied in 1999 and in 2000. Our results confirmed that there was a decline in a quantitative diminution of the number of predators in 2001 as compared to the previous years, however the species diversity was relatively unaffected-35 species in Heltiu Forest, 30 species in Forest Păltinata and 28 species in Forest Cornățel.

References Cited

Ciornei, C.; Mihalache, GH. 1999. *Apethymus abdominalis* (Hym., Tenthredinidae) a new pest of the oak forests in Romania. Proc of the Second Workshop of IUFRO WP: 7.03.10, April 20-23, Sion-Chateauneuf, Switzerland WSL Birmensdorf: 268-270.

Ciornei, C.; Popa, N. 2000. Control experiments of pest *Apethymus abdominalis* Lep. (Hym., Tenthredinidae) in oak forests from Romania. Proc. Of the IUFRO WP 7.03.10. Workshop, Sept 24-28, Bușteni, Romania, 17-21.

Ciornei, C.; Popa, N., Rang, C., Ciucă, L. 2001. The influence of natural limitative factors an the outbreak of *Apethymus abdominalis* Lep. (Hym., Tenthredinidae) from oak forest Heltiu – Romania, Fourth Workshop of the IUFRO, WP 7.03.10, Sept. 17-20, Prague, Czeh Republic, 59-61.

Thiele, H-U. 1977. Carabid beetles in their environment. A study on habitat selection by adaptation in physiology and behavior, Springer-Verlag Berlin-Heilderberg-New York, 362 pp.

Titovsek, K. 1992. Gradacija hrastasih grizlic (*Apethymus abdominalis* Lep. Un *A. braccatus* Gmelin) v krakovsken gozdei. Gozd. Vest, Liubljana, 50, 9 :386-393.

Parasitoid Communities of Two Invading Leafminers of Black Locust in Hungary: First Year Results

György Csóka[1], Anikó Hirka[1] and George Melika[2]

[1]Forest Research Institute, Department of Forest Protection, Mátrafüred, Hungary
[2]Systematic Parasitoid Laboratory, Kőszeg, Hungary

Black locust (*Robinia pseudoacacia*) is a significant plantation tree in Hungary, which was introduced to Hungary in the mid 18th century and now occupies more than 21.6% of the forested area (nearly 370 thousand hectares). Two species of leaf miners, *Parectopa robiniella* Clemens 1859 and *Phyllonorycter robiniella* Clemens 1859 have invaded Hungary in the last two decades. Both species have become widespread and abundant on black locust throughout the country and serious infestations cause early leaf abscission on affected trees. No detailed study on parasitoids associated with these species have been conducted; this abstract reports results from the first year of the study on their parasitoid communities.

The work was carried out at two locations in 2001; Gödöllő is ca. 30 km NE-E of Budapest and Visonta is ca. 80 km in the same direction. Black locust is an abundant tree species at both sites and the stands that were sampled at both locations were relatively young (12-15 years). We deliberately chose younger stands because on younger trees (up to 6-8 m in height), the entire crown can be sampled using a long stalk brunch cutter. This way the sampling can be more representative than sampling only lower branches of larger trees. Beginning in early June, both sites were visited at 3-5 days intervals in order to determine the optimal time for sampling.

A significant difference was found in development of the two species. The 1st generation of *Parectopa* completed its development later than *Phyllonorycter*. In case of the 2nd generation, the difference was even larger, therefore the two species had to be sampled separately. At both sites for all sampled generations, 15 ca. 60 cm long branches were selected at random and were cut. Only the mines of the sampled generations were counted, whereas the old mines and the very young mines (under 10 mm) were neglected. We counted and recorded the following characteristics:

- number of leaves on sample branches
- number of leaflets by leaves
- intact leaflets
- leaflets with *Phyllonorycter* mines and leaflets with *Parectopa* mines
- leaflets with mines of both species
- number of larvae in each mine

About 500-600 mined leaflets were collected randomly during each sampling period. The first 300 mined leaflets containing either final instar larvae or pupae of the host were put into plastic tubes for individual rearing. The number of mines/leaflet and number of larvae in mines were counted in advance. If the leaflet contained mines of two species, the larva of the "secondary" species were removed from the mines (i.e. in case of *Phyllonorycter* sampling, larvae of *Parectopa* were removed from mines and vice versa). The rearing tubes were checked weekly and the emerged parasitoids were put into vials together with labels. The dead specimens were kept dry, while those that were still alive were placed into 70% alcohol. The braconids were identified by Dr. Jenö Papp (Natural History Museum, Budapest) and the chalcids were identified by Dr. George Melika (Systematic Parasitoid Laboratory, Kőszeg).

The first mines of *Parectopa* appeared ca. 2-3 days later than first mines of *Phyllonorycter*. While *Phyllonorycter* produced three generations *Parectopa* produced only two generations. *Parectopa* mines nearly always contain a single larva, whereas *Phyllonorycter* mines often contain more than one larva (as many as five) In this case it is still not clear whether they originate from one female or from several females whose eggs are laid close to each other.

The most striking result of the rearing experiment is that hardly any parasitoids were reared from *Parcetopa*. The highest attack rate (*Visonta,* first generation) was only 1%. The attack rates by parasitoids were much higher for *Phyllonorycter*. The very low attack rate that we recorded for the third generation at both sites is due to the fact that the parasitoids that developed in the third generation of the host entered diapause along with their hosts. The most significant parasitoid of *Phyllonorycter* at both sites was the braconid *Pholetesor nanus*. It was responsible for 54-76% of the total parasitism. This species is known to attack a range of native *Phyllonorycter* leaf miners in Europe.

Intercept™ Panel Trap (INT PT) Effective in Management of Forest Coleoptera

D. Czokajlo[1], J. McLaughlin[1], L.I. Abu Ayyash[1], S. Teale[2], J. Wickham[2], J. Warren[3], R. Hoffman[1], B. Aukema[4], K. Raffa[4] and P. Kirsch[1]

[1]IPM Tech, Inc., 4134 N. Vancouver Ave. #105, Portland, OR, USA 97217, tel. (503)288-2493, fax. (503)288-1887, e-mail: ipmtech@ipmtech.com, web: www.ipmtech.com
[2]SUNY ESF, Syracuse, NY, USA,
[3]Cloquet Forestry Center, Cloquet, MN, USA,
[4]University of Wisconsin, Madison, WI, USA

Introduction

Trap efficacy in capturing economically important forest Coleoptera was measured in field trials comparing the Intercept Panel Trap (INT PT) with the Multi-Funnel Trap. The INT PT was designed to provide a better option for the monitoring of forest Coleoptera. The trap is made of corrugated plastic and is very robust under rigorous field conditions, but still lightweight, easy to carry, weather- and waterproof, and easy to install. The trap disassembles rapidly and stores flat, therefore requiring less storage space than Funnel Traps. The INT PT also costs significantly less than the Funnel Trap.

Methods and Materials

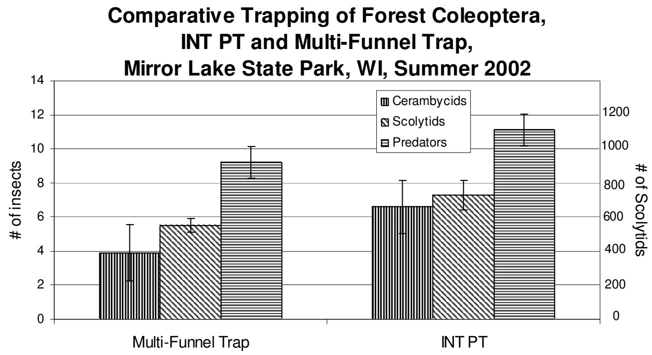
Field trials were conducted on five sites within the United States: OR, NC, MN, WI, and NY. In OR, NC, MN, and NY three types of traps were tested: INT PT treated with Rain-X (INT PT-R), INT PT untreated (INT PT), and Multi-Funnel Trap (Phero Tech, Inc.). The traps were baited with three prototype lures: (1) standard lure (alpha-pinene (ap), ipsdienol(id), ipsenol (ie)), (2) turpentine lure (turpentine, id, ie), and (3) ethanol lure (ethanol, ap, id, ie). Five combinations of trap and lure determined the treatments: (A) INT PT-R + lure 1, (B) Funnel trap + lure 1, (C) INT PT + lure 1, (D) INT PT-R + lure 2, and (E) INT PT-R + lure 3. In WI, INT PT and Funnel Traps were both baited with lure 1. The wet-cup method was used, and captured insects were collected every 10 days.

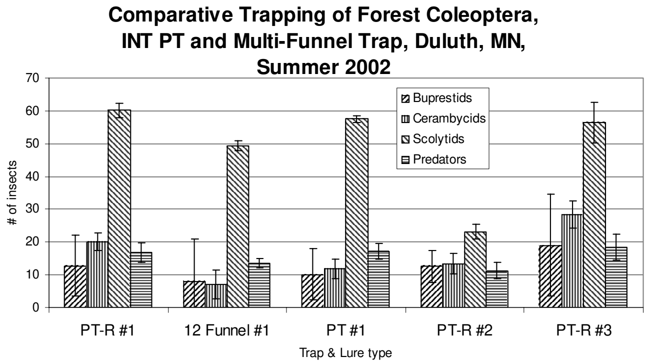
Results

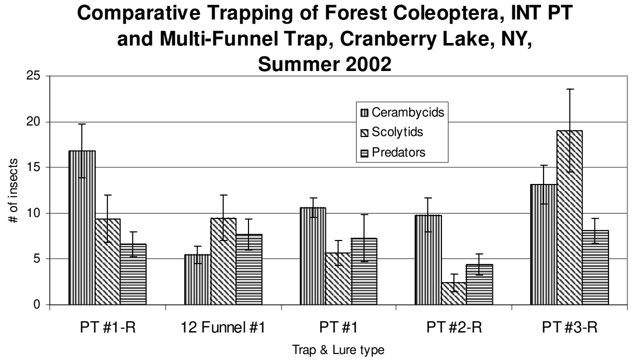
Data from captures in individual states are provided in the attached figures. The INT PT performed equal to or better than the Multi-Funnel Trap for Cerambycids and Scolytids. Captures of Buprestids were lower in the INT PT than in the Funnel Trap. The INT PT captured more bark beetles and consistently fewer predators than the Funnel Trap. The turpentine lure (2) caught equal or fewer numbers of beetles than the standard lure (1); the ethanol lure (3) caught more bark beetles than the standard lure (1).

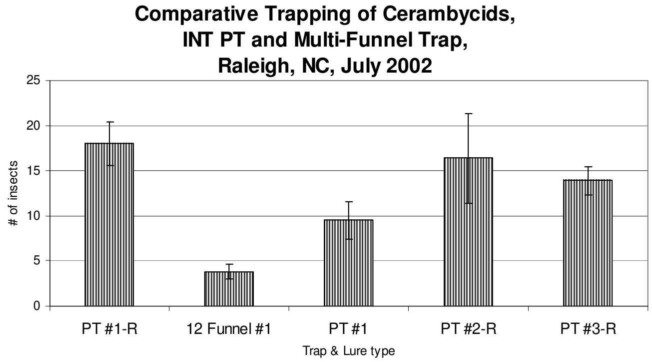
Discussion

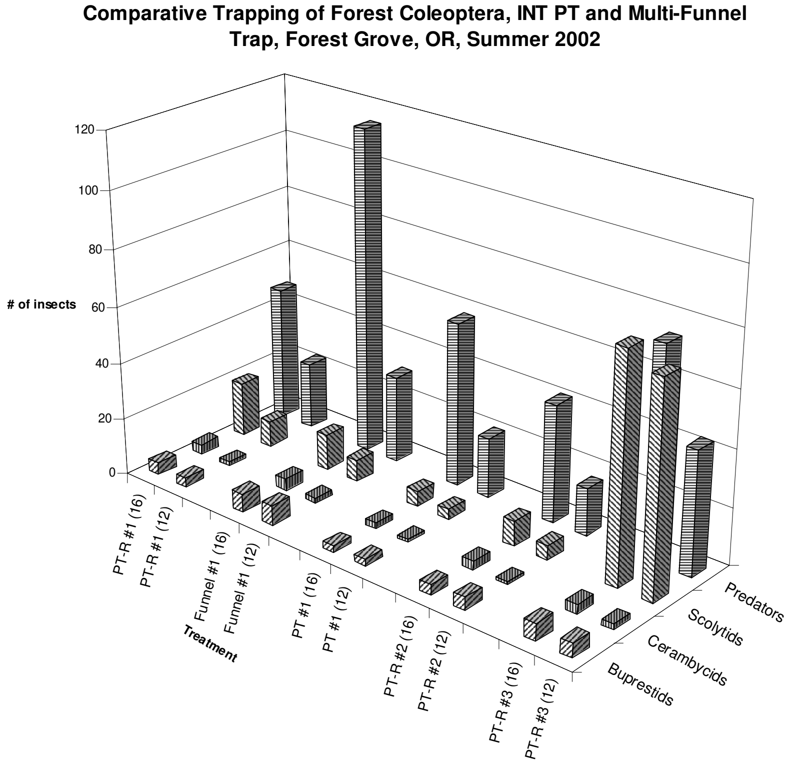
The Intercept Panel Trap is an effective tool for monitoring Cerambycids, as well as bark beetles, Buprestids, and other forest Coleoptera. It also captures fewer beneficial insects. The INT PT outperformed Phero Tech's Multi-Funnel Trap for most tested insect species. Higher beetle captures and increased detection capability in a less expensive trap equates to greater efficiency of forest pest monitoring programs. The Intercept Panel Trap is now commercially available.


Comparative Trapping of Forest Coleoptera,
INT PT and Multi-Funnel Trap,
Mirror Lake State Park, WI, Summer 2002
# of insects
# of Scolytids
0
2
4
6
8
10
12
14
0
200
400
600
800
1000
1200
Cerambycids
Scolytids
Predators
Multi-Funnel Trap
INT PT


Comparative Trapping of Forest Coleoptera,
INT PT and Multi-Funnel Trap, Duluth, MN,
Summer 2002
# of insects
0
10
20
30
40
50
60
70
Buprestids
Cerambycids
Scolytids
Predators
PT-R #1
12 Funnel #1
PT #1
PT-R #2
PT-R #3
Trap & Lure type


Comparative Trapping of Forest Coleoptera, INT PT
and Multi-Funnel Trap, Cranberry Lake, NY,
Summer 2002
# of insects
0
5
10
15
20
25
Cerambycids
Scolytids
Predators
PT #1-R
12 Funnel #1
PT #1
PT #2-R
PT #3-R
Trap & Lure type


Comparative Trapping of Cerambycids,
INT PT and Multi-Funnel Trap,
Raleigh, NC, July 2002
# of insects
0
5
10
15
20
25
PT #1-R
12 Funnel #1
PT #1
PT #2-R
PT #3-R
Trap & Lure type


Comparative Trapping of Forest Coleoptera, INT PT and Multi-Funnel
Trap, Forest Grove, OR, Summer 2002
# of insects
0
20
40
60
80
100
120
PT-R #1 (16)
PT-R #1 (12)
Funnel #1 (16)
Funnel #1 (12)
PT #1 (16)
PT #1 (12)
PT-R #2 (16)
PT-R #2 (12)
PT-R #3 (16)
PT-R #3 (12)
Treatment
Predators
Scolytids
Cerambycids
Buprestids

Imaginal Diapause in the Bark Beetle, *Ips typographus*

Petr. Doležal and František Sehnal

Academy of Sciences and Faculty of Biological Sciences, University of South Bohemia,
Branisovska 31,370 05 Ceské Budejovice, Czech Republic

Abstract

In *I. typographus*, the development of immature stages can proceed at various day lengths, however ambient temperature must reach at least 5°C. In central Europe, the adults fly and reproduce only when temperatures are above 14°C and photoperiods are in excess of 15 hrs. of light. When the last instar larvae, pupae, or adults develop at a short photoperiod (SD, 12:12 hrs. in our experiments) and at a temperature of less than 23°C, only diapausing adults are produced. Imaginal diapause, which is characterized by a reproductive block, reduction of flight muscles, and behavioral changes, is a crucial adjustment to seasonal changes. In Central Europe, bark beetles terminate egg laying in August, just in time so that the already present immature stages can complete their development into adults before winter ensues. The gonads of diapausing adults may slowly develop at 5°C but reproduction does not resume even when the adults are transferred to conditions that normally favor development (20°C and 18 hr day length). After a couple of weeks at 5°C however, the adults initiate reproduction when they are transferred to a regime of 20°C and 18 hr day length. Long exposures at 5°C render the adults insensitive to photoperiod and they reproduce efficiently under conditions (12 hr day length and 20°C) that would cause the non-chilled beetles to induce or maintain diapause. Under field conditions, diapause is terminated sometime in January and reproduction is halted thereafter due only to low temperature. Diapause can be induced only after one reproductive cycle and in the new bark beetle generation.

Xylobios: Patterns, Roles and Determinants of Saproxylic Diversity in Belgian Deciduous Forests

Philippe Fayt[1], Etienne Branquart[1], Marc Dufrene[1], Jean-Marc Henin[2], Christophe Pontegnie[3] and Veerle Versteirt[4]

[1]Research Centre of Nature, Forests and Wood
[2]Gembloux Agricultural University
[3]Catholic University of Louvain
[4]Royal Belgian Institute of Natural Sciences

Abstract

The XYLOBIOS project aims to study patterns, roles and determinants of saproxylic diversity (i.e., species richness and abundance of organisms which are dependent upon the dead or dying wood of moribund or dead trees, or upon the presence of other saproxylics) found in Belgian beech *Fagus sylvatica* and oak *Quercus spp.* forests. The project originates from recent international recommendations to retard loss of species and link biodiversity with ecosystem functioning. Main objectives, study sites and sampling methods are briefly described.

Key words: beech; biodiversity; ecosystem functioning; monitoring; oak; saproxylic organism; woody debris

Introduction

Saproxylic organisms (1) account for a significant part of forest biodiversity (20-25% of all forest-dwelling species) (Siitonen 2001), (2) speed up wood decomposition and recycle large amount of nutrients through multitrophic interactions (Harmon et al. 1986, Edmonds and Eglitis 1989), (3) are threatened over much of their range, as a direct consequence of large-scale intensive forest management practices and the loss of primeval growth conditions (Speight 1989), and (4) suffer from a bad reputation world-wide in the northern hemisphere, based mainly on the tree damage and economic losses a few species may cause once their population increases above some abundance threshold (Vité 1989). Ultimately, one of the main arguments for maintaining dead wood habitats and preserving saproxylic assemblages is that losses of diversity may impair processes required for the long-term functioning of the ecosystems (Bengtsson et al. 2000), which, in turn, is expected to increase societal costs in a non-linear manner (Tilman 2000). This emphasises a need for a better understanding of interrelationships between biological diversity and forest management.

Objectives

XYLOBIOS is a four-year research project started in Belgium in 2001 to address simultaneously and link both ecological and economical issues raised by forest management of beech *Fagus sylvatica* and oak *Quercus* spp. forests. Its goals are:

- clarify the national distribution of selected saproxylic families and species, indicators of microhabitats and processes found in natural and extensively managed deciduous forests
- identify the multi-scale determinants of their diversity
- relate saproxylic diversity and site factors with tree mortality and soil properties
- study co-variation in species richness among different saproxylic taxa

Material and Methods

Studied taxa: insects (Coleoptera, Diptera), fungi (Polyporale, Corticiale) and cavity-nesting birds

Monitoring: enquiries sent to naturalists, biogeographical databases

Field inventories:

Study sites: 22 sites (10 beech/12 oak stands = 11 site pairs), distributed over 4 biogeographic areas (Fig. 1). A pair: sites with similar plant composition, soil properties and abiotic factors (altitude, climate) but with contrasting management histories and supply of woody debris

Insects: (i) a 0.8 ha circular study plot per site, in which 8 flight-window traps, 8 trunk-window traps[1], 1 Malaise trap, and 3 stump eclectors, and (ii) bark sampling and gallery eclectors on recently logged beech trees ([1] if standing dead trees available)

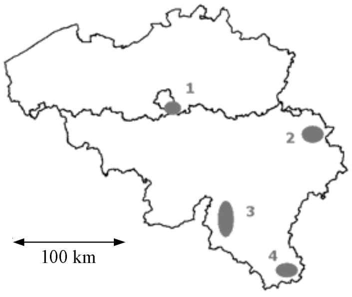


Figure 1.—Study sites

Fungi: hand-collected within the 0.8 ha study plots

Birds: point counts or transects within circular plots of 20 ha, centred on the 0.8 ha plots

Soil: 3 sample cores in the Ah layer (0-20 cm) per 0.8 ha study plot

Other habitat variables: (i) nested circular sample plots (0.006, 0.05 and 0.1 ha) located on a grid network of 50 x 50 m covering the study sites to gain information on small-scale structural heterogeneity, and (ii) regional circular sample plots (1,256 ha, centred on the 0.8 ha study plots), to measure modern landscape characteristics and its historical changes (Fig. 2)

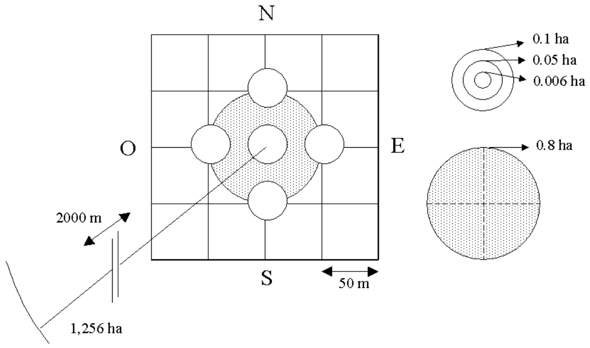


Figure 2.—Grid-based nested plots

Acknowledgments

This project is financially supported by the Belgian Federal Office for Scientific, Technical and Cultural affairs (OSTC). The research team of Prof. Laurent Bock, University of Gembloux, is kindly acknowledged for providing help in soil analyses.

References Cited

Bengtsson J., S.G. Nilsson, A. Franc, and P. Menozzi. 2000. Biodiversity, disturbances, ecosystem function and management of European forests. For. Ecol. Manage. 132: 39-50.

Edmonds, R.L., and A. Eglitis. 1989. The role of the Douglas-fir beetle and wood borers in the decomposition of and nutrient release from Douglas-fir logs. Can. J. For. Res. 19: 853-859.

Harmon M.E., J.F. Franklin, F.J. Swanson, P. Sollins, S.V. Gregory, J.D. Lattin, N.H. Anderson, S.P. Cline, N.G. Aumen, J.R. Sedell, G.W. Lienkaemper, K. Cromack, JR., and K.W. Cummins. 1986. Ecology of coarse woody debris in temperate ecosystems. Adv. Ecol. Res. 15: 133-302.

Siitonen, J. 2001. Forest management, coarse woody debris and saproxylic organisms: Fennoscandian boreal forests as an example. Ecol. Bull. 49: 11-41.

Speight, M.C.D. 1989. Saproxylic invertebrates and their conservation. Council of Europe, Strasbourg.

Tilman, D. 2000. Causes, consequences and ethics of biodiversity. Nature 405: 208-211.

Vité, J.P. 1989. The European struggle to control *Ips typographus* – past, present and future. Hol. Ecol. 12: 520-525.

Reproduction of a Woodwasp, *Urocerus japonicus* (Hymenoptera: Siricidae) Using No Maternal Symbiotic Fungus

Hideshi Fukuda

Unit of Environmental Systems, Faculty of Social and Informational Sciences,
Nihon Fukushi University Higashiehaemi-cho, Handa, Aichi Japan

Abstract

Most woodwasps (Siricidae) are symbiotically associated with the specific fungus, *Amylostereum* spp. Female adults inoculate the fungus during their oviposition in sapwood of the host trees (Morgan 1968). Woodwasp larvae can digest sapwood with low nutritional quality with the aid of symbiosis (Kukor and Martin 1983). In the earlier study, we clarified that a woodwasp with no fungal symbionts, *Xeris spectrum* can utilize the fungal symbionts of other woodwasp species without possessing any symbiotic fungi of its own (Fukuda and Hijii 1997). Moreover, the larvae of fungus-carrying woodwasp species cannot develop on living trees. The female adults oviposit selectively on fresh trees that are presumed to be suitable for fungus propagation, because the conditions of the wood at the time of oviposition affect propagation of the fungus (Fukuda 2002). Whether fungus-carrying woodwasps can develop using no maternal symbiotic fungus or not has never been studied. Thus, I conducted fungus-isolation and oviposition experiments to evaluate the preference and performance of *U. japonicus* on fungus-inoculated trees.

Experiments were conducted from 1999 to 2001. In July 1999, the first year, new female adults of *U. japonicus* were allowed to oviposit on living trees of *Cryptomeria japonica* (oviposited trees). In October, the symbiotic fungus of *U. japonicus* was artificially inoculated on living trees of *C. japonica* (inoculated trees). In November, oviposited trees, inoculated trees and control (not oviposited and not inoculated) trees were felled and a part of the inoculated trees were bucked to 2 m. In July 2000, the second year, new female adults were allowed to oviposit on each tree. At the same time, fungi were isolated from both oviposited and inoculated trees. In 2001, the third year, I counted the number of new adults that emerged from each tree where oviposition occurred in the 2nd year, and I also counted oviposition holes on each tree.

The inoculated symbiotic fungus propagated on both oviposited trees and inoculated trees 8 months after tree-felling, oviposition period of the next year. Moreover, on inoculated trees, especially on bucked trees, the symbiotic fungus was distributed widely in the wood. The oviposition by *U. japonicus* was higher on oviposited trees and inoculated trees than on control trees; moreover, the oviposition was higher on inoculated trees than on oviposited trees. On inoculated trees, many oviposition holes were observed near vertical lines from inoculated positions, where the symbiotic fungus would propagate vigorously. Next generation adults emerged from inoculated trees, whereas no adults emerged from oviposited and control trees. The number of emerged adults was especially high on bucked trees. From these results, I demonstrated that a fungus-carrying woodwasp species, *U. japonicus,* can reproduce using no maternal symbiotic fungus. These results indicate that both *X. spectrum,* a woodwasp species that has no maternal symbiont, and *U. japonicus* a fungus-carrying woodwasp species, can utilize the *Amylostereum* fungi which had already propagated in the wood. This information is important for clarifying the coevolution between woodwasps and *Amylostereum* fungi.

Key Words: *Amylostereum* fungus, fungus-isolation, oviposition preference, survival rate, *Urocerus japonicus*

References Cited

Fukuda, H. 2000. Trunk sapwood utilization by woodwasps. Japanese Journal of Ecology 52:75-80.

Fukuda H. and Hijii N. 1997. Reproductive strategy of a woodwasp with no fungal symbionts, *Xeris spectrum* (Hymenoptera: Siricidae). Oecologia 112:551-556.

Kukor J.J. and Martin M.M. 1983. Acquisition of digestive enzymes by siricid woodwasps from their fungal symbiont. Science 220:1161-1163.

Morgan F.D. 1968. Bionomics of Siricidae. Annual Review of Entomology 13: 239-256.

Spatial Patterns of First Spruce Bark Beetle (*Ips typographus* L.) Infestation of Standing Norway Spruce (*Picea abies* [L.] Karst.) After Heavy Storm Damage in Switzerland

R. Gall and A. Heimgartner

Swiss Federal Research Institute WSL, Birmensdorf, Switzerland

Abstract

On December 26, 1999, Switzerland was struck by the most severe storm in the country's history. An extensive dataset from the Canton Berne allowed us to test the hypothesis that in regions where windthrown wood was cleared a) the intensity of the first *Ips typographus*-infestation on standing trees after the storm depends on the distance from windthrow areas and b) the intensity of the first infestation depends on the temperature differential at different altitudes. Both hypotheses have been verified, however our results suggest that the first infestation of standing trees after the storm is not caused by the emigration of bark beetles from adjacent windthrow areas.

Material and Methods

Windthrow areas (>0.5 ha) were digitized from orthophotos. Additionally, the forest managers recorded the center-coordinate of scattered windthrow groups with the corresponding amount of wood. The clearing of windthrow areas and the removal of scattered windthrow trees was completed approximately one year after the storm. Furthermore, the forest managers recorded the infestation spots on standing trees with the corresponding amount of spruce. The trees were harvested in the same year. For horizontal analysis we classified the data in different distance rings around the windthrow areas. For vertical analysis we classified the data in different altitudinal belts. For each distance class and altitudinal belt we calculated the forest area, the volume of infested standing spruces, and the volume of scattered windthrown wood. For the altitudinal belts, we calculated also the total standing volume of Norway spruce from data of the Swiss National Forest Inventory.

Results and Discussion

We found a dramatic decrease in the proportion of beetle-infested spruce trees per forest area with increasing distance from windthrow areas (Fig. 1). This was also found by Wichmann and Raven (2001). These authors concluded that the spatial pattern of bark beetle infestation of standing spruce after heavy storm damage reflects the spread of *I. typographus* emigrating from the windthrow areas. Our study indicates, however, that the first infestation of standing trees after heavy storm damages may not reflect the spread of *I. typographus*. We found a strong positive relationship between the

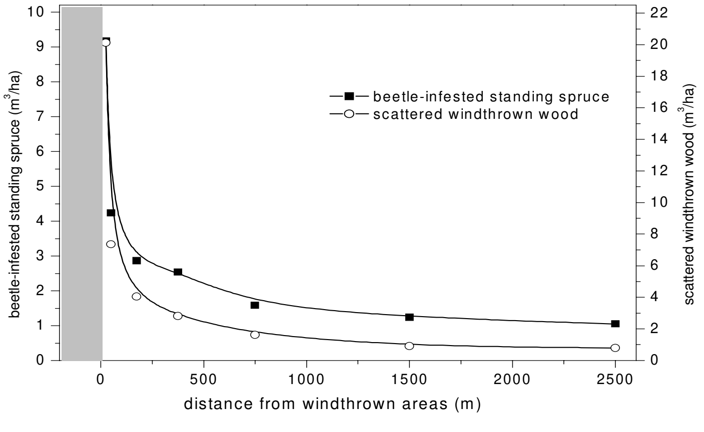


Figure 1.—Densities of beetle-infested standing spruce (■) and scattered windthrown wood (○) in relation to the distance from windthrow areas.

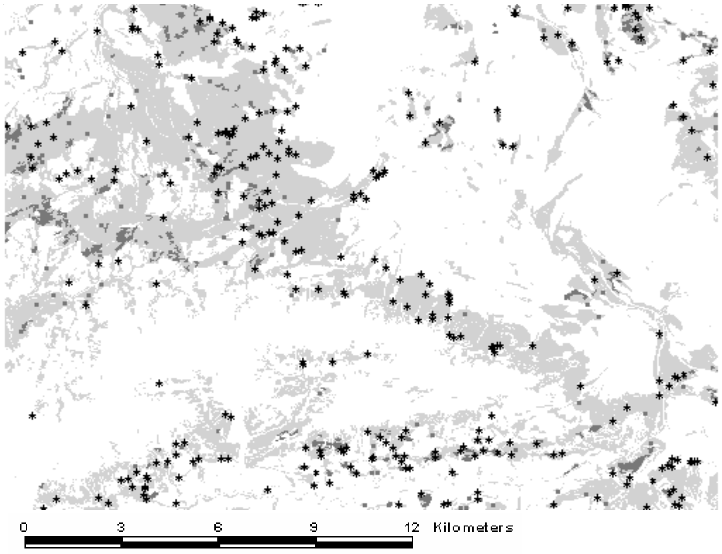


Figure 2.—Representative part of the Canton Berne with forest area (light grey), windthrow areas (dark grey), scattered windthrow groups (●) and spots of infestation (✶) for the year 2001.

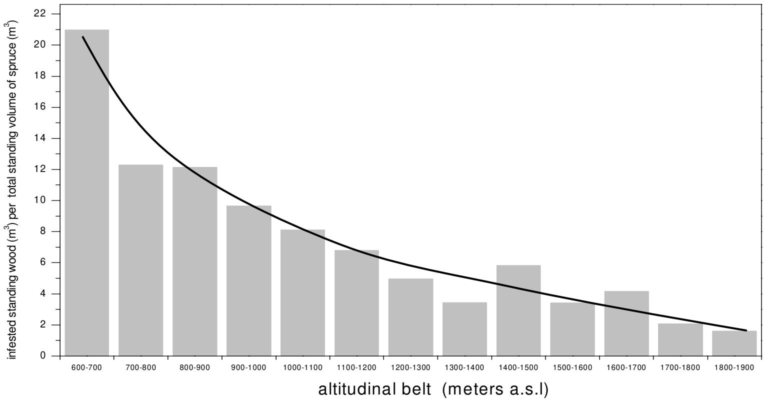


Figure 3.—Beetle-infested spruce per total standing volume of spruce in relation to altitudinal belts (meters above sea level).

volume of scattered windthrown trees and the volume of bark beetle infested spruce ($r^2 = 0.996$, $p < 0.0001$, c.f. Fig. 1). Considerable infestation was found also at greater distances (> 500 m) from the windthrow areas (Fig. 2). We hypothesize that the volume of scattered windthrown wood might be an indicator of reduced host-tree resistance of the residual stands after heavy storm damage. This means that the first infestation of standing spruce occurred mainly in weakened trees.

In Switzerland, an altitudinal increase of 100 m corresponds to an average temperature decrease of 0.65°C. Therefore, the gradual decrease in beetle-infested spruce from the lower elevations up to higher altitudes (Fig. 3) stresses the importance of temperature on the velocity of spruce bark beetle development; this was reported also by Wermelinger and Seifert (1998) but under laboratory conditions.

References Cited

Wermelinger, B. and M. Seifert. 1998. Analysis of the temperature dependent development of spruce bark beetle *Ips typographus* (L.) (Col., Scolytidae). J. Appl. Ent. 122: 185-191.

Wichmann, L. and H.P. Raven. 2001. The spread of *Ips typographus* (L.) (Coleoptera, Scolytidae) attacks following heavy windthrow in Denmark, analysed using GIS. For. Ecol. Manag. 148: 31-39.

Trypodendron domesticum and *Trypodendron signatum*: Two Scolytid Species Involved in Beech Decline in Belgium

B. Gaubicher[1], M. De Proft[1] and J.-C. Gregoire[2,3]

[1]Department of Phytopharmacy, Agricultural Research Center of Gembloux, Belgium
[2]Laboratoire de Biologie animale et cellulaire, Université Libre de Bruxelles, Belgium
[3]Fonds National Belge de la Recherche Scientifique, Bruxelles

Introduction

Xylophagous scolytids (Ambrosia beetles) have long been known to prefer fallen or seriously weakened trees and stumps. They are attracted to this host material by ethanol produced by the fermenting phloem and sapwood. However, these insects have begun aggressively attacking living beeches in Southern Belgium, raising the issue of a possible shift towards primarity. More than 1.3 million m³ have been attacked in 2001 (Huart and Rondeux 2001). Strikingly, similar occurrences of ambrosia beetles attacking living broadleaf trees have been observed worldwide recently. A series of experiments have been carried out since December 2000 to answer a series of rather basic but essential questions : what is the beetles' phenology ? Do they have two generations a year ? What are the patterns of emergence for both species ? How far from an outbreak focus do they represent a threat to other stands?

Material and Methods

Phenology

Four baited Theyson traps (distance between traps : 50 m) were placed in four attacked sites in the Ardennes. Catches were counted and identified once each week from the begining to the end of the flight period for both species.

Patterns of Emergence

15 individual and 23 collective emergence traps were placed on infested trees at the end of the 2001 flight period. Catches were counted and identified once each week from 12 July to 3 October for individual traps, and from 1 August to 1 October for collective traps.

Life Cycle and Parental Care

In 2001, galleries of the two species were opened periodically during the attack period, from early April to the end of June, in order to observe the behaviour of adults inside, check on the development of progeny, and to determine whether or not a second generation exists.

Dispersal of *Trypodendron* spp. from Beech Stands to Open Areas

In Recogne and Witry, three and four baited (ethanol+lineatin) traps were placed in an open area at 50, 100 and 200 m, and at 50, 100, 200, and 400 m from the edge of an infested beech stand. Catches were counted and identified once each week during the flight period - from 2 April to 23 May, 2002 for Recogne, and from 24 April to 23 May for Witry.

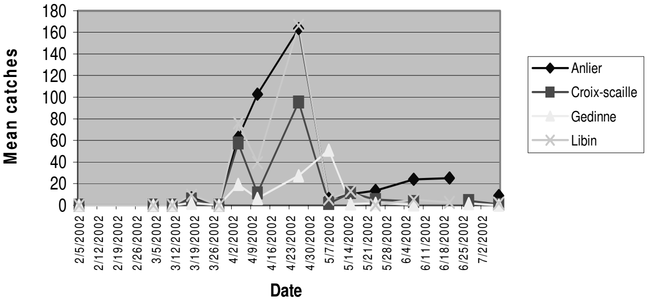


Figure 1.—Phrenology of *T. signatum*.

Results

Phenology

The flight period for *T. signatum* was about one month later than for *T. domesticum* (Fig. 1 and

Fig. 2). The earlier flight of *T. domesticum* might perhaps be connected to the fact that it overwinters in the galleries where it might be able to feed throughout the winter on fungi.

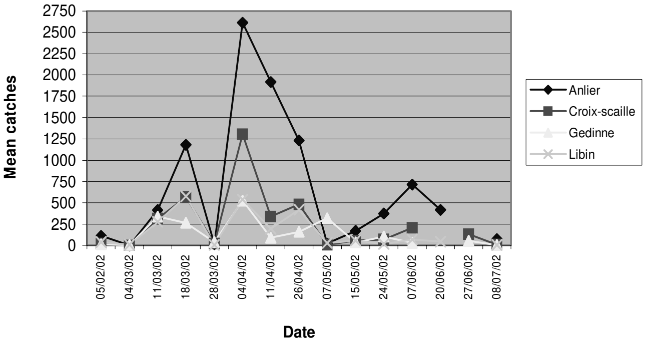


Figure 2.—Phrenology of *T. domesticum*.

Patterns of Emergence

We observed that most young adults of *T. signatum* emerged from their galleries at the end of the summer. They probably spent the winter in the litter, at which time they were not attracted to pheromone traps. *T. domesticum* did not emerge from their galleries before spring. They overwintered in the galleries.

Life Cycle and Parental Care

For both species, parental care (essentially cleaning of the gallery by the female) is continuous until pupation is completed. We have observed one male at the entrance of each gallery. The exact role of the male during this period is still not clear; males may be guarding the female or may help to clean the gallery. Egg laying occurred in one single period, after which the larvae developed and pupated. There was thus no sister generation within any single gallery.

Dispersal of *Trypodendron spp.* from Beech Stands to Open Areas

The two *Trypodendron* species are obviously able to disperse beyond beech stands at least as far as 400 meters (Fig. 3 and Fig. 4). This suggests that dispersal could occur between beech stands during outbreaks. Lines of baited traps placed at the edge of attacked stands might possibly prevent or reduce these movements.

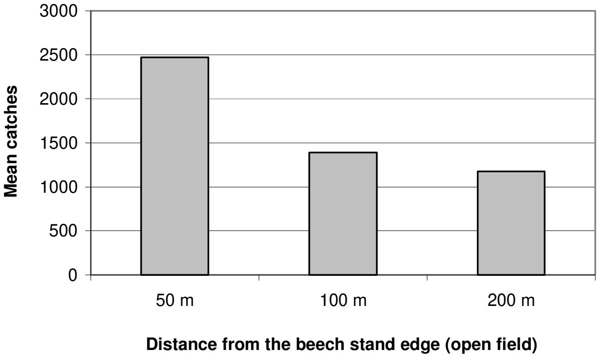


Figure 3.—Dispersal of Trypodendron spp. in recogne, Wallonia, Belguim (02/02/02 to 23/05/02).

Open Questions

T domesticum and *T. signatum* diverge in many respects, for example in their reproductive biologies, modes of overwintering, spectra of host-trees, and competitiveness. We need to conduct further studies to help us understand how these species share their resources, to assess more accurately the risk that they represent, and to design appropriate control measures.

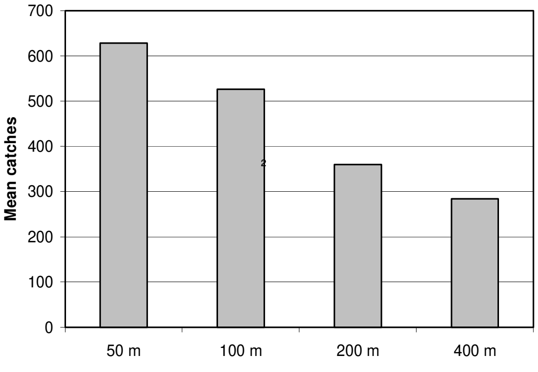


Figure 4.—Distance from the beech stand edge (open field).

References Cited

Huart, O. and Rondeux, J. 2001. Genèse, évolution et multiples facettes d'une maladie inhabituelle affectant le hêtre en région wallonne. Forêt wallonne 52 :9-19. DNF. 2002. Maladie du hêtre wallon : évolution et mesures. Paysages 22 :4-9.

Forest Litter Insect Community Succession in Clearcuts of Norway Spruce

Dr. Artūras Gedminas

Lithuanian Forest Research Institute

Abstract

Insects are subjected to stress in fresh clearcuts due to changes in microclimate, vegetation, and trophic links. The objective of this study was to investigate succession in litter insect communities (most abundant by number of species and individuals of all clearcut insects).

Representatives of the order *Coleoptera* order were dominant and represented 78% of all trappped arthropods; 9% were *Aranei* and 4% were *Hymenoptera.* The most abundant beetles were in the families Carabidae (65%), *Curculionidae* (16%) and *Staphylinidae* (7%). Entomophagous arthropods (carabids, spiders, ants) consisted of 69% of all insects found in the litter; 17% of insects recovered were phytophagous insects, *Hylobius* weevils, which represented 78% of this number.

Insects in fresh clearcuts aggregate in the periphery or near piles of forest residues. Diversity is lower within the forest because vegetation in the understory of spruce forests is rather scarce. Special attention should be directed to the margins of clearcut where most *Hylobius* weevils were found.

Keywords: clearcut, litter arthropod, pitfall traps, trophic specialization.

Introduction

There have been few investigations of the composition of insects in the litter of forest clearcuts; most research studies have been limited to insects pests of planted trees (*Hylobius, Melolontha, Evetria, Aradus*).

The objective of this research was to investigate the complex of insect communities and their changes in clearcuts under different management practices. Only the results from investigations conducted in spruce clearcuts are presented in this report.

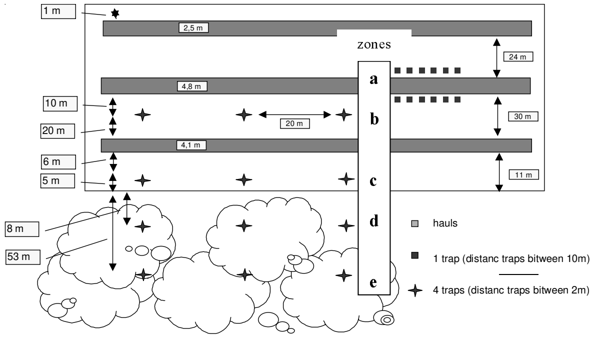


Figure 1.—Scheme of the distribution of the pitfall traps on the clearcut.

Material and Methods

Research was carried out in 2001 at the Vaišvydava forest of Dubrava experimental-training enterprise.

Forest litter insects were trapped using pitfall (Barber) traps – plastic 7 cm diameter 150 ml cup, burrowed in the soil with its top at the level of the litter. Each cup was filled with 50 ml of 10% formalin which was changed each month to prevent trapped specimens from decaying and to prevent removal by birds. Pitfall traps were installed on April 24 and inspected (emptied, cleaned, replaced, if needed) every 2-3 weeks (Fig. 1).

Seasonal Dynamics in the Abundance of Clearcut Insects

There were two declines in insect abundance during the summer seasons that were recorded in all trapping zones. Possibly, decrease in insect numbers in June was conditioned by the life history properties of carabid beetles (egg and larval stages are seldom recovered in pitfall traps). The dynamic curve of the abundance of insects was similar in both open areas and inside the forest. The least number of arthropods was trapped in ‘b’ and ‘c’ zones, which were exposed to direct sunlight. Highest catches were recovered in forest zones ‘d’ and ‘e.’ This suggests that arthropods concentrate at the periphery of clearcuts and near piles of residues.

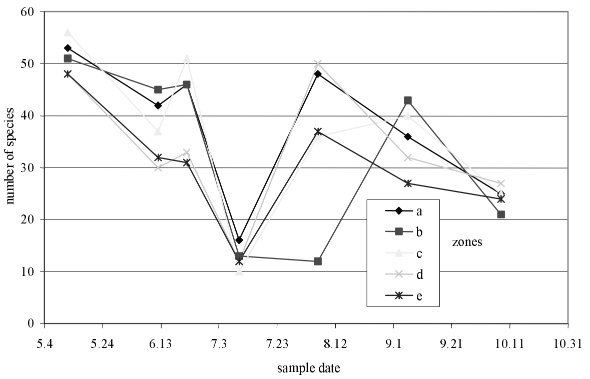


Figure. 2.—Litter arthropod species richness dynamics by zones

This evidence is true for the dominant species of *Carabidae* and *Aranei,* while weevils, most of which are pests of planted trees, were concentrated in the 'c' zone (clearcut 10 m from the forest edge). This suggests that species of *Hylobius* prefer light and accumulate closer to breeding sites (stumps) and feeding sites (seedlings).

Ants can also be considered heliophilous species, since most of them were trapped in 'b', 'c' and 'd' zones. Forest litter habitats were preferred also by rove (*Staphylinidae*) and scarab beetles (*Scarabeidae*). Species richness was lower inside forests zones'd' and 'e' (Fig. 2). This is expected because there is little plant diversity within a closed canopy spruce stand. The decrease in the number of species collected in the middle of July corresponds to a general decline in insect abundance that occurs during this period. High species numbers recorded in spring catches can be explained in part by the migration of species to new ecological niches created in the modified environment.

Trophic Associations of Litter Insects

Entomophagous insects were most abundant in the litter as determined by the abundance (69%) of predacious ground beetles, spiders and ants in trap catches. Entomophagous arthropods prey upon phytophagous species and are numerous in traps placed within forests; phytophagous insects are also scarce due to the lack of host plants. The seasonal dynamics curve of phytophagous species corresponds to the general pattern for all species.

Phytophagous arthropods are more numerous in the clearcuts where forest succession is in the initial stage with establishing microclimate, vegetation and trophic relations. The number of phytophagous insects in the clearcut area was dominated by *Hylobius* weevils. These pests migrate to fresh clearcuts from nearby stands, attracted by the odor of freshly cut stumps. In addition they find spare food – planted trees. Concentrations of weevils were noticed in the zone near the forest edge. Therefore special emphasis on pest management activities should be directed to the peripheral 10 m strip adjacent to clearcuts.

Conclusions

1. Species of *Coleoptera* order were dominant and represented 78% of all trappped arthropods; nine percent of trapped arthropods were *Aranei,* 4% *Hymenoptea,* and the remaining 9% consisted of 10 different insect orders.

2. Representatives of the families *Carabidae* (65%), *Curculionidae* (16%), and *Staphylinidae* (7%) were the most abundant.

3. Decrease of arthropod abundance in June was influenced by the life history of carabid beetles (most are in the egg and larval states at that time).

4. Arthropods concentrate in the periphery of fresh clearcuts near piles of slash and logs.

5. Forest litter arthropod species diversity was lower inside spruce stands due to reduced abundance and diversity of vegetation.

6. Entomophagous arthropods make up 69% of the species recovered in the litter complex, and consisted mainly of predaceous ground beetles, spiders and ants. Phytophagous arthropods account for 17% and are dominated by *Hylobius* weevils (78%).

7. Pest management activities in clearcuts should be directed at the peripheral 10 m strip adjacent to the residual forest.

Qualitative Survey of Five Beech Damaging Coleoptera (Scolytidae and Lymexylonidae) in Wallonia (Southern Belgium)

Jean-Marc Henin, Olivier Huart, Philippe Lejeune and Jacques Rondeux

Unit of Forest Management and Economics, Gembloux Agricultural University, Belgium

Abstract

In 2000 and 2001, *Trypodendron domesticum* L. and *T. signatum* (F.) (Col.: Scolytidae) were one of the main causes of the depreciation of more than 1,600,000 m³ of standing beech trees, *Fagus sylvatica* L., in Wallonia (Southern Belgium). In 2001, a survey aiming at assessing the range of those indigenous ambrosia beetles, so far discreet and poorly studied, pointed out that they are omnipresent all over Wallonia. Two other scolytids and one lymexylonid (Col., Lymexylonidae) were also frequently caught, which made it possible to outline their regional distribution too.

Key Words: Scolytidae, *Trypodendron* spp., *Xyleborus dispar*, *Taphrorychus bicolor*, Lymexylonidae, range, Southern Belgium

Introduction

As a consequence of an exceptional frost that severely affected beech trees over a broad area of Southern Belgium in November 1998, populations of *T. domesticum* and *T. signatum* reached epidemic levels in 2000 and 2001 (Huart and Rondeux 2001). More than 1.6 million m³ of beech trees were damaged within the two years, almost exclusively at elevations above 350 m a.s.l. (Rondeux et al. 2002). Apart from the fact that these outbreaks were an economic disaster, the 2001 attacks were very worrying since they occurred on standing and apparently healthy trees, which is quite uncommon for both *Trypodendron* species. Information on these species was very incomplete, especially from a biogeographical point of view : a survey was thus initiated to outline their range. *Xyleborus dispar* (F.) and *Taphrorychus bicolor* Herbst (Col.: Scolytidae), as well as *Hylecoetus dermestoides* L. (Col.: Lymexylonidae) were also frequently caught, which made it possible to outline their regional distribution.

Materials and Methods

In order to get an idea of the beetles' distribution, a network of 172 traps was set up throughout the six natural regions of Wallonia (Fig. 1), from April to October 2001. The traps were hooked on beech trees (of variable dbh) and baited with ethanol (release rate ca. 250 mg/day). All traps were located in beech stands (beech relative basal area > 66 %) that were >1 ha., attempting to obtain a homogenous sample of the Walloon beech forest. Because of the small size of the traps (10 X 23 cm), of the low number or traps/site, and of the relatively low attractivity of the traps (as compared to attractive woody material) in physiologically weakened stands, the absence of a species in captures at individual sites does not necessarily indicate that the species is not present there. For the same reasons, the number of insects captured was not compared between sites: only the presence was recorded.

Results and Discussion

The number of traps (NT) placed in each Walloon natural region, the number of sites where each species was caught (number of presences, NP) and the observed presence rate (OPR=NP/NT) is provided in Table l. Table 1 also provides some characteristics of the Walloon natural regions, such as the percentage of beech forest (42,400 ha in total) present within each region (BC, according to Lecomte, in press) and the elevation (E).

Table 1 shows that the scolytid beetles are omnipresent in Wallonia, in all natural regions and at all elevations. Only *H. dermestoides* was not captured in the sandy loam and loess regions, but its ecology and the sampling methodology led to an undervaluation of its range.

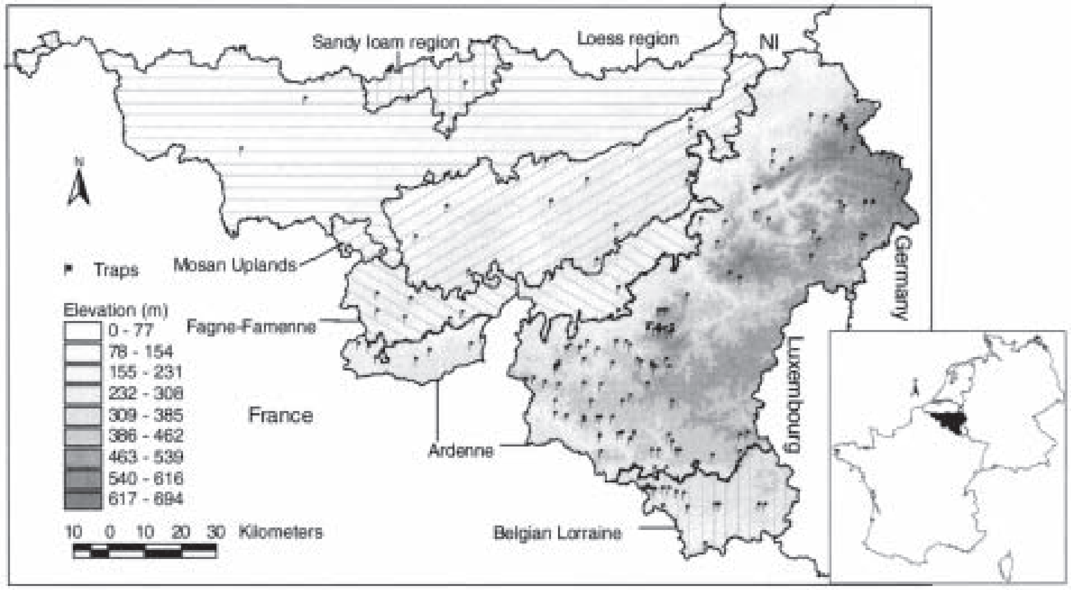


Figure 1.—Distribution of the traps in Wallonia (Southern Belgium)

The wide distribution of both secondary *Trypodendron* spp. confirmed that the triggering factor of the attacks was limited to natural regions where beech trees had undergone damage (Ardenne and Belgian Lorraine). With other elements, this fact supports the climatic accident hypothesis (early, sudden and deep frost) since the Ardenne and Belgian Lorraine are the more elevated natural regions of Wallonia (where the elevation may exceed 350 m), and are characterized by greater and more sudden fluctuations in temperature.

The attacks were thus probably triggered by an exceptional accident occurring in 1998 (unusual frost). In 2001, while their populations were at very high levels, *T. domesticum* and *T. signatum*

Table 1.—Number of presence(s) and observed presence rate of each species in different Walloon natural regions (sandy loam and loess regions are clustered).

	BC	Elevation (m)	NT	*T. domesticum*		*T. signatum*		*X. dispar*		*T. bicolor*		*H. dermestoides*	
				NP	OPR	NP	OPR	NP	OPR	NP	OPR	NP	OPR
Sandy loam and Loess regions	6	20<E<200	4	3	75	2	50	4	100	4	100	0	0
Mosan Uplands	8	200<E<350	15	11	73	7	47	11	73	13	87	5	33
Fagne-Famenne	2	100<E<250	9	6	67	5	56	8	89	6	67	2	22
Ardenne	69	200<E<700	128	111	87	69	54	85	66	36	28	20	16
Belgian Lorraine	15	200<E<450	16	13	81	7	44	11	69	6	38	1	6
Wallonia	**100**	**20<E<700**	**172**	**144**	**84**	**90**	**52**	**119**	**69**	**65**	**38**	**28**	**16**

BC: Beech cover (in % of the total beech forest area in Wallonia)
NP: number of presence(s)
NT: number of traps
OPR: observed presence rate (%).

attacked standing and apparently healthy trees over large areas, which is quite uncommon for these species. Some additional factors, such as previous storms, repeated droughts, air pollution, deterioration of soil properties and stand over-ageing probably worsened the situation. So far however, the reasons of the high and apparently temporary attractivity of many beech trees in 2001 (that did not exhibit frost injuries) are not fully understood. Nevertheless, these events indicate some fragility of the Walloon beech forests and suggest that silvicultural practices improving the vigor of the trees (early and regular thinnings, diversification of stand composition and structure) should be encouraged. At the same time, stress-inducing practices, such as logging methods that damage the forest floor, or late heavy thinnings creating sudden exposure to light of shade tolerant species (like beech), should be avoided. In our deciduous forests, it would be also interesting to leave some dead wood and overmature trees, in order to increase the population level of generalist entomophagous predators. Some of these, like woodpeckers, have been shown to exert a significant impact on scolytid population levels (Moore 1972), when the latter are endemic. Such an integrated approach should enable Walloon forest ecosystems to resist more efficiently such “natural accidents”.

References Cited

Huart, O., and J. Rondeux. 2001. Genèse, évolution et multiples facettes d’une maladie inhabituelle affectant le hêtre en région wallonne. Forêt Wallonne 52: 8-19.

Lecomte, H. in press. La forêt wallonne, état de la ressource à la fin du 20ème siècle. Ministère de la Région Wallonne, Direction générale des Ressources naturelles et de l’Environnement, Division de la Nature et des Forêts, Jambes.

Moore, G.E. 1972. Southern Pine Beetle (Col., Scolytidae) Mortality in North Carolina Caused by Parasites and Predators. Environmental Entomology **1** (1) : 58-65

Rondeux, J., N. Bourland, O. Huart, and H. Lecomte. 2002. Importance et dispersion de la maladie du hêtre en région wallonne : premiers résultats d’un inventaire spécifique. Sylva Belgica 109: 22-30.

Management of Shoot Boring Moths from Genera *Rhyacionia* and *Eucosma* with Attract and Kill Technology

R. Hoffman[1], D. Czokajlo[1], G. Daterman[2], J. McLaughlin[1], J. Webster[3], R. Rynearson[4], M. Gray[5], A. Eglitis[6], C. Jensen[6], B. Hughes[7], P. Flanagan[7], L. Spiegel[8], W. Berisford[9], C. Asaro[9], S. Cameron[10], J. Seckinger[10], L. Sukovata[11], A. Kolk[11], W. Strong[12] and P. Kirsch[1].

[1]IPM Tech, Inc., 4134 N. Vancouver Ave. #105, Portland, OR, USA 97217, tel. (503) 288-2493, fax. (503) 288-1887, e-mail: ipmtech@ipmtech.com, Web: www.ipmtech.com
[2]USDA Forest Service, Corvallis, OR, [3]Roseburg Resources, Weed, CA,
[4]W.M. Beatty & Associates, McArthur, CA, [5]Sierra Pacific Industries, Redding, CA,
[6]USDA Forest Service, Bend, OR, [7]USDA Forest Service, Wenatchee, WA,
[8]US Forest Service, La Grande, OR, [9]University of Georgia, Athens, GA,
[10]International Paper Corp., Savannah, GA, [11]Forest Research Institute, Warsaw, POLAND,
[12]BC Ministry of Forests, Vernon, BC, CANADA

This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture under agreement No. 2001-33610-11232.

Introduction

LastCall™ (LC), an attract and kill bait matrix, was deployed for the management of shoot boring moths in pine plantations and seed orchards. The targeted moths were the Western pine shoot borer, *Eucosma sonomana* (WPSB), European pine shoot moth, *Rhyacionia buoliana* (EPSM), Ponderosa pine tip moth, *Rhyacionia zozana* (PPTM), and Nantucket pine tip moth, *Rhyacionia frustrana* (NPTM) in pine plantations and seed orchards. Attract and kill technology very selectively removes male moths of the target species from the ecosystem with negligible impact on non-target organisms. Baits combine the selectivity of pheromone (only 0.21 g/ha, compared to 3.5-20 g/ha for mating disruption) with the rapid toxicity of insecticides (only 7.92 g/ha, compared to 500-800 g/ha for conventional sprays). This bait retains the insecticide within a hydrophobic matrix that precludes run-off or drift, and thus prevents ecosystem contamination and damage.

Results

1. Trap catch shut down was observed on all LC treated plots (Fig. 1).

2. On small experimental plots, WPSB will re-infest pine leaders if not treated for one year (Fig. 2).

3. WPSB damage in California was reduced from 55-78% to 2.5-15% (Fig. 3). EPSM damage was reduced by 30-50% in Poland. This test was limited by the small size of the plot. Studies will be conducted in British Columbia in 2003.

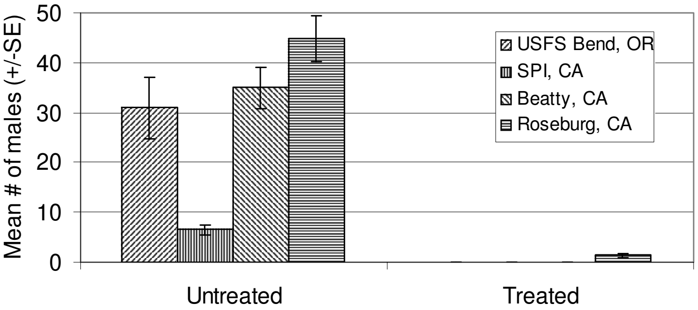


Figure 1.—Trap captures of *Eucosma sonomana* on *LastCall*™ experimental plots in ponderosa pine, Spring 2002.

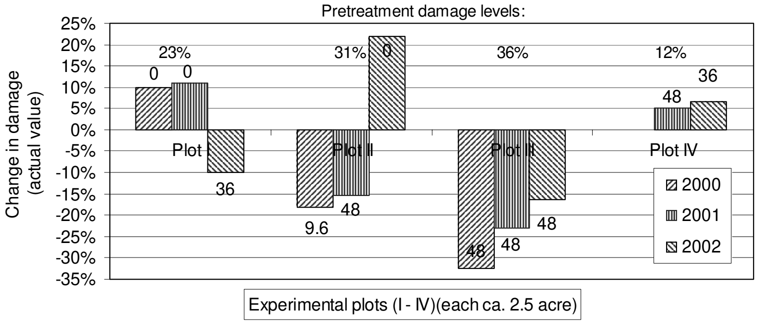


Figure 2.—Year to year *Eucosma sonomana* damage in ponderosa pine under four different treatment regimes with LastCall EusosmAK near Bend, OR, 1999-2002. Numbers indicate amount of pheromone (mg/acre) used in the treatment.

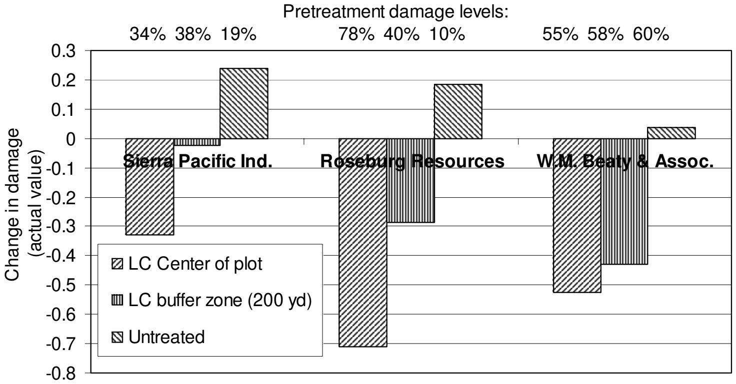


Figure 3.—Change in ponderosa pine damage by *Eucosma sonomana* on LC WPSB treated 250-acre plots in NE California, 2002. Plantations received 60g of LC containing 48mg of pheromone per acre.

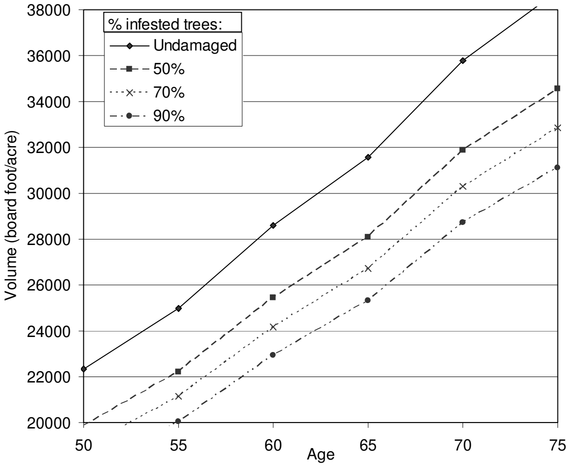


Figure 4.—Growth predictions for model, undamaged, and *Eucosma sonomana*-damaged ponderosa pine in NE California, 2002. The values were calculated for measured, mean 22% reduction in annual elongation of terminal. Site index 80, CACTOS model.

5. Damage by NPTM on LC treated plots in North Carolina was reduced by 58% when compared to untreated plots (Fig. 6).

Discussion

LastCall technology is an effective and environmentally safe method for managing shoot boring moths in the genera *Rhyacionia* and *Eucosma*. With LC treatment, the 60-year harvest rotation of ponderosa pine can be reduced by at least 5 years and timber yield can be increased by at least 3,940 board feet per acre (Fig. 4). Lack of management of *Eucosma sonomana* can lead to a decrease in timber value at the end of the rotation that amounts to at least $1,181 per acre (Fig. 5). IPM Tech expects EPA registration in Spring 2003 for LC EucosmAK, followed by rapid adoption of this innovative tactic in western ponderosa pine plantations.

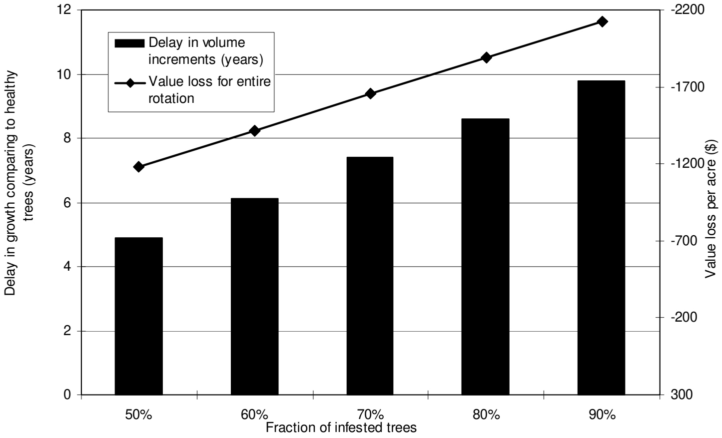


Figure 5.—Growth delay (years) and value loss ($) of ponderosa pine infested with WPSB at different levels and average 22% loss of terminal elongation. Values calculated for 70 year rotation in NE California, CACTOS model, SI 80, $300/Mbf. Maximum value = 35,790 bf.

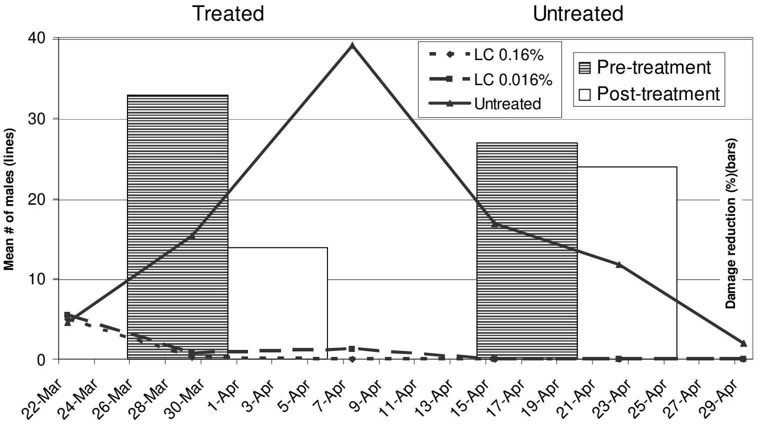


Figure 6.—(1-Lines) Trap catch: *Rhyacionia frustrana*, (2-Bars) Damage reduction (%) on LC 0.16% treated plots, Georgia, 2002.

Fire as a Tool in Restoring and Maintaining Beetle Diversity in Boreal Forests: Preliminary Results from a Large-scale Field Experiment

E. Hyvärinen, H. Lappalainen, P. Martikainen and J. Kouki.

University of Joensuu, Finland

During the 1900s, the amount of dead and decaying wood has declined drastically in boreal forests in Finland because of intensive forest management. As a result, species requiring such resources have also declined or have even gone extinct. Recently it has been observed that in addition to old-growth forests, natural, early successional phases are also important for the biota of boreal forests. Because of the effective prevention of forest fires and clearing of forests after storms, the early successional stages that normally contain an abundance of dead wood, have become almost absent in forest dynamics. The development of more ecological approaches to manage production forests is needed to protect threatened species successfully and to enhance their recovery.

The natural-like, early successional phases can be created in several ways in managed forests. Based on previous descriptive studies, the two most important factors to be considered are the number of trees left in the regeneration areas, and the use of fire to promote more natural characteristics. The ecological and quantitative effects of these factors are, however, largely unknown.

Our large-scale field experiment is being conducted in mature pine-dominated forests with some mixture of spruce and birch. The size of each study plot is 3–4 hectares, corresponding roughly to the size of a typical regeneration cutting in southern Finland. There are three levels of green tree retention—0 m^3/ha, 10 m^3/ha, 50 m^3/ha—and no cuttings as control. Each treatment combination is replicated three times. Prescribed burning was conducted on 12 of the 24 study plots. All the study areas are located in eastern Finland. In every study plot, 20 window flight traps and 20 pitfall traps are installed to catch beetles. The data have been collected before and after the experimental cuttings and burning; the trapping of beetles will be continued until the end of year 2003.

Since only part of the vast amount of material is identified completely, the results are preliminary. The data presented here represent only the one-month period immediately after the burnings conducted in 2001. According to the results, it seems clear that threatened species benefit from forest burning. It's likely that the treatments affect the beetle assemblages, but so far the data consist of only the first colonizers arriving at the areas. The effect of the level of green tree retention to the beetle assemblages will be examined further when all of the data are available. It also appears that many beetle species are very rapid to colonize new resources produced by fire, and also by cuttings. These preliminary results indicate that by using fire also in commercial forests, population levels of at least some threatened species can be enhanced significantly.

Location, Evolution and Importance of *Cephalcia spp*. (*Hym: Pamphiliidae*) Populations in Polish Carpathian Mountains

Marcin Jachym

Forest Research Institute, Department of Forest Management in Mountain Regions
Ul. Fredry 39, 30-605 Cracow, Poland

The web-spinning sawflies (*Cephalcia* Panz.) are members of the *Symphyta* that are of economic significance, and which constitutes an integral part of the spruce forest environment. Spruce, which is the dominant component of Western Carpathian forest stands, is the only known host plant for all the species of *Cephalcia*. Species in this genus occasionally appear in high densities at which time they become a major threat to coniferous forest stands especially in the mountains. Gradations develop very slowly but may persist for several years. Defoliation by these insects causes a reduction in radial increment and weakens trees so that they are susceptible to attack by secondary organisms and by drought. This may result in extensive tree mortality over large areas. Monolithic spruce forest stands of artificial origin are attacked, as are stands of natural origin in middle and older age classes that are located at altitudes of 800-1200m.

C. *alpina* (Klug) (= *fallenii* Dalm) was found for the first time in the Gorce Mountains of Poland; this also represented the first mass appearance of this species in Europe. *C. alpina* occurred in Gorce spruce forest stands at altitudes of from ca. 900 to 1200 m. The insect finds optimum conditions for its development and survival in monolithic spruce forest stands in the upper mountain regions associated with the plant community characterized by *Piceetum excelsae carpaticum*. During the only gradation recorded so far, traces of feeding damage were noticed before the 1979 growing season on the mountain sides of Kudłoń, Mostownica and Jaworzyna Kamienicka. In the summer of 1979, the feeding damage expanded around these original foci, including artificially established spruce stands of middle and older age classes. The forest stands located there were damaged significantly (60-90%) and moderately (30-60%) in an area of ca. 580 ha. Forest stands on 1600 ha located around these foci were lightly damaged (>30%). Despite extensive swarming in 1980, the population declined and remained at low levels until 1982. In subsequent years, the population declined even further and, beginning in 1985, *C. alpina* was not considered to be a threat to forest stands. One may conclude from this description of the gradation that populations probably increased for several years prior to 1979. It is probable that its onset was synchronized with a gradation that occurred in the Radziejowa massif, where light feeding damage first appeared in 1976; at that time, the population of the insect, initially called *C. abietis* (L.), and the area of its incidence were definitely smaller than in Gorce. The gradation period was therefore 10 years (1976-1985). As a result of several years of defoliation of spruce growing at high altitudes, resistance thresholds of natural spruce stands were exceeded. Weakened trees were killed by *Armillaria* spp. and species of bark beetles in areas above 850 m. Spruce trees were drying out in large numbers so that during the period from 1984 to 1990, a forested area of 140 ha was salvaged. Over another 266 ha, tree mortality varied from 21-100%.

After the C. *alpina* gradation in Gorce disappeared, a sudden increase in population was detected in Beskid Ślaski in an area near the summit at Skrzyczne at an altitude of 1000-1200 m. Populations of this pest persisted there from 1982 to 1986. Analysis of entomological material collected from the areas of mass incidence of C. *alpina*, Beskid Śląski, in an area near the summit at Skrzyczne at the altitude of 1000-1200 asl. Populations of this pest persisted there from 1982 to 1986. Analysis of entomological materials collected from the areas of mass incidence of *C. alpina,* (Beskid Śląski from the 1976-84 gradation period, the Gorczański National Park (1978-85), the Sudety mountains (1982-84) and Gdańsk (1993-1996) allowed us to conclude that a large percentage of web-spinning sawflies identified as C. *alpina*, possessed morphological features of C. *annulicornis* (Hartig). Both species appeared together in the gradation areas, but their ratio varied considerably from area to area without any apparent relationship to environmental aspects, type of forest stands, altitude, and local climate. This species has been known to occur in the Beskidy region since the 1980s. Observations of the major swarming in the Skrzyczne massif during those years indicated that possibly several variations of C. *alpina* might exist. Research to identify the characteristics of the two web-spinning sawflies was conducted in Italy from 1990-1995. Entomological materials used for research on the biology of these species were obtained from the Czech Republic, Poland and Italy. The role of each species in high-density populations was determined based on analyses of insects in entomological collections from the Czech Republic, Germany, Poland and Italy, and on examination of published literature.

Since 1980, *C. arvensis* (Panz) has been recorded along with these species. Since 1978, in the lower elevations a new species appeared, *C. abietis* (L.), which has displaced the other species of this group over the past twenty years. The gradation has been spreading towards the south along the mountain ridge and towards the valleys on the western and eastern sides of the mountain ridges at an altitude of 600-800 m.

A detailed analysis of the data available on *Cephalcia* spp. incidence in the last 20 years indicate that there is a lack of permanent outbreak foci of these insects at a micro-geographical scale. The incidence of web-spinning sawflies resembles a mosaic overlaid on a background of spruce forest stands. Individual 2- and 4-year cycles are apparent for particular species on small areas, as is the expansion of populations and their appearance in new locations. The replacement of existing populations by other species has also been noticed: initially, C. *arvensis* was the dominant species, then C. *alpina*, and ultimately *C. abietis*.

Currently, the incidence of web-spinning sawflies in the Carpathian Mountains is common but at low populations. However, an increase in the population of *C. alpina* has been noticed, associated with C. *erythrogaster* (HTG). Monolithic spruce forest stands located at an altitude of 600-1200 m in the western part of the Carpathian mountains in Beskid Ślaski and Żywiecki, at their summit and along mountain ridges, will continue to be the most affected.

Gradations of *Cephalcia spp*. have persisted in spruce forest ecosystems in mountainous regions because of disturbances caused by forest management activities and exacerbated by atmospheric soil and water pollution, which in turn are related to poor economic conditions.

References Cited

Battisti A., Boato A., Zanocco D. 1998. Two sibling species of the spruce web-spinning sawfly *Cephalcia fallenii* (*Hymenoptera: Pamphiliidae*) in Europe. Systematic Entomology 23:99-108.

Blank S.M., Shinohara A., Taeger A. 1998. Revisionary Notes on Pamphilid Sawflies. Mitt. Mus. Nat.kd. Berl., Dtsch. Entomol. Z. 45:17-31.

Capecki Z. 1982. Masowe wystapienie zasnui wysokogorskiej – *Cephalcia fallenii* (DALM) (*Pamphiliidae, Hymenoptera*) w Gorcach, Sylwan 126 (4): 41-50.

Honowski, J. Huflejt, T. 1998. O wystepowaniu zasnui wysokogorskiej, *Cephalcia fallenii* (DALM.)(*Hymenoptera, Pamphiliidae*) w Gorczanskim Parku Narodowym. Polskie Pismo Entomologicane 58: 433-446.

Jachym, M. 1999. Forecast and control of the spruce web-spinning sawflies (*Cephalcia* sp.) in the Beskidy mountains in Poland in 1998. Methodology of Forest Insect and Disease Survey in Central Europe. Proceedings of the IUFRO WP 7.03.10. Sion: 164-167.

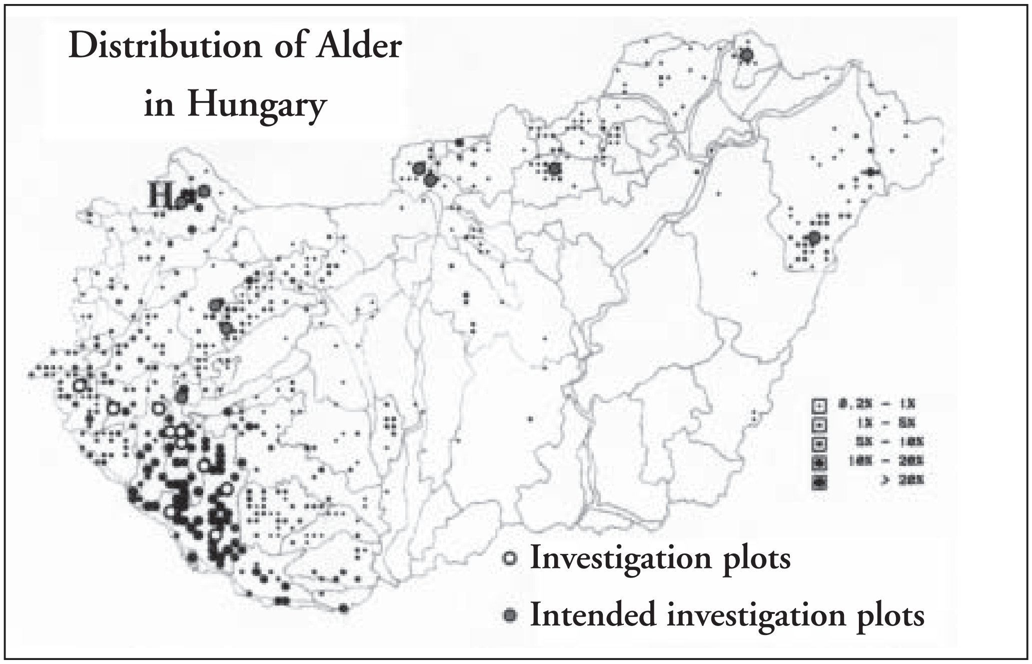
Jasica, T. 1985. Zasnuja wysokogorska w.Beskidzie Sadeckim. Las Polski, 5:9-10.

Kosibowicz, M., Jachym, M. 1998. The spruce web-spinning sawflies (*Cephalcia sp.*) in the Beskidy mountains in Poland – occurrence, importance and control. Methodology of Forest Insect and Disease Survey in Central Europe. Proceedings of the IUFFO WP 7.03.10. Jaszowiec. Poland: 85-87.

Methods Used for Investigating the Incidence of *Phytophthora* Disease of Alder in Hungary

A. Koltay[1]*, J. Bakonyi*[2] *and Z. Á. Nagy*[3]

[1]Hungarian Forest Research Institute, 1023 Budapest, Frankel L. u. 42-44.
E-mail: h13852kol@ella.hu
[2]Plant Protection Institute, Hungarian Academy of Science, PO Box 102, Budapest
E-mail: Jbak@nki.hu
[3]Plant Protection Institute, Hungarian Academy of Science, PO Box 102, Budapest
E-mail: Znagy@nki.hu



Phytophthora decline of alder was first observed in Hungary in 1999 in Hanság (NW Hungary, close to the Austrian border –designated by "H" on the map.

The Department of Forest Protection, Hungarian Forest Research Institute (FRI) started a long term monitoring project in 2001 on *Phytophthora* decline of alder, specifically to determine the importance of the disease, the extent of damage, and severity of the infection in different regions of the country.

During preliminary investigations in 2001, 57 fen type alder forests and riparian type alder forests were investigated over a distance of 100 km. Results of this investigation were reported by Koltay (2002) in Prague. Experimental plots are being established in 2002 in order to determine presence/absence of the disease, and to measure the rate and intensity of the infection. Ten new plots have been established to date and another 10 plots will be established in the future (*see map*). Stands that contained more than 3% of infected trees in different age classes and of different origins were selected as experimental plots. All plots contain 50 sample trees with the exception of two plots which contain 100 trees. Up to now we have examined each site once per year, but beginning in 2003 we will visit the plots twice each year (late spring and autumn).

Investigative methods are as follows:

Data sheet for each tree

- Location of plot
- Number of plot
- Date of investigation
- GPS code
- Tree number
- Age
- Origin - *Seed, Coppice, or Mixed*
- Diameter at 1,3 m
- Height class by Kraft (1-4)

- ALNUS (1-5) - General condition of the tree on the strength of crown condition
  1. *Previously killed tree, usually without dead twigs*
  2. *Recently killed tree, without leaves but with some dead twigs.*
  3. *Typical decline symptoms in the crown, reduced foliage with leaves smaller than normal, abundance of dead twigs and branches*
  4. *Initial symptoms of crown decline, sparse crown, and in many cases leaves smaller than normal.*
  5. *Healthy and full crown, with green, normal sized leaves*

- Leaf cast (0-10), *measure of lost leaves, 0 = no leaf cast, 10 = 100% leaf cast*
- Leaf chewing (0-1), *0 = No, 1 = Yes*
- Leaf discoloration (0-1), *0 = No, 1 = Yes*
- Leaf measurement (0-1), *0 = No, 1 = leaves smaller than usual*

- Twig dying (0-1), *0 = No, 1 = Yes*
- Branch dying (0-1), *0 = No, 1 = Yes*
- Top drying (0-1), *0 = No, 1 = Yes*
- Abnormal fruiting (0-1), *0 = No, 1 = Yes*

- Tarry spots (0-1-2), *0 = No, 1 = Yes, 2 = Not clear*
- Number of tarry spots on root swelling, *from the soil to 50 cm high on trunk*
- Number of tarry spots on trunk, *higher than 50 cm*

- Wound on stem, (0-1), *0 = No, 1 = Yes*
- Wound callus on stem, (0-1), *0 = No, 1 = Yes*
- Insect damage on stem (0-1), *0 = No, 1 = Yes*
- Water sprout (0-1), *0 = No, 1 = Yes*

In addition to monitoring the incidence of *Phytophthora* decline of alder in Hungary, we have begun identifying *Phytophthora* from our experimental plots in different regions of Hungary. These investigations are conducted in laboratories of the Plant Protection Institute, Hungarian Academy of Sciences.

Isolation methods are described below:

Soil samples containing infected roots were collected around obviously declining trees that exhibited typical tarry exudation on the lower stem. Two or three subsamples were taken from different cardinal directions at 0.5-1.5 m from the stem and were mixed. Isolates were baited by leaves of common Cherry-laurel (*Prunus laurocerasus*) according to Themann and Werres (1998). Symptomatic leaves were then washed under running tap water, disinfected in 10% sodium hypochlorite, rinsed in sterile tap water and dried on paper towels. Pieces of leaves were then placed on selective pea-broth agar (Tuite 1969) amended with 250 mg ampicillin, 10 mg pimaricin, 10 mg rifampicin 50 mg benomyl, 50 to 100 mg PCNB and 50 mg hymexazol per litre.

In addition to baiting, isolations were also made by direct plating of washed and surface disinfected root pieces onto selective media. Plates were incubated at 25 °C in the dark. Developing colonies were purified from contaminants by repeated transfer of the cultures onto the selective medium or 3% water agar (Abdelzaher et al. 1994). Pure cultures were subjected to morphological examinations.

These investigations are supported by the Hungarian Science Foundation (OTKA *F 038325*, OTKA *T 038309*)

References Cited

Abdelzaher, H. M. A., Ichitani, T. and Elnaghy, M. A. 1994. A technique for isolating bacteria-free *Pythium* spp. from pond water. Mycoscience 35 433–434.

Koltay, A. *Phytophthora* disease of alder in Hungary. Methodology of Forest Insect and Disease Survey in Central Europe, Proceedings of the Second Workshop of the IUFRO WP. September 17-21, 2001, Prag

Themann, K. and Werres, S. 1998. Verwendung von Rhododendronblattern zum Nachweis von Phytophthora-Arten in Wurzel- und Bodenproben. Nachrichtenbl. Deut. Pflanzenschutzd., 50, 2: 37–45.

Tuite, J., ed. 1969. Plant Pathological Methods. Burgess, Minneapolis, USA

Varga, F. 2000. A mézgás éger fitoftórás betegségének megjelenése Magyarországon. 46. Növ. Véd. Tud. Napok. Összefoglaló p. 126

Migration Features of *Ips typographus* in the Tatra Mountains: Using a Genetic Method

Ferenc Lakatos

University of West-Hungary, Institute of Forest and Wood Protection, H-9400 Sopron, Bajcsy-Zs. u. 4.

The genetic structure of *Ips typographus* populations in the Tatra Mountains was studied based on the observed differences of gene flow and migration rate. It was a highlighted question as to what extent different natural barriers influence the migration potential of the species.

Material and Methods

Samples of *Ips typographus* adults were collected from attacked trees (first generation) in the following valleys of Tatra: *Southern part*, Ticha dolina (**TI**), Koprova dolina (**KO**), Mengusovska dolina (**ME**), Velka Studena dolina (**VS**), *Northern part*: Javorova dolina (JA), and Bielovoda dolina (BI). Within the Bielovoda dolina samples were taken at different altitudes: 900m (BI9), 1100m (BI11), 1300m (BI13 and BI13B), and 1400m (BI14) respectively. Only parental beetles were taken to avoid the effects of the homogeneity of the "one-family" beetles. Isoenzyme analyses were carried out using the NATIVE PAGE method.

Statistical analyses of the results were made applying different genetic structure describing statistics (FStat, Biosys, Popgene, and Slatkin's). Allele frequency and genetic distance values were calculated. Dendrograms were constructed to demonstrate the relationships among the locations. Gene flow and migration rate was estimated using graphical (Slatkin's method) and statistical (F statistics) methods. All analyses were made over all populations and loci.

Results and Discussion

The proteins of 12 enzymes (22 loci) were stained and five of them were polymorph. The five polymorph loci (*Aat-2, Amy-1, Est-2, Est-3, Est-4*) had 8 10, 15, 9, and 4 alleles (Table 1.).

All investigated loci were in the Hardy-Weinberg equilibrium at the significance level of p=0.001. The effective number of alleles varied strongly from 1.054 (*Est-4*) to 5.152 (*Est-2*), with an average of 2.319. The observed heterozygosity ($H_{Obs.}$) was high, with heterozygote deficiencies on two loci (*Est-2, Est-3*).

Table 1.—Observed number of alleles

Locus	**Population**										**All Populations**
	BI9	BI1	BI13	BI13B	BI14	TI	JA	ME	KO	VS	
Aat-2	7	5	5	5	5	3	3	4	4	4	8
Amy-1	5	6	7	8	7	7	6	9	9	6	10
Est-2	14	13	12	12	11	12	11	13	12	12	15
Est-3	9	8	8	5	7	4	6	7	6	7	9
Est-4	4	1	3	2	2	3	1	2	2	1	4
Mean	7.8	6.6	7.0	6.4	6.4	5.8	5.4	7.0	6.6	6.0	9.2
St. Error	1.8912	2.1966	1.6956	1.8908	1.6432	1.9171	1.8908	2.1506	1.9875	2.0310	1.9812

```
  +--------------------------------------------------BI9
  !
  !                                 +----------------BI11
--9                                 !
  !                                 !                     +BI13
  !                                 !                  +--4
  !                                 !                  !  +BI14
  +---------------------------------8               +--5
                                    !               !  !  +BI13B
                                    !            +--6  +--3
                                    !            !  !     +TI
                                    !            !  !
                                    +------------7  +--JA
                                                 !
                                                 !       +ME
                                                 !    +--1
                                                 +----2  +VS
                                                      !
                                                      +KO
```

Figure 1.—Dendrogram based on Nei's genetic distance values (1972), neighbour joining method (populations in *italics* are from lower /1100m and below/ elevation, populations in **bold** are from the southern part, all the others from the northern part of the Tatra Mountains)

Nei's genetic distance values (D = 0.0067 to 0.0167) in the investigated area were rather close to the values found in an area of similar size in Hungary (D = 0.0018 to 0.0289). All populations showed high genetic variation. Most of the genetic differences were found within the individual populations; only 1.6% of the differences could be attributed to differences between populations (F_{ST}=0.016).

Using Nei's genetic distance values for constructing a dendrogram for the locus *Aat-2* with the "neighbor joining" procedure (Fig. 1.), the investigated populations were grouped into three main groups: (a): the populations from Bielovoda dolina lower elevations (BI9 and BI11), (b): the populations from Bielovoda dolina higher elevations (BI13, BI13B and BI14) with the neighbouring Javorova dolina (JA) and (c): the populations from the southern valleys (**ME**, **KO**, **VS**). Only the population from Ticha dolina (**TI**) did not group with its geographical origin (group c), but with northern populations (group b).

The migration rates (Nm) are high among all investigated *Ips typographus* populations. These results support previous observations that imagines fly greater distances and cover significant distances in areas where there are no host plants, and that they can disperse over higher mountain peaks.

Comparative studies showed migrational potentials in the Tatra (Nm = 19.70 to 51.16) were similar those in Hungary (Nm = 10.96 to 63.37; Lakatos, 1998) and in Southern Germany (Nm = 22.96 to 64.35; Gruppe, 1997).

References Cited

Gruppe, A. 1997. Isoenzymatische Variation beim Buchdrucker *Ips typographus*. Mitt. Dtsch. Ges. Allg. Angew. Ent. 11: 659-662.

Lakatos, F. 1998. Genetic variation of *Ips typographus* L. populations from in and outside of the native range of its host *Picea abies* (L.) Karsten. In: J. Hayes and K. Raffa ed.: Proceedings of a Workshop on Bark Beetle Genetics: Current Status of Research. Madison, Wisconsin, USA: 12-14.

Braconid (Hymenoptera, Braconidae) Parasitoids of Bark Beetles in Upland Spruce Stands of the Czech Republic

Aurel Lozan and Jiří Zelený

The Institute of Entomology, Czech Academy of Sciences, Branišovská 31, 370 05
České Budějovice, Czech Republic. E-mail: lozan@entu.cas.cz

Introduction

Several species of bark beetles occur frequently in the upland spruce forests of the Czech Republic; some of them are serious pests that may cause vast destruction of forest stands. In the last decade, a complex of several species from the genera *Ips, Pityogenes* and *Polygraphus* contributed to large-scale devastation of thousand hectares of spruce forest in the Šumava Mountains and in Northern Moravia. To understand the course of such outbreaks and to appreciate the role of natural enemies in bark beetle population dynamics, we investigated the importance of braconid parasitoids that attack several species of bark beetles.

Braconids represent the second most numerous family of parasitic Hymenoptera and include more than 20,000 species worldwide. Thirty-eight percent of braconid genera are associated with different stages of Coleoptera, most often from families (Scolytidae, Bostrychidae, and Cerambycidae) that are rarely attacked by other hymenopetrans (Belokobylsky 1996).

The present work extends these observations by demonstrating the occurrence of two additional braconid species and providing counts of bark beetles and braconids that emerged from sample logs collected in several upland (550-1200 m) spruce stands in the Czech Republic.

Methods and Materials

The communities of spruce bark beetles and their insect enemies, especially braconid wasps, were examined in sample logs that were cut twice per year during 2000-2002 from spruce trees felled in the listed forest localities. Logs were placed in photoeclectors, which are light-tightly closed tin cylinder about 1 m long and 25 cm in diameter, with a small hole near the top and another one close to the bottom where the emerging insects escape into collecting vials. Emerged insects were collected every 4 days, during the season, and at longer intervals in early spring and late autumn. Almost 10,000 specimens of bark beetles and 700 specimens of braconids were obtained.

Areas Investigated

The samples (tree logs) were collected from eight localities within four upland forest areas throughout the Czech Republic: Šumava Mountains/National Park (Březník (near Modrava, 1000-1200m; Černá hora, 1100-1200m; Strážný, 1000m; České Žleby, 800m; Stožec, 900m), Krkonoše Mountains (Špindlerův Mlýn, 750m), Bílé Karpaty Mountains (Velké Karlovice, 550m) and Českomoravská vrchovina hills (Čiměř, 550m).

Braconids Associated With Bark Beetles

Eight braconid species - *Coeloides bostrichorum* Giraud, *Cosmophorus regius* Niez., *Dendrosoter middendorffi* Ratz., *Cosmophorus klugii* Ratz., *Rhopalophorus clavicornis* Wesm., *Ecphylus sylesiacus* Ratz., *Spathius rubidus* Rossi, and *Meteorus varinervis* Tobias - were found in the logs attacked by the bark beetles of the genera *Ips, Pityiogenes* and *Polygraphus*.

Rate of Control

The rates of bark beetle control by the braconids were assessed from the ratio between the numbers of emerged bark beetles and parasitoids. Assessments were done separately for each locality and year.

The rate of parasitism varied in space and time between 1.6% and 40.5% and was often high in comparison with the abundance of other natural enemies, suggesting that braconids may play a significant role in the regulation of bark beetles. In exceptional cases registered in the Šumava Mountains, *Coeloides bostrichorum* destroyed 40% of the host complex *Ips typographus* + *Ips amitinus*, and *Ropalophorus clavicornis* 30% of *Polygraphus poligraphus. Cosmophorus klugii* eliminated 1.6% *Polygraphus poligraphus* + *Ips typographus* in Černá hora and as much as 19% of *Polygraphus poligraphus* in Březník. *Dendrosoter middendorffi* was present in five photoeclectors showing a low parasitism rate, from 0.3% of *Ips typographus* + *Pityogenes chalcographus* (Velké Karlovice) to 4.6% of *Ips typograpus* (Čiměř). *Ecphylus silesiacus* killed from 0.5% hosts in the complex *Ips amitinus* + *Ips typographus* + *Pityogenes chalcographus* in České Žleby to 5.2% of *Ips typographus* + *Ips amitinus* in Březník. The three remaining braconid species had negligible impact on the host populations.

Conclusion

Our results demonstrate that considerable numbers of spruce bark beetles can be killed by braconids in the upland forests of the Czech Republic. From the eight braconid species we collected, *Coeloides bostrichorum* destroyed as much as 40% of the complex *Ips amitinus* + *I. typographus*, and *Ropalophorus clavicornis* 30% of *Ips typographus*. We conclude that braconid wasps may regulate the population dynamics of bark beetles.

Forest management should take advantage of such natural processes, as is the biological control of xylophagous species. Minimally managed "microreserves" should be set aside for the maintenance and regeneration of insect predators and parasitoids.

Acknowledgments

The work was possible due to financial support of the Research Project of the Academy of Sciences of the Czech Republic (Grant No. S5007015). We want to thank Dr. M. Čapek (Brno) for his help in identifying some of the collected braconids and Prof. F. Sehnal for the help with the poster preparation.

References Cited

Belokobylsky, S.A. 1996. Parasitism on the beetles (Coleoptera) as important stage in the evolution of braconid wasps (Hym., Br.) I. Entom.Obozr. 55: 660-677; II. Entom.Obozr. 55: 790-814. (In Russian).

Bouček Z., Půlpán, J. and Śedivý, J. 1953. Poznámky o blanokřídlých cizopasnících kůrovce smrkového, *Ips typographus* L., v ĆSR. Folia Zool. Ent. 2: 145-158. (In Czech). [Notes on parasitic hymenopterans of the bark beetle *Ips typographus* L.].

Čapek, M. 1996. Lumčícovité (Hym.: Braconidae) ako parazitoidy podkornikovitých (Col.: Scolytidae). Conf. Proceedings Biodiverzita. z aspektu ochrany lesa a polovnin, Zvolen, pp. 27-33. (In Slovak). [Braconids (Hym.: Braconidae) as parasites of bark beetles].

Doležal, P. and Zelený, J. 2001. Bark beetles (Scolytidae, Col.) and their insect bioregulators in mountain spruce stands. J.Forest Sci. 47: 73-76.

Hedquist, K.J. 1998. Bark beetle enemies in Sweden. II. Braconidae (Hymenoptera). *Entom. Scandin., Suppl.,* 88 pp.

Turčáni, M. and Čapek, M. 2000. Výsledky štúdia parazitoidov a hmyzích predatorov podkornych škodcov borovice lesnej (*Pinus sylvestris* L.) v reliktných borinách Slovenského raja. Forestry J. 46: 381-392. (in Slovak). [Results of investigations on the parasitoids and predators of the bark pests of the scotch pine (*Pinus sylvestris* L.) in relict pine forests of Slovenskí raj].

Effect of Aerial Sprays on the Abundance of Litter Insects

Jūratė Lynikienė and Paulius Zolubas

Lithuanian Forest Research Institute, Girionys, 4312 Kaunas, Lithuania

Abstract

The research objectives were to determine the species composition and seasonal dynamics of pine litter arthropods and examine the effect of insecticide treatments on non-target organisms associated with pine beauty moth (*Panolis flammea* Schiff.*)* outbreaks. Representatives of beetles (*Coleoptera*) were the dominant arthropods collected (65.6% of 20,500). The average numbers of arthropods captured per trap were as follows: 37.03 ± 7.16 in Foray 48 B sprayed plots; 30.45±1.66 in Arrivo sprayed plots; 24.10±3.78 in control (unsprayed) plots.

Keywords: *Panolis flammea*, aerial sprays, insecticides

Introduction

Damage caused by defoliating insects usually expands over large areas and in many cases may cause extensive tree dieback in pine forests. Chemical or biological insecticides are often applied to prevent defoliation. Arthropods are very important in the self-regulation of forest ecosystem processes; spiders and other arthropods can efficiently control insect pest abundance in the forest litter (8B28=>20 1985). However 40% of beneficial insects were impacted by aerial treatment of forests with pyrethroids, 15% of them being entomophagous species (Žiogas 1995). Therefore, investigations of the impact of aerially applied chemical and biological insecticides on non-target organisms during area-wide pest suppression programs are always of high importance.

In May, 2001, 3150 ha of pine forests were sprayed with Foray-48B and 1547 ha with Arrivo to control the pine beauty moth (*Panolis flammea* Shiff.) in 2001. The research was conducted to evaluate the impact of these forest protection treatments (aerial spray) on the abundance of pine litter arthropods.

Methods

The research was carried out in pine beauty moth (*P. flammea*) outbreak populations in Druskininkai, Varėna forest enterprises and Dzūkija national park pine forests. Litter arthropods were captured in pitfall traps (150 ml, 6.5 cm diameter plastic cups) filled with 10% formalin. Traps were installed two weeks before spraying was conducted and emptied once or twice each month between May and October. 24 traps were placed in forest plots sprayed with Arrivo (conventional pyrethroid), 24 traps in plots sprayed with Foray 48B (microbial pesticide), and 24 traps in a forest plot designated as an untreated control. Traps were placed in 2x2 m rectangle design with three replications; the distance between replications was 20 m (Фасулати 1971). Trap results were calculated for 20-day periods in order to compensate for irregularities in collecting dates between treatments.

Results

Approximately 20,500 arthropods were collected and identified in the study plots. Beetles (Coleoptera) dominated the collections and represented 65.6% of all collected arthropods. Within the Coleoptera, the three dominant families were as follows: Carabidae (ground beetles) 70.8%; Curculionidae (weevils) 13.2%; Staphilinidae (rove beetles) 9.6%. Other groups captured included Aranei (mites) 11.7%, and Hymenoptera (11.7%) (Table 1).

Table 1.—Pitfall trap captures in pine beauty moth plots

Order	Abundance	Family	Abundance
Coleoptera	65.6%	*Carabidae*	70.8%
Diptera	1.1%	*Elateridae*	1.3%
Hymenoptera	11.7%	*Scarabaeidae*	3.4%
Lepidoptera	1.1%	*Curculionidae*	13.2%
Aranei	19.9%	*Staphilinidae*	9.6%
Other insects	0.6%	*Silphidae*	0.8%
		Other beetles	0.9%

The number of arthropods in Foray 48B sprayed plots averaged 37.03±7.16 specimens per trap. In Arrivo sprayed plots the average number was 30.45±1.66, and in the control (unsprayed) it was 24.10±3.78. The increased abundance of pine beauty moth larvae in outbreak areas had a positive influence on the number of litter insects captured. The abundance of litter arthropods essentially increased after treatment with Arrivo; in June-July the catch was over two times greater than in May (Table 2). These differences were statistically significant. A similar increase in trap captures was observed in Foray 48B treated plots, where catches after treatment increased from 38.15±9.42 to 65.78±6.32. This difference can be explained by the large number of pine beauty moth larvae that dropped from the forest canopy after treatment; this created a vast food supply which was attractive to entomophagous arthropods (spiders and ground beetles in particular) from surrounding stands.

Table 2.—Effect of different treatments on arthropod abundance

Month	Abundance in different treatments, number/trap/20 days					
	Arrivo		Foray 48B		Control	
May	23.25 ± 2.54	a	38.15 ± 9.42	ac	33.19 ± 5.10	ab
June	53.44 ± 2.41	b	28.56 ± 2.67	b	17.42 ± 2.14	bc
July	55.17 ± 2.51	b	65.78 ± 6.32	a	33.80 ± 2.82	a
August	8.15 ± 78	c	42.42 ± 6.72	a	15.51 ± 1.86	c
September	26.09 ± 0.63	a	39.87 ± 6.01	ab	40.92 ± 5.90	a
October	8.81 ± 1.11	c	8.54 ± 0.83	c	12.86 ± 4.86	c
Average	**30.45 ± 1.66**		**37.03 ± 7.16**		**24.10 ± 3.78**	

Values followed by same letter do not significantly differ (Student t-test, p=0.90)

The seasonal dynamics of ground captures/trap in the Foray 48B plot as compared to the unsprayed control can be explained by the slower action of the biological preparation (Žiogas 1995). The number of arthropods captured in the pyrethroid sprayed plots increased immediately after treatment (June), however in the Foray 48B treated plots, this increase came later (July-August) and was not as large. Three months after treatment (September) there was no significant difference in the average abundance of litter insects among the treatment and control plots.

Conclusions

1. The representatives of the order *Coleoptera* (beetles) dominated the pitfall trap captures and represented 65.6% of all collected arthropods.

2. Number of arthropods per trap in the Foray 48 B sprayed plots was 37.03±7.16 in Arrivo sprayed plots 30.45±1.66, and 24.10±3.78 in the control plot (unsprayed).

3. After treatment with Arrivo, the abundance of litter arthropods increased significantly for two months (June-July) and later decreased to the same level as in the control plots.

4. After treatment with Foray 48B, there was a slower increase in the abundance of litter arthropods however the average number/month was higher.

References

Žiogas A. 1995. Biologinio preparato Foray-48B poveikio pušynų entomofaunai įvertinimas. Kaunas, 30-37 p.

Фасулати К.К. 1971. Полевое изучение насекомых безпозваночнык. M, . C. 320.

Литвинова А. Н., 1985. Панкевич Т. П., Молчанова Р. В. Насекомые сосновых лесов Минск, С. 22-28.

Bark Beetles (Scolytidae, Coleoptera) in Slovenia with Special Regard to Species in Burnt Pine Forests

Maja Jurc

University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable
Forest Resources,Večna pot 83, 1001 Ljubljana, Slovenia

Bark Beetles (Coleoptera: Scolytidae) in Slovenia

Ecological conditions in Slovenia are very complex and heterogeneous due to the influence and interaction among the various climatic, tectonic, edaphic, orographic, lithologic - transitional (ecotonic) regions. Slovenia is a meeting-point of the Alps, the Mediterranean, the Dinaric Mountain Region and the Pannonian Lowland. This complexity of ecological factors has created a wide variety of habitats and accounts for the high degree of biodiversity of flora and fauna. As a result of the work of Slovenian entomologists, we now have a preliminary catalogue of species from the family Scolytidae. At last count (Grüne 1979) there were 154 species in the Scolytidae family in Europe. From publications and Slovenian collections (Central Collection of Slovenian Museum of Natural History, Coleoptera-Rhynchophora, S. Brelih; Gspan collection; Collection of the Department of Forestry and Renewable Forest Resources, Biotechnical Faculty, M. Jurc) we have established that there are 88 species from the family Scolytidae in Slovenia:

> *Scolytus scolytus* (Fabricius), *S. laevis* Chapuis, *S. multistriatus* (Marsham), *S. pygmaeus* (Fabricius), *S. ratzeburgi* Janson, *S. intricatus* (Ratzeburg), *S. mali* (Bechstein), *S. rugulosus* (Müller), *S. carpini* (Ratzeburg), *Phloeotribus scarabaeoides* (Bernard), *Phthorophloeus spinulosus* Rey, *Phloeophthorus latus* (Wichmann), *P. geschwindti* (Seitner), *Hylastes ater* (Paykull), *H. opacus* Erichson, *H. linearis* Erichson, *H. attenuatus* Erichson, *H. angustatus* (Herbst), *H. cunicularius* Erichson, *Hylurgops glabratus* (Zetterstedt), *H. palliatus* (Gyllenhal), *Tomicus minor* (Hartig), *T. piniperda* (Linnaeus), *Hylurgus ligniperda* (Fabricius), *Dendroctonus micans* (Kugelann), *Polygraphus poligraphus* (Linnaeus), *P. subopacus* Thomson, *Hylesinus crenatus* (Fabricius), *H. oleiperda* (Fabricius), *Leperesinus fraxini* (Panzer), *Hylastinus obscurus* (Marsham), *H. fankhauseri* (Reitter), *Xylechinus pilosus* (Ratzeburg), *Pteleobius vittatus* (Fabricius), *P. kraatzi* (Eichhoff), *Phloeosinus thujae* (Perris), *Hypoborus ficus* Erichson, *Liparthrum mori* Aube, *L. genistae* Aube, *Crypturgus cinereus* (Herbst), *C. hispidulus* Thomson, *C. pusillus* (Gyllenhal), *Dryocoetes autographus* (Ratzeburg), *D. villosus* (Fabricius), *D. alni* (Georg), *Xylocleptes bispinus* (Duftschmid), *Cryphalus piceae* (Ratzeburg), *C. saltuarius* Weise, *C. abietis* (Ratzeburg), *C. intermedius* Ferrari, *Ernoporus fagi* (Fabricius), *E. caucasicus* (Lindemann), *E. tiliae* (Panzer), *Pityophthorus pityographus* (Ratzeburg), *P. lichtensteini* (Ratzeburg), *P. carniolicus* Wichmann, *P. balcanicus* Pfeffer, *Taphrorychus bicolor* (Herbst), *T. alni* (Pfeffer), *T. villifrons* (Dufour), *Pityogenes chalcographus* (Linnaeus), *P. trepanatus* (Nördlinger), *P. bidentatus* (Herbst), *P. quadridens* (Hartig), *P. bistridentatus* (Eichhoff), *P. conjunctus* (Reitter), *P. calcaratus* (Eichhoff), *Pityokteines curvidens* (Germar), *P. spinidens* (Reitter), *P. vorontzowi* (Jacobson), *Orthotomicus suturalis* (Gyllenhal), *O. laricis* (Fabricius), *O. proximus* (Eichhoff), *O. erosus* (Wollaston), *Ips acuminatus* (Gyllenhal), *I. typographus* (Linnaeus), *I. amitinus* (Eichhoff), *I. cembrae* (Heer), *I. sexdentatus* (Börner), *Xyleborus dispar* (Fabricius), *X. saxesenii* (Ratzeburg), *X. monographus* (Fabricius), *X. pfeilii* (Ratzeburg), *X. dryographus* (Ratzeburg), *X. germanus* Blandford, *Xyloterus domesticus* (Linnaeus), *X. signatus* (Fabricius), *X. lineatus* (Olivier).

Thus, our data show that 57% of European species of the family Scolytidae are currently extant in Slovenia. However, we expect closer to 120 species to be eventually identified in Slovenia according to data in the literature (Jelínek 1993; Pfeffer 1995).

Dendroctonus micans was first recorded in the Gspan collection and later found on location in Podbrezje, Gorenjska region, 1973; it was detected in a gradation in a spruce monoculture near Ormož (northwest part of Slovenia), 2000. In 2001 the beetle was found in 24 small groups (1 to 5 trees) of spruce trees, equal to approximately 80 m^3 of wood when the dying trees were cut down.

Bark beetles on fir (*Pityokteines spinidens, P. curvidens, Cryphalus piceae, Pityokteines vorontzowi)* have only been found in a few locations throughout the country in recent years. In 2002, these beetles, combined with the drought from the previous year, caused large gradations in several regions in the central and particularly the southern (Kočevje region) parts of Slovenia. By 1. 7. 2002, about 36,000 m^3 of fir and 20,000 m^3 of spruce (spruce death was caused by *Ips typographus* and *Pityogenes chalcographus*) had been cut in the Ko´evje region.

Species of Bark Beetles in the Burnt Pine Forests of the Kras Region

Within the framework of the project "Forests Fires in Slovenia" (1998-2001, financed by the Ministry of Science and Technology and the Ministry of Defence), we studied the abiotic (soil) and biotic (succession of vegetation, nourishment of some herbivores, entomofauna) parameters at chosen locations in limestone and flich regions of Kras. A study of the impact of fires on the insects in trunks in burnt-out areas of Austrian pine plantations *(Pinus nigra* Arn.) was carried out in the Kras region from 1999 to 2001. The work was performed in three locations differing from one another in terms of soil condition, size of burnt areas, as well as in the type and duration of burning.

Methods

We collected various species of insects at each location, at three times during the year (May, June/July, September) from under a 50 x 50 cm bark patch at breast height from five Austrian pine trees chosen at random. A Shannon –Wiener Diversity Index was used in order to demonstrate and explain the diversity of the insects collected at the different experimental locations.

Locations

P1. Mlave: August 2000, over an area of 2.4 ha, crown fire, vegetation at location: Austrian pine forest – *Seslerio autumnali*s-*Pinetum nigra*e.

P2. Kojnik: April 1998, over an area of 46 ha, characterized by a ground and crown fire, pastures as well as Austrian pine forest and thermophilic deciduous trees.

P3. Podgovci: August 1998, over an area of 7.53 ha, ground fire, Austrian pine forest –*Seslerio autumnali*s-*Pinetum nigrae.*

Results

We collected a total of 1590 specimens from the family Scolytidae. The identified species are listed in Table 1.

The highest index of entomofauna diversity was found in the youngest burnt area while the lowest index was found in the oldest burnt area. We can conclude that the most suitable habitat for the species found occurs on freshly damaged trees, while aging and dried-out material served as less suitable habitats for bark beetles.

Table 1.—Survey of insects collected in pine monocultures in trunks of declining and dead Austrian pine trees in Kojnik (P1), Podgovci (P2) in Mlave (P3) from 1999 to 2001.

Family SCOLYTIDAE	P1	P2	P3	TOTAL
Ips sexdentatus (Börner)	964	7	220	1191
Ips acuminatus (Gyllenhal)		8		8
Orthotomicus laricis (Fabricius)	158	7	7	169
Orthotomicus suturalis (Gyllenhal)		2		2
Pityogenes chalcographus (Linnaeus)	131			131
Pityogenes trepanatus (Nördlinger)			6	6
Pityogenes bistridentatus (Eichhoff)			45	45
Tomicus minor (Hartig)	3		2	5
Tomicus piniperda (Linnaeus)		2		2
Hylastes ater (Paykull)	14	1		15
Hylastes Erichson, (two species)	12	4		16
Total	1282	31	277	1590

References Cited

Grüne, S. 1979. Handbuch zur Bestimmung der europäischen Borkenkäfer.- Hannover, M. & H. Schaper: 182 p.

Jelínek, J. 1993. Check-list of Czechoslovak Insects, IV (Coleoptera).- Folia Heyrovskyana, Supplementum 1, Praha, 172 p.

Pfeffer, A. 1995. Zentral- und westpaläarktische Borken- und Kernkäfer (Coleoptera: Scolytidae, Platypodidae).- Basel, Pro Entomologia, 310 p.

Phenological Prediction of Forest Pest-Defoliators

Valentina Meshkova

Ukrainian Research Institute of Forestry & Forest Melioration

The methodology for predicting phenological events are useful for predicting the seasonal development of insects in the current year, for analyzing terms and rate variation of insect population development in different years, and for comparing different geographical and ecological insect populations after terms and rate of different stages of seasonal development.

A mathematical sense of the proposed approach is in the determination of such period (*n* days) in the year temperature course, the average temperature of which allows to complete development of a particular stage of insect for the same *n* days. The values of *n* are determined by graphical solution of the system of two or more empirical equations, where one equation characterizes the heat resources of a geographical region and the others define the heat demands of biological objects (Podolskij 1967)

The heat requirements of insects are represented as curves that show the dependency of certain stage of instar development duration (*n* days) on the mean air temperature during the period of this development (*T*). Such curves are called “phonological” curves.

The basis of such curves are data on the developmental dates for objects obtained at constant temperatures in the laboratory as well as data obtained from field investigations or from the literature (Meshkova 2001a,b,c,d). Datasets for many years or for different points were plotted in the graphs and trend lines $n=f(T)$ were constructed (Fig.1,2).

Heat resources of a region were represented in such a way that it was possible to determine the mean air temperature for any time interval in a season. The net of heat resources consists of lines; every line is marked by the mean date for a respective period (for example, <<15.IV>>, <<25.VI>>). Every line consists of points whose coordinates are determined from values for 10 day periods. To build the net of heat resources, auxiliary tables were calculated for different geographical regions from data on mean air temperature over many years (Meshkova 2001 b). If necessary, intermediate lines can be built by graphical or analytical means.

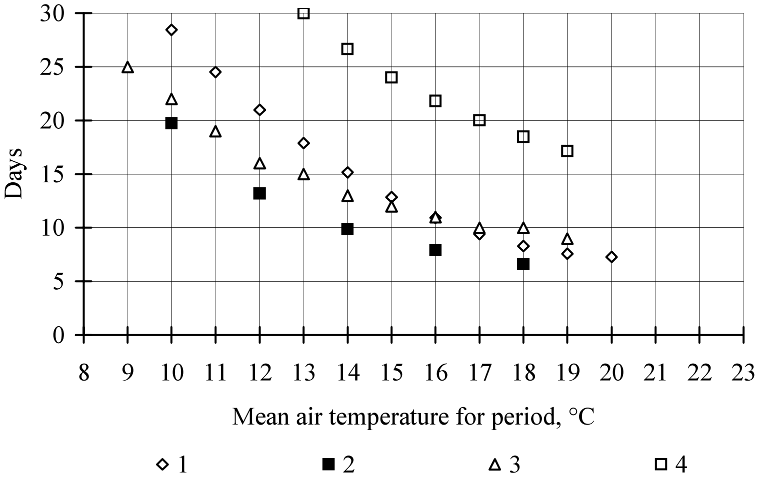


Figure 1.—Phenological curves for eggs development: 1 – *Lymantria dispar* L.; 2 – *Operophthera brumata* L.; 3 – *Tortrix viridana* L. 4 – *Archips crataegana* Hb.

For a graphical solution of the system of equations that describe heat demands of insects and heat availability, the net of heat resources and the phenological curve must be plotted at the same coordinates. One must find the line of heat resources that starts from the beginning date of a given stage and the point of its intersection with the phenological curve for that stage. Then the ordinate of the intersection point is equal to the number of days which are necessary for this stage to complete its development. The results of such estimations are represented as phenological calendars for a region (Meshkova 2001a, b, c, d).

It is known that air temperature growth temp depends on latitude and longitude. It transits over 0°C in Lviv (49°49’ N, 23°57’E) on March 14 and in Kharkiv (49°58’ N, 36°08’E) on March 22, but it

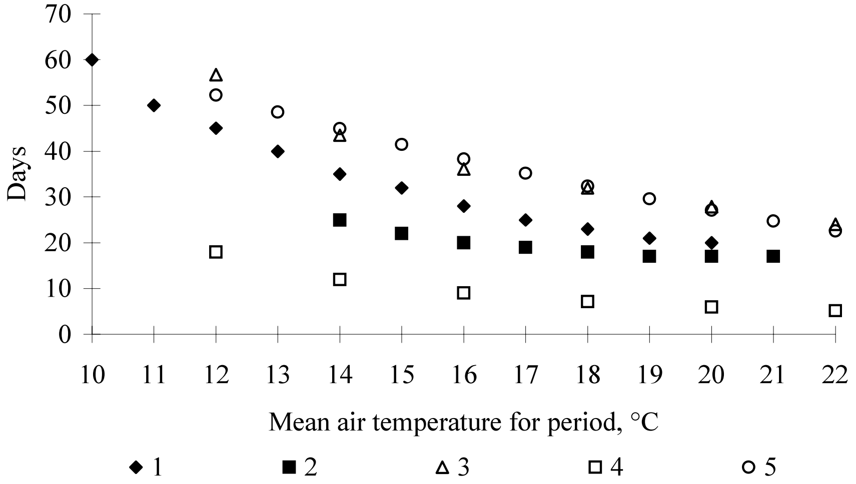


Figure 2.—Phenological curves for larvae development: 1 – *Neodiprion sertifer* Geoffr.; 2 – *Operophthera brumata* L.; 3 – *Panolis flammea* L.; 4 – *Archips crataegana* Hb.; 5 – *Euproctis chrysorrhoea* L.

transits over 10°C 6 days earlier in Kharkiv (24.IV), than in Lviv (30.IV). If winter moth eggs begin development on March 15, then larvae will hatch 42 days later in the Crimea and 57 days later in Kharkiv. If eggs begin development on April 15, then larvae will hatch almost simultaneously (two days difference) in Lviv and Kharkiv.

Based on analysis of data from many years, winter moth egg development begins on April 1 in Simferopol (44°41'N, 34°08'E) and larvae would appear there in 30 days or on May 1, on May 5, in Lviv, and on May 9 in Kharkiv. According to calculations, then larvae will pupate 24 days after April 1, that being May 25 in Simferopol, 25 days after May 5, or May 30 in Lviv, 23 days after May 9, or June 1 in Kharkiv.

However the suggested method can be used only for predicting insect development during the first part of the summer; after the solstice, the role of photoperiod in their development becomes more important. For example, the timing of winter moth swarming does not depend on the completion of larval feeding, but rather it coincides with the end of the vegetation period at a given point. Therefore, winter moth swarming is observed earlier in the northern regions and later in the southern regions.

References Cited

Meshkova, V. 2001a. Phenological prognosis of *Neodiprion sertifer* Geoffr. for different zones of Ukraine. Problems of ecology and forest use in Polissya of Ukraine. Zhitomir: Volyn. V.2 (8): 125–130 [In Ukrainian].

Meshkova, V. 2001b. Phenological prognosis of pine defoliators taking into account heat resources of region. Forestry & Forest melioration. Kharkiv. V.99: 112–120 [In Ukrainian].

Meshkova, V. 2001c. Prediction of the seasonal development of the gold-tail moth *Euproctis chrysorrhoea* L.. Proceedings of National Agricultural University / V.46: 164–171 [In Ukrainian].

Meshkova, V. 2001d. Prediction of *Tortrix viridana* L. seasonal development. Forestry & Forest melioration. Kharkiv V.100: 108–116 [In Ukrainian].

Podolskij, A.S. 1967. The new approach in phenological prediction. Nauka, Moscow. 232 p. [In Russian].

The Frequency and Intensity of Bark Beetle Infestations Recorded in Romanian Forests Affected by Windfall in 1995

V. Mihalciuc[1]*, A. Danci*[2]*, M. Bujilă*[1] *and D. Chira*[2]

[1]Forest Research and Management Institute Brasov, Romania
[2]Simon Fraser University Vancouver, Canada

Abstract

Research has been carried out during the past six years (1996-2001), to record the occurrence of wind damage in resinous stands and to monitor the evolution of pest infestations during this period. The level of pest attack has become moderate over time and depended on different types of damaged wood material (cut, broken and fallen trees). We also reported about the incidence of infested standing trees in correlation with the quantity of windthrown wood.

Introduction

A windfall of vast proportions occurred on November 5-6, 1995, that severely affected Romanian forest stands in the following counties: Covasna, Harghita, Mureş, and Bistriţa from Oriental Carpathians (Simionescu et al., 2001). Research was carried out over the years after windfall, and has been conducted in experimental plots characterized by the presence of a variety of stands and different environmental conditions. The purpose of these investigations was to study the evolution and the dynamics of pests attacking both windthrown and standing trees.

Materials and Methods

A large number of experimental plots were located in areas affected by windfall, where we registered damaged trees (fallen, broken, cut and pruned trees). These trees were analyzed in order to find out the diversity of bark and wood boring insects, the intensity of infestation, and their developmental stages. Relying on these data, we estimated the frequency of infestation over time, and recommended appropriate control measures and the opportune time for their application.

Results

The evolution of infested woody material over time. In the majority of circumstances, spruce trees were infested at a high level. The main pests which infested damaged trees were the following: *Ips typographus*, *Pityogenes chalcographus, Ips amitinus, Polygraphus poligraphus, Trypodendron lineatum, Hylurgops palliatus, Tetropium castaneum, Monochamus sutor, Urocerus gigas, Orthotomicus suturalis.* In the first year after the windfall (1996), the intensity of insect attack was generally low. Intensive infestations were observed only in areas where bark beetle outbreaks were recorded in the past. During the next years (1997-2000) the infestation increased significantly, and as a result in 2000 we registered high and very high levels of pest attacks in all damaged areas (Fig. 1).

The influence of damage type on infestations

In all damaged areas, about 40% of the trees were windthrown and 60% were broken at the base of trunks. The windthrown trees were still connected with the soil, and continued to vegetate during the next 1-3 years after the windfall. During this period, the frequency of infestation by pests was 34% in 1996, 61% in 1997, and 5% in 1998. Over 90% of the broken and fallen trees were infested in 1996, and less than 5% in 1997.

The period between the occurrence of damages and the time that trees were attacked varied in relationship with the type of tree damage – windthrown, broken or cut trees (Table 1). Cut and pruned trees were infested within 1-2 months, broken at the basal part of stem and fallen trees were

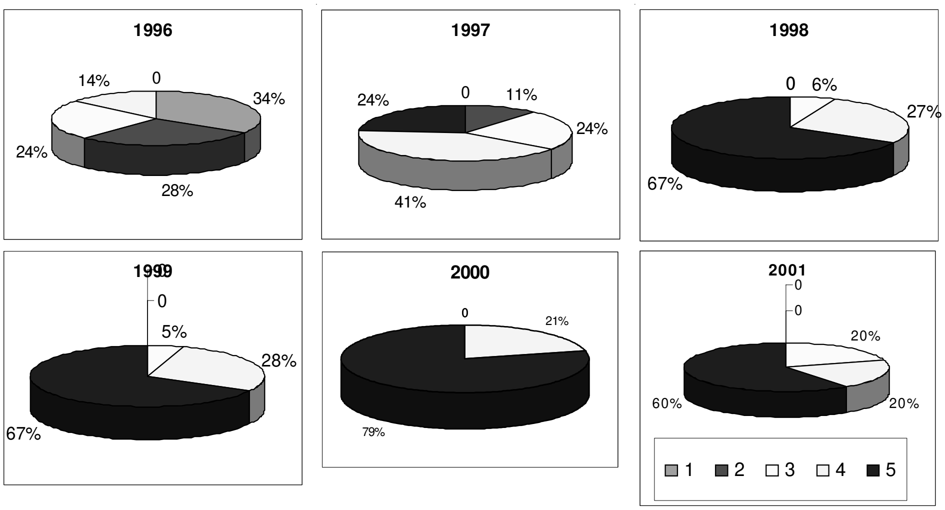


Figure 1.—Distribution of the intensity of bark beetle infestation after the November 5, 1995 windfall (Counties of Covasna, Harghita, Mureş, and Bistriţa; 1: very low, 2: low, 3: medium, 4: high, 5: very high)

infested after 6-7 months, and windthrown trees were infested within 7-18 months after windfall. Because of these results, we strongly recommend that damaged wood material should be remover before infestation by bark beetle species can occur.

The infestation of standing trees after the windfall

We established a correlation between the quantity of damaged wood material recorded in 1995 and the percentage of infested standing trees that were recorded between 1996-1998. The large number of fallen trees favored bark beetle outbreaks. This was reflected indirectly by the increased number of standing trees that were infested. This situation was especially evident in the Ranger Districts of Covasna and Comandău where the volume of damaged trees was the largest.

The highest number of infested standing trees occurred four years after the calamity - 8,300 trees in Ranger District Covasna and 14,548 trees in Ranger District Comandău. In 2000, the number of infested standing trees was reduced significantly as a result of the protection measures which were implemented in the damaged forests during 1996-1999 (Mihalciuc et al. 2001).

Table 1.—The period (months) between damage and stem infestation (County of Covasna, Mureş, Bistriţa, Braşov, Prahova, Sibiu; 1995-2001)

Type of damage	Main pests								
	It	Ia	Pc	Tl	Hp	Hg	Os	Ms	Ug
Windthrown trees	14.7	15.0	17.9	14.2	16.2	14.7	13.5	7.5	8.5
Trees broken by wind from the basal part of stem	7.1	7.0	7.3	6.2	-	-	-	-	-
Trees with basal stem sectioned (cut), and pruned	1.2	1.7	1.4	2.1	2.6	-	1.6	-	-

It: *Ips typographus*; **Ia**: *Ips amitinus*; **Pc**: *Pityogenes chalchographus*; **Tl**: *Trypodendron lineatum*; **Hp**: *Hylurgos palliatus*; **Hg**: *Hylurgos glabratus*; **Os**: *Orthotomicus suturalis*; **Ms**: *Monochamus sutor*; **Ug**: *Urocerus gigas.*

Conclusions

1. The level of infestation of damaged trees and the number of infested standing trees were highest 3-5 years after the windthrow of 1995.

2. In the first year after the damage (1996), over 90% of the trees broken at the basal part of stem were infested; the windthrown trees were infested during the next two years after the windfall (1996-1997); at high altitude and on slopes with intermediate exposure, the infestation took place beginning in 1998.

3. The larger volume of damaged wood material was favorable to the development of higher bark beetle populations; however, annual control measures have reduced the severity of pest outbreaks.

References Cited

Simionescu A., V. Mihalciuc, A. Vlăduleasa, O. Badea, T. Fulicea, M. Liţescu, A. Danci, M. Bârca, S. Popescu, and P. Enescu. 2001. The health state of Romanian forest between 1986-2000. Ed. Musatinii, Suceava (in Romanian).

Mihalciuc V. A. Danci, N. Olenici, and A. Vlăduleasa. 2001. Sanitary state of resinous stands from Romania and the protection measures applied in the 1990-2000 period. In: M. Knizek., B. Forster, W. Grodzki (eds.). Methodology of Forest Insect and Disease Survey in Central Europe. Proceedings of the Fourth Workshop of the IUFRO WP 7.03.10, September 17-20, 2001, Praha, Czech Rep. J. For. Sci., 47, Special Issue 2: 136-138.

Dendrochronological Analysis of Trees and Stands Attacked by *Dendroctonus ponderosae* in Colorado

José F. Negrón and John Popp

USDA Forest Service, Rocky Mountain Research Station
240 West Prospect, Fort Collins, CO 80526
e-mail: jnegron@fs.fed.us, voice: 970-498-1252 fax: 970-498-1314

Abstract

The mountain pine beetle, *Dendroctonus ponderosae* Hopkins, is the most important bark beetle associated with ponderosa pine, *Pinus ponderosae* Lawson, in Colorado. Periodic outbreaks of this insect have caused extensive tree mortality in the past. No data are available which relates stand conditions to the susceptibility of trees or stands to this insect in Colorado. In 1998, we initiated a study with the objective of developing a probability of infestation model and to examine the use of basal area increments as a predictor of bark beetle susceptibility. We established 35 clusters of fixed radius plots 0.04 ha in size. One plot was infested by mountain pine beetle while the other three were baseline plots. Ponderosa pine forests in Colorado are clumped in nature so by having more baseline plots we could reduce some of the variation associated with clumped ecosystems. We collected mensurational data from all the plots and collected cores from all trees at least 15.2 cm in diameter at breast height. All cores were sanded, dated, and tree rings were measured. A classification tree model was constructed which indicated that the probability of infestation was 0.7 when ponderosa pine basal area was equal to or greater than 17.1 m^2/ha, and 0.21 when ponderosa pine basal area was less than 17.1 m^2/ha. Tree ring records from individual trees indicated that a reduction in basal area occurred consistently in mountain pine beetle-killed trees since the 1900s. At the plot level, the mean difference in basal area increments between infested and baseline plots from the 1920s to the 1980s is essentially zero. After that, infested plots exhibit larger reductions in basal area increments. The observed reduction in basal area increments at both the tree and plot level in infested plots is associated with increased basal area. Our data agree with other studies that have implicated reduced growth rates with increase susceptibility to bark beetles. Additional data analysis is underway to determine if there is a threshold of basal area increments at which ponderosa pine trees become more susceptible to mountain pine beetle.

Insects in IBL-4 Pine Weevil Traps

I. Skrzecz

Forest Research Institute, Bitwy Warszawskiej 1920 r. no. 3, 00-973 Warsaw,
e-mail: I.Skrzecz@ibles.waw.pl

Abstract

Pipe traps (IBL-4) are used in Polish coniferous plantations to monitor and control the pine weevil (*Hylobius abietis* L.). This study was conducted in a one-year old pine plantation established on a reforested clear-cut area in order to evaluate the impact of these traps on non-target insects. Evaluation of the catches indicated that species of *Carabidae* were the most frequently captured group of non-target insects.

Key Words: *Hylobius abietis*, IBL-4 traps, non-target insects

Weevils of the genus *Hylobius* (*Coleoptera: Curculionidae*) are particularly important pests in European coniferous plantations. In Poland, the pine weevil (*Hylobius abietis* L.) has become the most harmful pest of 1-3-year old coniferous crops. To control the pine weevil, pipe traps IBL-4 baited with a mixture of a-pinene and ethanol (Hylodor ^{R}) were placed into coniferous plantations in order to monitor and control pine weevil populations. Hylodor ^{R}-baited traps often capture non-target insects in addition to pine weevils. This study was conducted to evaluate the species and numbers of non-target insects that are captured in pine weevil IBL-4 traps.

Materials and Methods

The observations were carried out in 1998 on one-year old plantation (1.5 ha) of Scots pine (*Pinus silvestris* L.) and Norway spruce (*Picea abies* L.) in the Celestynow Forest District (Central Poland). The plantation was established on a clear-cut area that resulted from harvesting a 100 year old Scots pine stand. In April, 15 IBL-4 traps were installed linearly (20 m apart) in the middle of the plantation. Captured insects were collected biweekly during the period April-September and identified as to species and family.

Results

IBL-4 traps caught in total 2839 the pine weevils, averaging from 1.18 ± 1.03 to 96.18 ± 15.83 beetles/trap and 284 non-target insects of 20 species that belonged to nine families (Table 1). The average number of non-target insects caught per trap was between 4 ± 1.67 and 8.82 ± 2.25 individuals.

The highest number of insects captured belonged to the family *Carabidae* (12 species from genera: *Carabus, Pterostichus* and *Harpalus*). Other individual species captured were from the families *Anobiidae, Byrrhidae, Cerambycidae, Cicindelidae, Dermestidae, Elateridae, Geotrupidae, Gryllidae, Lucanidae, Nitidulidae, Silphidae* and *Staphilinidae.*

Based on results obtained it appears that the most abundant group of non-target insects captured in IBL-4 traps resulted from their accidental walking into the traps or due to their search for shelter. This group includes species from the *Carabidae* and species from the *Anobiidae, Byrrhidae, Elateridae, Gryllidae, Lucanidae* and *Staphylinida*e. Representatives from the *Dermestidae* and *Silphidae* feeding on dead insects were probably attracted to the traps by the odor from decomposing insects inside the traps.

Table 1.—Number of non-target insects in IBL-4 traps

Species	Number of insects
Anobiidae:	
Anobium punctatum	1
Byrrhidae:	
Byrrhus pilula	1
Carabidae:	
Agonum sexpunctatum	3
Carabus arcensis	166
Carabus hortensis	22
Carabus violaceus	1
Chlenius nitidulus	1
Harpalus latus	1
Harpalus rufipes	15
Pterostichus angustatus	10
Pterostichus caerulescens	2
Pterostichus niger	20
Pterostichus oblongopunctatus	8
Pterostichus rufipes	2
Dermestidae:	
Dermestes laniarius	2
Elateridae:	
Melanotus erythropus	1
Gryllidae:	
Gryllus campestris	18
Lucanidae:	
Platycerus caprea	1
Silphidae:	
Necrophorus vespillo	1
Staphylinidae:	
Staphylinus erythropterus	8

*Ips typographus (*L.) (Coleoptera: Scolytidae) in Southeastern Alps: Results of a Six-Year-Long Monitoring Program

F. Stergulc[1] *and M. Faccoli*[2]

[1]Department of Plant Protection, University of Udine, Italy
[2]Department of Environmental Agronomy and Crop Production, University of Padua, Italy

Abstract

Beginning in 1996, populations of *Ips typographus* in the Friuli-Venezia Giulia region (NE Italy) have been monitored by using pheromone traps. Preliminary analysis of the data (1996-2001) reveals some interesting information:

1) the flight activity of *Ips typographus* is very extended and occurs over a period of four months (mid May until August)
2) the outbreak which began in 1996 has declined gradually over time as shown by lower levels of both insect captures and damage
3) there is a high correlation between spring captures (May-June) and total captures (May-August) and between spring captures and damage. The high correlation between spring captures and damage allows us to determine a reliable risk threshold (about 5,000 beetles/trap in spring), and at the same time reduce the period of monitoring. Pheromone traps are useful for studying both the biology and population dynamics of *Ips typographus* populations.

Key Words: *Ips typographus*, monitoring, pheromone traps, damage forecast

Most studies that involve the monitoring of populations of *Ips typographus* (L). (Coleoptera Scolytidae) have been carried out in central and northern Europe where the winters are long and cold and flight activity begins quite late in the season (June-July); therefore the short summer allows completion of only one generation per year and damage to spruce stands is not always severe. However, in southern European countries, *I. typographus* attacks host trees early in the spring (April-May) and very often two generations are completed; consequently spruce trees which survive the attacks of the first generation can still be attacked and killed by emerging second generation adults. In this paper we summarize some data obtained from monitoring *I. typographus* over a period of six years and discuss how pheromone trap data might be used to forecast damage caused by this species.

Materials and Methods

Beginning in 1996, populations of *I. typographus* have been monitored permanently in the main spruce forests of the Friuli-Venezia Giulia (north-eastern Italy) by using ca 30 pheromone traps (Theysohn® slot-trap) baited with methyl-butenil, cis-verbenol and ips-dienol. The traps are installed and baited each year at the end of April and are checked weekly at which time all beetles captured are determined and counted. All pheromone dispensers are replaced after two months. The trials last until the first half of September and data are reported as mean captures per trap. At the same time, damage caused by *I. typographus* is recorded from field observations carried out over an area of 300 m around the traps beginning on the 1st of May (initiation of *I. typographus* flight) and continuing until April 30 of the following year.

Results

Captures observed in 1996 are higher than those of the following years (ANOVA, d.f.= 1; 5, F=8.43, P<0.001; Tukey's test, P<0.01) (Fig. 1). The volume of timber lost between 1996-2001 (Fig. 2) shows the same trend as the captures (Fig. 1). In addition, there is a significant correlation between the captures observed during the entire monitoring period (May-September) and those obtained in

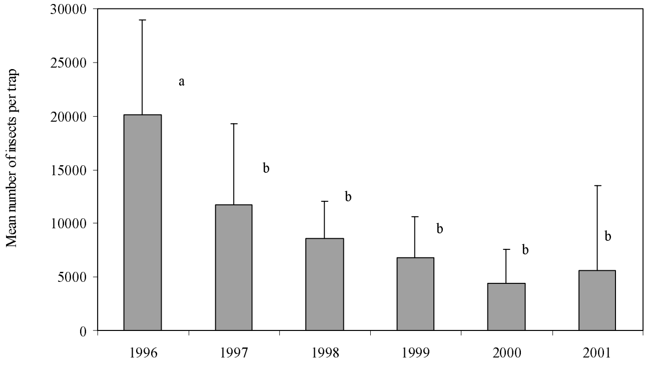


Figure 1.—Mean captures over the last six years. Different letters correspond to statistical differences (P<0.01).

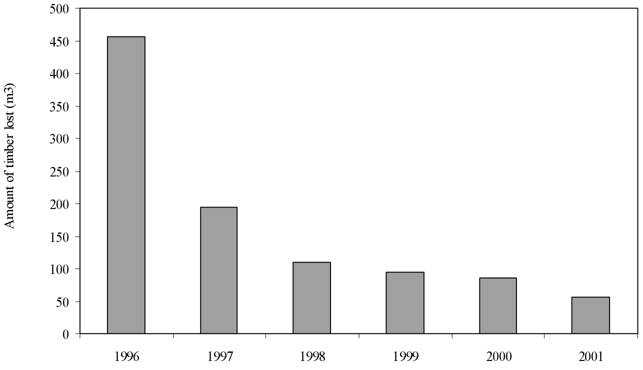


Figure 2.—Damage observed in the last six years.

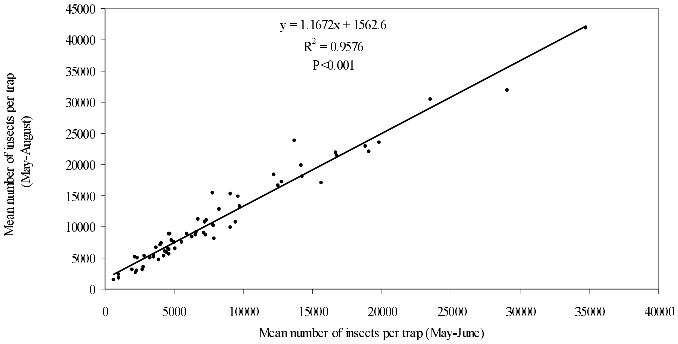


Figure 3.—Correlation between spring and total captures.

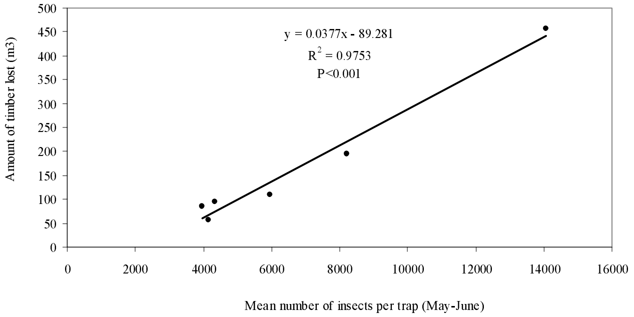


Figure 4.—Correlation between spring captures and damage.

spring (May-June) (d.f.= 1; 63, F=1400.95, P<0.001, R^2=0.957) (Fig. 3). Similarly, the spring catches are correlated with the total annual damage (d.f.= 1; 5, F=157.71, P<0.001, R^2=0.975) (Fig. 4).

Discussion

Both mean captures and damage declined considerably over time from 1996 to 2001 (Fig. 1 and 2). In northern Italy, *I. typographus* has a very long period of flight activity beginning early in May and ending at the beginning of September. Therefore, in order to follow the entire spring and summer activities of *I. typographus*, which covers more than 4 months, it was necessary to replace the pheromone dispensers at the middle of the spring monitoring period (the first week of July). Unfortunately, monitoring data are available only at the end of summer by which time the flight period of the beetle has concluded and most of the damage has already occurred. Consequently, early forecasts about the volume of timber lost during the season are very important in determining the need for applying useful and prompt control strategies. The correlation found in the present work between spring captures (May-June) and total captures (May-August) (Fig. 3) and between spring captures and damage (Fig. 4), provide us with an opportunity to assess in advance the risk of future outbreaks and the time necessary to apply pest controls. Based on our results, monitoring could be terminated after two months (at the end of June), which would reduce the overall costs; and because of the good correlation between mean captures and the damage observed, it might also be possible to determine a “catch threshold ”along with a relative “damage threshold”, which would help us to decide about the need for additional control measures. In Friuli – Venezia Giulia, by using a threshold of around 5,000 insects per trap during the spring monitoring period, we would expect that the damage in the monitored area would be lower than 100 m^3 (Fig. 4). In northern and central European spruce plantations, the kind of silvicultural and the orographical features might tolerate higher densities of *I. typographus* populations, however in the Alps, control would have to be more intensive because the expansions of severe outbreaks is more difficult to confine on the accentuated slopes where there is a less extensive network of forest roads.

Biotic Agents that Damage Black Locust in Hungary

József Tóth

Forest Research Institute, Department of Forest Protection, Budapest, Hungary

Black locust (*Robinia pseudoacacia*) plays an important role in Hungarian forestry and represents 21.6% of the total forested area (370 thousand hectares); approximately 19.2% of the area in Hungary is forested. Black locust forests have increased by more than one percent over the last 5 years demonstrating that it is a preferred tree species particularly among the owners of private forests (45% of Hungarian forests are privately owned). Consequently, there is a lot of concern about the health of locust stands throughout the country. In order to monitor the trend in locust stands, we established a network of 20 sample plots containing 2,400 individually marked trees. These trees are assessed in detail twice each year. In addition, we obtain data on tree health from the reports of the Forest Health Monitoring Network

There are relatively few pest species known to feed on black locust, however in the last few decades, new pest species have been introduced accidentally to Europe from North America where black locust also occurs. In the past 100 years, 11 new species have been introduced accidentally to the Carpathian basin and have become pests; the majority of them originated from North America. In the last 20 years, two species of leaf miners (*Parectopa robiniella and Phyllonorycter robiniella)* have been established as pests of *R. pseudoacacia* thus destroying its reputation as a relatively "pest free" species.

Based on our present knowledge, the main groups of organisms that attack black locust are as follows:

Viruses: three species

Nematodes: seven species

Insects: 42 species

Fungi: 30 species

Vertebrates: nine species

Parasitic plants: one species

Pine Shoot Beetles *Blastophagus piniperda* L. and *B.minor* Hart. Associated with Outbreaks of the Pine Beauty Moth (*Panolis flammea* Schiff.)

Skirmantas Vaivada

Lithuanian Forest Research Institute

Abstract

Numbers of pine shoot beetles *Blastophagus piniperda* and *B. minor* trapped in pheromone traps within a pine beauty moth (*Panolis flammea)* outbreak area were significantly greater in zones with total 100% defoliation (26.8±10.4 and 5.8±2.0 beetle/trap, both species respectively) as compared to undefoliated stands (1.8±1.3 and 1.4±1.0) and zones with moderate 50% (3.7±1.5 and 3.3±1.2) and heavy 75% defoliation (6.1±2.4 and 1.8±0.9, respectively). Peak flight of *Blastophagus piniperda* was observed in the last part of April, whereas *Blastophagus minor* was trapped at constant but small numbers for approximately a month up until the middle of May.

Keywords: *Blastophagus piniperda, Blastophagus minor*, pheromone traps, defoliation, *Panolis flammea*

Introduction

An outbreak of the pine beauty moth (*Panolis flammea* Schiff.) occurred recently in southern Lithuania pine stands and covered 44800 ha in 2000; an area of 4000 ha was totally defoliated. Pine trees can usually withstand a single total defoliation, however such stressed forests provide an opportunity for attacks by bark beetles and population expansion, which can result in a high risk for tree mortality. The key management option in Lithuania is to eliminate trees that are stressed by defoliation or freshly attacked by bark beetles and by using selective or clear cutting. However residual stands can provide an additional food source for pine bark beetles thus reducing the success of forest sanitation measures

The objective of this study was to assess the population levels and to determine the flight periodicity of the common (*Blastophagus piniperda L.*) and lesser (*B. minor* Hart.) pine shoot beetles in forests that suffered different degrees of defoliation. This will provide us with a rationale for determining the best management options for reducing the risk of attacks by bark beetles on residual living trees.

Material and Methods

Pine shoot beetles were trapped in barrier traps made of transparent polyethylene film and baited with Tomodor® commercial lure (Z.D. Chemipan, Poland). Pheromone traps were placed in the clear cuts within pine beauty moth outbreak areas in southern Lithuania. Thirty-five traps were placed at least 50 m apart from each other and 50 m from the edge of the stand defoliated by the pine beauty moth. The study was conducted in zones with four damage categories: undamaged control, moderate (50% defoliation), significant (75% defoliation) and heavy (100% defoliation). Traps were set out on 4 April and checked every 10-14 days for a period of four months. Differences among damage zones were tested using Student's T-test (Campbell 1989).

Results

The study was conducted in the year following pine beauty moth damage. Population levels of pine shoot beetles appeared to be low (Table 1) on all experimental sites. Captures of *B. piniperda* ranged from 1.8±1.3 beetles per trap in control sites to 26.8±10.4 in totally defoliated stands. Captures of *B. minor* were much lower – from 1.4±1.0 to 5.8±2.0 beetles/trap during the whole season.

Table 1.—Mean number of captured beetles/trap*

Defoliation	*Blastophagus minor*		*Blastophagus piniperda*	
100%	5.8±2.0	a	26.8±10.4	a
75%	1.8±0.9	b	6.1± 2.4	b
50%	3.3±1.2	b	3.7± 1.5	b
0%	1.4±1.0	b	1.8± 1.3	b

*numbers in the column, followed by same letter, did not significantly differ when tested with Student-t

Even at these low population levels, bark beetle number were related to the degree of defoliation on the study sites. Numbers of both species were significantly higher in traps located in totally (100%) defoliated stands as compared to captures in control and partially defoliated (50-75%) stands. There was no significant difference in the numbers of pine shoot beetles captured in control stands vs. stands that were partially defoliated although captures of *B. piniperda* clearly showed a trend to increase with increasing damage.

In 2000, pine shoot beetles initiated flight in the middle of April. Seasonal periodicity of bark beetle captures averaged over all levels of defoliation indicate that peak flight of *B. piniperda* occurred during the last 10 days of April and declined rapidly in May, while *B. minor* was captured at a constant but smaller number for approximately a month, and ended around the 20th of May. This flight pattern in 2000 differed significantly from the long-term average; in Lithuania, *B. piniperda* is reported to initiate flight in March and *B. minor* begins flight activity a few weeks later (Valenta 2000).

Conclusions

- Numbers of pine shoot beetles *B. piniperda* L. and *B. minor* Hart. captured in pheromone traps within pine beauty moth outbreak areas were significantly greater in zones with 100% defoliation (26.8±10.4 and 5.8±2.0 beetle/trap, both species respectively) as compared to undamaged stands (1.8±1.3 and 1.4±1.0) and zones with moderate 50% (3.7±1.5 and 3.3±1.2) and heavy 75% defoliation (6.1±2.4 and 1.8±0.9, respectively).

- Peak flight of *B. piniperda* was observed around the last week of April, whereas *B. minor* Hart was captured at a constant but smaller number for approximately a month up until the middle of May.

References Cited

Campbell, R.C. 1989. Statistics for biologists. Third edition. Cambridge University Press.

Anonymous. 2000. Annual report on sanitary condition of state forests. Forest Protection Station, Kaunas. p.16-38.

Valenta, V. 2000. Bark beetles. In: Manual of forest protection (ed. A. Ziogas). Kaunas, Lututė. p. 135-163.

Survey of *Hylobius abietis* (L.) and Associated Species in Reforestation Areas Using Baited Pitfall Traps

Kaljo Voolma

Forest Research Institute, Estonian Agricultural University, F.R. Kreutzwaldi 5,
51014 Tartu, Estonia; e-mail: kvoolma@eau.ee

Abstract

Intensive logging of pine and spruce forests in Estonia has led to a rapid increase in the populations of some insect species. A survey using ground traps baited with a blend of turpentine and ethanol resulted in the recovery of large numbers of the large pine weevil, *Hylobius abietis*, as well as bark beetles of the genus *Hylastes*. During an 11-year study (1990-2000) carried out in reforestation areas of Estonia, a total of 61,721 insect specimens were captured. The percentages of trapped insects were as follows: *Hylobius abietis* 65.6%, *Hylobius pinastri* 0.5%, *Hylastes brunneus* 17.8%, *Hylastes opacus* 5.3%, *Hylastes cunicularius* 0.5%, and all other insect species 10.3%. In newly created clear cuttings, an average of 1124 individuals of *Hylobius abietis* were caught per trap in 1999. The associated bark beetle species *Hylastes brunneus* and *Hylastes opacus* were more abundant in the second year after felling; the mean numbers of individuals caught per trap were 309 and 94, respectively.

Key Words: *Hylobius abietis*, *Hylastes*, logging, pitfall traps, clear-cutting, Estonia

The large pine weevil, *Hylobius abietis* (L.) (Coleoptera: Curculionidae), is the major insect pest affecting reforestation (Leather et al. 1999). Its abundance is strongly dependent on the intensity of forest cutting because this species utilizes stumps and roots of recently felled conifer trees as suitable breeding sites.

In Estonia, the extent of forest exploitation increased considerably during recent years. In 2000, the gross felling volume was 12.7 million solid cubic metres, i.e. about four times as much as in the early 1990s. The total area of felling activity was 28,800 hectares, of which 26,900 ha was attributed to clear cuttings (Adermann 2002). Of the volume felled, the prevailing tree species was Norway spruce, which accounted for 46%, followed by Scots pine (21%) and birch (17%). Intensive logging of pine and spruce forests has led to a rapid increase in populations of the pine weevil.

Several methods for using baited pitfall traps have been developed for monitoring *H. abietis* populations. A standardized method for trapping pine weevils, using pitfall traps baited with alpha-pinene and ethanol, was developed in Sweden (Nordlander 1987). Different modifications of this trap have been applied in Europe (Zumr and Stary 1993, Örlander et al. 1997) and have been used in North America to investigate related native species (Raffa and Hunt 1988, Rieske and Raffa 1999). Some investigations using baited ground traps have been conducted in Estonia (Voolma 2000, 2001, Voolma et al. 2001). In this study, trapping was used for estimating the relative size of the populations of *H. abietis* and associated bark beetle species of the genus *Hylastes*. Since some species of bark beetles, particularly *Hylastes brunneus* and *Hylastes opacus* respond to the same host volatiles as *H. abietis*, the same trap can be also used for monitoring these species.

Materials and Methods

Study sites

The study was conducted in 1990–2000 in an intensively managed forest area in the forest district of Räpina, Estonia (58°09' N, 27°08' E). Clear-cuttings of former pine-dominated stands (90% of *Pinus sylvestris* and 10% of *Picea abies*) on dry sandy soil were selected as the study sites. The clear-cuttings were reforested by sowing Scots pine in the first season following felling.

The traps

The traps used in this study have been described in detail in our previous publications (Voolma 2001, Voolma et al. 2001). The ground trap consisted of a plastic jar inserted in the ground and filled with water to 1/3-1/2 of its volume.

The above-ground part of the trap holds a glass vial containing the bait fluid, a blend of commercial turpentine (AS Flora, Estonia) and ethanol (1:5). To enter the trap, insects climb along the inclined plane to the top of the trap and fall into the jar. The traps were checked usually once each week. At each inspection, insects were collected and the baits were renewed. Most captures occurred from late April (early May) to September. As a comparison, Swedish pitfall traps described in Nordlander (1997) were also used in 1993-1995.

Results and Discussion

During the survey of 1990-2000, a total of 61,721 specimens were caught at the study sites. The percentages of trapped insects were as follows: *H. abietis* 65.6%, *Hylobius pinastri* 0.5%, *Hylastes brunneus* 17.8%, *Hylastes opacus* 5.3%, *Hylastes cunicularius* 0.5%, and all other insect species 10.3%. There was no difference in captures of *H. abietis* in 1993-1995 between the Swedish pitfall traps and the trap used in this study (Voolma 2000).

This trapping method enabled us to estimate the relative size of populations of *H. abietis* and associated species, particularly *H. brunneus* and *H. opacus*, in felled areas and at reforestation sites. In the study area, several clear-cut plots had been established in recent years within a range of 2-3 km; this resulted in a rapid increase in populations of *H. abietis,* a species which is abundant in fresh clear-cuts. Consequently, populations increased considerably in these clear-cuts and the average captures per trap reached 1,124 in 1999.

Bark beetle species such as *H. brunneus* and *H. opacus* were more abundant in the second year after felling; the mean numbers of individuals caught per trap were 309 and 94, respectively. The abundance of *H. abietis* at any particular site depends largely on the temporal and spatial arrangement of clear-cuts. Newly established clear-cuts attract dispersing pine weevils which influences trapping results at neighbouring sites. Therefore, the abundance of *H. abietis* was high not only in the first year after felling but also in subsequent years after new clearings were established in adjacent areas. In some clear-cuts *H. abietis* was abundant even 6–7 years after felling (Voolma 2001).

Hylobius pinastri and *Hylastes cunicularius* occurred in low numbers in the study sites. In general, these species are common in Estonia but they occur more numerously in felled areas of former spruce forests.

Acknowledgments

The study was supported by Grant No. 4728 from the Estonian Science Foundation.

References Cited

Adermann, V. (ed.) 2002. Forests of Estonia 2001. Tallinn. (In Estonian).

Leather, S.R., K.R. Day, and A.N. Salisbury. 1999. The biology and ecology of the large pine weevil, *Hylobius abietis* (Coleoptera: Curculionidae): a problem of dispersal? Bull. Entom. Research 89(1): 3–16.

Nordlander, G. 1987. A method for trapping *Hylobius abietis* (L.) with a standardized bait and its potential for forecasting seedling damage. Scand. J. For. Res. 2: 119–213.

Örlander, G., U. Nilsson, and G. Nordlander. 1997. Pine weevil abundance on clear-cutting of different ages: a 6-year study using pitfall traps. Scand. J. For. Res. 12(3): 225–240.

Raffa, K., and D.W.A. Hunt. 1988. Use of baited pitfall traps for monitoring pales weevil, *Hylobius pales* (Coleoptera: Curculionidae). Great Lakes Entomol. 21 (3): 123–125.

Rieske, L.K., and K.F. Raffa. 1999. Baited pitfall traps and evaluation of dispensing methods for root weevils (Coleoptera, Curculionidae) in newly established pine plantations in Wisconsin. J. Econ. Entomol. 92(2): 439–444.

Voolma, K. 2000. Comparison of two traps used for monitoring large pine weevil populations, *Hylobius abietis* L. (Coleoptera: Curculionidae). Transactions of the Estonian Agricultural University 209: 233–235.

Voolma, K. 2001. The large pine weevil, *Hylobius abietis* L., in the felling areas of the Räpina forest district: a case study with baited ground traps. Metsanduslikud Uurimused 35: 172–178. (In Estonian with English summary).

Voolma, K., I. Süda, and I. Sibul. 2001. Forest insects attracted to ground traps baited with turpentine and ethanol on clear-cuttings. Norwegian Journal of Entomology, 48(1): 103–110.

Zumr, V. and P. Stary. 1993. Baited pitfall and flight traps in monitoring *Hylobius abietis* (L.) (Col., Curculionidae). J. Appl. Entomol. 115: 454–461.

Pheromone Traps and Other Methods in Assessing Pine Beauty Moth (*Panolis flammea* Schiff.)

Dr. Algimantas Žiogas

Lithuanian University of Agriculture

Abstract

The objective of this research was to evaluate different methodologies for quantifying pine beauty moth (*Panolis flammea* Schiff.) populations in pine stands of Southern part of Lithuania. Evaluations were conducted in selected pine stands by assessing the following: pupae (in the litter); larvae (falling from trees after chemical knock down); and adult insects (using pheromone traps). Analysis of evaluation methods indicated that the populations can be assessed most accurately by using the counts of larvae. This method is used when outbreaks occur or aerial spraying of insecticides is needed. Assessment of pupae in the litter is the most suitable method for silvicultural purposes; the use of pheromone traps is less precise than the other two methods.

Key words: Pine beauty moth, population, assessment

Introduction

The pine beauty moth (*Panolis flammea* Schiff.) is one of the most serious defoliators of pine. The entomological and forest protection literature provides reviews of previous studies which describe observations on this pest and methods for forecasting its abundance however they are rather imperfect. Very often mass outbreaks are observed too late, forecasts are inaccurate, there is not enough time to conduct control activities. Thus control measures are often ineffective and mass outbreaks spread over thousands of hectares. The elimination of these outbreaks requires additional expenditures, and control activities may have an adverse influence on forests and non-target organisms.

Pine beauty moth (*P. flammea* Schiff.) infestations in Lithuania were increasing almost geometrically in the 20th Century (1100 ha in 1922, 4200ha in 1953, 27000 ha in 1979, 44800 ha in 2000). The purpose of this study was to compare methods used to evaluate populations of the pine beauty moth.

Methods

Observations were conducted in pine stands of the Druskininkai forest enterprise where the pine beauty moth damaged up to 70-100% of needles. A 100 ha area was divided into 100 equal squares in April, 2001. The number of pupae in the litter was determined at each point of two 0.25x1.0 m plots placed under each of 6 trees. The pupae were grouped according to their sex, and the presence of disease and the level of parasitism was measured. During the adult flight period, pheromone traps ("Panador") were placed in each plot. They were checked on 27 April, 3 May and 21 May.

A count of larvae was conducted using a "Chemical knock-down" method. At each point on 2001 05 30, a tree was selected and two 0.5 X 1.0 m blankets were placed under it on opposite sides of the trunk. The trees were sprayed with a ten times greater dose of Arrivo pyrethroid insecticide. A count of dead larvae was made 10 days after spraying. The trees were cut down so that their crowns fell on polyethylene sheets so that larvae remaining in the crowns could be counted.

Results

Counts of pine beauty moth pupae made early in the spring before emergence of adults has shown that pupae in the study area were distributed rather unevenly. The general ratio of females and males in the area was 1.9:2.3. This indicated that the mass outbreak is already in the third stage. The studies showed no essential differences in the dependence of male and female pupae ratio on the total number of pupae. However, there is a tendency that when the number of pupae in the litter is greater than $10/m^2$, their ratio is in favor of males.

Studies on flight dynamics of pine beauty moth were determined also in the same places by using pheromone traps. Males were found mostly in the places where females accumulated after emergence, or if they were not present there, males responded to a synthetic attractant. For the sake of convenience, traps can be placed at a height of 3-4 m. For calculating the abundance of males in the crowns, the coefficient is 7.8.

Determination of the location where the most intensive flying of females occurred could be ascertained only by secondary methods – according to the place of egg laying, i.e. where larvae were the most abundant in tree crowns. It appeared that areas of larval abundance did not coincide with where pupae occurred or where males were caught by pheromone traps.

We observed that the high density of the population seems to have moved to the northwest from the initial location of pupae; this may be related to the prevailing winds during the flight period of the moths. The counts of larvae accurately reveal the current state of the population at the place of infestation but they are hardly suitable for forecasting damage intensity in the following year, or for planning future protection measures.

Conclusions

1. Methods that are currently applied to evaluate pine beauty moth population densities reveal accurately the present state of the population, but they are hardly suitable for long-term forecasting.

2. Counts of pupae in the spring is the most accurate method for forecasting current densities of pine beauty moth.

3. Pheromone traps, at best, are suitable only to determine the periodicity and intensity of flying adult males and for convenience, they can be placed at the height of 3-4 m.

Pine Beauty Moth (*Panolis flammea* Schiff.) Outbreak Management: Suppression Versus Natural Enemies

Paulius Zolubas
Lithuanian Forest Research Institute, Girionys, 4312 Kaunas, Lithuania

Pine beauty moth (*Panolis flammea* Schiff.) is one of the most serious defoliators that periodically threatens Scotch pine forests on poor sandy soils in Lithuania. Population increase of this pest began in 1999. Because a maximum of only 15% defoliation was predicted in particular areas, no additional funding was required for suppressing the population and no apparent damage was realized.

Significant damage was predicted for 2000 and it was estimated that suppression measures would be needed on an area of only 13,000 ha, however funding was available to treat only 6,450 ha. Therefore, by the end of that summer, the outbreak expanded to an area of 44,800 ha, 4,000 ha of which was completely defoliated.

Extensive surveys revealed that in 2001, slight defoliation (30-50%) should be expected on an area of 8,500 ha, medium defoliation (50-75%) on 103,000 ha and heavy defoliation (>75%) on 19,100 ha. It was estimated that it would cost 3.1 million Lt (Lita; $0.32 U.S. = 1 Lita) to treat 37,900 ha (forest with >30% defoliation), 2.3 million Lt to treat 29,400 ha (>50% defoliation), and 1.2 million Lt to treat 19100 ha (forests with >75% defoliation). This resulted in a heated discussion about the justification for area-wide suppression measures:

- <u>Arguments against suppression</u>: (1) natural enemies will bring to an end the outbreak (59±8% of overwintering pupae were parasitised, mainly by the tachinid fly *Ernestia rudis* Fall. and ichneumonid *Rictichneumon pachymerus* Ratz.); (2) there is no money available in the current budget for these expenses.

- <u>Arguments for treatment</u>: (1) forests are at risk because repeated 80-100% defoliation can be fatal for pines; (2) parasites will not prevent tree damage because they kill *P. flammea* only during their final stages of development.

As a result of these deliberations, it was determined that suppression was justified to treat 18,620 ha of forests (~ 60%); conventional pyrethroids were used. Damage to varying degrees was recorded on an area of 1,243 ha (8,530 ha new), however the forests most at risk were protected against further defoliation and dieback.

Based on the forecast for 2002, slight defoliation on 4,485 ha, medium on 4,670 ha, heavy on 5,320 ha, and projected pupal parasitism of 54-61%, suggests that the current outbreak will persist and will spread to new territories. Aerial sprays, using mainly biological insecticides, were scheduled on an area of 12,880 ha and 1.2 million Lt funding was allocated. Pine beauty moth pupae overwintered and emerged successfully but, surprisingly, females laid very few eggs (67% of the eggs have not maturated). The suggested reason for that could be the lack of adequate food because of the high pest densities that occurred in the previous year. Consequently, only the most damaged forests were treated in 2002 (1,900 ha) to prevent any further defoliation, and 0.3 million Lt (25%) was expended. As a result the outbreak terminated.

Conclusions

- Parasites were not important in terminating pine beauty moth outbreaks.
- Pest management activities (suppression) effectively preserved forests at risk.
- Delaying funding for pest management is more expensive – 1.47 million Lt was spent over three years instead of about 0.5 million Lt that was needed in the first year of the outbreak. Furthermore the initial expenditure would have prevented 50,000 ha of damaged forests.

McManus, Michael L.; Liebhold, Andrew M., eds. 2003. **Proceedings: Ecology, Survey and Management of Forest Insects;** 2002 September 1-5; Kraków, Poland. Gen. Tech . Rep. NE-311. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 178 p.

Contains 46 papers and abstracts presented at a meeting sponsored by the International Union of Forestry Research Organizations (IUFRO) Working Party S7.03-06, “Integrated Management of Forest Defoliating Insects,” and Working Party S7.03.07, “Population Dynamics of Forest Insects.”

Keywords: Forest insect, defoliator, integrated management, population dynamics, ecology, gypsy moth, bark beetle, budworm, moth

Visit our homepage at: **http://www.fs.fed.us/ne**

Headquarters of the Northeastern Research Station is in Newtown Square, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

"Caring for the Land and Serving People Through Research"