Integrated Oak Timber Protection from Ambrosia Bark Beetles: Economic and Ecological Importance in Harvesting Operations

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Abstract

Ambrosia bark beetles belong to a group of xylomycetophagous insects from the order Coleoptera, family Curculionidae and are characterized as important pests of oak timber. Galleries they form during their life cycle and infect with »ambrosia fungi« significantly decrease the economic value of oak roundwood. A state owned Croatian company »Hrvatske šume« Ltd. manages FSC certificated forests, where pedunculate and sessile oaks account for 22.6% in the annual allowable cut. Methods of oak roundwood protection, that used to be implemented in the past, are now banned in accordance with EU legislation as well as FSC criteria of forest protection. In these forest management conditions, it becomes necessary to introduce new biotechnical methods for oak roundwood protection. Available commercial products, flight barrier traps and synthetic semiochemicals, as well as pretreated insecticide treated polymer nets, were tested as means of integrated oak roundwood protection. Implementation of these products was tested in field conditions. Good knowledge of phenology of ambrosia bark beetles, thorough understanding of timber harvesting operations and field conditions that dominate in even aged oak forests, is crucial if applied methods are to be effective and taken on time. Field experiments conducted in this research showed that early seasonal deployment of semiochemically baited flight barrier traps can reduce the number of bark beetles that infest oak timber. It was also concluded that without additional protection with polymer nets, it is not possible to protect oak timber in compliance with strict FprEN 1316-1: 2012 E standards for oak roundwood classes, which do not allow any timber infestation in the highest quality grades (A and B quality class). Semiochemicals used as repellents during the research were ineffective. In the early months of spring, oak roundwood is at high risk of infestation at the roadside landings, where it is waiting to be transported.

Keywords: oak roundwood, ambrosia bark beetles, integrated timber protection, FprEN 1316-1: 2012 E, pest control

1. Introduction

In Croatian even-aged oak stands, ambrosia bark beetles are important economic pests that degrade the value of oak roundwood exposed to these beetles during main felling. Ambrosia bark beetles belong to a group of xylomycetophagous insects from the order Coleoptera, family Curculionidae. Dispersal flight of these beetles starts in early winter months and continues in the spring, interrupted only by a few weeks of cold weather throughout the harvesting season. It is a serious threat to oak roundwood in landing areas. Phenology of ambrosia bark beetles, namely their infestation period, generally matches with the period of intensive harvesting operations in Croatian oak stands. According to Official Gazette (NN 17/2015) even-aged forests, managed by regeneration cuttings (preparatory, seeding, additional and final felling), cutting, bucking and timber extraction (from the forest stand) is prohibited during vegetation period i.e. from April 1 to September 30, unless forest stands were excessively flooded, and harvesting operations can only be performed in two months after the vegetation period starts. In both even-aged and un-even aged forests, thinning cutting is prohibited in the first two months of the vegetation period. Galleries produced by ambrosia bark beetles during the completion of their life cycle decrease the economic value of oak roundwood, both directly and indirectly by the discoloration as a consequence of their fungal symbionts (hence ambrosia beetles).

In the growing number of FSC certified stands, the application of insecticides for the protection of oak roundwood from ambrosia beetles is restricted because of FSC policy (in relation to the use of pesticides in FSC-certified forests and plantations) with the aim of minimizing the negative environmental and social impacts of pesticides whilst promoting economically viable management. This policy is implemented through compliance with the requirements of FSC-STD-01-001 FSC Principles and Criteria of Forest Stewardship and the associated national or subnational indicators and means of verification (FSC-POL-30-001 (2005) EN). According to Beuk et al. (2007), the company »Hrvatske šume« Ltd. manages 76% or 302.4 million m^3 of timber in Croatian state owned forests, where pedunculate oak (*Quercus robur* L.) accounts for 14.9% (45.0 mil m^3) and sessile oak (*Quercus petraea* (Matt.) Liebl.) for 9.5% (29 mil. m^3) of the total growing stock. Pedunculate oak accounts for 13.6% (0.79 mil m^3) and sessile oak accounts for 9.0% (0.52 mil m^3) in the annual allowable cut. The same authors state that the most valuable tree specie in the Croatian forests is pedunculate oak and that it is of high quality and very demanding management conditions. In 2002, the company »Hrvatske šume« Ltd. was awarded with the FSC certificate for forest management. According to the definition, »FSC certification means that forests are managed in accordance with strict ecological, social and economic standards« (Anon. 2015).

According to standard FprEN 1316-1:2012:2012: E Hardwood round timber – Qualitative classification Part 1: Oak and beech insect attack is not permitted in classes A (first class timber: generally corresponding to a butt log with clear timber or with only minor features not restricting the use) and B (average to first class timber, with no specific requirements for clear wood), while in class C (timber of average to low quality, allowing all quality features, which do not seriously reduce the natural features of wood) is only permitted in sapwood. Standard classification applies to the following species: Oak (*Quercus sessiliflora* SALISB. or *Quercus petraea* LIEBL., *Quercus robur* L. or *Quercus pedunculata* EHRH.) and Beech (*Fagus sylvatica* L).

The methods of oak protection, implemented in the past, are now banned following the FSC criteria. In the last decades, growing concern about environment protection and efficient forest protection has focused on a new approach to forest protection and formerly deployed IPM strategies – integrated pest management (IPM). Holistic in approach, it takes into account all the aspects of forest ecosystem and forest management operations chaining them together into an environmentally friendly and economically efficient protection of forests. Introduction of new biotechnical methods of oak timber protection seem as an obvious tool in the new ecological, economic and legal circumstances. The purpose of this research was to explore the possibilities of targeted ethological manipulation of adult ambrosia beetles during their swarming flight in search for oak timber suitable for infestation. Some of the commercially available products, as well as a few of those in the preproduction phase, were applied in trial testing their potential in the integrated oak timber protection. Intercept flight barrier traps with various semiochemicals and FSC approved polymer nets with incorporated insecticides were tested in field conditions during the years 2003, 2009–2011. Oak logs were used for the evaluation of efficiency in each of the tested chemicals/trial designs.

With the repeated population monitoring and consecutive catches of ambrosia beetles in oak stands, where trials were set up, it turned out that *Trypodendron domesticum* (Linnaeus 1758) has two generations per year in Croatian environment (Franjević 2013, Petercord 2006). It was also observed that the population of Asian species *Xylosandrus germanus* (Blandford 1894) has been established in Croatian oak stands within the last decade. Valuable biological knowledge was collected on several species of ambrosia bark beetles that inhabit our forests and causes damage to oak roundwood including *Xyleborus dispar* (Fabricius 1792), *Xyleborus monographus* (Fabricius 1792), *Xyleborus saxesenii* (Ratzeburg 1837). It was observed that *T. domesticum* is actively flying from the beginning of January, when weather conditions are favorable (characterized by warmer weather so typical for the last decade, which is consistent with the report of Intergovernmental Panel on Climate Change (IPCC 2007) that states that in 21st century ground air temperature rises from 1.8°C to 4°C depending on greenhouse gases emissions as stated by Meehl et al. 2007 and Ramanathan and Feng 2009. *Trypodendron signatum* (Fabricius 1792) activity follows in February. *Platypus cylindrus* (Fabricius 1792) has a period of activity from early June to early October. Asian bark beetle species *X. germanus* appeared for the first time in trials in 2009, and since then it became the second most frequent species in pheromone trap catches in 2011 (Franjević 2012). It has been concluded that attention should be paid to the spreading of this invasive species and population building. The same applies to its role in the, now expanded, Croatian ambrosia beetle group.

2. Materials and Methods

In lowland even-aged oak stands, methods of integrated oak roundwood protection were tested in the period from 2003 to 2011. Pheromone baited intercept panel traps were used as an olfactory manipulation, trapping and monitoring of ambrosia beetle flight periods. Two field locations were Jastrebarsko in Zagreb county and Otok near Vinkovci. They were selected as good representatives of pedunculate oak stands with Jastrebarsko as the most western part of its distribution in Croatia and ecologically inferior to oak stands in the eastern part of Croatia – Vinkovci. Ambrosia bark beetles that infest oak timber are equally represented through pedunculate oak area of distribution. IPM® Tech Intercept™ panel traps were used because of their advantages over Lindgren® and Theysohn® panel traps in Cerambycid and Scolytid trapping. IPM® Tech Intercept™ panel traps catch beetles from all four quadrants and are less susceptible to weather conditions and predatory entomofauna, which can influence the results of trapping (Czokajlo et al. 2002). Also, because of different strategies that were used in oak timber protection from ambrosia beetles, traps were not always active at the same time of the year. However, they were always active in the period when ambrosia bark beetle swarming can be expected. IPM®

Fig. 1 Pin holes visible on bark (top left) and holes on debarked one-meter logs (top right) and oak roundwood before protection (below left) and protected (below right) with Woodnet® system

Tech Intercept™ panel traps were completed with different attractive components in the years of experiment. Simultaneously with panel trap exposure, (pedunculate) oak timber was placed in various designs and separated in control and protected group. After the experiment was concluded, all timber was debarked and bark beetle pin holes counted on site (Fig. 1).

Data from the control and treated/protected group of oak timber were statistically analyzed. Also, trap catches and weather station data were used for the correlation analysis between phenology and species occurrence. Throughout the duration of these experiments, panel trap catches were collected weekly and analyzed in laboratory.

In 2003, panel traps were baited with lineatin, an attractive component of ambrosia beetles (Macconell et al. 1977). Six traps, in five repetitions, were set 10 meters from the logs in circular position and spaced 60° angularly from each other. The control group in Jastrebarsko consisted of 80 oak logs, and the protected group of 85 logs. Otok control group consisted of 61 oak logs and the protected group of 55 logs (with α-pinene as repelent). Otok trials were conducted just with the repellent component imitating the smell of conifers without panel traps. The experiment was carried out from March 4, 2003 to April 2, 2003.

In Jastrebarsko control group in the year 2009, GLV (Green Leaf Volatile) and Domowit-Trypowit D® were used for trapping in panel traps ETOH. Twelve traps, in five repetitions, were set 20 meters from the logs in circular position and spaced 30° from each other. ETOH and Domowit-Trypowit D® were used in panel traps as attractive components. As a repellent on exposed oak roundwood, ampoules of Tompin® were used. This is a pheromone component used for baiting of species from genus *Tomicus* (*Tomicus piniperda, Tomicus minor and Tomicus destruens*) and it contains aggregation pheromones but also α-pinen, which is the primary attractive component found in bark and resin of conifers. Six Tompin® ampoules were attached on every oak log bundle. The experiment was carried out from March 17, 2009 to April 28, 2009. Control and protected/treated group consisted of 50 oak logs each.

In Jastrebarsko in the year 2010, twenty-four traps were set 20 meters from the logs in circular position and spaced 15° from each other. ETOH and Domowit-Trypowit D® were used in panel traps as attractive components. As a repellent on exposed oak roundwood, ampoules of Hostowit® and Kombiwit® were used on oak log bundles. Hostowit® has a universal attractive component for bark beetles on conifers. Kombiwit® is aggregation pheromone for *Ips typographus* and *Pityogenes chalcographus*. Control and protected group consisted of 50 oak logs each. The experiment was carried out from April 21, 2010 to May 26, 2010. All oak logs used in trials were 1 m long.

On June 8, 2011, oak tree was cut down and logs were protected with Woodnet® system product of BASF® Chemical Company (Fig. 1).

According to »old« Croatian Standards of Forest Exploitation Products (Anon. 1995) that are still in use and derived from ex-Yugoslav standards JUS (Anon. 1989), oak roundwood is classified into two types of veneer (class I and II of veneer logs) and three sawlog classes (class I, II and III of sawlogs). Roundwood was protected within half an hour after cutting. Removal and evaluation of Woodnet® system protection was done on September 1, 2011. During the period of Woodnet® system evaluation, IPM Tech® panel traps were collecting data in the same forest management unit.

In the year 2011, monitoring of swarming period for ambrosia bark beetles was conducted in lowland oak stands with five randomly positioned traps that were set with ETOH and Domowit-Trypowit D® and used in panel traps as attractive components. The experiment was carried out from January 11, 2011 to June 6, 2011. ETOH is a known attractant for ambrosia beetles (Moeck 1970) and Domowit-Trypowit D® is a commercially available product for trapping of beetles from *Trypodendron* genus. In the year 2011, monitoring of ambrosia beetle phenology was conducted from

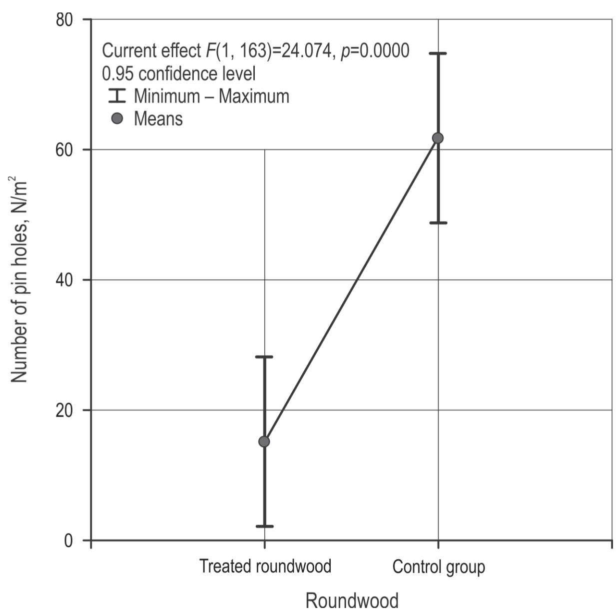

Fig. 2 Statistical analysis of pin holes in oak roundwood per square meter for treated (T) and control group of logs in Jastrebarsko 2003 protection with lineatin baited traps

Table 1 Descriptive statistics for Jastrebarsko 2003 field measurement

Effect	Factor level	*N*	Mean	Standard deviation	Standard error	–95.00%	+95.00%
Total		165	37.46703	65.26752	5.081069	27.43428	47.49978
Logs	Treated	85	14.82165	17.26183	1.872309	11.09836	18.54494
Logs	Control	80	61.52775	85.95576	9.610147	42.39923	80.65627

Table 2 Descriptive statistics for Otok 2003 field measurements

Effect	Factor level	*N*	Mean	Standard deviation	Standard error	–95.00%	+95.00%
Total		116	23.62087	50.06520	4.648437	14.41321	32.82853
Logs	Treated	55	22.27058	57.55435	7.760627	6.71146	37.82970
Logs	Control	61	24.83834	42.65842	5.461851	13.91301	35.76367

early January to early June and in that time Spectrum Technologies Inc. Watchdog® Weather Station 2000 Series were used for temperature measurements.

3. Results

During the period of trapping with lineatin in the year 2003, 30 panel traps were set. In that year, trials were conducted on two locations – Jastrebarsko and Otok. After debarking, the results showed insufficient level of protection regarding both experiment sites. However, on the location Jastrebarsko, a distinct difference between the protected (15 pin holes per square meter) and control (62 pin holes per square meter) group of oak timber (Fig. 2 and Table 1) was observed. The location Otok showed no distinct difference (Fig. 3 and Table 2) between the two groups of oak timber – protected (15 pin holes per square meter) and control (24 pin holes per square meter), meaning that α-pinene as repelent was ineffective.

The period of trapping in Jastrebarsko 2009 with panel traps baited with ETOH, GLV and Domowit-

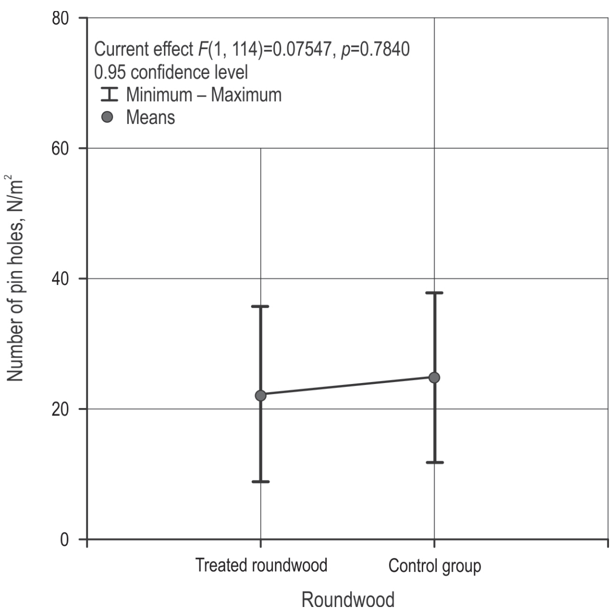

Fig. 3 Statistical analysis of pin holes in oak roundwood per square meter for treated and control group of logs in Otok 2003 protection with α-pinene as repellent

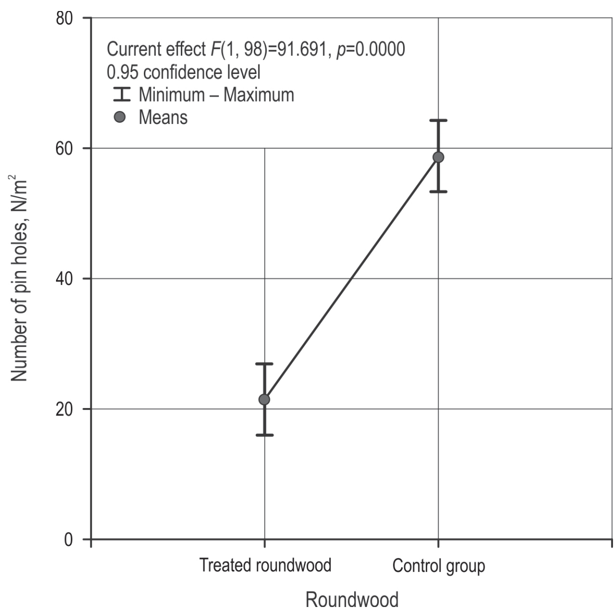

Fig. 4 Statistical analysis of pin holes in oak timber per square meter for treated and control group of logs in Jastrebarsko 2009 protection with ETOH, GLV and Domowit-Trypowit D® baited traps

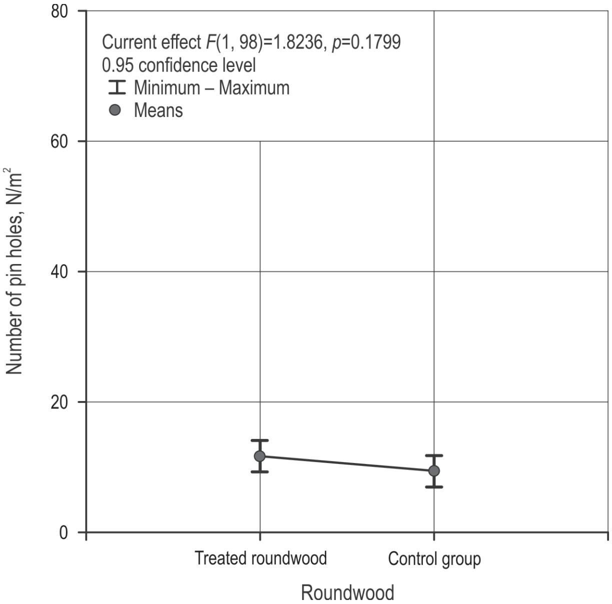

Fig. 5 Statistical analysis of pin holes in oak roundwood per square meter for treated and control group of logs in Jastrebarsko 2010 protection with ETOH, GLV and Domowit-Trypowit D® baited traps

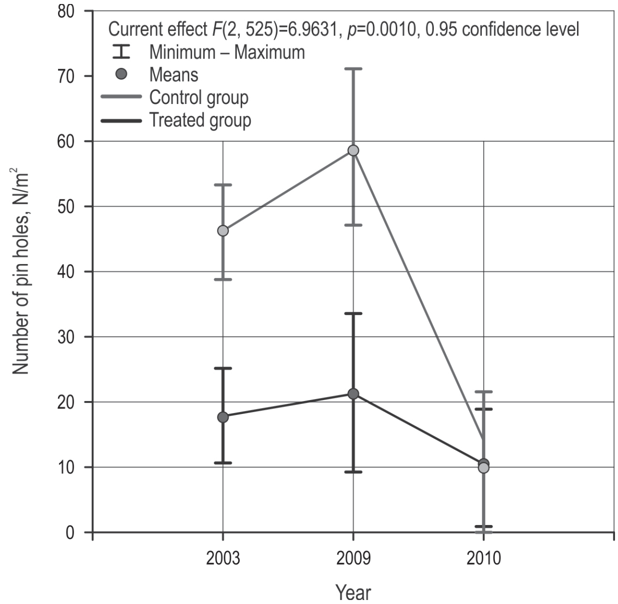

Fig. 6 Statistical analysis of pin holes in oak roundwood per square meter for treated and control group of logs in Jastrebarsko 2003, 2009 and 2010

Trypowit D® is shown in Fig. 4 and Table 3. There were 60 pheromone baited panel traps positioned in 12 traps around oak roundwood bunch in five repetitions, but the level of oak roundwood protection was also insufficient. There was a distinct difference between the control and protected group of oak roundwood but protection was low with the protected group of oak roundwood (22 pin holes per square meter) and control group (59 pin holes per square meter).

The period of trapping in Jastrebarsko 2010 with panel traps baited with ETOH, GLV and Domowit-Trypowit D® is shown in Fig. 5 and Table 4. There were 24 pheromone baited panel traps positioned around a single oak roundwood bunch with control group. The level of oak roundwood protection was also low, with control group less infested with ambrosia bark beetles. Protected logs had 11 pin holes per square meter and control group 9 pin holes per square meter.

Table 3 Descriptive statistics for Jastrebarsko 2009 field measurements

Effect	Factor level	*N*	Mean	Standard deviation	Standard error	–95.00%	+95.00%
Total		100	39.95691	27.10859	2.710859	34.57797	45.33584
Logs	Treated	50	21.20417	13.53189	1.913698	17.35845	25.04989
Logs	Control	50	58.70965	24.16511	3.417462	51.84200	65.57729

Table 4 Descriptive statistics for Jastrebarsko 2010 field measurements

Effect	Factor level	*N*	Mean	Standard deviation	Standard error	–95.00%	+95.00%
Total		100	10.22870	8.662325	0.866233	8.509903	11.94749
Logs	Treated	50	11.39364	9.558832	1.351823	8.677052	14.11023
Logs	Control	50	9.06375	7.580386	1.072028	6.909429	11.21807

Table 5 Ambrosia bark beetle trap catches in 2011 (January 18 to April 5) with weekly maximum and minimum average temperatures

2011	Jan. 18	Jan. 25	Feb. 1	Feb. 8	Feb. 15	Feb. 22	Mar. 1	Mar. 8	Mar. 15	Mar. 22	Mar. 29	Apr. 5
X. germanus	0	0	0	0	0	0	0	0	0	0	0	32
T. domesticum	171	7	0	99	226	1	0	0	317	55	59	27
T. signatum	1	0	0	84	352	0	0	0	2317	351	1609	856
X. saxesenii	0	0	0	0	0	0	0	0	3	41	62	189
X. dispar	0	0	0	0	0	0	0	0	0	0	35	39
X. monographus	0	0	0	0	0	0	0	0	0	0	0	11
Σ	172	7	0	183	578	1	0	0	2637	447	1765	1154
Max (°C)	10.8	3.8	2.1	8.9	11.8	4.5	1.4	3.4	15.6	13.3	19	22,6
Min (°C)	–0.2	–2.9	–3.3	–5.8	–3.9	0.1	–7.3	–3.6	–4.5	2.6	–0.2	1,3

In the year 2011, phenology of ambrosia bark beetles was monitored and correlated with average weekly temperatures (Fig. 7). If daily temperatures exceed 9°C, it is sufficient for activating early ambrosia bark beetles from *Trypodendron* genus (Petercord 2006). Overall catches for species of ambrosia bark beetles in periods of monitoring are presented in Tables 5 and 6.

Analysis of oak logs protected with Woodnet® system on September 1, 2010 was done after 3 months of exposure. Debarking of oak timber and detailed observation showed only 24 pin holes. All observed pinholes were on places were bark was previously damaged. In six pinholes, females of *X. monographus* were found. No other xylophagous insects or their remains were found on the Woodnet® system or near it. The remains of beetles from genus *Geotrupes* were the only evidence of system toxicity near Woodnet® system.

4. Discussion and Conclusions

During the experiments of integrated oak roundwood protection, insufficient levels of protection were achieved with pheromone baited traps. The reason can

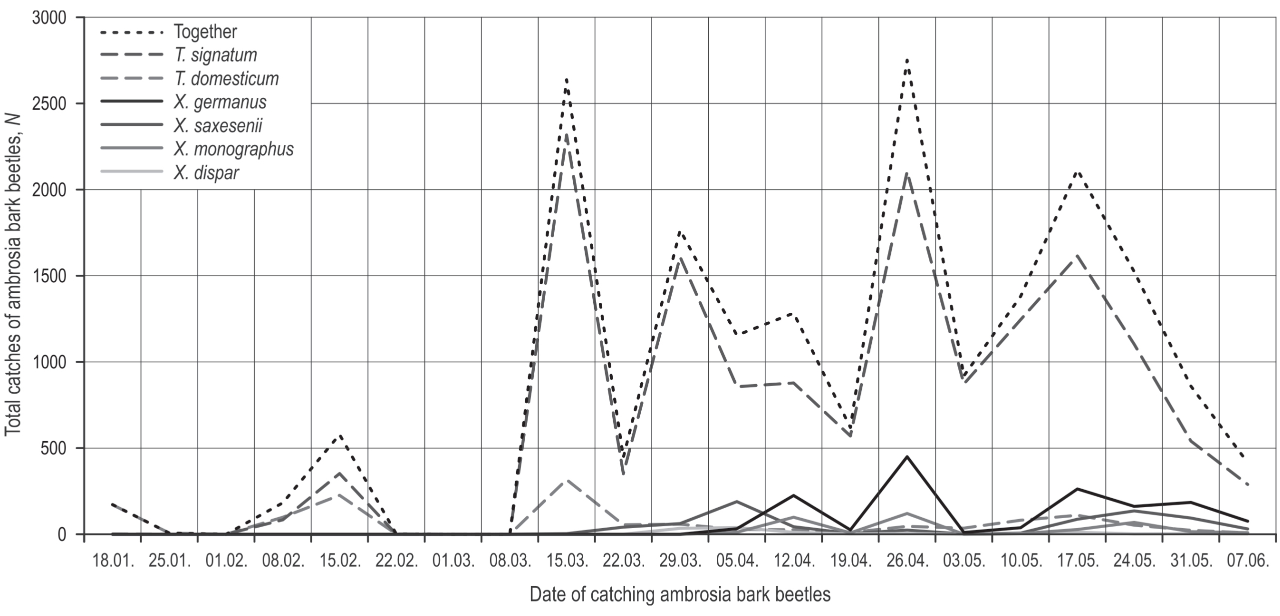

Fig. 7 Total catches of ambrosia bark beetles during monitoring

Table 6 Ambrosia bark beetle trap catches in 2011 (April 12 to June 7) with weekly maximum and minimum average temperatures

2011	Apr. 12	Apr. 19	Apr. 26	May 3	May 10	May 17	May 24	May 31	June 7	Σ
X. germanus	225	25	450	10	38	263	162	185	76	1466
T. domesticum	26	10	46	36	82	110	53	23	8	1356
T. signatum	878	570	2105	872	1245	1615	1103	540	289	14787
X. saxesenii	44	5	24	1	7	87	135	94	31	723
X. dispar	11	2	5	0	5	12	2	3	2	116
X. monographus	99	8	121	0	4	28	69	15	9	364
Σ	1283	620	2751	919	1381	2115	1524	860	415	18812
Max (°C)	23.1	18.7	24.7	18.3	21.1	24	26.6	26.4	27.5	–
Min (°C)	2.8	0.9	2	8.9	0.8	6.2	8.5	9.3	12.9	–

be explained by the fact that ambrosia bark beetles are polifagous species and each generation has to find their suitable host for development, so in managed forests there are relatively few of them. Suitable trees are randomly positioned in forests and their number varies from year to year. Position of suitable trees is unpredictable for ambrosia bark beetles and they have developed complex mechanisms for finding suitable hosts, which is generally based on semiochemicals and aggregation pheromones (Wood 1982). Ambrosia bark beetles are aggregation insects and their populations are pulse eruptive (Thalenhorst 1958, Berryman 1987). Periods of gradation usually last from 5 to 7 years and during that period bark beetles can damage a large number of trees (Bombosh 1954, Schroeder and Lindelöw 2002, Jakuš et al. 2003). Accordingly, during the experiments, protection of oak roundwood was more efficient in regard of protected/treated vs. control groups (pin holes) in the early period of ambrosia bark beetle swarming. Panel traps were more attractive during the early period of dispersion flight and sweeping forest for suitable hosts. Panel traps were more influenced by the period of exposure than by attractive component used during our experiments. Once aggregation process started in exposed oak logs, pheromone baited traps lost their efficiency in the protection of oak timber (Fig. 6).

Overall levels of protection achieved with pheromone baited traps were insufficient in accordance with strict FprEN 1316-1:2012:2012: E Hardwood round timber – Qualitative classification – Part 1: Oak and beech, which does not permit any insect attacks in A and B quality class, whilst for C class insect attacks are permitted only in sapwood. In terms of »old« Croatian Standards that are still in use, insect attacks are also not permitted in veneer classes.

Repellents used in experiments were inefficient although some species of ambrosia bark beetles are polyphagous (*X. dispar, X. germanus*).

Protection of oak roundwood with Woodnet® system achieved excellent results, and showed great modularity and usability in FSC certified forests. Data collected during 2011 is valuable for understanding phenology and is crucial for the implementation of integrated oak roundwood protection. Winter experiments show risks in forest operations for oak roundwood exposed to ambrosia bark beetles especially from *Trypodendron* genus in swarming periods (Fig. 8). Among monitored species of ambrosia bark beetles, the following species are mentioned in European literature: *T. domesticum, T. signatum, X. dispar, X. germanus* (Maksymov 1987, Bruge 1995), *P. cylindrus*, as univoltine species, and as bivoltine species *X. saxesenii, X. monographus* and according to some authors *X. germanus* (Faccoli and Rukalski 2004). Monitoring of ambrosia bark beetles in 2011 bivoltinism for *T. domesticum* was carried out in weather conditions favorable for early swarming, first in January and then in May (Tables 5 and 6, Fig. 7). Existence of the second generation of *T. domesticum* is described by some foreign authors (Eichhorn and Graf 1974, Petercord 2006).

Based on the results of these experiments, the recommendation would be to protect the exposed oak roundwood from the middle of the winter (January) when performing forest operations with oak roundwood. Weather in winter with daily maximum temperatures exceeding 9°C are favorable for the begin-

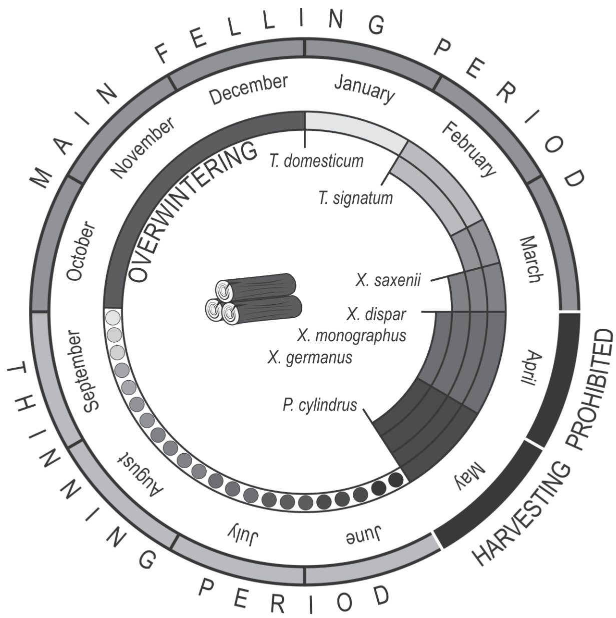

Fig. 8 Risk of pin hole damage on oak roundwood in relation to ambrosia bark beetle species swarming period and forest operations

ning of *T. domesticum* swarming. Protective systems like BASF Woodnet® for oak roundwood that was not possible to transport from landing areas and barrier panel traps equipped with attractive components were used as early warning for the start of ambrosia bark beetle swarming.

Strict European standards (FprEN 1316-1:2012:2012: E) do not allow any timber infestation for the most valuable assortments (A and B quality class) and oak timber is exposed to the highest risk in the period from mid January to mid March regarding dominant species *T. domesticum* and *T. signatum*.

The results of the research give some guidance to the ongoing development of a new approach to integrated oak timber protection. They reveal the actual potential of the use of semiochemicals in the process, either for their use as a monitoring tool (very usable) or means of reduction of timber damages (generally low) and mass trapping of timber beetles (also very low). A developing method of targeted mechanical protection by use of chemically treated (FSC and WHO approved) polymer reusable net has been recognized as highly promising. It identifies flight periods of species that infest oak timber and suggests methods of protection.

Even though the research was done on pedunculate oak timber and roundwood, the proposed integrated protection systems can be used on any roundwood because ambrosia bark beetles are polyphagous species that can successfully develop on a broad spectrum of both broadleaves and conifers.

Integrated timber protection, although with higher costs in the beginning (BASF Woodnet® price is 125 €/100 m^2, while previously used, but now banned, Deltacid in dose of 15 L/100 m^2 was 26 €), eventually

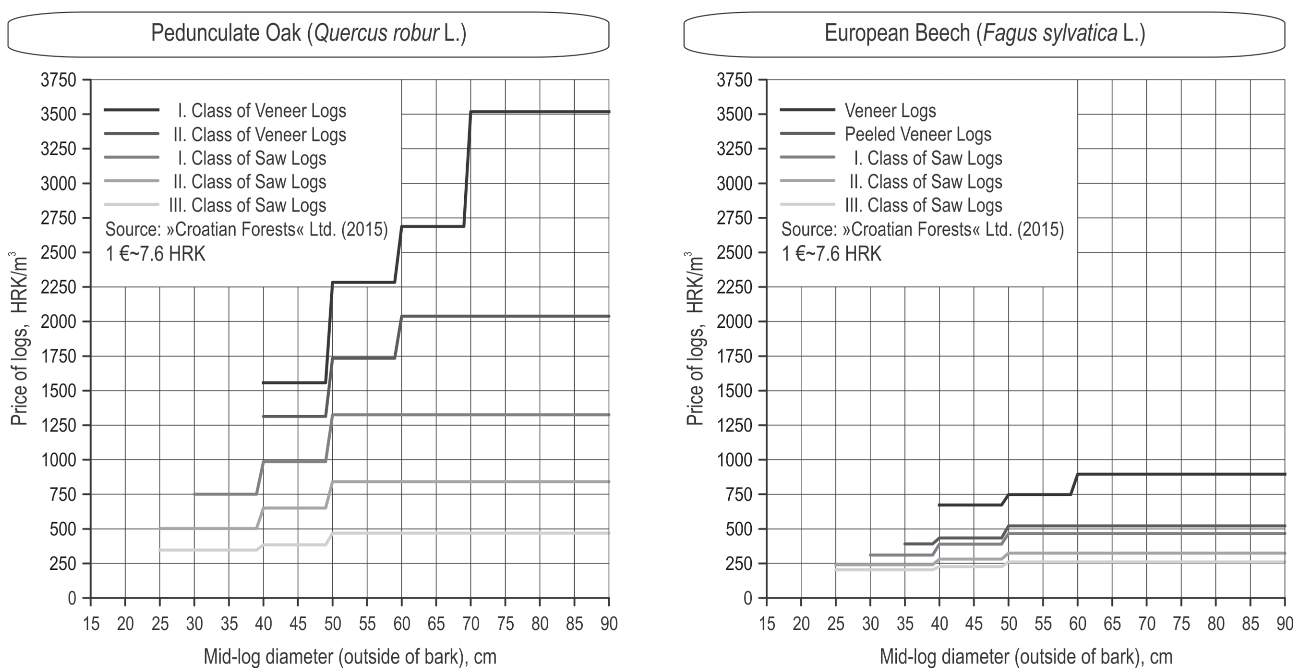

Fig. 9 Prices of pedunculate oak and European beech logs

Fig. 10 Typical forwarder roadside landing

brings both ecological (through FSC certification) and economic benefits. According to Business Annual Reports of the company »Hrvatske šume« Ltd. for the year 2009 and 2010, pedunculate oak and sessile oak Class I and II of veneer (which must also be free of insect attacks) account for 42.48% of all veneer assortments together. According to timber products price list (Fig. 9) of the company »Hrvatske šume« Ltd. (Anon. 2012), class I veneer logs of pedunculate and sessile oak are 3.15 times more costly than those of beech (*Fagus sylvatica*), the most common (Beuk et al. 2007) tree species in the Republic of Croatia (which accounts for 37.4% i.e. 113.2 million m^3 of timber), 1.52 time more costly than those of narrow-leaved ash (with overall share of 3.9% i.e. 11.8 million m^3) and other ash species (*Fraxinus anfustifolia* L. and other) and 4.33 time more costly than those of hornbeam (*Carpinus betulus* L.) with an overall share of 7.7% i.e. 23.2 million m^3.

Further to the above, it can be concluded that integrated timber protection can bring many advantages to forest management of broadleaved species. However, it should also be mentioned that the use of systems like BASF Woodnet® will require changing/adjusting of roadside landings (Fig. 10). The process of covering/uncovering logs presents a challenge (especially in terms of poorly organized landings or for example elongated skidder roadside landings), but nevertheless BASF Woodnet® systems should be used for the most valuable assortments, situated on the landing at the end of the harvesting season waiting for the binding process.

The results of the research give some guidance to the ongoing development of a new approach to integrated oak timber protection. They reveal the actual potential of the use of semiochemicals in the process, either for their use as a monitoring tool (very usable) or means of reduction of timber damages (generally low) and mass trapping of timber beetles (also very low). A newly developing method of targeted mechanical protection by the use of chemically treated (FSC and WHO approved) polymer reusable net has been recognized as highly promising. It identifies flight periods of species that infest oak timber and suggests methods of protection.

The use of the proposed integrated timber protection measures will also ensure the sustainability of holding (in terms of the company »Hrvatske šume« Ltd.) or receiving (in terms of private forest owners) the prestigious FSC certificate for forest management. As stated above, the FSC certificate represents a great honor, as it is an international acknowledgement that forests are being managed in accordance with very strict standards, and hence it is also a recognition to the forestry profession. The use of FSC approved measures for timber protection is aimed at minimizing the negative environmental and social impacts of pesticides while promoting economically viable management. The objective of FSC program is to promote environmentally responsible, socially beneficial and economically sustainable forest management.

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