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# PRACTICAL USE OF BRACONID WASPS FOR CONTROL OF THE COMMON FURNITURE BEETLE (COLEOPTERA: ANOBIIDAE)

**[1]STEPHAN BIEBL AND [2]JUDITH AUER**
[1]Ingenieurbüro für Holzschutz, Mariabrunnweg 15, 83671 Benediktbeuern, Germany
[2]Ostendstrasse 132, 90482 Nürnberg, Germany

**Abstract** This paper will show the practical use of a braconid wasp species (*Spathius exarator*) as a biological control method for *Anobium. punctatum*. The parasitic wasp parasitizes its host by piercing its ovipositor directly through the wood surface followed by oviposition onto the furniture beetle larva. Adult wasps emerge through a 0.5 mm wide hole, which can be distinguished from the 2 mm wide hole of *A. punctatum*. With the consultancy of an official expert for wood protection, the infestation of *A. punctatum* and the use of the braconid wasp *S. exarator* were controlled from 2014 till 2016 in a castle church (Schloßkirche Ellingen). Success was based on the count of new exit holes of wasps and furniture beetles on defined areas. The results of the three-year treatment period with the braconid wasp species showed improvement with a decrease of up to 80% emerging furniture beetles on monitored areas. The results of another representative chapel N., treated with *S. exarator* for two years, demonstrated a decrease of up to 100% emerging beetles with a slight rerise of *A. punctatum* activity after five years. These results show the promising state of affairs of biological control with the host-specific braconid wasp for *A. punctatum* infested objects. However, more practical experience will be required to optimise the treatment and rate of success. Furthermore, supportively integrated wood protection treatments, like the use of Anoxia, may be used to reduce partial tight infestations on removable objects.

**Key words** *Anobium punctatum*, *Spathius exarator*, castle, museum pests, integrated wood protection

## INTRODUCTION

Many chemical products for wood preservation are currently in a review process and will be restricted from the European Biocidal Product Regulation (BPR). This will lead to a lower supply of chemical products for pest control and necessitates the use of alternative methods, like physical treatments or biological control. While physical methods for controlling wood boring insects, like heat treatment or anoxia, have a long tradition in knowledge and practical experience, the biological control using natural enemies to control wood pests had not been applied so far. Despite the knowledge of a wide spectrum of antagonists against different common wood boring species (Haustein, 2010; Schmidt 1952) only few statements of laboratory research as well as practical experience had been reported from scientists (Lygnes, 1955; Haustein, 2010).

Described predators of the common furniture beetle *Anobium punctatum* are amongst others the checkered beetles (Cleridae) *Opilo domesticus* and *Corynetes coeruleus*, the soft-winged flower beetle (Malachiidae) *Anthocomus bipunctatus* and the parasitoids *Spathius exarator*, *Sclerodermus domesticus* (Schmidt, 1952), *Cephalonomia gallicola* (Paul et.al., 2008) and *Cerocephala cornigera* (Becker, 1942). Laboratory breeding experiments with predators from the family of Cleridae showed, that they do not seem to be optimal candidates for biological control, since mass development required for the release in pest-infested buildings was not achieved (Haustein, 2010). Because of the lack of a bulk of natural enemies of *A. punctatum*, the commonly used parasitoid wasp *Lariophagus distinguendus* (Pteromalidae) to control storage pests was released at an infested historic altar in Erfurt (Paul et al., 2008). However, scientific investigations showed, that *L. distinguendus* has no potential for controlling the furniture beetle.

Moreover, it was recommended to focus on the natural enemies of *A. punctatum* for biological control (Steidle et al., 2007). Further practical monitoring (Ott, 2005; Paul et al., 2008; Schöller et al., 2008) revealed, that the clerid beetle *Corynetes coeruleus*, the bethylid wasp *Cephalonomia gallicola* and the braconid wasp *Spathius exarator* are the most common natural enemies of the furniture beetle in historic buildings in Germany.

With the scientific knowledge of Becker (1942) and Lyngnes (1956) the innovative pest control company APC AG from Nuremberg bred the braconid wasp *Spathius exarator* as a commercial biological control method against *A. punctatum* (Auer and Kassel, 2014). After successful mass rearing, first results of laboratory as well as several praxis tests were published (Kassel and Auer, 2015).

This paper will show the practical use of the parasitoid *S. exarator* in two representative churches, selected from currently more than 50 *S. exarator* treated objects. Additionally, as the infested wood in churches often is heavily painted, the difference in the parasitation rate of painted versus unpainted wood is presented in laboratory experiments.

## MATERIALS AND METHODS

### Life cycle of *S. exarator*

The parasitic wasp *S. exarator* parasitizes its host by piercing its ovipositor directly through the wood surface followed by oviposition onto the furniture beetle larva. After hatching, the larva of *S. exarator* feeds on the anobiid larva and kills the pest insect. *S. exarator* larvae pupate and, after eclosion, adult wasps emerge through a 0.5 mm wide exit hole, which can be clearly distinguished from the 2 mm wide hole of *A. punctatum* (Figure 1).

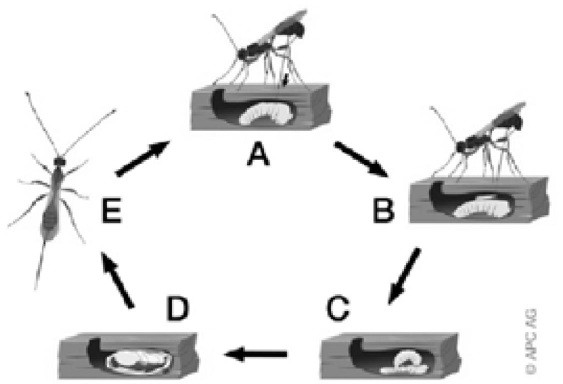


**Figure 1.** Life cycle of *S. exarator*. The female wasp drills its ovipositor through the wood surface (A), paralyses the *A. punctatum* larva and deposits one single egg on it (B). After development (C), *S. exarator* ecloses through a self gnawed exit hole with an average diameter of 0.5 mm (D).

### Release protocol and monitoring

Between five and eight treatments at intervals of four weeks from Mai to October within a period of up to three years were performed by the company APC AG. About 100 breeded wasps of the species *Spathius exarator* were applied for each defined infested area inside the building. In general, a total of 500 wasps was released per object and treatment. Success was monitored by the intensity of the infestation by *A. punctatum* compared to the effectiveness of the parasitic wasps. On exactly defined areas, the new exit holes of wasps and furniture beetles were counted and documented after each treatment. From these data, the reduction of newly hatched *A. punctatum* beetles per year was calculated. Additionally, the ratio of parasitism was determined as quotient of number of new *S. exarator* and *A. punctatum* exit holes per year.

As the lifespan of the wasps without nutrition ended after three weeks (unpublished data), all living wasps, detected before releasing new wasps, had emerged in the church and were termed as second generation. These second-generation wasps were counted and documented.

**Sample 1: Schloßkirche Ellingen**

With an official expert for wood protection, the infestation of *A. punctatum* and the use of the braconid wasp *S. exarator* were controlled from 2014 till 2016. Treatments were performed by the pest control company APC AG with eight applications in 2014, seven applications in 2015 and five applications in 2016. Monitoring the count of exit holes was done on one infested part of the pipe organ (1 x 0.4 m). At each treatment 400-600 braconid wasps were released at five infested positions in the castle church.

**Sample 2: Chapel N.**

The pest control company APC AG performed six applications in 2012 and eight applications in 2013 in the Chapel N. From 2014-2015 a yearly monitoring, without treatments was performed. In 2016 one single treatment with monitoring was done. Monitoring with the count of exit holes was made on two benches of the pewage (total 4 x 0.4 m). At each treatment, about 250 - 400 braconid wasps were released at three infested places in the chapel.

**Laboratory tests**

To studying the effect of paintworks on the ability of *S. exarator* to pierce wooden surfaces and parasitize *A. punctatum*, a laboratory experiment was conducted.

Small test lumbers (5 x 1.5 x 1.5 cm), each equipped with two larvae of *A. punctatum,* were prepared by the Bundesanstalt für Materialforschung und -prüfung (Berlin, Germany). Ten of the test lumbers were painted twice with a commercial wood lacquer (Obi 2in1 Buntlack). Five painted or unpainted lumbers each were stored in a plastic box (23 x 15.3 x 16.5 cm) with air permeable but tightly closing plastic covers. Ten female and five male parasitoids were added to each plastic container. A second charge of wasps were added after a period of about 4 month. Ten unpainted lumbers without any addition of wasps served for controlling the optimal conditions for surviving and developing of *A. punctatum*.

The plastic containers were kept in the laboratory with 18 hours daylight, 6 hours darkness, 21° C room temperature and 70% relative humidity.

The number of new exit holes of *S. exarator* per lumber, representing the number of parasitized *A. punctatum* larvae, was counted monthly. After a period of six month, the test lumbers were splitted using a pry bar to determine the exact number of surviving anobiid larvae.

**Data Analysis**

For each date of the laboratory experiment, cumulative parasitation rates were evaluated per test lumber. Differences in the parasitation rates between painted and unpainted lumbers were analysed by Mann-Whitney U tests using the software PAST (version 2.17c; Hammer et al., 2001).

## RESULTS

In both investigated churches, the number of new exit holes of *A. punctatum* clearly decreased after the release of the parasitoid *S. exarator*.

**Sample 1: Schloßkirche Ellingen**

Monitoring the defined area of the pipe organ revealed three hatching phases of *A. punctatum* during the three-year treatment period (Figure 2). The first hatching phase was long-lasting between June and October 2014, the second and the third hatching phase happened in July 2015 and 2016 and were well-defined. The number of emerged *A. punctatum* beetles decreased from eleven beetles in 2014 to four beetles in 2015 and to two beetles in 2016, implying an overall reduction of 64% after the first and of

82% after the second year of treatment. The reduction was caused by the parasitism of *S. exarator*, which killed 16 *A. punctatum* larvae in the monitored area during the entire treatment period, as identified by the exit holes of the wasps (Figure 3). The yearly ratio of parasitism was 1:2.75 after the first year of treatment, implying 2.75 emerged *A. punctatum* per emerged *S. exarator* on the monitored areas. This ratio was strongly reduced after the second year of treatment to 1:0.8 and even to 1:0.28 after the third year of treatment.

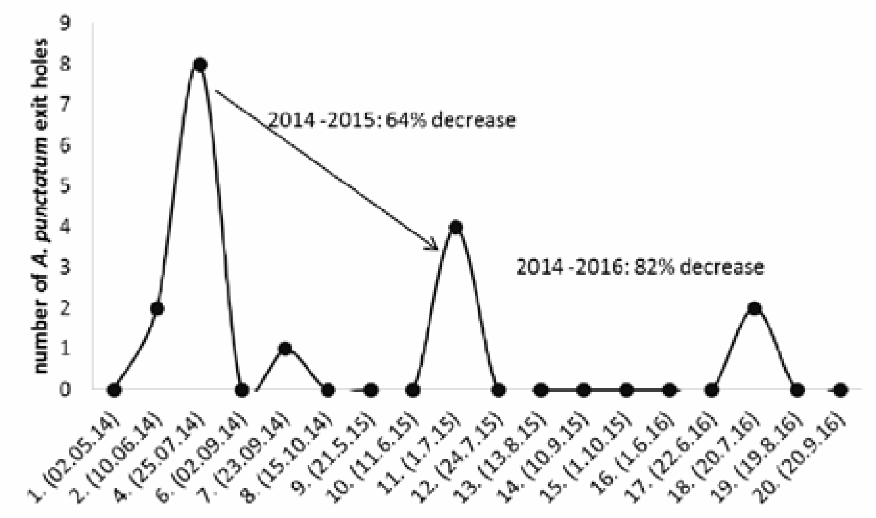


**Figure 2.** Number of new *A. punctatum* exit holes found at a defined Anobium infested area of the pipe organ between 2014 and 2016 in Schloßkirche Ellingen at the respective dates. Numbers before brackets indicate the number of treatment.

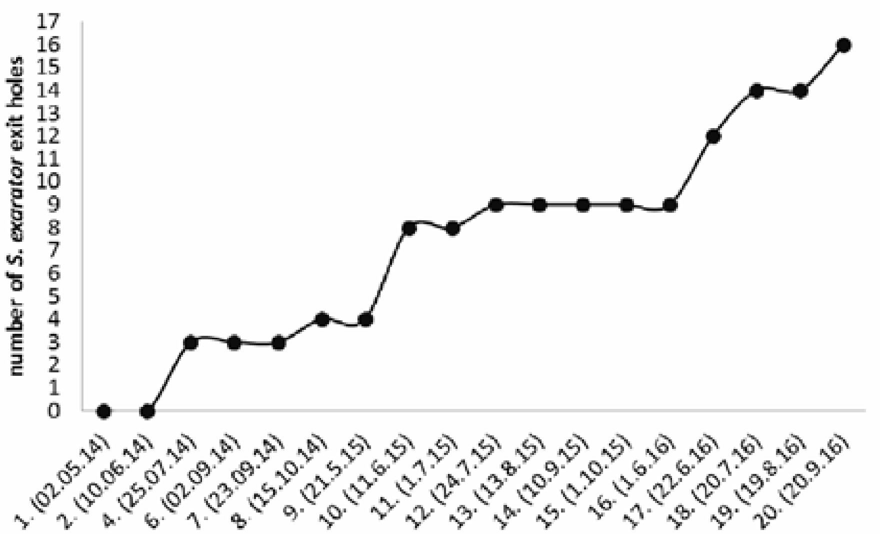


**Figure 3.** Cumulative number of *S. exarator* exit holes found at a defined Anobium infested area of the pipe organ between 2014 and 2016 in Schloßkirche Ellingen at the respective dates. Numbers before brackets indicate the number of treatment.

On selected infested places of the church, the second generation of *S. exarator* was searched and counted. The results show a continuous reproduction with a total of 148 autonomous developed parasitic wasps within the three years (data not shown).

**Sample 2: Chapel N.**

Between 2012 and 2013 the chapel N. was treated with *S. exarator*. After the two-year treatment period, yearly monitoring obtained long-term data of the infestation. Figure 4 illustrates the number of new exit holes of infested benches of the pewage. The results show a decrease from 25 exit holes of *A. punctatum* after the first year of treatment to 10 exit holes after the second year of treatment. In the third and fourth year without any additional treatment no new exit holes appeared, meaning a reduction of 100%. However, after two years without any application ten new exit holes of *A. punctatum* had to be recorded. Thus, a single treatment with the release of *S. exarator* was performed directly. As illustrated in figure 5 there was a strong parasitism of *A. punctatum* in the first two years, with a total of 128 parasitized *A. puncatum* larvae. In 2014, an overall number of 22 new exit holes (16 in spring, 6 in autumn) of *Spathius exarator* were found in the defined monitored area, even though no new wasps were released in this year. In 2015 no parasitism was detected in the monitored area, because of the weak infestation of *A. punctatum*. After the release of new parasitoids in 2016, the parasitation increased up to 167 new *S. exarator* exit holes within the monitored area.

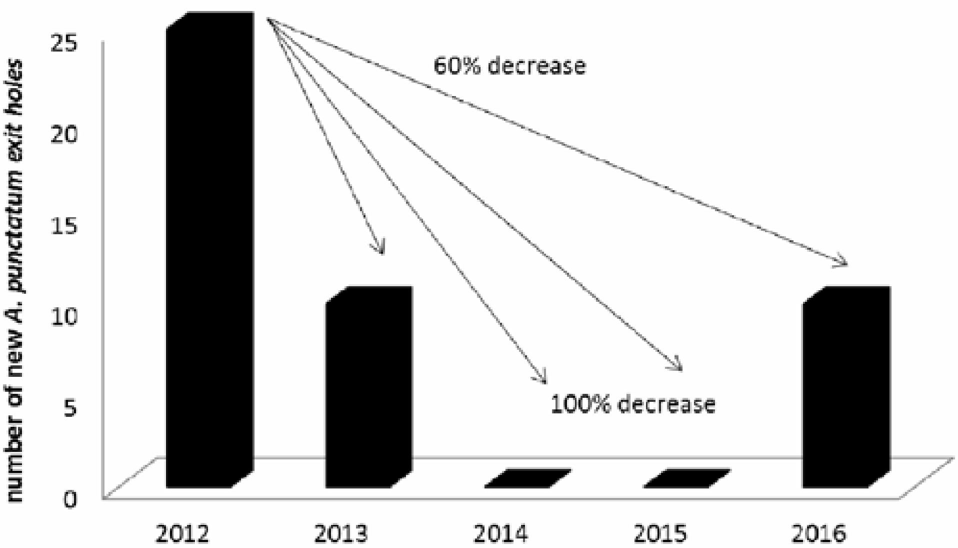


**Figure 4.** Number of new exit holes of *A.punctatum* over a period of 5 years for a defined area in chapel N. Treatments took place in 2012 and 2013. In the years 2014 and 2015 no treatments were performed. One further application occurred in 2016.

The yearly rate of parasitism in the church N. was 1:0.35 after the first year of treatment, implying 0.35 emerged *A. punctatum* per emerged *S. exarator* on the monitored areas. This rate was strongly reduced to 1:0.18 after the second year of treatment. In the third and fourth year, no beetles emerged. In the fifth year, an increased rate of 1:0.63 was documented.

The numbers of the second generation of *S. exarator* showed a continuous reproduction with a total of 39 *S. exarator* in the first and second year of treatment (data not shown). In the following years, no *S. exarator* were detected, because monitoring was done in late autumn.

**Laboratory tests**

After a period of six month, all *A. punctatum* larvae were parasitized and killed by *S. exarator* (Figure 6). In none of the pried tests lumbers living anobiid larvae were found. However, there are significant differences in the parasitation rates of painted and unpainted lumbers at three dates: while the parasitation rates in unpainted lumbers reached 100% after two months, the parasitation rates of painted samples is significantly lower in month 2, 3 and 4 of the experimental period (65%; Mann-Whitney U test, p < 0,01).

In the pried control samples without the addition of wasps 100% viable *A. punctatum* larvae were detected (data not shown).

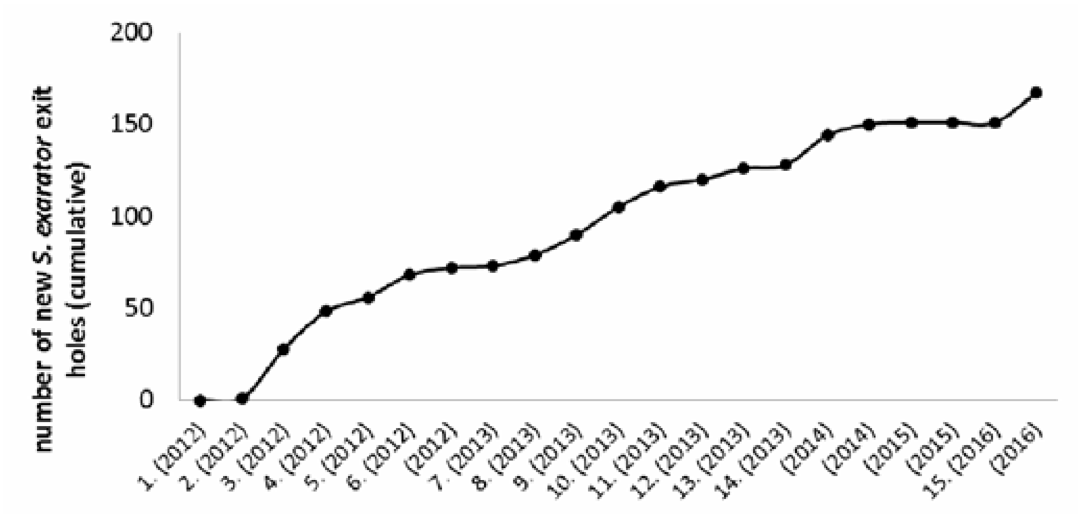


**Figure 5.** Cumulative number of *S. exarator* exit holes at a defined *A. punctatum* infested area in Chapel N. from 2012 till 2016 in chapel N. at the respective dates. Numbers before brackets indicate the number of treatment. In the years 2014 and 2015, no treatments were applied.

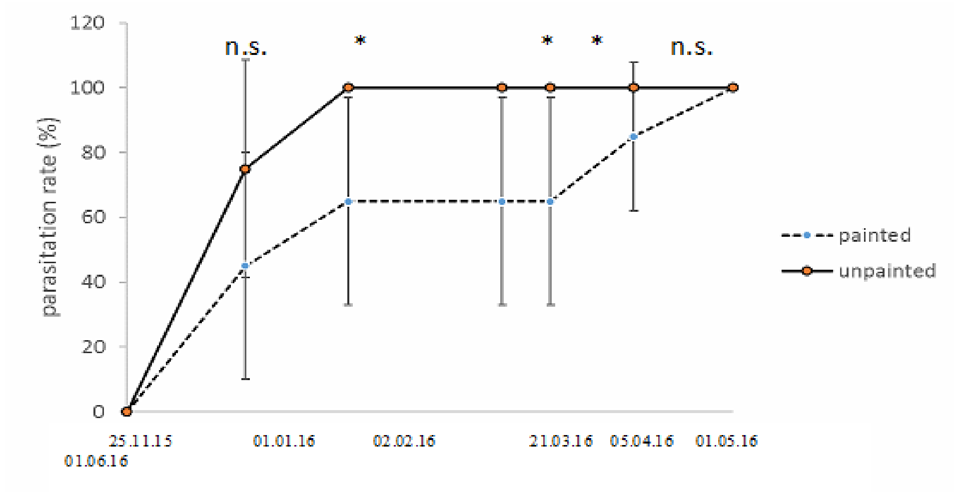


**Figure 6.** Cumulative parasitation rates of *A. punctatum* larvae in painted and unpainted test lumbers. (*: p < 0,01; n.s.:no significant difference; Mann-Whitney U test).

## DISCUSSION

In both *Spathius exarator* treated churches, the number of new *A. punctatum* exit holes decreased over the treatment period. On the defined monitored area of the pipe organ in the Schloßkirche in Ellingen, a decrease of 82% of emerging *A. punctatum* was found over a period of three years. In Chapel N., a decrease of 100% was observed over a treatment period of three years. However, after two years without any treatment, ten new exit holes of *A. punctatum* appeared.

In both churches under investigation, the reduction of *A. punctatum* can be attributed to the parasitation of the released parasitoid wasp *S. exarator*, as indicated by the increased number of new *S. exarator* exit holes and the resulting higher parasitation rates. Monitoring of success in Ellingen revealed a short and well-defined hatching phase of the furniture beetle after the first treatment year. The phenomenon of a shortened anobiid hatching phases also occurred in other *Spathius* treated objects (Auer, personal communication). The number of second-generation wasps prior to the release of new wasps proves the ability of the parasitoids to survive and to develop autonomously within the treated objects. Moreover, the fact that new exit holes were found in chapel N. after an annual phase without any treatments demonstrates the settling of the wasps, thus proving the efficiency of the biological control method.

However, the recurrence of new *A. punctatum* exit holes after a two-year period without any releases also shows the necessity of a well-defined application program.

Monitoring was initially performed by the count of wood dust heaps. However, the number of heaps does not correlate with the intensity of infestation, as wood dust heaps are caused by furniture beetles, as well as by antagonists (e.g. Cleridae), secondary guest insects, vibrations or even swelling/shrinking after change of wood moisture (Biebl 2015).

It is well known that, due to the natural predator-prey relationships, biological pest control does not result in a 100% containment of pest organisms after a few treatment applications (Graf, 1992; Querner, 2017). Instead, a continuous monitoring program with periodic single treatments is strongly recommended. This is even more important in the light of the relatively long development period of *A. punctatum* which can take up to 5 years (Pinniger, 1996).

The results of the laboratory experiment show that *S. exarator* parasitizes furniture beetle larvae in unpainted as well as in painted wood. However, parasitation of painted lumbers seems to be delayed in comparison to unpainted wood. The hundred percent survival rate of *A. punctatum* larvae in the control lumbers without addition of wasps proves optimal laboratory conditions for the surviving and development of the furniture beetle. Further experiments with different materials (e.g. varnish, shellac, leaf gilding) will reveal more insights in the parasitation abilities of *S. exarator* and thus allow more sophisticated programs of application.

Nowadays some individual objects (buildings, artworks, etc.) with historic pesticide contaminated wood are known to have an active infestation with furniture beetles. However, parasitoid wasps are known to react very sensitive to historic pesticides (Querner, 2017). Therefore, in case of suspicion about pesticide contamination, infested wood should be checked using chemical analyses prior to biological control with parasitoids. In case of contamination, the application of braconid wasps could fail and other treatment methods should be applied after careful evaluation.

Fundamentally, the biological pest control results in a reduced infestation and keeps it below a certain minimum level, like longtime experiences from plant protection had shown (Haustein, 2010). After a period of intensive treatment, one or more further annual single-treatments will be recommended, to control the low infestation and hold it under a defined damage threshold.

Although research and application of biological control against the furniture beetle lasted only several years it showed already considerable success. Nevertheless, more practical experience will be required to develop a sophisticated, continuous application program to control the furniture beetle using its natural enemy.

## CONCLUSIONS

The results show the promising state of affairs of biological control with the host-specific braconid wasp for *Anobium punctatum* infested objects. In comparison with chemical treatment methods and their negative effects, the success rate of this biological method up to 100% indicates the ability for effective wood preservation in historic buildings, for artworks, etc.

Integrated wood preservation always includes the combination of different methods (Graf, 1992). Elements of the integrated wood preservation are structural-, physical-, chemical- and biological methods. Supporting methods should also be applied in addition to the biological pest control to treat heavily infested removable objects as term of integrated wood protection.

However, more practical experience will be required to optimise treatment and rate of success with *Spathius exarator*, to fulfill the requirements of conservation without further damage of the historic objects by *Anobium punctatum* larvae.

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