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Comparison of AE-apparatus for detection of activity of Old house borer larvae, including reality check

Jos Creemers[1], Burkhard Plinke[2], Uwe Noldt[3]

[1]SHR Timber Research, Nieuwe Kanaal 9e, 6709 PA Wageningen, The Netherlands

[2]Fraunhofer Institut für Holzforschung WKI, Bienroder Weg 54E, 38108 Braunschweig, Germany

[3]Noldt Consulting - holzzerstörende Insekten, Lehmweg 5, 21481 Lauenburg/Elbe, Germany

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IRG SECRETARIAT
Box 5604
SE-114 86 Stockholm
Sweden
www.irg-wp.com

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Jos Creemers[1], Burkhard Plinke[2], Uwe Noldt[3]

[1] SHR Timber Research, Nieuwe Kanaal 9e, 6709 PA Wageningen, The Netherlands, j.creemers@shr.nl

[2] Fraunhofer Institut für Holzforschung WKI, Bienroder Weg 54E, 38108 Braunschweig, Germany, burkhard.plinke@wki.fraunhofer.de

[3] Noldt Consulting - holzzerstörende Insekten, Lehmweg 5, 21481 Lauenburg/Elbe, Germany, dr_uwe_noldt@web.de

ABSTRACT

As part of the German funded project 'InsectDetect' comparative measurements were done with three different Acoustic-Emission-(AE)-apparatus on 14 pine beams in order to assess presence of active attack by the Old house borer (*Hylotrupes bajulus* (L.)).
In all beams active attack was measured, though in varying intensity. This was corroborated by completely dissecting 10 of the beams. All three AE-systems proved suitable to find active attack, although their results in terms of numbers of events are different even when used in the same situation. Therefore, it is important that the operator is familiar with the technical functioning of the system that is used in order to be able to interpret the results reliably.
The dissection of the beams showed that there is also an element of chance in these measurements regarding proximity of sensors to gnawing larvae and temporal larval inactivity. Still, such measurements with these apparatuses can give an answer to the question whether active attack of wood-boring insects is present.

Keywords: Acoustic Emission, activity, *Hylotrupes bajulus*, InsectDetect, Old house borer, Pine, wood attacking insects.

1. INTRODUCTION

The possibility to record sound or register acoustic emissions (AE) for the purpose of identifying active attack of wood by insects was already reported long ago (e.g. Pence *et al.* 1954, Pallaske 1986, Fujii *et al.* 1989) but got renewed attention in recent years (Nowakowska *et al.* 2017) and may now include the use of signal analysis and artificial intelligence (Bilski *et al.* 2017). Also commercial 'remote sensing' applications are becoming available (e.g. Potamitis *et al.* 2019).
As part of the German funded project 'InsectDetect' comparative measurements were done with three different Acoustic-Emission-(AE)-apparatus on 14 pine beams previously assessed to possibly harbour attack by the Old house borer (*Hylotrupes bajulus*).

1.1 Background project 'InsectDetect'

The project concerned the detection of active insect pests in the timber trade.
Due to both the globalization of the timber trade and climate change, there is an increasing risk of wood-destroying insect species being introduced. Rapid spreading of the insects may cause extensive damage to indigenous forests and possibly commercial timber. Existing control procedures for the timber trade are not sufficient. Especially larvae of wood-boring insects like e.g. the Asian Longhorned Beetle (*Anoplophora glabripennis*) are carried across the borders of the

European Union, despite of existing rules for phytosanitary treatment, and cause damages in tree populations in Central Europe.
The aim of this research project was to develop and test an effective control procedure for the inspection of imported goods and wood-based packaging with regard to infestation by larvae of wood-boring insects. The objective of the project was a practicable and economical detection method which encompasses two steps.

Step 1 - Visual inspection of the delivery
In the first step of the control procedure, imports of wood products and wood-based packaging are to be inspected visually. In the case of infestation being suspected, samples are to be selected and taken for further testing (Step 2). Within the framework of the project, a strategy for the visual inspection as well as handling instructions for sample selection were developed (not reported here).

Step 2 – Acoustic procedure for the testing of suspicious samples
In the second step of the control procedure, an acoustic method would be applied in order to determine the active infestation by means of the sound emissions of insect larvae gnawing.
It is known that feeding larvae in solid wood cause externally measurable structure-borne sound emissions and that through analysis of the emission pattern over a certain period of time, the vitality of the larvae can be determined. In the 'InsectDetect' project this procedure was adapted and developed further. A test chamber including handling instructions was developed, which may be used by e.g. border inspectors, the timber trade and the forestry sector.

1.2 Reported work

This paper describes part of the work done for work package WP7 'Testing' of the project. It involves comparative tests of the apparatus composed and used in the 'InsectDetect'-project with the existing SHR Woodworm Detector (WWD), the practical application of which has been developed by SHR over more than 14 years.

2. MATERIAL AND METHOD

2.1 Assessment and material

The activity assessments were done on June 24 and 25, 2020 at Heidelbeerhof Pehmöller at Schnakenbek, Germany. The measurements were assisted by the organizer, Dr U. Noldt of 'Noldt Consulting - holzzerstörende Insekten' in Lauenburg/Elbe, Germany.
Measurements with the 'InsectDetect' apparatus were carried out by Dr B. Plinke of the Fraunhofer Institut für Holzforschung in Braunschweig, Germany. The activity assessments with the WWD were done by J. Creemers MSc.
All measurements were done under the roof of a large barn, which was open at the front side. Both days the air temperature reached 30 °C in the afternoon.

The material, organized by mr Noldt, consisted of a selection of squared beams, about 16 cm wide and 12 cm thick, total length between 3.7 and 4 m. The beams are normally used to close the front of drying rooms for grain by piling them on top of each other. The wood species of the beams was microscopically confirmed to be pine (*Pinus* sp.).
Mr Noldt had made a selection out of a larger stack of available beams, mainly concentrating on visual characteristics of possible ongoing attack by the Old house borer (*Hylotrupes bajulus*) according to Noldt (2014). The beams were numbered and in order to keep track of their orientation one of the beam ends was additionally marked with a piece of duct tape with the same number. Location designations like '1/4' and '3/4' use this end as starting point and indicate a position at a

quarter and three quarters of the length of the beam respectively. Also the numbering of sub-sections during the reality check (see § 2.3) starts at this end.

2.2 Apparatus and method

2.2.1 SHR apparatus

The SHR Woodworm Detector or WWD is based on the AED 2010, a product of former AEC Inc. at Fair Oaks CA, USA. This specific set-up is furnished with an SP-1L probe (L for lower frequency). The AE-sensor is built into a handle, which may be attached to a screw in the timber using a magnet. The WWD is a one-channel apparatus, which can be handled completely manually, but for longer lasting measurements it is preferably attached to a computer running the accompanying AEC-software. In the present set-up the computer was attached and hits and counts were accumulated and registered every 30 seconds. All measurements were done 'filtered', meaning that acoustic emissions with frequencies up to 25 kHz were dismissed. Sensitivity was set to position 5, which setting is described in the resulting datafiles as 'Thresh(v)=1,00 Thresh(dB)=36 Var gain=24 Fixed gain=20 Preamp gain=40 Total gain=84'. Measurements were done with the sensor at positions 1/4 and 3/4 of the beams, in a few cases also at 1/2.

2.2.2 'InsectDetect' apparatus

The 'InsectDetect'-project apparatus was an AMSY-6 system (hereinafter referred to as AMSY) manufactured by Vallen Systeme GmbH at Wolfratshausen, Germany. The system has four channels, enabling measurement with four sensors at the same time. For these measurements, Vallen VS45-H sensors were used, having a wide frequency response. The system is hooked up to a laptop, running the corresponding Vallen software. The lower cut-off frequency of the AMSY-system is approx. 95 kHz which makes it less sensitive to surrounding noise. Details about the system and evaluation method are given elsewhere (Becker *et al.* 2020). During the first measurements the four sensors were evenly spaced over one beam. For the simultaneous measurements the sensors were placed at positions 1/4 and 3/4 of 2 beams.

Figure 1: spotWave system (little red box) and all 3 system sensor connections (on the left)

2.2.3 SpotWave apparatus

Shortly before this experiment the Vallen firm supplied mr Plinke with a prototype of spotWave, a newly developed mobile one-channel AE-system. SpotWave (Fig. 1) consists of an AE-sensor (here also a Vallen VS45-H was used), a small processing unit, and a mobile phone for data processing, presentation, and storage. As with the AMSY-system the sensor can easily be clamped to the timber under study. Fig. 1 shows the spotWave-system and to the left the connection of all three systems is visible side-by-side. At the first glance, results of this system seemed to be similar to those of AMSY, as we expected. A thorough comparison of the AMSY and the spotWave device is scheduled and not further discussed here.

2.2.4 Method

On the first (half) day measurements with the different devices were carried out largely independent from each other, for instance measurements on different beams or during distinct periods in time. On the second day of the measurements, an approach for simultaneous measurements was developed. In this set-up the four channels of the AMSY-system were clamped to two of the beams and the measurement was continued for about 1 hour. During that time the WWD was connected to a location close to each of the sensors of all four channels and an activity measurement was done for about 10 minutes at each location. During the placement and shifting of the WWD-sensor the AMSY-system was paused in order to avoid disruptions in those measurements. Figure 2 shows the synchronized measurements on beam 9. In a few cases also the spotWave was activated simultaneously.

Figure 2: Synchronized measurements WWD-AMSY on beam 9 (upper left)

2.3 Reality analysis

As soon as possible after the AE-assessments 10 of the 14 beams were tenaciously dissected by mr Noldt. After sawing the beam into 15 subsections of about 25 cm length and coding them with 1-15, starting at the tape marked end, each part was completely cleaved and split and all *Hylotrupes*-larvae found were scored (large – medium – small, see Fig. 3) and registered.

Figure 3: Left to right: 2 large, 2 medium, and 2 small larvae of *Hylotrupes*

Other finds like pupae or beetles were also noted. The complete disassembly of the beams was done to check the conclusions with regard to the presence of ‘active attack’ and to try to relate the number of hits registered by the AE-apparatus to the number and location of the living larvae.

2.4 AE-data comparison

The AE-apparatus used have different sensitivities and data processing and presentation and they were activated during time periods of differing lengths. In order to compare their results a common activity indicator was needed. The options considered were the ‘maximum number of hits per 30 second period’ and ‘the number of hits/hour’. The latter, ‘hits per hour’ was selected. The ‘max hits/30 sec’ would be a short-term indicator, relying heavily on a measurement during one specific period of 30 seconds, whereas the ‘hits/hour’-indicator can be related to the whole measurement period, no matter how long, and would therefore use the collected information to the fullest.

3. RESULTS AND DISCUSSION

3.1 AE-data

Table 1 shows the data acquired with the AMSY- and the WWD-apparatus according to their location (‘Part of beam’) during measurement. As acquisition durations differed for the two apparatus, the results are expressed as ‘events (or hits) per hour’. Measurements were synchronized for beams 7 to 14 (4 shorter 1-channel measurements during 1 longer 4-channel measurement).

Table 1: Sensor location and results of AMSY*- and WWD-apparatus [events per hour]

Beam	AE-app.	Part of beam														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	AMSY			10			150				600			1000		
	WWD				400				600				300			
2	AMSY			50			150				50			50		
	WWD				350				100				200			
3	AMSY			1300			300				1500			1100		
	WWD								250							
4	AMSY			200			10				70			1000		
	WWD				250								150			
5	AMSY			30			70				150			700		
	WWD				100								250			
6	AMSY			350			450				250			600		
	WWD				250								200			
7	AMSY				200								500			
	WWD				250								250			
8	AMSY				1000								2000			
	WWD				700								450			
9	AMSY				30								200			
	WWD				300								1250			
10	AMSY				150								50			
	WWD				150								50			
11	AMSY				2000								500			
	WWD				150								550			
12	AMSY				100								150			

Beam	AE-app.	Part of beam														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	WWD				350								350			
13	AMSY				200								100			
	WWD				50								250			
14	AMSY				400								80			
	WWD				500								400			

* AMSY-data are preliminary. Final results will be presented in the 'InsectDetect' project report.

When comparing the bare numbers for AMSY and WWD over the locations, there is no obvious relation. Where one is high, the other is low and vice versa. It is clear that the apparatus respond differently to the measurement situations. This relates to different sensor frequency characteristics, chosen threshold values, and data processing variables. During the measurements it became clear that the WWD is more sensitive to sounds from the surroundings and disturbances through contact with the beam or cables when compared to the other two systems used. For example, the AMSY-system and the spotWave were much less or even hardly disturbed by clapping hands. The dissimilarity in sensitivity might be caused by the external coupling (screw – magnet – handle) of the WWD or by the lower cut-off-frequency of 25 kHz of the WWD in comparison to 95 kHz for the other two apparatus.

Even if a beam does not contain any active attack, it is possible that some tens of events (per hour) may occur during measurements as a result of e.g. drying of the timber, temperature change, installation noise, incidental contact with cables or beams or other disturbances. Still, for all assessed beams, even beam 10, the conclusion was that active attack by insects was present. After dissection (see par. 3.2) this first conclusion proved to be correct and corroborates the visual assessment when selecting the beams.

3.2 Reality check

As it is not possible to present the dissection results of all beams, we have chosen three of them, representing maximum, minimum and average number of larvae in a beam (Fig. 4-6).

The **maximum** number of larvae was found in beam 9: 62 larvae (see **Fig. 4**). As can be seen in the graph, the majority of the larvae was found in the right-hand part, and also the results of both AE-apparatus are higher there. However, these larvae were mostly small ones, whereas the large larvae were predominantly present in the left-hand part. As larger larvae may cause more and higher energy events, one would also expect higher AE-numbers on this side, but that was not the case. We know that *Hylotrupes*-larvae have periods of inactivity (Pallaske 1986, Creemers 2015), so some of the larvae may have been temporarily inactive at the time of measurement. Also, in wood, (ultra)sound travels more easily along the grain than across (Forest Products Laboratory 2011), making it obvious, that a larger number of events is also acquired when the sensor is attached in the direction of a gnawing larva along the grain. However, as the exact position of the larvae is not known when we attach our sensors, this means that there is also a clear element of chance in the results.
In order to address such concerns (temporal inactivity, coincidental proximity of larvae) in more detail, measurements might need to be longer lasting and done at more locations.

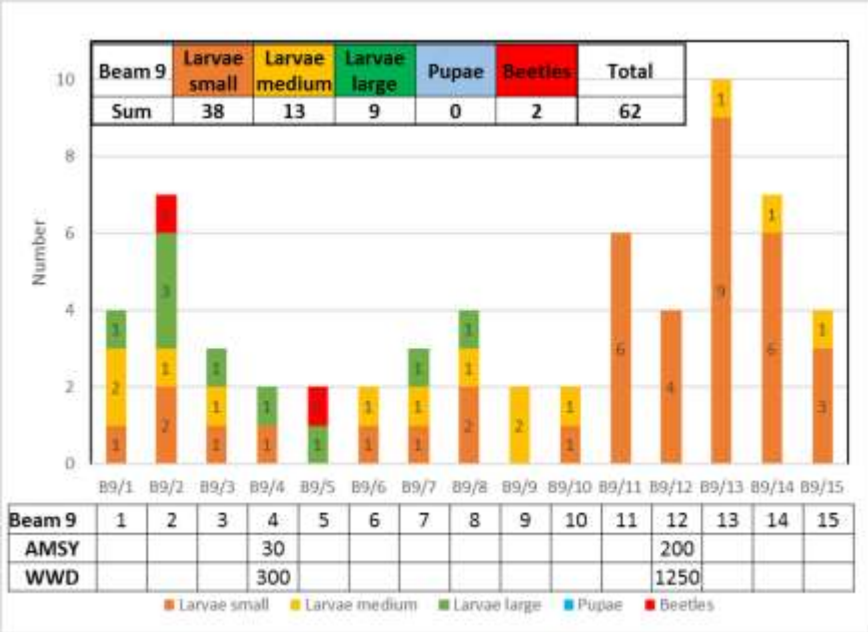

Figure 4: Representation of results of beam 9

Figure 5 deals with the **minimum** situation: beam 10, with only 1 large larva on the far left end. Both AE-apparatus generate equal results. Considering 50 hits per hour as a minimum for active attack, these numbers suggest that there is nothing or at least not much going on in the right-hand part of the beam and that there is some evidence of live attack on the left hand side of the beam. In such cases it may be extra helpful to use the headphones to identify the source of the events and whether they might be related to external sources, e.g. passing traffic, installations activating etc. The higher number on the left also shows that vibrations can be picked up at distances of almost 1 meter along the grain.

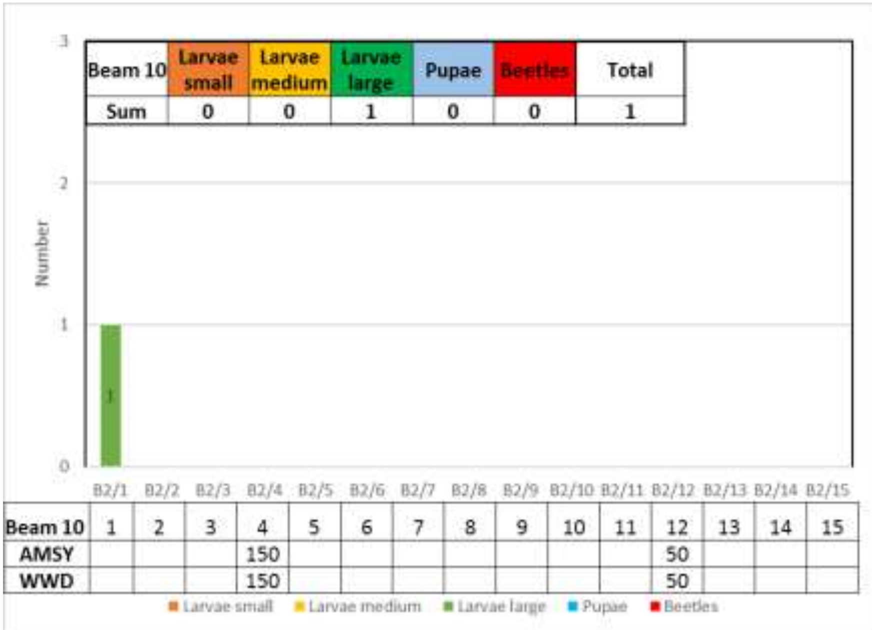

Figure 5: Representation of results of beam 10

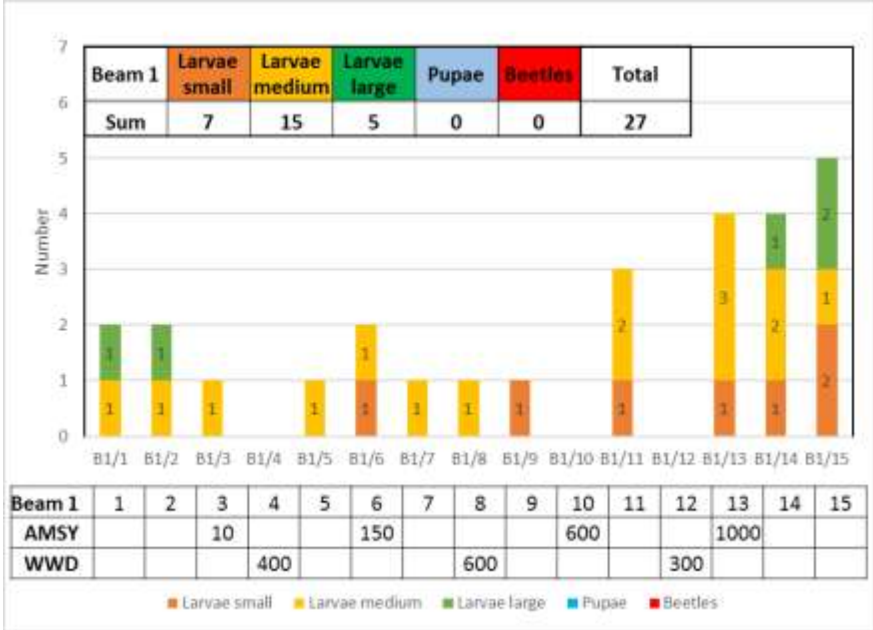

Figure 6: Representation of results of beam 1

Figure 6 deals with an average situation in this experiment: beam 1, containing a total of 27 larvae, mostly of medium size. Whereas the WWD results clearly show active attack at all three measurement positions, this is not the case for AMSY at the left-hand end. The measurements on this beam were not synchronized yet, so the AMSY might have encountered these larvae in a non-active situation, although its measurement time was always longer than that of WWD.
The higher number of small larvae at the right-hand side is evident from the high number of hits of the AMSY at that end. If larger larvae generate lower frequency events, say around 50 kHz, the low number of hits with AMSY at the left end could be explained by its cut-off-frequency of 95 kHz. The cut-off-frequency of the WWD at 25 kHz allows registration of these hits. The higher sensitivity of the WWD to external disturbances would then be a trade-off with the sensitivity to lower frequencies and thus activity of larger larvae.

4. CONCLUSIONS

A batch of 14 visually assessed pine beams was studied regarding presence and activity of larvae of Old house borer (*Hylotrupes bajulus*) using different AE-systems. In all beams active attack was registered, though in varying intensity. The presence of live larvae was corroborated afterwards by completely dissecting 10 of the beams.
The WWD was specifically designed to find activity of wood attacking insects and did its job. The AMSY-system is a generally used 4-channel-AE-system, but also proves suitable to find active attack, as did its smaller, one-channel counterpart spotWave. Beams or sections of beams with no activity, low and high activity levels can be distinguished to a certain extent with both devices. However, the use of these systems leads to differing results, i.e. numbers of events when used in the same situation. This means that the operator should be really acquainted with the functioning of the system he uses in terms of registered frequencies, data filtering, and data processing in order to be able to interpret the results reliably.
What the dissection of the beams (‘reality check’) shows is that there is also an element of chance in these measurements. Placing the sensor in close proximity of a gnawing larva will certainly lead to the correct answer. However, when the larva is gnawing on the opposite side of the beam, when it is further away from the sensor, or when the larva is temporarily inactive, the results, the number of hits, will vary. ‘Fortunately’ we normally deal with situations in which there is more than one

larva present and they do not pause all at the same time. Still, such AE-measurements can give an answer to the question whether active attack of wood boring insects is present, but not (yet) to how many there are and where they are exactly located.

5. ACKNOWLEDGEMENT

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