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Editorial

Biodeterioration and biodegradation are natural processes during which all "dead" organic materials are degraded by microorganisms. Wood is an organic material and this process quickly affects felled trees in the forest. However, the situation is different in case of manmade buildings and structures. In these cases, degrading organisms are considered harmful organisms and therefore it is important to ensure that the service life of wood and wood based materials used in buildings and structures is as long as possible. It is also important to be well aware of the living conditions and "habits" of such organisms. It is possible to solve durability problems by introducing chemical or physical methods to change the conditions. The most environmentally friendly methods are physical methods – i.e. regulation of water content, thermal conditions, etc.

On the other hand, it is very important to preserve wood and wood-based materials in buildings even if they are biodeteriorated, especially in case of buildings belonging to cultural heritage. Over the time, several non-destructive and semi-destructive methods have been developed for assessment of wood elements and nowadays it is possible to evaluate timber properties without destroying wooden elements or structures. Preservation of timber details used in structures represents a sustainable way of thought.

The special issue of the journal "International Biodeterioration and Biodegradation" continues with papers from the Conference on Biodeterioration of Wood and Wood Products held in Tartu on 24–27 of April 2013. The topics discussed at the conference included the following:

Biodeterioration of wood by fungi
Biodeterioration of wood by wood boring insects
Waterlogged wood
Assessment of the condition of wood biodeterioration by using non-destructive methods
Wood conservation (incl. cultural heritage)

I would like to thank all the authors, reviewers, technical personnel and financial supporters for their contribution to completion of this issue. I would especially like to thank COST Action IE0601, Central Baltic program Interreg IVA, Federation of European Microbiological Societies and International Biodeterioration and Biodegradation Society.

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In-situ measurement of microclimatic conditions and modeling of mechanical properties of timber structures – A case study on new church on Ruhnu Island, Estonia

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ABSTRACT

There are many factors which affect durability of wood in the existing timber structures. One of the most important factors affecting durability is biological, especially the wood-rotting fungi and wood-boring insects. This paper gives an overview about fieldworks on Ruhnu Island and investigations on damages caused by house longhorn beetle and common furniture beetle in the church built in 1912 AD, respectively. Since the church is architectural heritage, only non-destructive methods were used to determine residual cross-sections of existing timber structures. The activity and distribution of beetles were connected with indoor microclimate measurements that were conducted in different locations inside the church. No relations between house longhorn beetle and common furniture beetle spreading in forest and timber elements were found. A thorough renovation and pest control treatment were set based on the results of this investigation. The living conditions and nutrition habits of common furniture beetle and house longhorn beetle were confirmed, and correlation between the mentioned beetles living in forest and in buildings is small. In spite of intensively damaged church's steeple, the strength and stability calculations showed only the need for minor reinforcement of load-bearing timber structures.

1. Introduction

The need for structural health evaluation of old wooden buildings can emerge in order to assure or extend its service life. Historic timber structures must be preserved in order to maintain their original structural purpose as much as possible, while taking into account the safety aspect for the habitants of the building. Thus, structural integrity must be assured: structure should be durable, have the necessary strength and be able to withstand all types of loadings (Larsen and Marstein, 2000). The New Maarja Magdaleena church – a century old masonry-wooden building – is situated on Ruhnu Island. This island with the area of 11.9 km^2 is situated 40 km off from the mainland (Fig. 1). The church's walls are made of hewn quarry stones, the steeple and roof structures from softwood timber. The church is usually not used in winter, but it is highly frequented by tourists in summer time.

Previous investigations in 1997 and 2009 have revealed that almost all wooden parts in the new Maarja Magdaleena church are intensively damaged by the house longhorn beetles (*Hylotrupes bajulus* (L.)) and the common furniture beetle (*Anobium punctatum* (Deg.)) (Parmakson and Danil, 1997; Noldt, 2009). The house longhorn beetle is one of the most common destroyers of coniferous timbers like pine, spruce and fir, particularly in roofing timbers. Its larvae infests generally the sapwood part of softwoods and feeding may be audible on warm days as scraping noise. The life cycle of this large beetle can last up to ten years. The common furniture beetle's larvae infests mainly sapwood timber of softwoods and European hardwoods. This reddish to brown colored beetle's life cycle is one to three years (Bravery et al., 2003; Noy and Douglas, 2005). In investigations of Ruhnu Church the wooden benches, pillars, stairs, and walls show characters of former and also active attack. The most intensive characters of attack are found in the structures of the steeple and in the roof structures (Fig. 2) (Noldt, 2009). According to the Integrated Pest Management (IPM)

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b)

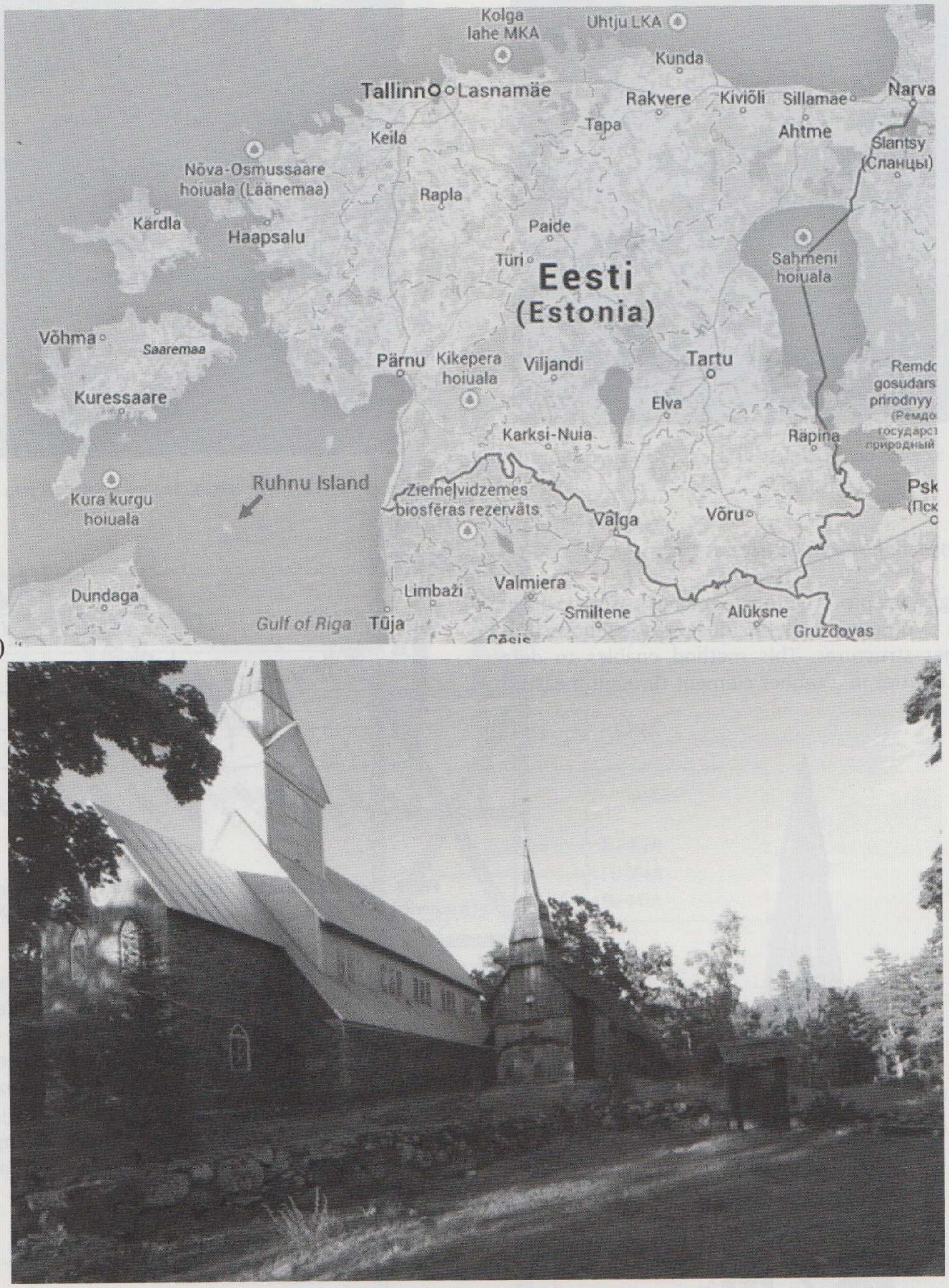

Fig. 1. a) Map of Estonia, b) The New Maarja Magdaleena church on the left.

this overall infestation requires immediate control measures. The main idea of the IPM is to prevent damage of art, ethnological or natural history collections made of timber, textiles from animal fibers or other organic materials from beetle pests or mould (Querner et al., 2013).

The main purpose of this study was to assess the condition and residual strength of the timber members that serve as the main framing structure of the steeple, and to conserve its stability by using sustainable methods. In this context sustainable means keeping as much as possible timber elements (Larsen and Marstein, 2000). In addition, it was important to investigate connections between beetles living in forest and in the buildings of Ruhnu Island.

2. Materials and methods

2.1. Microclimate condition measurements

Two temperature and relative humidity data loggers were mounted inside the church to monitor the indoor air condition inside the building with the measuring interval of one hour for the period of 13 months starting from October 2011 until to the end of October 2012. First data logger was mounted near the altar on the first floor and the second one in the middle of the attic. In addition, records from Estonian Environment Agency of outdoor climate data measured in Ruhnu Island were used.

Fig. 2. Intensive attack by wood-boring beetles found in the New Maarja Magdaleena church.

Fig. 4. The trunk-window trap.

2.2. The basis of modeling steeple structures

In the modeling of steeple structures, a micro-resistance drilling method was used to determine the residual cross-sections of the elements of timber structures. This method enables to detect deterioration and cavities in a timber element through measuring the relative resistance in the drilling path. The output of a micro-drilling test is a resistance profile showing density changes along the penetration path (Kotlinova et al., 2008). Geometric measurements were performed using a digital distance meter and tapeline. Lengths and residual cross-sections of the beams and loads of the supporting structures were modeled (Fig. 3), whereas the joints were modeled as pinned joints. In the modeling of beams, the worst possible option was chosen, that is, the smallest cross-section

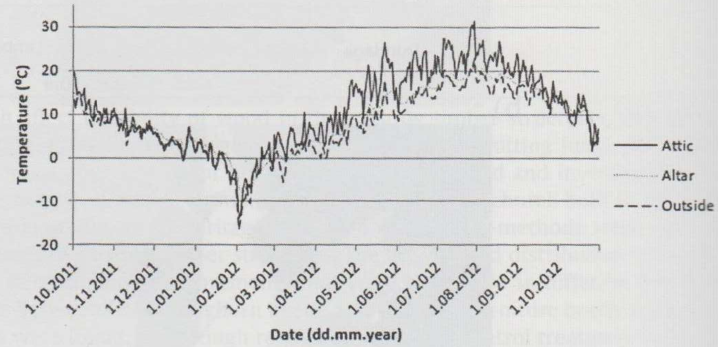

Fig. 5. Daily measurements of air temperature inside and outside the church for a period of 14 months starting from September 2011 until October 2012.

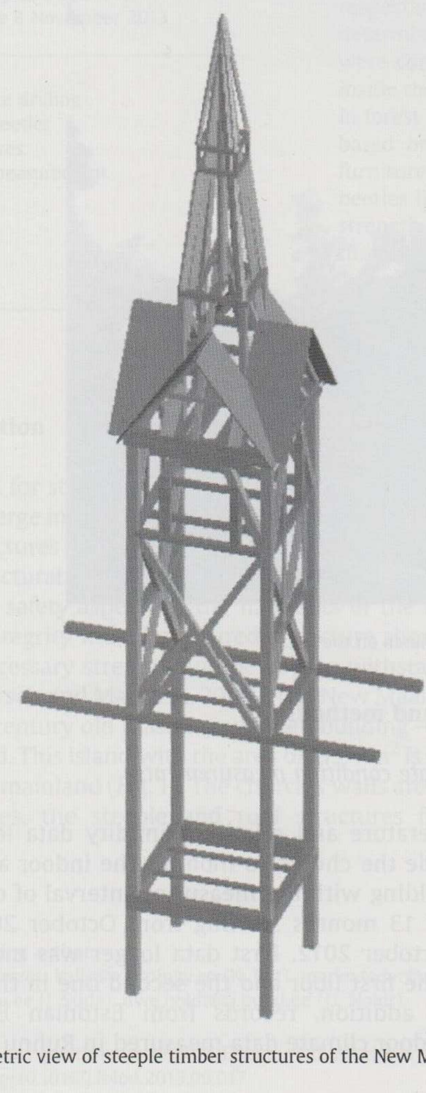

Fig. 3. Axonometric view of steeple timber structures of the New Maarja Magdaleena church.

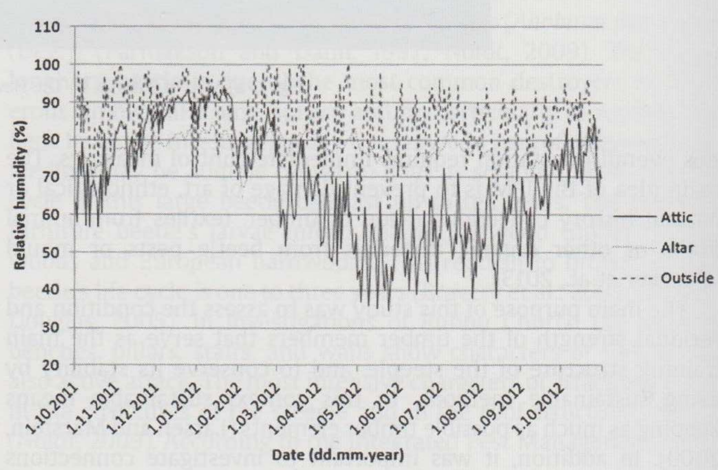

Fig. 6. Daily measurements of relative humidity inside and outside the church for a period of 14 months starting from September 2011 until October 2012.

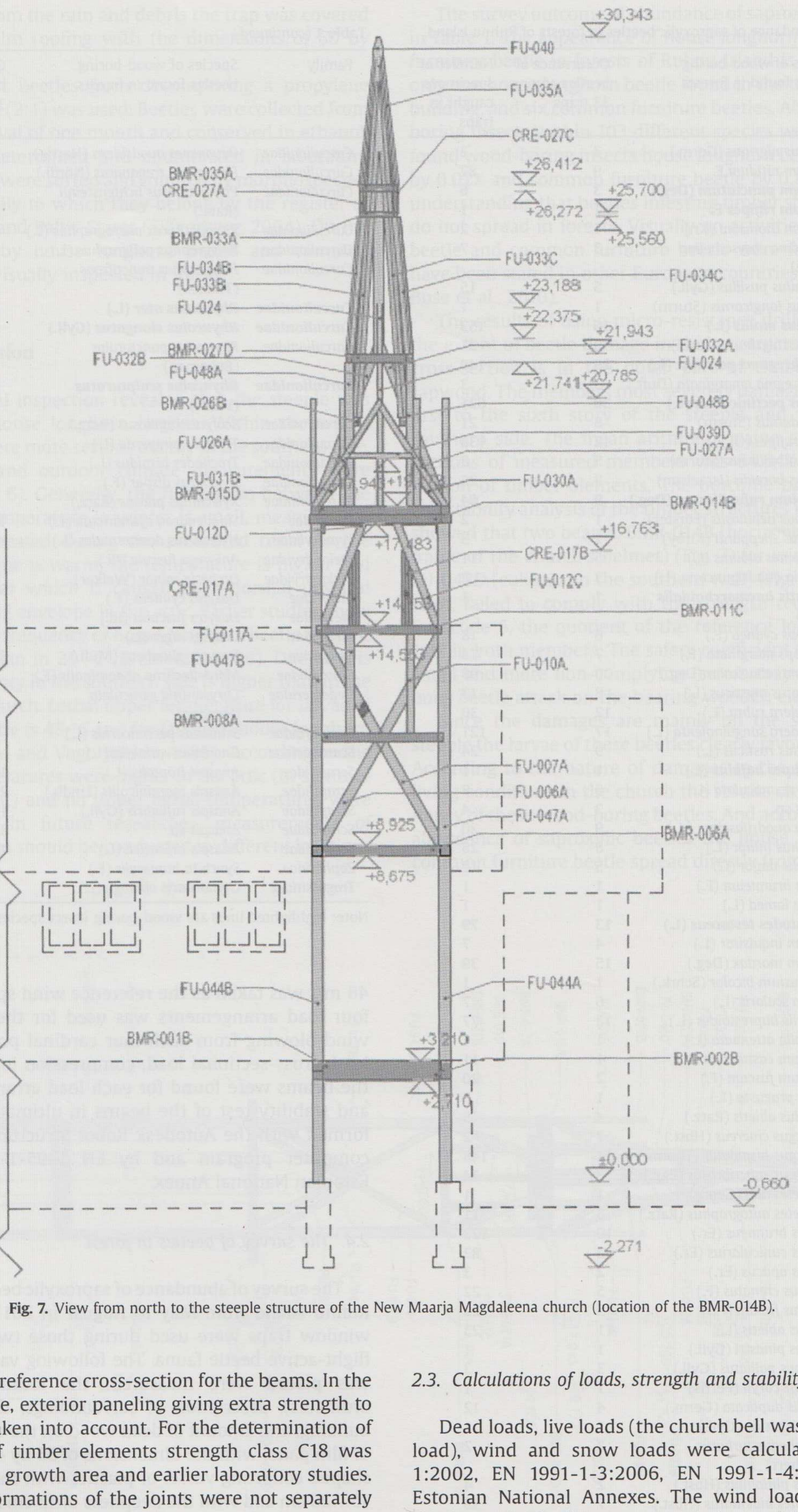

Fig. 7. View from north to the steeple structure of the New Maarja Magdaleena church (location of the BMR-014B).

found was used as the reference cross-section for the beams. In the modeling of the steeple, exterior paneling giving extra strength to the steeple was not taken into account. For the determination of strength properties of timber elements strength class C18 was assigned based on the growth area and earlier laboratory studies. The strength and deformations of the joints were not separately calculated.

2.3. Calculations of loads, strength and stability of structures

Dead loads, live loads (the church bell was considered as static load), wind and snow loads were calculated by EN 1991-1-1:2002, EN 1991-1-3:2006, EN 1991-1-4:2007, applying the Estonian National Annexes. The wind load was taken as the dominant load. The greatest wind speed in the last 50 years,

Table 1
The survey results of abundance of saproxylic beetles in forests of Ruhnu Island.

Family	Species of wood-boring beetles found in forests	Occurrence of beetles among 33 traps	Number of specimens caught in traps
Aderidae	*Anidorus nigrinus* (Germ.)	3	3
Anobiidae	*Anobium nitidum* F.	9	82
Anobiidae	***Anobium punctatum* (Deg.)**	**3**	**6**
Anobiidae	***Anobium rufipes* F.**	**1**	**1**
Anobiidae	*Anobium thomsoni* (Kr.)	1	2
Anobiidae	*Dorcatoma chrysomelina* (Sturm)	3	7
Anobiidae	*Dryophilus pusillus* (Gyll.)	5	15
Anobiidae	*Ernobius longicornis* (Sturm)	1	1
Anobiidae	***Ernobius mollis* (L.)**	**16**	**153**
Anobiidae	*Ernobius nigrinus* (Sturm)	8	21
Anobiidae	***Hadrobregmus pertinax* (L.)**	**29**	**140**
Anobiidae	*Microbregma emarginata* (Duft.)	3	3
Anobiidae	***Ptilinus pectinicornis* (L.)**	**30**	**621**
Anobiidae	*Ptinus dubius* (Sturm)	8	21
Anobiidae	*Ptinus rufipes* (Ol.)	12	138
Anobiidae	*Ptinus subpillosus* (Sturm)	5	8
Anobiidae	*Stagetus borealis* (Israelson)	3	25
Anobiidae	***Xestobium rufovillosum* (Deg.)**	**9**	**64**
Anthribidae	*Anthribus nebulosus* (Forster)	1	2
Anthribidae	*Choragus sheppardi* (Kirby)	2	3
Anthribidae	*Platystomos albinus* (L.)	5	11
Buprestidae	*Anthaxia quadripunctata* (L.)	3	8
Buprestidae	***Buprestis haemorrhoidalis* (Hbst.)**	**1**	**1**
Buprestidae	*Phaenops cyanea* (F.)	6	18
Cerambycidae	*Acmaeops marginata* (F.)	7	73
Cerambycidae	*Alosterna tabacicolor* (Deg.)	20	98
Cerambycidae	*Anaglyptus mysticus* (L.)	8	13
Cerambycidae	*Anoplodera rubra* (L.)	12	30
Cerambycidae	*Anoplodera sanguinolenta* (L.)	17	121
Cerambycidae	*Arhopalus rusticus* (L.)	9	24
Cerambycidae	***Hylotrupes bajulus* (L.)**	**1**	**1**
Cerambycidae	*Judolia sexmaculata* (L.)	6	8
Cerambycidae	*Leiopus* sp.	3	4
Cerambycidae	*Leptura quadrifasciata* (L.)	9	20
Cerambycidae	*Molorchus minor* (L.)	8	25
Cerambycidae	*Necydalis major* (L.)	5	12
Cerambycidae	*Obrium brunneum* (F.)	1	1
Cerambycidae	*Pachyta lamed* (L.)	1	1
Cerambycidae	***Phymatodes testaceus* (L.)**	**13**	**79**
Cerambycidae	*Rhagium inquisitor* (L.)	4	7
Cerambycidae	*Rhagium mordax* (Deg.)	15	39
Cerambycidae	*Rhamnusium bicolor* (Schrk.)	1	1
Cerambycidae	*Saperda scalaris* (L.)	6	7
Cerambycidae	*Spondylis buprestoides* (L.)	12	77
Cerambycidae	*Strangalia attenuata* (L.)	1	1
Cerambycidae	*Tetropium castaneum* (L.)	1	11
Cerambycidae	*Tetropium fuscum* (F.)	2	20
Cerambycidae	*Tetrops praeusta* (L.)	1	3
Curculionidae	*Cryphalus abietis* (Ratz.)	4	5
Curculionidae	*Crypturgus cinereus* (Hbst.)	2	2
Curculionidae	*Crypturgus hispidulus* (Thoms.)	11	148
Curculionidae	*Crypturgus subcribrosus* (Egg.)	5	14
Curculionidae	*Dryocoetes alni* (Georg)	1	1
Curculionidae	*Dryocoetes autographus* (Ratz.)	5	11
Curculionidae	*Hylastes brunneus* (Er.)	10	123
Curculionidae	*Hylastes cunicularius* (Er.)	2	82
Curculionidae	*Hylastes opacus* (Er.)	2	3
Curculionidae	*Hylesinus crenatus* (F.)	5	22
Curculionidae	*Hylesinus fraxini* (Pz.)	5	22
Curculionidae	*Hylobius abietis* (L.)	11	23
Curculionidae	*Hylobius pinastri* (Gyll.)	1	1
Curculionidae	*Hylurgops palliatus* (Gyll.)	3	3
Curculionidae	*Lymantor coryli* (Perris)	1	1
Curculionidae	*Magdalis duplicata* (Germ.)	4	12
Curculionidae	*Magdalis nitida* (Gyll.)	1	1
Curculionidae	*Phloeophagus turbatus* (Schönherr)	2	2
Curculionidae	*Pissodes piniphilus* (Hbst.)	2	4
Curculionidae	*Pityogenes bidentatus* (Hbst.)	7	39
Curculionidae	*Pityogenes chalcographus* (L.)	2	2
Curculionidae	*Pityogenes quadridens* (Hartig)	5	15
Curculionidae	*Pityogenes trepanatus* (Nördl.)	5	57
Curculionidae	*Pityophthorus lichtensteinii* (Ratz.)	5	9
Curculionidae	*Pityophthorus micrographus* (L.)	7	11
Curculionidae	*Polygraphus poligraphus* (L.)	5	7
Curculionidae	*Polygraphus punctifrons* (Thoms.)	2	2
Curculionidae	***Rhyncolus ater* (L.)**	**4**	**4**
Curculionidae	***Rhyncolus elongatus* (Gyll.)**	**8**	**51**
Curculionidae	*Rhyncolus punctatulus* (Boheman)	2	3
Curculionidae	***Rhyncolus sculpturatus* (Waltl)**	**8**	**35**
Curculionidae	*Scolytus rugulosus* (Ratz.)	1	1
Curculionidae	*Tomicus piniperda* (L.)	2	2
Curculionidae	*Trachodes hispidus* (L.)	5	5
Curculionidae	*Xyleborus dispar* (F.)	3	5
Curculionidae	*Xylechinus pilosus* (Ratz.)	2	2
Lucanidae	*Sinodendron cylindricum* (L.)	16	94
Lymexylidae	*Hylecoetus dermestoides* (L.)	1	1
Melandryidae	*Anisoxya fuscula* (Ill.)	3	3
Melandryidae	*Orchesia minor* (Walker)	8	18
Melyridae	*Dasytes cyaneus* (F.)	2	2
Melyridae	*Dasytes fusculus* (Ill.)	1	1
Melyridae	*Dasytes niger* (L.)	9	85
Melyridae	*Dasytes plumbeus* (Müll.)	33	1220
Mordellidae	*Mordellochroa abdominalis* (F.)	1	1
Oedemeridae	*Chrysanthia geniculata* (Heyden)	5	11
Pyrochroidae	*Schizotus pectinicornis* (L.)	8	28
Scarabaeidae	*Gnorimus variabilis* (L.)	4	9
Scraptiidae	*Anaspis frontalis* (L.)	16	70
Scraptiidae	*Anaspis marginicollis* (Lindb.)	20	80
Scraptiidae	*Anaspis rufilabris* (Gyll.)	10	16
Scraptiidae	*Anaspis* sp.	33	206
Scraptiidae	*Anaspis thoracica* (L.)	13	60
Zopheridae	*Synchita humeralis* (F.)	4	12
Trogossitidae	*Grynocharis oblonga* (L.)	1	1

Note: highlighted lines are wood-boring insect species found in buildings.

48 m/s was taken as the reference wind speed. A combination of four load arrangements was used for the wind load, with the wind blowing from each four cardinal points, and the bending load, cross-sectional load, compression load and tensile load of the beams were found for each load arrangement. The strength and stability test of the beams in ultimate limit state was performed with the Autodesk Robot Structural Analysis version 22 computer program and by EN 1995-1-1:2007, applying the Estonian National Annex.

2.4. The survey of beetles in forest

The survey of abundance of saproxylic beetles was conducted on Ruhnu Island from May to August in 2011 and 2012. 33 trunk-window traps were used during those two years to survey the flight-active beetle fauna. The following variables where the trap was placed were measured: the location (geographical coordinates), description of surroundings, distance to the closest building, and amount of dead wood on the tree. The trap consisted of film panel with the dimensions of 55 by 45 cm, and a rectangle-shaped collecting vessel of plastics with the dimensions of 55 by 15…20 cm and with the deepness of 13 cm (Fig. 4). Timber-framed trap was fixed by a metal rod to the tree trunk about 1.3 m above ground. To protect it from the rain and debris the trap was covered with a polyethylene film roofing with the dimensions of 60 by 60 cm.

In order to prevent beetles from decomposing a propylene glycol aqueous solution (2:1) was used. Beetles were collected from the traps with an interval of one month and conserved in ethanol. Later on they were determined and enumerated in laboratory conditions. Individuals were sorted and counted by morphospecies, also recording the family to which they belong by the register of Fennoskandia, Danish and Baltic States (Silfverberg, 2004). During the survey damages by house longhorn beetle and common furniture beetle were visually inspected in forest.

3. Results and discussion

The results of visual inspection revealed that the steeple was mainly damaged by house longhorn beetles. Within the whole church the damages were more serious mainly in the southern side. Indoor microclimate and outdoor climate measurements were compared (Figs. 5 and 6). Generally, the fluctuation between the indoor and outdoor temperature in winter is small, meaning that the church was not heated during the measured time. As the weather in summer time is warm, the temperature is higher and relative humidity lower which is caused by a normal physical performance in building envelope in the attic. Earlier studies show that stridulation sound frequency of house longhorn beetle in 30 °C is 1.82 times higher than in 20 °C (Breiobach, 1986). Due to this finding the boring activity in the southern side is higher than in the northern side of the church. Lethal upper temperature for larvae of common furniture beetle is 48 °C and for larvae of house longhorn beetle is 55 °C (Hansen and Vagn Jensen, 1996). According to the Figs. 5 and 6 the temperatures were higher in the attic (in summer time mostly over 20 °C) and no upper lethal temperatures were measured. Therefore, in future researches, measurements of microclimate conditions should be conducted in different locations of cardinal points.

The survey outcome of abundance of saproxylic beetles is shown in Table 1. The appearance of house longhorn beetle and common furniture beetle in forests of Ruhnu Island is very low. There was only one house longhorn beetle found in the trap that was near the building, and six common furniture beetles. Altogether 4678 wood-boring insects within 103 different species were found. Among all found wood-boring insects house longhorn beetle was represented by 0.02% and common furniture beetle by 0.13%. This refers to an understanding that beetles infesting timber structures in buildings do not spread in forests. Visually no activities by house longhorn beetle and common furniture beetle were found. Similar results have been stated in other European countries (Bouget et al., 2009; Buse et al., 2010).

The results of using micro-resistance drilling method revealed the extent of beetle damage in timber structures. The main loss in cross-section is in the outer part of timber elements, mainly sapwood. The members most severely damaged were found on the first to the sixth story of the steeple and were mainly on the southern side. The mean arithmetic value of the residual cross-sections of measured members was 84.64% of the initial cross-section of timber elements. The outcome based on the strength and stability analysis of the timber structures in ultimate limit state showed that two beams, BMR-014B (horizontal beam of the lower frame of the church's helmet) (Fig. 7) for wind from the east and FU-048D (column on the southern wall) (Fig. 8) for wind from the west, failed to comply with the strength requirements based on Eurocode 5, the quotient of the reference load and strength was 1.02 in both members. The safety coefficient of several beams was small and more non-complying factors may appear upon continuous beetle attack on the bearing wooden elements.

Since the damages are mainly on the southern side of the steeple the larvae of these beetles clearly favor higher temperature. According to the nature of damages to the timber elements and living conditions in the church the results clearly favor the inhabitancy of these wood-boring beetles. And according to the survey of abundance of saproxylic beetles the house longhorn beetle and common furniture beetle spread directly from building to building

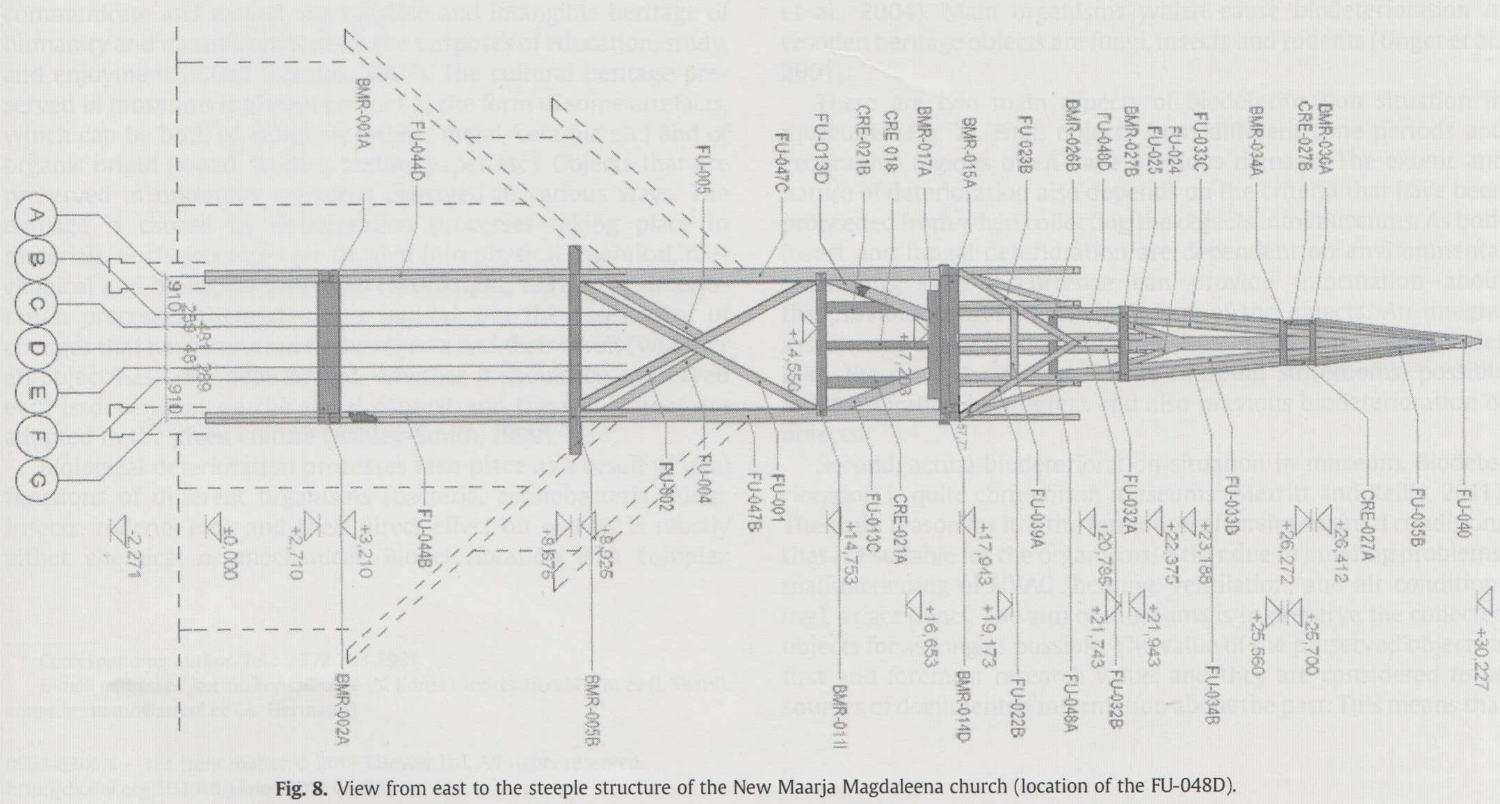

Fig. 8. View from east to the steeple structure of the New Maarja Magdaleena church (location of the FU-048D).

rather than through forests. Therefore, instead of diminishing population in forests, it should be done in the buildings on the island in order to subject the problem under control. The ecosystem of islands are generally closed, thus, the spreading of these beetles to the Ruhnu Island can only be accidental. Generally, the domination of different species of beetles on different islands is caused by occasions and suitable living conditions.

4. Conclusions

This study concludes the following statements:

- There are no boring activity traces by house longhorn beetle and common furniture beetle in forests of Ruhnu Island, thus, they are not able to hibernate in forest. These beetles rather spread from building to building, thus, instead of diminishing population in forest it should be done in the buildings on the island.
- With non-destructive assessment and modeling of steeple structures along with strength calculations it is possible to save more existing timber elements and reinforce structures with sustainable methods.

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References

Bravery, A.F., Berry, R.W., Carey, J.K., Cooper, D.E., 2003. Recognising Wood Rot and Insect Damage in Buildings. BRE Bookshop, London.

Breiobach, O., 1986. Studies on the stridulation of *Hylotrupes bajulus* (L.) (Cerambycidae, Coleoptera): communication through support vibration – morphology and mechanics of the signal. Behav. Processes 12, 169–186.

Buse, J., Levanony, T., Timm, A., Dayan, T., Assmann, T., 2010. Saproxylic beetle assemblages in the Mediterranean region: Impact of forest management on richness and structure. Original Research Article. Forest Ecol. Manag. 259, 1376–1384.

Bouget, C., Brustel, H., Brin, A., Valladares, L., 2009. Evaluation of window flight traps for effectiveness at monitoring dead wood-associated beetles: the effect of ethanol lure under contrasting environmental conditions. Agri. Forest Entomol. 11, 143–152.

EN 1991-1-1, 2002. Actions of Structures. General Actions. Densities, Self-weight, Imposed Loads for Buildings. European Committee for Standardization, Brussels, Belgium.

EN 1991-1-3, 2006. Actions on Structures. General Actions. Snow Loads. European Committee for Standardization, Brussels, Belgium.

EN 1991-1-4, 2007. Actions on Structures. General Actions. Wind Actions. European Committee for Standardization, Brussels, Belgium.

EN 1995-1-1, 2007. Design of Timber Structures. General. Common Rules and Rules for Buildings. European Committee for Standardization, Brussels, Belgium.

Hansen, L.S., Vagn Jensen, K.-M., 1996. Upper lethal temperature limits of the common furniture beetle Anobium punctatum (Coleoptera: Anobiidae). Original Research Article. Int. Biodeterior. Biodegradation 37, 225–232.

Kotlinova, M., Kloiber, M., Vasconcelos, G., Lourenco, P.J.B.B., Branco, J.M.G., 2008. Non-destructive Testing of Wood. Portugal.

Larsen, K.E., Marstein, N., 2000. Conservation of Historic Timber Structures. Reed Educational and Professional Publishing Ltd, Great Britain.

Noldt, U., 2009. Report on visit of the two churches of the Island of Ruhnu/Estonia. In: Estonian Open Air Museum FaBBi Project Proceedings. Tallinn.

Noy, E.A., Douglas, J., 2005. Building Surveys and Reports, third ed. Blackwell Publishing Ltd, Great Britain.

Parmakson, T., Danil, A., 1997. Ruhnu Uus Kirik. Puitkonstruktsioonide Tehnilise Seisukorra Ülevaatus. A-4036. State Archives, Tallinn.

Querner, P., Simon, S., Morelli, M., Fürenkranz, S., 2013. Insect pest management programmes and results from their application in two large museum collections in Berlin and Vienna. Int. Biodeterior. Biodegradation 84, 275–280.

Silfverberg, H., 2004. Enumeratio nova coleopterorum Fennoscantiae, Daniae et Baltiae. Sahlbergia 9, 1–111.