Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites

Final report

EVK4-CT-2001-00043

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Bacpoles

Final report
(with eight appendices)

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Front cover: (picture left: foundation piles under family house (1937) Koog aan de Zaan, the Netherlands; upper picture middle row: foundation piles under Ponte Balbi, Venice, 16th century, Italy; middle picture middle row: foundation Medieval Castle, Travenhorst, Germany; lower picture middle row: Roman ship and embankment piles, Leidsche Rijn, the Netherlands; picture right: foundations under Parliament Stockholm, 1894, Sweden

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Summary

From February 2002 to January 2005, the European Commission funded a scientific project with the title “Preserving cultural heritage by preventing bacterial decay of wood in foundation piles and archaeological sites”, EU number “ EVK4-2001-00043” with the acronym or work name “BACPOLES “.

For a long time it was believed that storage in water or use below the ground water table prevents wood from biological degradation. However in the 1990ies serious problems with Dutch wooden foundation piles, were caused by bacteria. This shows that bacterial wood degradation should be regarded as a serious problem when dealing with wooden constructions under water and that even wooden objects other than foundations could be affected. In contrast to fungal degradation where the economical impact was realised a long time ago, research on bacterial degradation had until now low priority and therefore little knowledge was available on the process.

Objectives
One of the main objectives of BACPOLES was to provide basic knowledge on the impact of bacterial degradation on wood stored under different environmental conditions like foundations and archaeological wooden remains. Another issue was to protect wood under water against bacterial decay and to develop practical preservation methods for wooden foundations. In the last decades, scientists from all over the world did not succeed in identifying wood degrading bacteria. Yet, to understand the process of degradation the identification is crucial. Hence, the isolation and identification of wood attacking bacteria was one of the main challenges of the project.

Contributions
Experts on wood and soil sciences as well as microbiologists, archaeologists and geophysicists from Germany, Great Britain, Italy, The Netherlands, and Sweden collaborated in this project. The universities and research institutes concentrated on fundamental research whereas the companies were responsible for the in-situ investigation of wooden foundations and the incorporation of new technologies for wood preservation into existing techniques.

Methods
In all five collaborating European countries inquiries were made on the impact of bacterial degradation on wood stored in sediment. Based on scientific and local reports as well as on interviews with archaeologists and wood constructors it has to be concluded that bacterial wood degradation is not recognised as an important threat to wood stored in sediments, in 3 of these 5 countries. Mainly in the Netherlands the importance of this type of wood degradation is realised.
A standard procedure was developed to study the impact of bacterial degradation in different environments. Research was carried out at 27 sites in six European counties. There were 13 piling sites, of which two were older than 250 years, five marine sites and 9 archaeological sites. It was assured that bacterial wood degradation could be expected. At all sites wood, soil, and water samples were taken and analysed and an environmental characterisation was made based on visual observations and field measurements. During the project it became evident that seasonal dynamics could be of importance and therefore two long-term-field-measurements were carried out additionally throughout a period of 12 months.
Wood samples were taken to isolate and identify wood degrading bacteria. Because no standard techniques were available, the main effort of the microbiologists was the development of new methods.
Already in the beginning of the project microcosms were installed to simulate bacterial wood degradation in the laboratory to learn more about the process of degradation by manipulating the sediment conditions.

Results

The results from the 27 sampled sites indicate no justification to ignore the impact of bacterial wood degradation for piling constructions and archaeological remains. The concern for wood foundation as appeared in the Netherlands and a little bit in Sweden, should also be aware in the rest of Europe. Especially in Venice the role of bacterial wood degradation is considerably underestimated.

With new techniques it was possible to isolate consortia of bacteria which cause wood degradation. It became obvious that there is a wide variety in novel species and that these species belong to the CFB (*Cytophaga-Flavobacterium-Bacteroides*) complex. The bacteria are mobile by gliding. The shape of wood degrading bacteria varies, they can be short and thick as well as long and thin rods, but they can also be round. Each of the wood degrading bacteria species seems to have its own environmental amplitude, suggesting that bacterial wood degradation occurs under a wide range of soil conditions which was actually confirmed by the presence of bacterial wood degradation in all sampled sites. Additional research showed that wood degrading bacteria are present in all watery environments. Consequently, the infection (always from the outside inwards) with wood degrading bacteria is not the important factor, but the intensity of the degradation. The characteristic factor for wood degrading bacteria is that they can live or even need to live in environments with low nitrogen and oxygen contents. The natural nitrogen content in wood is typically low and in combination with the absence of oxygen, wood degrading bacteria are able to adapt to these circumstances as one of few micro-organisms. Although no relation was found between the degree of degradation and the sediment, shortage of nutrients seems to promote the degree of bacterial wood degradation. Furthermore it is evident that the intensity of degradation differs with timber species. Wood structures with a low resistance against water transport like alder, poplar and the sapwood of pine and oak are much more susceptible to bacterial decay than wood structures with a high resistance like spruce, and the heartwood of pine and oak. The reason behind this is not fully understood while it seems that the process of degradation is not only stimulated by a unidirectional water stream through the wood but also by an oscillating water flux inside the wood. Beside permeability it was already known that also lignin content determines whether a wood species is susceptible to bacterial decay. Pine and spruce have higher contents than alder and poplar. Furthermore it was proven that oak heartwood is very resistant against wood degrading bacteria.

Outlook

The methods and knowledge built up as well as promising preservation techniques tested already under laboratory conditions in BACPOLES enable us to start preservation tests in the field. There are three promising approaches and for all the approaches it is necessary to make a full description of the field to be treated. The site hydrology as well as the identification of the bacteria consortium, which causes bacterial degradation, is most important. Conventional as well as in this project developed methods should be used. Based on these inquiries specific mixtures of phages can be made and tested in the field on its generality and efficiency using monitoring techniques as developed in this project. A second approach is related to the hydrology. It became clear that bacterial wood degradation is mainly active when there is a water flux through the wood. In order to investigate a static situation, either the hydrology can be manipulated or the wood can be impregnated in the field to close its structure or both strategies can be combined with such a result that in addition the strength of the wood is improved. As the efficiency of all conventional wood preservatives against bacteria is not reliably proved, a third approach should be tried using an active product, which is not toxic but affects the already weak competition position of wood degrading bacteria by promoting others.

It can be concluded that the impact of bacterial wood degradation for our European cultural heritage is underestimated and methods are available to carry out a test program with promising preservation methods in the field.

Keywords
Wood degrading bacteria, wooden foundations, archaeological wood, DNA identification, phages, wood conservation, wood preservation

Content

Chapter 1

Introduction

(by Klaassen)

This project was funded by the European Commission and was carried out from February 2002 till January 2005.

Submerged wood was previously considered to be safe from any form of fungi decay due to the absence of oxygen. In the eighties of last century it became clear that bacteria could be active in these conditions and although the process of bacterial wood degradation is slow it is a threat for timber which is stored in the soil under the ground water level over a longer time. This is the case for wooden foundation piles but because time is almost unlimited within archaeology, the process of bacterial wood degradation in this field forms a special threat for wooden remains.
Wooden foundations have traditionally been used in areas with weak soils to support buildings, many of which are of historic importance. Well-known examples are the buildings in Venice (e.g. Santa Maria Della Salute church on 1.150.657 piles; Rialto bridge on 120.000 elm piles), Sint Petersburg (Hermitage), Berlin (Reichstag), Scandinavia (Gothenburg, Stockholm, Helsinki) and the Netherlands (Palace in Amsterdam on 14.000 piles).
Over the last three decades more and more wooden foundations (in different locations throughout Europe) were found where piles were seriously damaged by biological attack like in Stockholm (Sweden) and Haarlem (The Netherlands). If this process of bacterial degradation can continue over decades many monumental buildings standing on wooden piles might need expensive foundation repair or even be severely damaged. An inventory was therefore needed to know what the impact is of this relatively new form of decay for the European situation.
Archaeological wood is conserved either in dry or very wet environments (under surface water or ground water) and is of great importance because it provides us with information about the life style of our ancestors and sometimes even about the past climate (tree ring sequences, Bailey 1993). Not all archaeological sites found are automatically excavated because of missing funding or the lack of appropriate techniques to do a full analysis on the whole site. In order to save the information, which is inside the wood, it has to be protected against bacterial degradation.

Before the start of this project the knowledge on the process of bacterial degradation was limited and wood attacking bacteria had not been isolated nor identified. All information available was based on empirical results of the morphology of the bacteria and the patterns of degradation in the wood.
The main aim of this project was therefore to isolate and identify wood degrading bacteria and to get an idea of the impact of bacterial degradation as threat for wooden foundations under monumental buildings and for wood in archaeology. To understand the ecology and the mechanisms of degradation of the bacteria laboratory experiments were carried out and many sites spread all over Europe were sampled and the environment in which bacterial wood degradation occurred was characterised.
Based on all gathered information environmentally friendly concept conservation techniques were developed and tested on laboratory scale.

In chapter 2, as a state of the art an overview is given of the present knowledge of the impact of bacterial wood degradation in the countries of the participants of the project, i.e. Germany, Great Britain, Sweden, Italy and the Netherlands. Chapter 3 describes the standardised sampling and analyses method, which was used for 27 sites. Each site is characterised and based on the results of the wood, soil and water analyses general trends are discussed. Chapter 4 is dealing with new developed isolation and identification techniques and describes the environment of the bacterial species found in relation to wood degradation. Several microcosm experiments with wood degrading bacteria are described in chapter 5 and conclusions on the environmental interactions with wood degrading bacteria are discussed. Chapter 6 deals with water flow through wooden piles. It describes the experiments and discusses the results in relation to velocity of bacterial wood degradation. As the behaviour of sulphur in the soil seems to be linked in one way or another with the

process of bacterial wood degradation some background information is given on this element in chapter 7. In the final chapter 8 general conclusions are made and concept conservation techniques are proposed.