

## DONIESIENIA – REPORTS

**Iwona POMIAN, Andrzej FOJUTOWSKI,  
Hanna WRÓBLEWSKA, Magdalena KOMOROWICZ,  
Aleksandra KROPACZ, Andrzej NOSKOWIAK**

### RESEARCH ON WOOD SUBMERGED IN THE SEA

*The Polish Maritime Museum in Gdansk participated in the EU project MACHU aiming at creation of a system of location, making information on European subaqueous maritime cultural heritage available and dissemination of it. 7 EU countries co-operated in the project. The Wood Technology Institute contributed to research on durability of small oak wood samples submerged in the sea. The samples were considered bioindicator of changes. The outline of research in the project is presented below.*

**Keywords:** marine research, cultural heritage, wood, oak, bioindicator

Subaqueous cultural heritage is rich and diverse, and in many places in Europe also well preserved. European history is closely connected with its maritime heritage. Unfortunately, we do not know much about subaqueous cultural heritage, because usually it is invisible and almost inaccessible. The advantage of

---

Iwona POMIAN, Polish Maritime Museum, Gdansk, Poland

e-mail: i\_pomian@cmm.pl

Andrzej FOJUTOWSKI, Wood Technology Institute, Poznan, Poland

e-mail: A\_Fojutowski@itd.poznan.pl

Hanna WRÓBLEWSKA, Wood Technology Institute, Poznan, Poland

e-mail: H\_Wroblewska@itd.poznan.pl

Magdalena KOMOROWICZ, Wood Technology Institute, Poznan, Poland

e-mail: M\_Komorowicz@itd.poznan.pl

Aleksandra KROPACZ, Wood Technology Institute, Poznan, Poland

e-mail: A\_Kropacz@itd.poznan.pl

Andrzej NOSKOWIAK, Wood Technology Institute, Poznan, Poland

e-mail: A\_Noskowiak@itd.poznan.pl

this situation is that submersed in water for centuries remains of maritime floating objects and loads carried by them were naturally protected from treasure hunters. However, contemporary, dynamic development of new technologies makes the subaqueous heritage more accessible, but also more threatened. In the case of popular, well-known locations of underwater objects pillage poses a serious problem, and projects assuming commercial exploitation also use a valuable source of knowledge about the location of objects. Hitherto subaqueous cultural heritage management was not based on any special planning or coordination; although in some places it was effective thanks to a database of locations. Still, the level of understanding of fundamental processes (regional as well as local) that threaten the underwater sites is limited. Better understanding of the process of creation and changing of the sites is necessary because of more and more popular national and international policy consisting in preservation, conservation, and management of the sites *in situ* (ICOMOS Charter, UNESCO Convention, 2001). In the framework of the European Union Programme "CULTURE 2000" the project on Managing Cultural Heritage Underwater (MACHU) was undertaken. The participants of the project were Belgium, Germany, the Netherlands, Poland, Portugal, Sweden, and Great Britain, thus countries located on the routes of the sea coast that for centuries were very important for the development of Europe. The Programme commenced in September 2006 and ended in August 2009. The Polish Maritime Museum in Gdansk represented Poland in the project.

The essential aim of MACHU project was to make the information on cultural heritage underwater available to the academia, strategy creators, and a wide public. It was possible thanks to creation, on a basis of Geographic Information System (GIS), of a Decision Support System that operates as a database used in research and an Internet tool which allows broader access to resources of data on subaqueous heritage. Special benefits for the academia consist in improvement of data and information exchange which will help promoting research connections between particular countries. On a wider European base the information on the condition of sites located at the sea bottom and on development of the research project will become more available to the academia. Thanks to this it will be possible to avoid copying in the field of research and management methods.

Devastation of underwater sites in large part is invisible to a wide public, thus gaining support for implementation of legal remedies is difficult. It is assumed that if the information on the sites is made available to wider groups, the society will better understand the need for protection of the sites and it will be easier to promote involvement for support of this protection. Additionally the fact that representatives of many countries are involved in this matter will be adequately promoting higher mobility of both information and researchers who deal with common subaqueous cultural heritage. Due to these reasons the project

is a significant contribution to cultural dialog and mutual knowledge about culture and history of the partner countries.

In the framework of MACHU project GIS application and archaeological and historical information from sites and locations are set against information concerning natural environment (including geophysical, geochemical data on sedimentation and oceanographic data) and against threats to the sites that may occur in the short-term (e.g. erosion, works connected with infrastructure construction, mining, and fishery) and in the long-term (e.g. stronger erosion due to climate change and deterioration of chemical composition).

A special emphasis was put on physical control of creation and management of sites, including development of erosion and sedimentation models. These models will be developed on a regional (through manipulation of data inside GIS system) and local scale as well.

It was especially stressed that final Internet-based GIS application becomes a basic tool for culture professionals from all over Europe to manage the underwater sites effectively. This part of the project should be continued in the future in particular countries as well as on the ground of international co-operation. The goal should be development of a Decision Support System that will integrate knowledge based on ongoing processes with information on legal status and management of a site, as well as potential impact of human on any site or environment (e.g. from local or regional perspective).

The Polish Maritime Museum in co-operation with the Polish Geological Institute – Marine Geology Branch, which was a subcontractor of the Polish Maritime Museum, carried out the following tasks in the project:

- collection, compilation and processing of geological and bathymetric data in GIS format,
- collection of data on investment works (deepening, port expansion, fishery, beach reclamation, etc.) and converting it into GIS format,
- palynological analysis with the view of reconstructing paleogeographic areas covered by research,
- interpretation and visualisation of collected geological, bathymetric and archaeological data.

Research was conducted in three areas: “Ustka”, “Puck”, and “Gdansk”.

Marine field works encompassed geophysical research and collection of cores with a vibrocorer. Geophysical research aimed at determination of the features of the bottom and definition of its shallow geological structure. To this end bathymetric measurements were conducted, sonar picture was taken, and seismoacoustic profiling was done.

The interpretation of all the results obtained within the subject leads to a conclusion that researched areas are interesting fields for archaeological research.

The test area “Ustka” was at the shore of the Ancylus Lake, but it was not covered by the lake. It developed on the land until around 8200 years BP, when it was flooded by the Littorina Sea. For sure during this process part of older sediments of land habitats was destroyed. However, due to specific shape and development of the shoreline the extent of erosion processes accompanying the transgression was limited and relicts of land habitats’ sediments were preserved on this area. The known extent of the early Holocene lake reservoirs allows precise location of future areas where artefacts from the Paleolithic will be searched for [Uścińowicz 2003, Miotk-Szpiganowicz et. al. 2009].

Puck was located in the area, which in the Middle Ages belonged to the family of Sobiesławicowie, the deputies of the king Bolesław Krzywousty, sent to the Gdańsk Pomerania after 1116, in order to strengthen his connections with Poland. Location of the oldest land properties of Sobiesławicowie is based on the foundation privilege of the Oliwa Monastery. It is the earliest document written on the area of the Gdańsk Pomerania, known today, now available only in a form of a forgery from the forties of the XIII century, but based on the unpreserved original from ~1186 [Śliwiński 1998].

The archaeological site was discovered in 1977 by amateur scuba divers. During preliminary excavation in Puck Lagoon a massive system of timber structures, fascine and stone as well as earthen embankments were found scattered over an area of more than 12 hectares.

Looking at the chronological arrangement of site, slowly created on the basis of obtained dendrochronological analysis result, and supplemented with a radiological research, it should be assumed that the northern strip of the construction is a continuation of the quay strengthening construction, the root of harbour pier. It is probably the earliest stage in the development of the Puck harbour.

Taking into both the layout of the construction working as defences of the swampy alluvial estuary of the Płutnica river parallel in relation to the present coastline as well as chronological layout of the stand which gets younger and younger the closer you get to the present shore it may be assumed that the changes of location of the port construction were influenced by quite quick deepening of the basin and movement of Medieval shore line. During the inventory of the archaeological structures visible on the surface the archaeologists came to the conclusion that its unusual size may be connected with the movement of the coastline of the Puck Bay in the early Medieval times and gradual flooding of the coastal parts which in turn forced the necessity of building new coastal defences as well as the location changes of the fishing and boat building hinterland.

The test area “Puck” is, together with all the Zalew Pucki (the Puck Lagoon), the most prospective area for archaeological research in the Polish coastal zone

of the Baltic Sea. It is known that in the early Holocene this area was covered with peat bogs, wetland and lake reservoirs. The first inflows of sea water, recorded only in the deepest part of the Zalew Pucki (Puck Lagoon), i.e. in the Jama Kuźnicka, occurred no earlier than 7200–7000 years BP, when the water level in the Gulf of Gdansk was approximately 13–12 metres lower than it is today [Uścińowicz 2003]. The sea inflows causing gradual conversion of the whole area of the contemporary Lagoon into a brackish water lagoon did not occur before 5500 years ago [Uścińowicz, Miotk-Szpiganowicz 2003]. That lagoon was protected from the sea inflows by the strengthening sandy barrier of the contemporary Hel Peninsula on the one side and the Rewę Mew (Seagull Reef) on the other, and this had a bearing on the low intensity of erosion processes. Low thickness of the lagoon sediments is the reason why the contemporary bottom of the Zalew Pucki (Puck Lagoon), is at the same time the Paleolithic surface from before ca. 5500 years. Taking this into consideration archaeological artefacts from the Paleolithic to the Neolithic inclusive may be found at the surface of the Zalew Pucki (Puck Lagoon) bottom, especially on the areas shallower than around 3 m [Miotk-Szpiganowicz et al. 2009].

The test area “Gdansk” is located within the underwater part of the mouth cone of Wisła Martwa (the Dead Vistula).

Gdansk was founded in 980 as a defensive port and a stronghold with watch towers. Surrounded by the waters of the Vistula and the Motława and the swamps, Gdansk was 4 km away from the sea. Such a localization of the town let the inhabitants organize an effective defence against the attacks from land and sea. The mouth of the Vistula formed the sea-land junction of the Royal Way: Gdansk – Krakow – Hungary and the Merchants' Way.

In the thirteenth century about 800 meters of piers 3–6 m wide belonged to the port in Gdansk. In the seventeenth century the piers were 2,500 m long. The port was equipped with the craft and trade facilities, but the most significant feature, which made Gdansk the most important city at that time, was that it was both a sea and a river port. According to different sources, from 1555 to 1574 some 1,200 to 1,900 river boats entered the port.

The most serious problem in the port of Gdansk was to keep the homestead, the entrance to the port, and the canals deep enough for the ships to sail. Changes of depth was one of the reasons of sinking many ships around the old enter to the Gdańsk harbor.

In the seventeenth century the authorities of Gdansk tried to solve the problem definitely by digging the so called New Canal, which was 2 meters deep, 600 meters long, and 14–37 meters wide. In 1840 the hydro-graphic changes in the water gap of the Vistula River in the region of Gorki Wschodnie solved the problem of sliming the port of Gdansk [Pomian et.al. 2000, Pomian 2004].

The area of the estuary cone (delta front) is an unusually dynamic environment strongly dominated by sediment accumulation processes, but they are not constant in time and space. Migration of supply beds, floods, and storms are the reason why the internal structure of sediment layers forming the delta front is much diverse and heterogeneous.

The contemporary shoreline of the Wisła Martwa mouth cone is located from 2 to 3 km from the cone's base, i.e. from the shoreline from before 2000–3000 years, when the Vistula River created its estuary to the sea in the region of Gdansk. For over 2000 years the cone had been expanding to reach its maximum extent in the first half of the 19<sup>th</sup> century. Most probably the rate of the cone's expansion was not even for it was not the only estuary of the Vistula River to the sea. In all likelihood there were periods of the cone's accelerated expansion as well as stagnation. The analysis of historical maps confirms these assumptions [Miotk-Szpiganowicz et al. 2009].

Within the project other research was conducted as well and it concerned hydrodynamics of the Gulf of Gdansk [Robakiewicz 2009], analysis of sea oscillation in terms of wreck locating [Swerpel 2009], and changes in oak wood submersed in the sea [Wróblewska et al. 2009].

## **Test on submerged oak wood**

### **Introduction and test methods**

Due to its high density and high tannin content oak heartwood has been quite commonly used under conditions of much exposure to atmospheric and biological factors [class 4 acc. to PN-EN 335-2 and PN-EN 350-2]. The oak wood products that are archaeological objects buried in the ground or submerged in fresh or salt water (in the sea) demonstrate various stages of degradation by biological and physical factors. The environmental conditions at the sea bottom simultaneously preserve and destroy an object located there. Among other things the following factors are of importance: temperature and movement of water, its salinity and chemical composition, organism that are found in this environment and the depth to which the object is buried in the bottom sediments. Despite much research that has been conducted already, the knowledge about the rate and extent of changes occurring in oak wood as a result of its laying at the sea bottom is still incomplete, inter alia due to high diversity of environmental conditions characteristic of bottoms of different seas [Archaeological Wood... 1990; Björdal, Nilsson 2008]. For the first time in Poland in the framework of MACHU project broader research was undertaken with the aim to determine possibility of using test samples of oak wood as bioindicators of changes occurring in wood in sea environment – monitoring. Determinations and evaluation covered such areas as changes of physical and chemical properties, mass

loss, and susceptibility of submersed wood to decay caused by *Basidiomycetes*, after wood samples were taken out of the sea. Test samples of oak wood (250×10×10 mm) were placed in the coastal waters of the Baltic Sea in the area of medieval port in Puck and in the waters of the Gulf of Gdansk at the longitude of Orłowo (near the wreck of Swedish warship *Solen*). The samples were subjected to the following tests:

- a) organoleptic evaluation (appearance, surface condition and colour, and condition of edges), presence of microorganisms,
- b) mass loss, wood density [PN-77/D-04 101], moisture content in wood after taking out of the sea and equilibrium moisture content in wood [PN-EN 13 183-1] under standard climate conditions 20°C/65%,
- c) bending strength and modulus of elasticity at three-point bending [PN-77/D-04 103 and PN-77/D-04 117],
- d) content of major and minor constituents of wood by methods described by Prosiński [1984]:
  - moisture content by oven-dry method,
  - content of extraction substances by Soxhlet method (ethanol:benzene 1:1),
  - content of substances soluble in cold and hot water,
  - content of substances soluble in 1-percent NaOH,
  - cellulose content by Seifert method,
  - Klason lignin content by Tappi method,
  - content of pentosans by Tollens method,
  - ash content (in the temperature of 600°C),
  - pH determination (Gray method),
- e) resistance of wood to *Basidiomycetes* [PN-EN 113] using pure culture of *Trametes versicolor* (Linnaeus ex Fries) Pilat (CTB 863 A) fungus causing white rot of wood.

The properties of samples taken out of the sea after 6 and 12 months were compared with the properties of control (identical-twin) samples of oak wood that were not submersed.

## Test results and conclusions

The results of the tests led to a conclusion that submersion of oak wood in the waters of the Baltic Sea for a period from 0.5 to 1 year may have the following effects in the 10 mm-thick area of wood:

- decrease in bending strength (by ~20–40%) and modulus of elasticity of wood (by ~10–36%) connected with a loss of wood mass due to submersion of wood in the sea ( 2.8–14.1%),

- increase in moisture content to approximately 120%,
- decrease in wood density (by ~5 – 10%),
- much (20 – 30 times) increase in oak wood susceptibility to decay caused by *Basidiomycetes* – white rot fungi (*Trametes versicolor*),
- clear change of wood surface colour (from light to dark) and structure,
- increase in the content of mineral substances (ash), increase in pH value, and decrease in the content of substances soluble in water, ethanol-benzene mixture and 1-percent NaOH solution (table 1).

**Table 1. Changes of chemical composition in oak wood submersed in the test areas in Puck and Orłowo**

*Tabela 1. Zmiany składu chemicznego w drewnie dębu zatopionym na stanowisku w Pucku i Orłowie*

Tested property <i>Badana cecha</i>	Oak wood samples <i>Próbki drewna dębu</i>		
	control (not submersed) <i>kontrola (nie zatapiane)</i>	submersed for 1 year Puck <i>zatopione na 1 rok Puck</i>	submersed for 1 year Orłowo <i>zatopione na 1 rok Orłowo</i>
Substances soluble in: <i>Substancje rozpuszczalne w:</i>	% of oven-dry wood <i>% absolutnie suchego drewna</i>		
Ethanol-benzene <i>Etanol-benzen</i>	3.3	1.2	1.5
Water <i>Woda</i>	10.5	5.8	7.1
1% NaOH	23.5	20.4	22.3
Ash content <i>Zawartość popiołu</i>	0.2	1.2	1.5
pH	4.0	6.3	6.2

Already after a year the samples in the area of Orłowo were settled by large numbers of common in the Baltic Sea crustacean *Balanus improvisus* and by not so large numbers of Baltic mussel *Mytilus trossulus* (fig. 1).

Hitherto obtained data indicates that visible and measurable changes in oak wood submersed in the sea occur already in the first year from submersion, therefore observation of them may serve protection and monitoring of underwater archaeological objects.





**Fig. 1.** The sample of oak wood taken out from the Baltic sea after 12th months from submersion in water – visible Baltic mussel (*Mytilus trossulus*)

**Rys. 1.** Próbkka drewna dębu wyjęta z Morza Bałtyckiego po 12-tu miesiącach od zanurzenia w wodzie – widoczny omulek bałtycki (*Mytilus trossulus*)

Determinations are to be continued, but data, that has been gained already, suggests that changes in wood occur fast and with great intensity, and the applied samples allow quick evaluation of occurring changes.

## References

- Archaeological Wood Properties, Chemistry, and Preservation** [1990]: Eds. R.M. Rowell, R.J. Barbour. American Chemical Society, Washington, DC
- Björdal C.G., Nilsson T.** [2008]: Reburial of shipwrecks in marine sediments: a long-term study on wood degradation. *J. of Archaeological Science* [35]: 862–872
- MACHU Report Nr 1** [2008]: A Maritime Research Project Funded by the European Union. Culture 2000

- MACHU Report Nr 2** [2009]: A Maritime Research Project Funded by the European Union. Culture 2000
- Miotk-Szpiganowicz G., Uścińowicz Sz., Przeździecki P., Jegliński W.** [2009]: Reconstruction of the paleo-land scapes of the southern Baltic. In: MACHU Report Nr 2, 80–84
- Pomian I.** [2004]: Changes to the coastline in the neighbourhood of the Medieval port in Puck in the light of the research done so far by the Central Maritime Museum in Gdansk. In: Uścińowicz Sz., Anagnostis B., Kramarska R., Zachowicz J.(ed.), Proceedings of Conference Rapid Transgressions Into Semi-enclosed Basins. 2003, Polish Geological Institute Special Papers, vol. 11, 31–36
- Pomian I.** [2009]: Investigations at the three MACHU test areas in Poland. MACHU Report No 2: p.14–15
- Pomian I., Latalowa M., Łęczyński L., Badura M.** [2000]: Preliminary results and interdisciplinary project of palaeoenvironmental reconstruction at the site of the medieval harbour in Puck (North Poland). In: J. Litwin (ed.), Down the river to the sea. Proceedings of the Eighth International Symposium on Boat and Ship Archaeology, Gdańsk 1997. Gdańsk, 27–36
- Prosiński S.** [1984]: Chemia drewna. PWRiL, Warszawa
- Robakiewicz M.** [2009]: Zarys hydrodynamiki Zatoki Gdańskiej. Instytut Budownictwa Wodnego Polskiej Akademii Nauk
- Swerpel B.** [2009]: Analiza falowania morskiego, w oparciu o dostępne dane pomiarowe i wyniki modelowania, jako czynnika lokalizacji skansenu wraków. Instytut Budownictwa Wodnego Polskiej Akademii Nauk
- Śliwiński B.** [1998]: Dzieje Pucka w świetle najstarszych źródeł pisanych (do 1308 r.). In: Grot A. (ed.), Historia Pucka, Marpress, Gdańsk, 55–68
- Uścińowicz Sz.** [2003]. Relative sea level changes, glacio-isostatic rebound and shoreline displacement in the Southern Baltic. Polish Geological Institute Special Papers Vol. 10: 1–79
- Uścińowicz Sz., Miotk-Szpiganowicz G.** [2003]: Holocene Shoreline Migration in the Puck Lagoon (Southern Baltic Sea) based on the Rzucewo Headland case study. Landform Analysis Vol.4: 81–95
- Wróblewska H., Fojutowski A., Noskowiak A., Komorowicz M., Kropacz A.** [2009]: Ocena zmian fizycznych, chemicznych i biologicznych w próbkach dębu umieszczonych w obrębie dwóch podwodnych stanowisk badawczych w wodach przybrzeżnych Morza Bałtyckiego. Instytut Technologii Drewna, Poznań

## Standards

- PN-EN 113: 2000/A1:2004 Środki ochrony drewna – Metoda badania do oznaczania skuteczności zabezpieczania przeciwko podstawczakom rozkładającym drewno – Oznaczanie wartości grzybobójczych
- PN-EN 335-2:2007 Trwałość drewna i materiałów drewnopochodnych – Definicja klas użytkowania – Część 2: Zastosowanie do drewna litego
- PN-EN 350-2:2000 Trwałość drewna i materiałów drewnopochodnych - Naturalna trwałość drewna litego – Wytyczne dotyczące naturalnej trwałości i podatności na nasycanie wybranych gatunków drewna mających znaczenie w Europie
- PN-EN 13 183-1:2004 Wilgotność sztuki tarcicy – Część 1: Oznaczanie wilgotności metodą suszarkowo-wagową

PN-77/D-04 101 Drewno – Oznaczanie gęstości

PN-77/D-04 103 Drewno – Oznaczanie wytrzymałości na zginanie statyczne

PN-77/D-04 117 Fizyczne i mechaniczne własności drewna – Oznaczanie współczynnika sprężystości przy zginaniu statycznym

## **BADANIA DREWNA ZATOPIONEGO W MORZU**

### **Streszczenie**

Centralne Muzeum Morskie w Gdańsku uczestniczyło w projekcie UE MACHU zmierzającym do stworzenia systemu lokalizacji, udostępnienia i upowszechnienia informacji o europejskim podwodnym morskim dziedzictwie kulturowym. W projekcie współpracowało 7 krajów UE. Instytut Technologii Drewna wziął udział w pracach w zakresie badań trwałości w warunkach zatopienia w morzu małych próbek drewna dębu traktowanych jako bioindykator zmian. Przedstawiono zarys badań w projekcie.

**Słowa kluczowe:** badania morskie, dziedzictwo kulturowe, drewno, dąb, bioindykator

