Structure from Motion as a tool for documenting barge wrecks in the event of looting by treasure divers and threats from a newly immigrated species, the quagga mussel.

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Abstract: In the 18th and 19th centuries, wooden barges, so-called "Kaffenkähne", were particularly essential for the transport of building materials, food and other goods within the Mark Brandenburg. The large transport barges are also an integral part of the contemporary cityscape of Berlin. Some of the few well-preserved witnesses of the Wilhelminian era or "Gründerzeit" are now lying on the bottom of lakes and rivers. At least ten such boats are located in the Werbellinsee in the district of Barnim in Brandenburg. Since 2007, the wrecks have been documented and researched by the registered association Kaffenkahn e.V., which consists of sports divers, archaeologists, research divers and interested laypersons.

In the last ten years, especially those wrecks have been systematically documented which lie in a depth of up to 25 m, and are therefore easily accessible for divers. In particular, the application of the "Structure from Motion" (SfM) method and the use of vertical photographs makes the massive and rapid changes to the wrecks visible and traceable. On the one hand, these changes can be attributed to a changed ecosystem due to immigrant species. On the other hand, looting was noted, which was rarely noticed before the systematic documentation, and could only be reported to the responsible authorities in individual cases. Using the example of the so-called "Ziegelwrack", the importance of regular monitoring is shown in order to document the natural and anthropogenically influenced decay of the historic transport barges. The results of our monitoring in the years from 2012 to 2019 have shown that the physical structure has already changed dramatically over the past seven years of observation. In addition to the loss of individual components, such as frames or planks, the theft of bricks, which are part of the cargo, can be observed. Furthermore, the entire wreck is overgrown with the newly immigrated species quagga mussel, which has a strong impact on the appearance and decay process of the boat.

Keywords: *transport barges—Structure from Motion—monitoring—looting—quagga mussel*

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Introduction

The Werbellinsee (Fig. 1) is located about 60 km northeast of Berlin, in the Brandenburg district Barnim and is part of the Schorfheide-Chorin Biosphere Reserve. With a length of about 10 km, a maximum width of 1.3 km and an area of 785.92 ha, it is one of the largest lakes in Brandenburg (Zühlke, 1981, p. 46). At least since the 18th century, the region around the Werbellinsee experienced an economic boom through the exploitation and transport of building materials such as wood, field stones, bricks or clay. Easy transfer by boat was made possible mainly by the expansion of the Finow Canal and the Werbellin Canal (Zühlke, 1981, pp. 119f; Meyer, 1994, p. 100; Uhlemann, 1998, p. 439). Through the Werbellin Canal, the lake is connected to the Finow Canal and the Oder-Havel Canal, along which a boat can sail to the North and Baltic Seas, or in the opposite direction to Berlin. The significance of the Kaffenkahn as the most important and cost-effective means of transport for the emerging Berlin of the Wilhelminian era is clearly demonstrated by the motto “Berlin ist aus dem Kahn gebaut” (Berlin is built from the barge) (Polandt, 1987, p. 20; Polandt and Menzel, 1989, p. 51).

Fig. 1. Aerial view of the Werbellinsee, photographed from southwest to northeast (© M. Reinfeld).

The Kaffenkähne and the registered association Kaffenkahn e.V.

For years, local divers have observed the constant disintegration of the wrecks in the Werbellinsee. In 2007, they decided to form an association for the protection of these important cultural legacies. Since then, the association “Kaffenkahn e.V.” has been committed to researching, preserving and protecting the barges in the Werbellinsee. In order to educate themselves historically and

archaeologically, and to meet the requirements of the Monument Protection Act ("Denkmalschutzgesetz"), archaeologists were invited to work with the association. The consortium of historically interested sport divers, archaeologists and research divers soon resulted in the first underwater archaeological courses and smaller projects, which served the further training of the team members and the documentation of the wrecks (Fig. 2). The voluntary work was approved and supported by the Brandenburgisches Landesamt für Denkmalpflege und Archäologisches Landesmuseum (BLDAM) (Knepel, 2010, p. 106; Reinfeld, 2010, pp. 72f; Reinfeld, 2014, pp. 17–20; Reinfeld, 2018, p. 470f).

Fig. 2. Lecture during an "Underwater Cultural Heritage Discovery Course" for sport divers at Werbellinsee (© Wilfried Kroneder).

A documentation of all Kaffenkähne known in the Werbellinsee is necessary in order to be able to differentiate between several types of barges, and to work out special features. The transport vessels differ essentially in their range, size and their technical construction because they were designed specifically to suit the needs of the skipper and the cargo to be carried. Other type variations resulted from local construction traditions or adjustments that had to be made due to the routes taken (Polandt and Menzel, 1989, pp. 52f; Sohn, 2013, pp. 23–35). In the middle of the 19th century, the so-called "Finowmaß" (Polandt and Menzel, 1989, p. 56; Uhlemann, 1998, p. 440) was implemented. This is a measurement for boats that was introduced specifically for the Finow Canal and the vessels that navigated it. The barges in the Werbellinsee had a maximum length of 40.20 m, a maximum width of 4.6 m, a draft of up to 1.4 m, and a carrying capacity of up to 170 t in order to allow them to pass through the channels and locks of the Finow Canal.

The wooden transport barges were built mainly from pine or spruce, with oak used for particularly stressed components. Depending on the conditions of the water, the barges could be sailed, hauled or punted. They were flat-bottomed and the stem and stern were both curved upwards and bent inwards, whereby the typical ends were formed. This shape facilitated landing on the shore. In addition, the high stem was an important aid in navigation (Fig. 3). From the stern, the skipper navigated his barge with a huge rudder, and the aid of a tip attached to the bow, the so-called “Kaffenspitze”, served as a bearing when he could no longer see the barge’s actual bow due to the high stacked cargo. In addition, a massive mast step that could hold a mast more than 20 m high was located in the front third of the boat. The skipper and his family were housed in a simply furnished cabin in the stern (Fig. 4) (Polandt and Menzel, 1989, pp. 53f, 58; Teubert, 191, p. 272, Sohn, 2013, pp. 36–54). The cabins of the Kaffenkähne are often no longer preserved. They were either destroyed during the accident that led to the vessel sinking, or by treasure divers in search of valuable objects.

Fig. 3. Raised stem, to which an additional Kaffenspitze was attached (© Kai Dietterle).

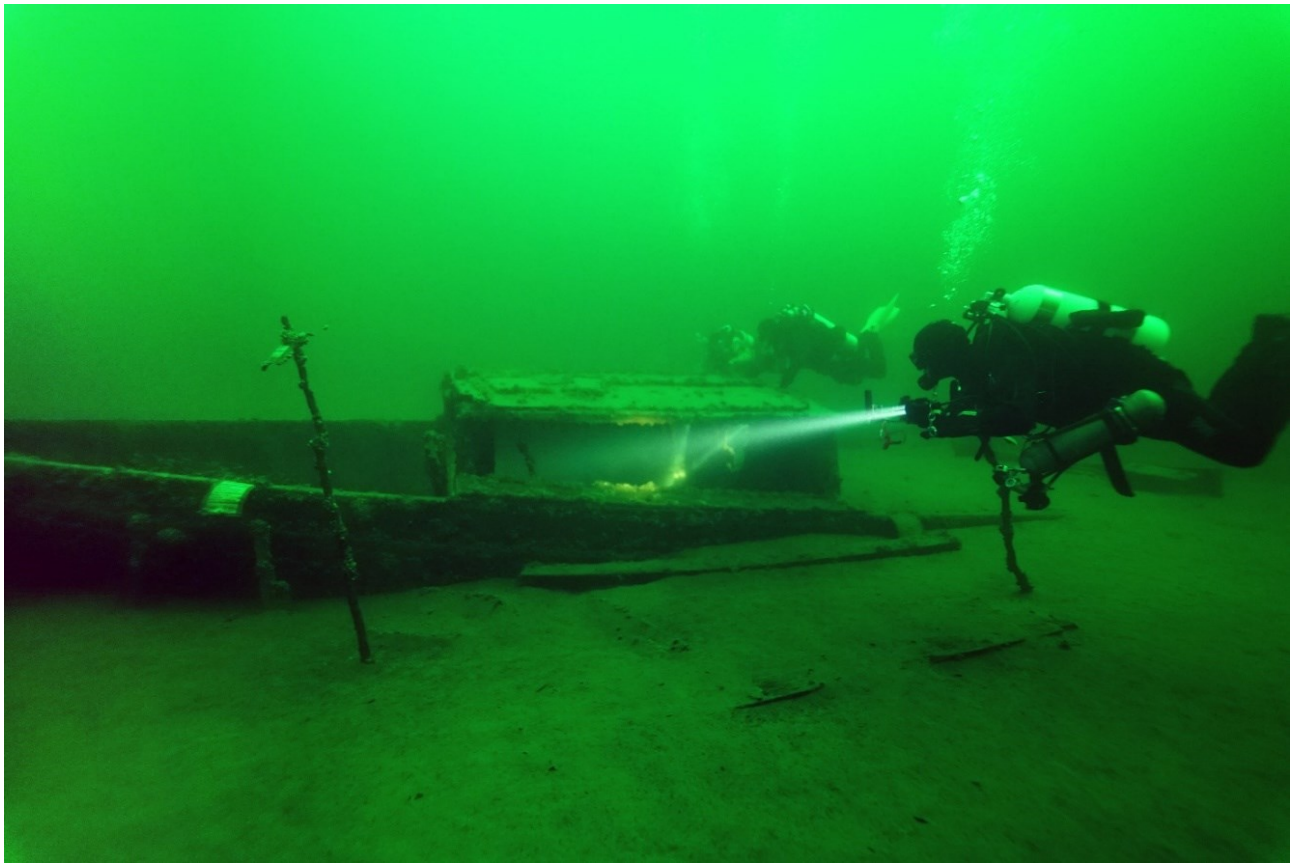

Fig. 4. One of the rarely preserved cabins of a Kaffenkahn. The signs on the wreck should remind divers that it is an important cultural heritage site (© Kai Dietterle).

The first photo mosaic of a 30 m long wreck

In addition to the traditional documentation with pencil and drawing frame, or the recording with modern sonar technology, the three-dimensional documentation of the vessels using SfM has proven successful (Fig. 5).[3] In a relatively short time, in one or two dives, an entire wreck about 30 m in length can be documented true to scale despite moderate visibility conditions. This not only enables laymen to get an impression of the appearance and size of the wrecks, it also allows quick monitoring of the condition of and potential threat to the wrecks. Another advantage is that interested sport divers can be easily introduced to the techniques of three-dimensional photography, thus making an important contribution to the documentation of the barges. Requirements are made only of the camera and the technique of photography as well as the diving skills.

A good buoyancy, that is hovering freely over the object without touching the ground or the wreck, is an essential prerequisite for good photos. Otherwise, the photos, and later the three-dimensional model, will become unusable due to sediment clouds or other objects, such as diving equipment hanging in the picture. Learning the survey techniques under water—that is the correct measuring, drawing and describing an object—require not only diving skills, but also a lot of practice, patience and extreme caution in order not to damage the barges. The difficult working conditions in the Werbellinsee, such as low temperatures, poor visibility, darkness and sometimes great depths, make it

[3] For the previous documentation work on the barges in the Werbellinsee see: Reinfeld 2010; Reinfeld 2014; Reinfeld/Knepel 2016 and Reinfeld 2018. For the application of SfM in underwater archaeology see: McCarthy et al. 2019.

necessary to adapt the underwater archaeological work to the respective season. This means that the photographic work focuses on winter and spring, as visibility under water can occasionally be up to 10 m during these months. In summer and autumn, when visibility is rarely more than 2 m, surveying and other work is preferably carried out.

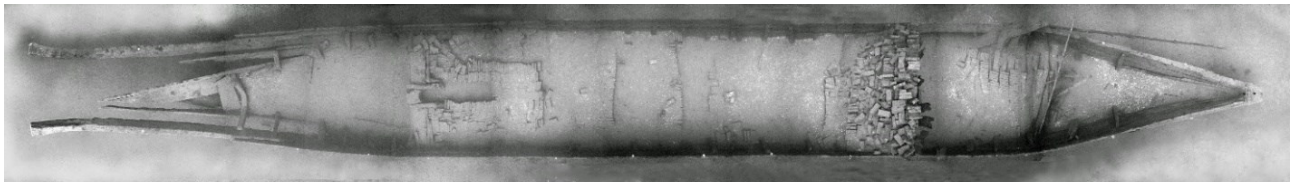

Fig. 5. Photo mosaic of the Ziegelwrack (Brick Wreck) in 2012 (© Kaffenkahn e.V.).

In 2012, for the first time it became possible to create a complete photo mosaic of a Kaffenkahn. At that time, it was a big step forward in the monitoring work, because the difficult conditions make it impossible to see one of the wrecks as a whole. The wreck, the "Ziegelwrack" (Brick Wreck) mentioned above, dates from the first half of the 19th century, is about 30 m long, 3.5 m wide and had a loading capacity of around 50 t. On the photo mosaic you can see individual details of the boat, such as the raised ends, the mast step, the remains of the cabin and even the individual bricks of the royal brickyard Joachimsthal, which are still neatly stacked in the boat. The elongated gap between the stacked bricks in the area of the mast chair was intentionally created in order to facilitate the raising and lowering of the mast. The bow area has already broken apart, so that individual planks protrude from the hull. In the area of the stern, at least one plank has also been pulled out from the hull. Such damage often happens when sport boats accidentally anchor in the barges because unfortunately no corresponding anchor buoys exist. The cabin in the stern has collapsed and the bricks are still nestling in a large pile against the cabin wall. It seems that the bricks were once stacked on the roof of the cabin. The brick cargo of the roof has fallen into the interior of the cabin and is still arranged in series.

Seven years later, the next step was the documentation of the vessels using SfM. The three-dimensional documentation should make it possible to look at the wreck from both the port and starboard sides, as well as from the inside. Measurements on the hull, which had previously been laboriously collected by the divers, can now be carried out on the 3D model in the shortest possible time. A comparison of the measurements of the divers and the 3D model shows their reliability. In addition, the association Kaffenkahn e.V. received information that the wreck had been looted by scuba divers. According to local divers, bricks were stolen from the wreck on a large scale and subsequently sold on eBay. The question therefore arose whether possible illicit excavations could be traced on the basis of the photographic documentation. However, there was also the possibility that any traces of illegal excavations had already become unrecognizable due to the sediment growth on the wreck.[4]

Traces of destruction in the 3D model

In May 2019, a two-day photo campaign was undertaken to produce a three-dimensional documentation of the wreck (Fig. 6 and 7). This resulted in around 3000 individual photos, which were

[4] The sedimentation rate of a lake depends on the supply of biomass into the lake. This means that animal and plant organisms, such as algae, sink to the bottom of the lake and form sediment layers that are several meters thick. See: Bogdal et al. 2010, pp. 561.

processed into a 3D model using the software *Agisoft PhotoScan*[5] (AgiSoft PhotoScan Professional, 2016). In order to record the wreck as completely as possible, measuring tapes were laid on the starboard and port side as a reference and orientation for the photographer and the software. The soft, monotonous sediment offers hardly any identifiable objects or contrasts that allow the software to find similar images and mesh them together, meaning that without additional reference points holes can result in the 3D model. The measuring tapes were placed at a distance of 2 m from the boat's side, so that the photographer could easily recognize both the wreck and the measuring tape despite the limited visibility. In the post-processing, the measuring tapes can simply be cut out of the model. Surprisingly, the visibility conditions deteriorated massively within a day. This not only affected the conditions for photography but also the quality of the photo model. On the first day, while the measuring tapes were being laid out, the divers enjoyed a visibility of 5 to 6 m, which made it possible to recognize both sides of the wreck. On the second day, when the photos were to be taken, the visibility was reduced to only 1 to 2 m. Now the photographer had to keep the smallest possible distance from the wreck in order to be able to take usable photos. On the one hand, this increased the number of photos. On the other hand, the risk of accidentally whirling up a sediment cloud[6] and additionally worsening the view also increased.[7]

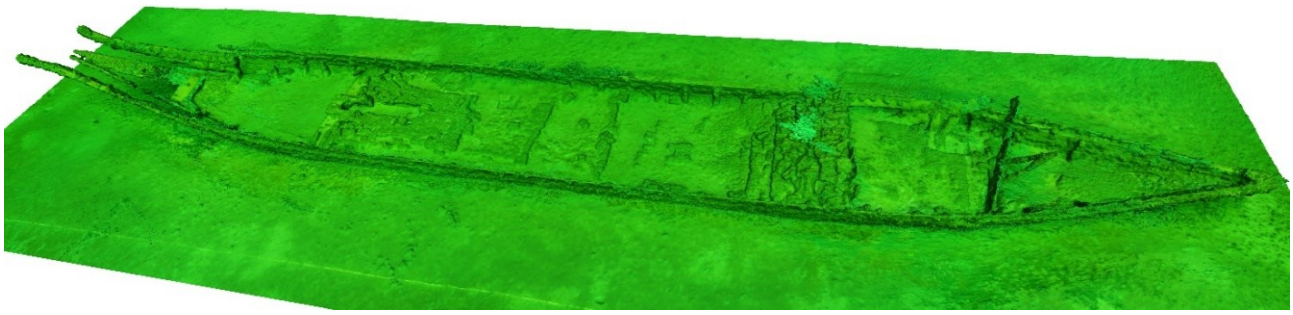

Fig. 6. 3D model of the Ziegelwrack (Brick Wreck) in 2019 (© Kaffenkahn e.V., Bernhard Fritsch).

Fig. 7. Vertical image of the Ziegelwrack (Brick Wreck) in 2019 (© Kaffenkahn e.V.).

A comparison of the two vertical photos from 2012 and 2019 (Fig. 5 and 7) reveals massive changes in the hull and in the overall appearance of the wreck. Particularly noticeable is the strong mussel growth, which affects both the wooden hull and the brick load, and even continues on the sediment. Now, the partially multi-layered mussel growth hides individual construction details and the carefully stacked bricks are difficult to detect.[8] However, holes can be identified within the rows of bricks, for

[5] https://www.agisoft.com

[6] Such a sediment cloud can be seen in Fig. 6 above the pile of bricks in the area of the cabin. The sediment cloud was accidentally whirled up by the photographer due to the poor visibility and can also be seen in the 3D model.

[7] A comparison with automated methods, for example the use of a ROV (Remotely Operated Vehicle) to create 3D models, has not yet taken place due to the high acquisition costs. In particular, this would be very useful for wrecks that lie at greater depths, i.e. from approximately 25 m.

[8] The following section will go into more detail about the extreme mussel growth that now affects all wrecks in Werbellinsee.

example in the area of the elongated gap for the mast. These holes are due to the theft of bricks. The same applies to the large pile of bricks in the area of the former cabin, which has apparently become smaller, as well as in some other places. Research on the internet trading platform eBay could not provide evidence of a sale of the bricks on the Internet, but “ancient bricks” were not uncommon as a sales object. Here, it should be emphasized that the Brick Wreck is protected as a registered monument (“Bodendenkmal”) by the Monument Protection Act of the federal state of Brandenburg, and the theft of the bricks is a criminal offense. Unfortunately, illegal underwater activities can only be detected and prosecuted in a few cases. Even public awareness of the cultural heritage under water is often insufficient. In addition, changes have been identified in the wooden hull which demonstrate the progressive decay of the boat. In the bow area, individual frames are missing and a plank has come loose in the stern. In 2012 the plank still protruded from the hull. Overall, it can be seen that the condition of the vessel has deteriorated massively over the past 7 years.

In a next step, we will try to put together old photo and video material of the brick wreck, for example from 2012 and older, into a three-dimensional model. The direct comparison of the two models will show the rapid deterioration of the ship even more clearly, both the slow destruction of the hull and the heavy fouling with mussels. Since the old photos and videos from 10 years ago were unfortunately not yet made with the aim of a three-dimensional model, the photo and video material must now be carefully searched for suitable recordings, which means a long post-processing. In view of the rapidly progressing decay, these recordings are nonetheless very important and valuable documentation. In addition, possible sources of error, which are caused by blurred or distorted images when generating the 3D model, can be better identified and corrected in this way.

The new immigrant – the quagga mussel

The vertical image of the Brick Wreck from 2019 (Fig. 7) looks almost blurry due to the strong mussel growth, so that individual details of the boat’s hull or the cargo are no longer recognizable. The mussel is the so-called quagga mussel (*Dreissena rostriformis bugensis*), which was first detected in Germany in 2005 and probably arrived at Werbellinsee in 2014 at the latest (Imo et al., 2010, pp. 735, 737f; Müller et al., 2016, pp. 14f). The home of the mussel is the region of the Black and Caspian Seas and the river Dnieper. Attached to the outside of the hull of ships or in their ballast water, the shell has found its way to Germany via the shipping routes through the rivers Main, Rhine, Danube and the Main-Danube Canal (Imo et al., 2010; Heiler et al. 2013, p. 56; Oldorff et al., 2018, p. 349). Due to its high reproductive rate, its high adaptability and resistance to temperatures and depths, the mussel spreads quickly. Natural predators, such as fish or ducks, can hardly stop the alien species. It colonizes both hard and soft substrates, that is wood, sediment and even living organisms, such as crayfish or native large mussels, with which it competes for food (Fig. 8 and 9). By mass reproduction and its occurrence in multi-layered colonies, the quagga mussel can change the entire ecosystem of a lake, for example, by replacing native mussel species and sponges (Imo et al., 2010, pp. 737f; Heiler et al., 2013; Müller et al., 2016, p. 13f; Oldorff et al., 2018, p. 349).

Fig. 8. Diver at the open raised end of a Kaffenkahn that is completely overgrown with the quagga mussel (© Herbert Frei).

Fig. 9. The mussel colonizes hard and soft substrates until the entire bottom of the lake is covered (© Herbert Frei)

For the wooden wrecks in Werbellinsee and probably all wrecks and sunken remains in other waters, the immigrant quagga mussel represents a significant threat. With its adhesive filaments, the so-

called byssus, the mussel not only sits on the surface of the objects. The fine filaments penetrate into the sensitive wood structure and can damage it. In addition, the widespread growth in multi-layered colonies is a considerable weight for the wrecks. This not only speed up their progressive decay, it could also promote the further sinking of the wrecks in the sediment.[9] The question of whether climate change and increasing warming of the waters further boost the reproduction and spread of the mussel has not yet been scientifically investigated. A solution to this problem is currently not in sight. Scratching off the mussels from the wrecks, as is customary with boats and ships, is out of the question because this would destroy the sensitive wooden surface. In addition, the mussel would very likely colonize the wreck again in a short time. For archaeological work on the wrecks in the Werbellinsee and many other sunken cultural heritage sites, the advance of the immigrant species means that archaeologists have to work against time. The sunken heritage must be documented before it is completely overgrown by the quagga mussel colonies and is no longer visible or even destroyed. Only the wrecks at depths of about 25 m and below are not completely overgrown, but that too is only a matter of time.

This is why the association Kaffenkahn e.V. is trying to motivate as many sport divers as possible to take photos and films of the wrecks, so that at least a digital documentation exists before all the wrecks have disappeared under thick clumps of mussels. The three-dimensional photographic documentation using SfM is the simplest and most effective method to make a complete recording of a wreck in the shortest possible time.

Conclusion

The Kaffenkähne in the Werbellinsee are important witnesses to the history of technology and transport, as well as the Wilhelminian era in Berlin-Brandenburg. In addition, they are listed as registered monuments under the protection of the Monument Protection Act of the federal state of Brandenburg. Documentation using SfM, which enables a quick three-dimensional recording of vessels, has now become the standard in underwater archaeological documentation. In particular, the wrecks in the Werbellinsee can only be satisfactorily documented within a short period of the year due to the difficult working conditions.

This is why the SfM method is the method of choice for fast documentation, even with laymen and voluntary sport divers. The targeted monitoring of individual wrecks, here using the example of the Brick Wreck, shows destruction and theft of parts of the cargo of the wreck. In addition, a complete overgrowth with the newly migrated quagga mussel (*Dreissena rostriformis bugensis*) was found which will probably make the wrecks disappear under thick mussel colonies within a few years. A struggle against time has begun in order to document as many cultural heritage sites under water before they are no longer visible or even destroyed.

[9] For their valuable information regarding possible damage caused by fouling with the quagga mussel we would like to thank Ms. Silke Oldorff (Landesamt für Umwelt Brandenburg and Naturschutzbund Deutschland e.V. [NABU]), Mr. Volker Krautkrämer (NABU) and Mr. Mirko Hauswirth (Bundesamt für Naturschutz [BfN]).

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