Research and Review

– Advancements in Conservation and Assessment of Previous Experiences

NKF XXII Congress

Nordiska Konservatorförbundets XXII Kongress

Stockholm, Sweden

October 21–22, 2021

This preprint is compiled and edited by
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The preprint contains the papers and poster abstracts
for the NKF XXII Congress held in Stockholm, Sweden
October 21–22, 2021.

The preprint is distributed to the attendees of the
NKF XXII Congress and is available on the congress
website:
www.konservering.org
and on:
www.nkf-s.se
www.nordiskkonservatorforbund.org

The congress logo is a detail of the ceiling at
Nationalmuseum in Stockholm.
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ISBN 978-91-527-0804-0

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nkfs NORDISKA KONSERVATORFÖRBUNDET SVERIGE

IIC INTERNATIONAL INSTITUTE FOR CONSERVATION OF HISTORIC AND ARTISTIC WORKS

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Content

Foreword

The NKF-S, Nordic Association of Conservators in Sweden/The IIC Nordic Group Sweden, has the pleasure of hosting the NKF XXII Congress, 21–22 October 2021 in Stockholm.

The topic ***Research and Review – Advancement in conservation and assessment of previous experiences*** illustrates how the conservation–restoration discipline has evolved over the last decades. Progress through research and trial-and-error has been made. Analytical methods, documentation, treatments, choice of material, as well as the circumstances under which conservators-restorers work has developed.

The congress' purpose is to evaluate how we utilize and share our experiences within the profession. We analyse the viability of conservation treatments, ethical choices, use of best-practice and collaborations we have had, including the guidelines which we have been following since the 1980´s until now.

The program consists of paper and poster presentations.

The congress working team 2019–2021 has been:

Anne Braun, conservator, Västernorrlands museum, Härnösand, Sweden

Pia Christensson, conservator, Arbejdermuseet, Copenhagen, Denmark

Veronika Eriksson, conservator, Nationalmuseum, Stockholm, Sweden

Elisabeth Geijer, conservator, MTAB Sverige AB, Stockholm, Sweden

Helen Skinner, conservator, Helen Skinner AB, Stockholm, Sweden

Lisen Tamm, conservator, Sigtuna Museum & ART, Sigtuna, Sweden

Acknowledgement

The congress could not have been accomplished without the generous support from Articheck, Bruynzeel, Estrid Ericssons fond, Fokus, Intab AB, Konstlist AB, Letterstedtska fonden, MTAB, Museiservice Norden AB, Märta, Gunnar and Arvid Bothéns stiftelse, Nordtec Instruments AB, Thermo Lignum, TransArt AB and Tru Vue Inc

And our special thanks goes to Alice Sunnebäck for editing and Lisa Nilsen for proofreading the preprint.

A complex conservation challenge
Consolidation of Norwegian distemper paint decorations

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Abstract

Around 30 years ago, a consolidation treatment method for distemper paint decorations using sturgeon glue was developed by the Directorate for Cultural Heritage and the Norwegian Institute for Cultural Heritage Research. The method has been in use since then and remains favourable. Based on an evaluation of previous consolidation treatments, the Sturgeon-Glue Project was initiated in 2014 to find out how the sturgeon-glue consolidation treatment would affect distemper paint structures.

Different analytical techniques, such as enzyme-linked immunosorbent assay (ELISA) and immuno-fluorescence microscopy (IFM), have been undertaken to provide some answers. We have detected unspecific collagen in the paint structures, although we have been unable to find the specific animal collagen used as the binding medium. Ovalbumin from egg has been detected as an additive but only in a medieval paint structure.

By reviewing past and present consolidation treatments and performing multiple analytical techniques, we have found that problematic areas might be related to thick paint structures, strong binders in the original paint and pigments that variously ”quenched” the binder and the glue. The sturgeon glue is unevenly dispersed in the structure and is not evident between the wooden support and the paint layer. Future analytical techniques are suggested to completely understand the challenges of consolidating distemper paint.

Keywords: Distemper paint, matt paint, consolidation, analysis, sturgeon glue, ELISA.

Introduction

In many Norwegian churches and private houses, one can see interior decorations made of distemper paint. This decorative paint dates back from the medieval period to the early 19th century. The oldest preserved distemper decorations are found in Torpo, Heddal and Nore stave churches, among others (Solberg 1997; Weisser-Svendsen 2007). The paint has animal glue as its main ingredient and is water soluble, both in making it and after drying. The additional ingredients and recipes vary due to the preferences of the painter, geographical variations and the availability of products. The decorations have a matte finish and are vulnerable to moisture and changes in indoor climate. Therefore, the choice of the consolidation medium is dependent on the right properties to contribute to a successful result.

A comprehensive registration of distemper paint in Norwegian churches was undertaken in 1984 by the Directorate for Cultural Heritage (DCH) (Brænne and Havrevold 1984), followed by an updated overview in 2011 by the Norwegian Institute for Cultural Heritage Research (NIKU) (Olstad and Kaun 2011). One of the most important findings in 1984 was the expressed need for treatment of loose paint. This revealed the lack of knowledge and experience in how to undertake an ideal treatment for distemper paint decorations in churches.

The main research question after the registration in 1984 was to find a consolidation material for matte distemper paint that would not alter the paint structure or the surface appearance. Other key factors were avoiding water stains between treated and untreated areas, as well as finding a consolidation material that would not pose a health risk, would be practical to use *in situ* and could be applied in unheated buildings (Solberg and Olstad 1994). These questions were raised in addition to the standard ethical requirements for conservation treatments. After testing, sturgeon glue has become the preferred and the most frequently used material for treating loose distemper paint[1] since the 1990s, as shown in a considerable number of reports. During treatment, other questions arose, as follows: How does the treatment affect the paint structure? Where is the consolidation material located within the paint structure? Can excess consolidation material be removed successfully?

In the late 1990s, the Conservation of Medieval Paintings on Timber through European Co-operation (COMPOTEC) Project thoroughly investigated the properties of sturgeon glue (Solstad 2002). In 2014, the Sturgeon-Glue Project was initiated by the DHC and NIKU after a thorough condition assessment of previously treated distemper paint decorations discovered undesirable conditions in some areas.[2]

Due to the many factors to consider when choosing a consolidation treatment, the Sturgeon-Glue Project set out to define some of the parameters that would be important for the successful consolidation treatment of distemper paint in stave churches. This has proven to be a difficult task, given the vast number of relevant parameters, for example, temperature and relative humidity (during conservation and in normal use), heated/unheated churches, painting technique, binding medium, pigments used, additives, past treatments (often unknown), changes in consolidation methods from 1990 to the present, and wear and tear due to rubbing and the increased number of visitors.

As part of the project called The Sustainable Management of heritage Buildings in a Long-term perspective (SyMBoL Project)[3] commenced in 2018, an array of analyses has been undertaken to broaden the knowledge about distemper paint decorations in Norwegian stave churches. The research results have not been published yet.

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1 Isinglass and sturgeon glue both refer to the glue made from the bladder of the sturgeon fish. In this paper, we use the term sturgeon glue. The definition of consolidation follows the Standard NS-EN 15898 (2011: 11): Stabilisation, improvement of internal cohesion or mechanical stability, usually by adding material. In this article, the focus is on the properties of the actual added material.

2 Tone Marie Olstad, researcher and paintings conservator at NIKU, was the key person initiating this project. Olstad was project leader in the period 2014–2018. Anne Apalnes Ørnhøi has been the project leader since 2018.

3 SyMBoL is a project that aims to develop a better understanding of climate-induced risks for stave churches and ultimately, to improve environmental risk management. Here, the project has also incorporated research on the stave churches' distemper paint. The partners in the project are the Norwegian University of Science and Technology (NTNU-MTP), the Norwegian Institute for Cultural Heritage Research (NIKU), Jerzy Haber Institute of Catalysis and Surface Chemistry, Polish Academy of Sciences (PAS) and the Getty Conservation Institute (GCI). Website: https://www.ntnu.edu/symbol

Due to these challenges, in this paper, we aim to provide an overview of past and current treatment methods and hopefully answer this question that was already raised in the 1990s: *How does the sturgeon-glue treatment affect the paint structure?* We do so by means of the following objectives:

1 Present the distemper painting technique and provide an overview of the treatment history of distemper paint in Norway.
2 Present the results of our analysis on the binding media and the presence of sturgeon glue in treated paint structures.
3 Discuss the results in the light of the distemper painting technique and treatment history.

Background

The distemper painting technique

Distemper paint was probably applied warm, and the paint dried fast, leaving little time for adjusting or using a wet-in-wet technique (Fig. 1). The painter or painters often started to paint by applying a light base layer on the wooden support. There are traces of sketching the motif on the ground, which indicates that the painter either knew the chosen motif well or that the decorations were copied. The application of the local colour was followed by applying the contours (Fig.1). The painting technique followed a certain logic propulsion; for example, the painter worked from top to bottom to hide spills, and when painting the details, the same colours in the same area were painted while the batch was fresh (Olstad 2016: 74). The painter had to work fast, layer by layer. Because of the needed fresh mixture of distemper paint, the painter could possibly have mixed smaller batches of paint at a time. Here, a variety of paint medium strength concentrations might have occurred, which could be the reason why the same colours in different areas differed in glue concentrations. One can see some flaking of paint related to specific colours (Fig. 2). Therefore, it might have been caused or amplified, either partly or, by the inherent characteristics of the paint itself. A too strong concentration of glue could cause flaking and cupping of the paint, as indicated in Hopperstad and Nore stave churches (Solberg 2004: 4; Berg 2011: 8).

Overview of the national consolidation treatment history of distemper paint

The materials used for consolidating loose paint are often not thoroughly described in older reports, for example, for the consolidation of loose paint in Gol stave church, done in 1948, where the used material was described as ”a mixture of glues” (Johansen 2013, personal communication). One of the earliest pieces of data on the consolidation materials used in distemper paint referred to the 1939 treatment (with chondrin[iii] and gluten) of the medieval canopy of Torpo stave church (Stein and Matheson 2007: 3). We know that rabbit skin glue, casein, wax and linseed oil have been used, without achieving a good consolidation with no change in the paint structure and aesthetics (Olstad and Solberg 1998: 122). Residues on the surfaces indicate the use of gelatine in the 1940s and the 1950s (Stein and Matheson 2007: 3; Wedvik 2008: 19; Berg 2011: 9). In the 1960s and the 1970s, synthetic materials, such as soluble nylons, were tested and used for the consolidation of distemper paint decorations (Brænne 1982; Plahter 1997). From the late 1980’s, sturgeon glue has been the preferred material (Olstad and Solberg 2001: 40).

In a series of tests undertaken in 1992 at the DCH, an array of consolidation materials was regarded as interesting due to the unaltered paint surface and the avoidance of aesthetical

Fig. 1. Details of distemper paint in Uvdal church. (Photo: Kjersti M. Ellewsen, DCH, 2020.)

Fig. 2. Monitored area in Nore stave church where flaking paint has recurred multiple times after being consolidated. (Photo: Nina Kjølsen Jernæs, NIKU, 2020.)

changes caused by the drying of the glue. Paraloid B-72, Klucel EF and L, Plextol B 500 and sturgeon glue were tested (Olstad 1992: 6; Solberg and Olstad 1994: 123). In all the tests, each material dried as a matte surface; the Klucels darkened the surface the most, followed by Plextol and Paraloid B-72. Additionally, sturgeon glue was thoroughly investigated during the COMPOTEC Project, whose results also favoured sturgeon glue as a consolidation material suited for the conservation of distemper paint decorations (Solstad 2002). Methyl cellulose has also been proven to fulfil the demands of a suitable consolidation material, being re-treatable in the future and not changing the aesthetics. However, methyl cellulose has not been in use for a long time in Norwegian distemper paint decorations.

The application method developed around 30 years ago for sturgeon glue consolidation involved brushing sturgeon glue (at approximately 40°C) on the surface through the Japanese paper type Bip Tengiuo 11 g/m^2 (Fig. 3). Excess glue is absorbed through the Japanese paper. The Japanese paper is then removed slowly by peeling it off before

the glue starts to dry. Excess glue can be removed multiple times to achieve a glue-free surface. Raking light is used for checking the presence of excess glue on the surface.

Earlier analytical techniques on distemper paint and sturgeon glue

Prior to the presented results in this article, a limited number of scientific examinations have been performed to determine any chemical evidence on the materials used in Norwegian distemper paint decorations. Thus far, analyses of the binding media have shown the use of animal-based collagen and additives in the form of egg, casein and oil (Olstad and Solberg 1998). No additives have been found in only one sample out of ten (Olstad and Solberg 2001). Soppa et al. (2014) conducted analytical research on the adhesion and the penetration of sturgeon glue and gelatines. The tests were performed on dummies with oil paint, not distemper. The test showed that sturgeon glue penetrated less into the structure at 28°C compared with 40°C (Soppa et al. 2014: 7). However, the lower concentration of sturgeon glue at 3 % was too weak to be measured for bonding strength, but a 5 % concentration was measurable (Soppa et al. 2014: 7).

Analytical techniques, 2014–2019

The analyses under the Sturgeon-Glue Project within the period 2014–2019 were carried out in the Department of Conservation and Restoration at Stuttgart Academy of Art and Design and in the Centre for Art Technological Studies and Conservation (CATS) in

Fig. 3. Consolidation of distemper paint in Ringebu stave church. (Photo: Anne Apalnes Ørnhøi, NIKU, 2010.)

Copenhagen. The NIKU contacted both institutions concerning our need for a method of detecting previously used protein-based consolidation materials in paint layers. Fourier transform infrared spectroscopy mapping in attenuated total reflectance (FTIR-ATR), spot-testing for proteins and oil, and scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) analysis were undertaken by the CATS in Denmark. The analyses undertaken in Stuttgart Academy concerning the enzyme-linked immunosorbent assay (ELISA) and immuno-fluorescence microscopy (IFM) proved to be efficient attempts.

Fourier transform infrared spectroscopy mapping in attenuated total reflectance (FTIR-ATR)

The samples were analysed with a Bruker Tensor 27® spectrometer coupled to a Hyperion® 3000 microscope equipped with a focal plan array (FPA) detector. ATR measurements were performed using a Ge crystal with a refractive index of 4.01, which has an anvil design with an 80-µm tip. The lowest contact pressure level available (0.8 N) was used for all measurements. With the FPA detector, measurements were obtained in the 3600–900-cm-1 range, with a 4-cm-1 resolution and 64 scans (CATS 2015).

Spot-testing for protein and oil

In spot-testing, the presence of protein was detected by pyrolysing a small part of the sample material in a capillary tube, which was achieved by creating a colour reaction between the pyrolysate and the indicator p-dimethylaminobenzaldehyde. Drying oil was detected by an alkaline saponification test, performed by adding a drop of a 1: 1 mixture of hydrogen peroxide (30 %) and ammonia water (25 %) to a sample particle. If the binder is saponified, a spread of foam is formed, which is stable for at least 15 minutes (CATS 2015).

Enzyme-linked immunosorbent assay (ELISA) and immuno-fluorescence microscopy (IFM)

ELISA is one of the most widely used immunological techniques in biotechnology for the identification of proteins, among others. It is based on the specific reaction of target molecules and antibodies. The latter binds specifically to the antigens and forms an antigen-antibody complex. The application of the indirect ELISA method leads to the amplification of the detection indicator that reflects an increase in the assay's sensitivity. The unlabelled primary antibody binds to the antigen, and the enzyme-conjugated secondary antibody binds to the primary antibody. Thus, the primary antibody acts as an antigen (target molecule) for the secondary antibody (Krekel and Schultz 2017a: 2).

By labelling the secondary antibodies with an enzyme that creates a coloured reaction product (detection indicator), this antigen-antibody complex can be visualised and measured. A positive response for a target molecule (e.g., a specific protein) is visualised by a change of colour (e.g., from colourless to green) and measured by its optical density (the amount of light absorbed) using a spectrophotometer.

Each sample was extracted in an aqueous buffer solution and tested for collagen (unspecific), fish collagen (unspecific), sturgeon collagen (specific), ovalbumin, casein and gums (unspecific) to detect different possible proteinaceous binding medias.

This ELISA protocol cannot be used for quantitative measures. Additionally, each antibody has a variable response to its antigen, which also results in a variation in colorimetric response relative to concentration. This ELISA protocol was designed to definitively confirm the presence of those proteins and/or gums that were part of the assay screening.

Ultimately, this means that the intensity of the colorimetric response does not indicate a direct correlation to antigen concentration (Krekel and Schultz 2017a: 1–3).

To locate the sturgeon glue within the stratigraphy, cross-sections were prepared, and IFM was applied to the samples. With IFM, detection is achieved by using a fluorescence microscope and secondary antibodies that are conjugated to a fluorochrome. Upon excitation with light at a given wavelength, the fluorophore emits light at a wavelength that is proportional to the energy released after excitation. The fluorochrome used in this study was excited with blue light (490–495 nm) and emitted a green signal (520–530 nm). Thus, following antibody treatment, the sample is imaged using a microscope that can emit and detect light at specific wavelengths. When IFM is used for artwork samples, its main drawbacks are swelling of layers, washing out of materials, autofluorescence of materials and accessibility of the proteins/gums on the cross-section surface. Therefore, IFM should only be used in combination with ELISA analysis (Krekel and Schultz 2017a: 3–4). In part three of Krekel and Schultz's (2019) analysis, the cross-sections were, in addition to the IFM, stained with Sypro™ Ruby, a fluorescent stain for proteins in general. Sypro™ Ruby can distinguish neither between the proteins and their origin nor between original and later additions. However, the methodology can detect and place proteins in a cross-section (Krekel and Schultz 2019: 2).

Scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS)
SEM/EDS is a well-known method of elemental analysis of paint samples. In SEM/EDS, a sample is bombarded with an electron beam. From a spectrum of the X-rays, the elemental composition of a sample can be observed. By EDS, all elements with a higher atomic number than that of boron can be detected. The equipment allows low "maps" of the distribution of the individual elements in a specific area of the sample. Two types of images can be recorded in SEM; secondary electron images provide information about the shape of the surface, while backscatter images provide information about the elements in the sample (CATS 2015).

Results of the analysis of binding media and consolidation materials, 2014–2019

As part of the first analysis undertaken in the Sturgeon-Glue Project, spot-testing, FTIR-ATR and SEM/EDS were executed by the CATS to find binders and adhesives (Appendix 1). In total, 27 samples from six stave churches were analysed.[4] Spot-testing by the CATS showed the presence of proteins, with drying oil as an additive in five out of eight tested samples from five stave churches. Several cross-sections were made, and SEM/EDS analysis was performed (CATS 2015). FTIR-ATR did not produce any results in terms of mapping the detection of proteins or drying oils due to extremely low concentrations (CATS 2015). Additional analysis was conducted for the detection of pigments and hence, outside the scope of the requested analysis.

For the second part of the Sturgeon-Glue Project, ELISA and IFM analyses were implemented. In total, 16 samples were analysed with ELISA and 12 samples with IFM. The samples were taken from five stave churches,[5] and all samples had been treated with sturgeon glue (2–3 % solution) between 1992 and 2009. Additionally, parts of the interior of Heddal stave church might have been treated with gelatine in the 1950s. Samples were

4 Eidsborg, Flesberg, Heddal, Nore, Ringebu and Uvdal stave churches
5 Eidsborg, Heddal, Nore, Ringebu and Uvdal stave churches.

taken in challenging consolidation areas, within a range of the pigments used and different layer structures. The analysis was undertaken in three stages due to the uncertainty of finding the correct technique that could detect such small amounts of adhesives. In stage one, six samples were analysed with ELISA, while IFM was applied to one sample. In stage two, six additional samples were analysed with ELISA, while IFM was applied to four samples. In stage three, eight samples were analysed with ELISA, while IFM was applied to seven samples.

Identification of a collagen without the detection of fish collagen or sturgeon collagen means that other types of unspecific collagen are used in the distemper paint or as consolidation materials (Appendix 2). An unspecific collagen might be animal collagen. Unspecific collagen was detected in all samples but with a weak signal in sample #R1 from Ringebu stave church and in sample #E7 from Eidsborg stave church (Krekel and Schultz 2019: 5–6). The protein staining with Sypro™ Ruby showed the presence of proteinaceous binding media in all analysed samples (Table 1 and Figs. 3–9). This corresponds to the results of the ELISA analysis.

Regarding additives in the binding medium, ELISA detected the presence of ovalbumin in samples taken from the decor in Heddal stave church (Fig. 4). Ovalbumin is a protein found in egg. No casein or gums was found in any of the samples analysed with ELISA (Krekel and Schultz 2017a: 2; Krekel and Schultz 2019: 2).

Concerning the detection of consolidation materials, all samples contained collagen, fish collagen (specific) and sturgeon glue. All three collagen types were analysed to identify the precise collagen type, where a detection of both fish and sturgeon collagen supports the presence of sturgeon, while a detection of fish collagen without the detection of sturgeon collagen only indicates the general presence of fish collagen (All sturgeon collagen is collagen, but not all collagen is sturgeon collagen) (Krekel and Schultz 2017b: 2). Sturgeon collagen was unambiguously identified and located in the samples from Heddal stave church (samples #H3–4); however, they showed differences in penetration, where the sturgeon glue in sample #H4 had penetrated farther than in sample #H3. Nonetheless, in both cases, the consolidation medium did not appear to reach the wooden support. In samples #U2 and #N6, the results were unclear. Sample #U2 only showed a very weak fluorescence on the edge of the uppermost layer, and in sample #N6, the finding could not be interpreted due to the autofluorescence of the wood.

All samples analysed with IFM revealed the presence of sturgeon glue used in recent conservation treatments. Some indicated that the detected sturgeon glue was linked to specific pigments, such as black (sample #E5; Krekel and Schultz 2017a). In sample #H3, it seemed that the black paint layer suppressed the fluorescence. In artworks in general, the IFM results are not as clear as they normally are in other types of samples. This is due to the antibodies' difficulties in binding to a two-dimensional surface as a cross-section. Additionally, there might be disturbing and/or destructive swelling of layers, washing out of materials and quenching of pigments (Schultz, personal communication 18 November 2019).

Discussion

Following the substantial condition assessments in Norwegian churches that highlighted the need for consolidation of distemper paint wall decorations, we needed to understand how consolidation materials, especially sturgeon glue (the consolidation medium found to be most preferable), affected the paint structure. To answer the question of how sturgeon

Fig. 4. Decorations in the chancel in Heddal stave church, where the medieval decorations lie underneath the 17th-century decorations. (Photo: Kjersti M. Ellewsen (DCH 2020.)

glue would affect the paint structure, ELISA and IFM analyses produced the most detailed results, indicating both the origin of the binding medium and the presence and location of the consolidation medium. The samples taken from consolidated areas showed the presence of sturgeon glue.

The identification of collagens other than fish or sturgeon relates to animal collagen. However, here, we do not know if this is from the binding media or gelatine from a previous conservation treatment, for example. Animal collagen was present in all 16 samples analysed by the ELISA method. When the ELISA analysis was performed (2017–2019), no antibody for calf collagen was available. The use of calf hides as a binding media for distemper paint is known through old written sources (Olstad 2016: 85) and would be essential to investigate in future analysis. Using IFM on artworks is still at the starting point, with the need for further research. Spot-testing for both sturgeon and calf has been proposed to find out where the original binding media would be present in the paint structure compared with the consolidation materials. So far, there are only possibilities for using one fluorescent marker at a time in each cross-section.

In problematic areas in need of re-treatment within 5–10 years, it has been suggested that sturgeon glue might not be present in the paint structure; when removing excess glue, a huge quantity of the applied glue is extracted. The findings reject the assumption that the absence of a consolidation material is the reason for loose paint in already consolidated areas. However, some of the IFM analysis detected a limitation of sturgeon glue in the absorbance of the paint, and the sturgeon glue had not reached the area between the wood and the ground layer. The Sypro™ Ruby protein staining detected protein in all samples. However, Sypro™ Ruby can distinguish neither between the proteins and their origin nor between original and later additions (e.g., sturgeon glue applied as a consolidation material). Thus, the protein staining produced too unspecific results for further understanding of the content in the paint structures.

IFM analysis offered the possibility to see the location of sturgeon glue within the paint structure, although it did not generate as clear results as hoped for. Ideally, we want the consolidation material to be present in the whole paint structure and down to the wooden support, enabling attachment of the loose and flaking paint. When the presence of sturgeon glue is especially linked to black pigments, this enhances the understanding about different pigments that need varying amounts of the binding medium – we can therefore expect a difference in impact when adding more consolidation materials to the structure. However, we do not know yet how this affects the structure.

In Uvdal stave church, where the paint layers are thin and with fewer structures, the consolidation treatment applied in the early 1990s remains in good condition, yet thicker paint layers and problematic areas do not produce positive results after re-treatment. Monitoring distemper paint over the decades shows recurring flaking paint in the same areas, mainly in those areas with several paint layers. It is still uncertain why this occurs. Hence, the analysis showed differences in the presence of sturgeon glue within the paint structure. A reason for this might be the painting technique or the used pigments that quench the binder and the glue in various ways.

The penetration of the consolidation material might also be influenced by the temperature of the glue, as indicated by the tests performed by Soppa et al. (2014: 5–7). Often, the temperature of both the consolidation material and the surface can be an issue; when working in unheated churches, certain parameters are difficult to control and measure. The consolidation material might be around 40°C in the container, but the temperature when applied on the (cold) surface is unknown. The tests by Soppa et al. (2014) used three different dummies, none of them on distemper paint. Regarding the uncertainties due to consolidation treatments, a dummy test could be a method that would provide a better understanding of the mentioned challenges.

Multiple applications might need a rigid system for application according to differences in concentration and monitoring of the temperature in the structure and on the surface in order to penetrate through the whole structure. This procedure remains to be performed.

Based on the undertaken analytical techniques, we cannot state anything regarding a possible interference of older consolidation glues when treating the distemper paint with sturgeon glue.

Methyl cellulose is a product that so far has yielded desirable results in consolidating flaking distemper paint in Norway. It is expedient to know more about how this material disperses in the paint structure. However, in the period when the analyses were undertaken (2017–2019), no antibody of methyl cellulose was available. The presence and the dispersion of methyl cellulose in consolidated distemper paint would be interesting to investigate further.

Regarding the detection of additives, analyses were conducted to detect the presence of egg protein, drying oil and casein. Regarding the detection of egg protein in relation to the Sturgeon-Glue Project, ovalbumin would most likely be found in the distemper paint from the Middle Ages (MA), as this was only found in Heddal stave church, the only church where samples that included MA distemper paint were taken. Additionally, no ovalbumin was found in other samples, which were taken from the 1600s distemper paints only. In contrast, the addition of egg protein had previously been proven in distemper paint decorations from the 1600s and the 1700s (Olstad and Solberg 1998). This indicates that even if egg protein is

not detected in five of the six stave churches analysed in the period 2017–2019, egg as an additive may be present in distemper decorations in other churches.

As mentioned earlier, the analyses undertaken by the CATS in 2015 showed the presence of drying oil as an additive in five out of eight tested samples from five stave churches. These findings correspond to the results of Olstad and Solberg's (1998) study, where four out of eight samples tested positive for oil. The analysed samples included distemper paint from the MA, the 1600s, the 1700s and retouching. Most of the samples that tested positive for drying oil were taken from those areas with distemper paint from the 1600s and the 1700s. The drying oil might have been used as an additive in the original distemper paint, as part of an earlier treatment or from the retouching medium.

Casein was not detected in any of the samples. There has been a theory that casein was used as an additive for distemper paint and could complicate a consolidation treatment. Based on the samples from the five stave churches, this is clearly not the case, and the theory is weakened. However, casein additives can still be detected in other distemper decorations, such as in the analysis conducted by Olstad and Solberg (1998).

Conclusion

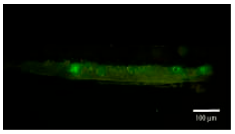
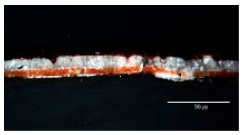
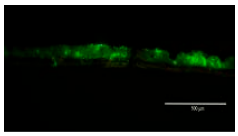
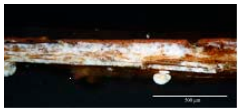
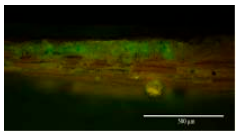
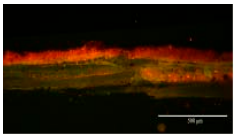
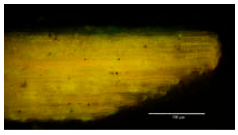
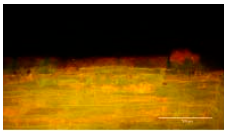
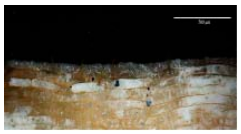
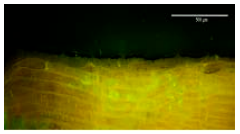
Since the 1990s, research projects like COMPOTEC and the "Sturgeon-Glue project" have been carried out to examine the properties of distemper paint and the challenges of consolidation. Nonetheless, many unanswered questions cause uncertainties in undertaking conservation work. Since the 1970s, distemper paint has been treated with a variety of materials and methods, where sturgeon glue has proven to produce the best results regarding re-treatability and no or little visual change. For decades, there have been ambiguities in how sturgeon glue affects the distemper paint structure. When challenging areas in distemper decorations in Norwegian stave churches recur and need reconsolidation of loose and flaking paint, we need to know what occurs within the paint structure. Analytical techniques, including FTIR-ATR, SEM/EDS, ELISA, IFM and Sypro™ Ruby protein staining, have recently given us some answers. First, these have provided us with additional information on what techniques can produce results in terms of detecting small quantities of different collagens; ELISA and IFM have detected the presence and the location of sturgeon glue within the structure of distemper paint samples despite challenges in obtaining good enough results from IFM on artwork.

Challenges regarding treatment of distemper paint might be deduced from the differences in painting techniques and thickness of the paint layers, as variations of locations and uneven dispersions of sturgeon glue within the paint structure after conservation treatment have shown us. Different pigments that quench the binder and the glue in various ways can constitute one reason. Surface and glue temperatures both affect the penetration of the consolidation material, and this might have affected the differences in penetration, as IFM and protein spot-testing have shown. Future research should focus on finding the types of animal collagen used as binding media to increase knowledge of the binding media, improve the IFM for artworks for enhanced readability, detect and locate methyl cellulose in distemper paint samples and make dummies on consolidated distemper paint for further tests in order to increase the understanding of the impact of temperature. Only by improving the analytical techniques will we be able to understand the distemper paint and the challenges related to consolidation of flaking paint.

Appendix 1: Results of analyses executed by CATS in 2015

Stave church	Sample	Date	Paint layers	Top colour	Binding media/ consolidation material
Heddal	Heddal 1	Middle Ages (MA), 1600	2	Red	Protein/oil
	Heddal 2	MA, 1600	2	Brown	
	Heddal 3	MA	1	Black	
	Heddal 4	MA, 1600	2	Brown	
	Heddal 5	MA	1	Red	
	Heddal 6	MA, 1600	2	Blue/grey	Protein/oil
	Heddal 7	MA, 1600, retouch	3	Black	Protein/ negative for oil
	Heddal 8	MA, 1600, retouch	3	Red	
Ringebu	Ringebu 1	1921	Several	Black on red	Protein/oil
	Ringebu 2	1921	Several	Red	Animal glue
Flesberg	Flesberg 1	1735	Several	White	Protein/oil
	Flesberg 2	1735	Several	White	
Eidsborg	Eidsborg 1	1604	1	Yellow	
	Eidsborg 3	1604	1	Black	
	Eidsborg 5	1649	1	Red	Protein/ negative for oil
Nore	Nore 1	1655	1	Grey/green	
	Nore 2	1655	1	Black	
	Nore 3	1680	1	Yellow/red	
	Nore 4	1680	1	Black on blue	
	Nore 5	1709	1	White on red	
	Nore 6	1709	1	Black	
	Nore 7	1714	1	Yellow	Protein/ negative for oil
	Nore 8	1714	1	Black on blue	
Uvdal	Uvdal 1	1655	1	Red	
	Uvdal 2	1655	1	Red on black	
The sample is strongly attacked by black fungus, (Aspergillus niger)	Uvdal 3	1655	1	Grey	Protein/oil
	Uvdal 4	1680	1	Reddish-brown on yellow	

Appendix 2: ELISA, IFM and Sypro™ Ruby results of the analyses in 2017 and 2019

				ELISA*						IFM results*	Protein staining*
Stavechurch	Sample#	Description	Year of analysis	Collagen	Fish collagen	Sturgeon collagen	Egg	Casein	Resins (AGPs) **	Sturgeon collagen	Sypro™ Ruby
Heddal	H2	White and brown paint layer + wood Middle Ages, 1600s	2017	x	x	x	x	-	-	n/a	n/a
	H3	Black and thin, white paint layer + wood Middle Ages 	2017	x	x	x	x	-	-	(x) 	n/a
	H4	Brown paint layer + wood Middle Ages, 1600s? 	2017	x	x	x	x	-	-	X 	n/a
	H5	Red and thin white paint layers + wood Middle Ages 	2019	x	x	(x)	(x)	-	n/a	(x) 	x 
Nore	N5	Red, grey and thin white paint layers + wood 1709 decor 	2019	x	x	x	-	-	n/a	X 	X 
	N6	Black paint layer + wood 1709 decor 	2017	x	x	x	-	-	-	- 	n/a
	N7	White, brown and yellow paint layer + wood 1714 decor	2017	x	x	x	-	-	-	n/a	n/a
	N8	White, blue and black paint layer + wood 1714 decor	2017	x	x	x	-	-	-	n/a	n/a

* -: no detection, (x): positive but weak signal; ambiguous, x: positive detection, n/a: not applied

**Arabinogalactan proteins

(Appendix 2 continues on next page...)

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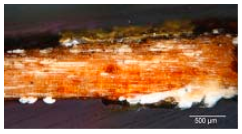
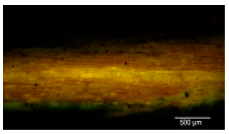
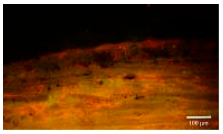
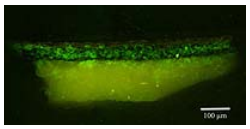
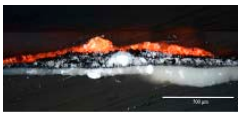
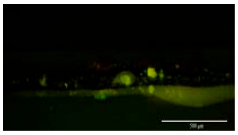
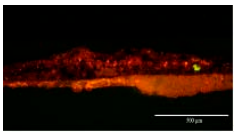
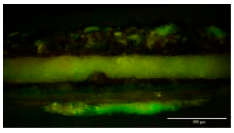
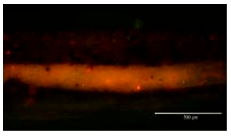
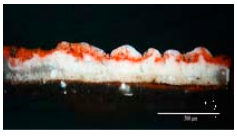
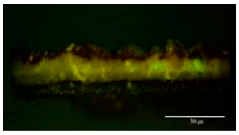
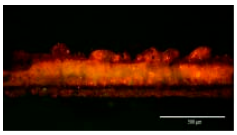
				ELISA*						IFM results*	Protein staining*
Stavechurch	Sample#	Description	Year of analysis	Collagen	Fish collagen	Sturgeon collagen	Egg	Casein	Resins (AGPs) **	Sturgeon collagen	Sypro™ Ruby
Eidsborg	E1	Yellow and thin grey/white paint layers + wood 1604 decor 	2019	x	x	x	-	-	n/a	- 	X 
	E3	Black and white paint layers + wood 1604 decor	2019	x	x	x	-	-	-	n/a	n/a
	E5	Red, black and white paint layers + wood 1649 decor 	2017	x	x	x	-	-	n/a	(x) 	n/a
	E7	Red, black and white paint layers; no wood 1649 decor 	2019	(x)	x	x	-	-	n/a	- 	x 
Ringebu	R1	Red paint layer with ground from 1921; red, black, white ground and white paint layers from 1700s + traces of wood 	2019	(x)	x	x	-	-	n/a	X 	X 
	R3	Red, black, grey and white ground from 1921; red paint layer with ground from 1700 tallet; no wood 	2019	x	x	x	-	-	n/a	x 	x 

* -: no detection, (x): positive but weak signal; ambiguous, x: positive detection, n/a: not applied

**Arabinogalactan proteins

(Appendix 2 continues on next page...)

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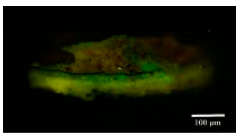
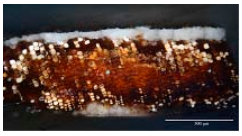
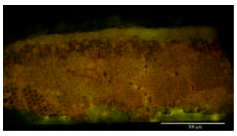
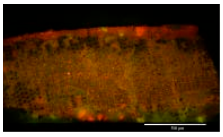
				ELISA*						IFM results*	Protein staining*
Stavechurch	Sample#	Description	Year of analysis	Collagen	Fish collagen	Sturgeon collagen	Egg	Casein	Resins (AGPs) **	Sturgeon collagen	Sypro™ Ruby
Uvdal	U2	Red, black, and white paint layers + wood 1655 decor 	2017	x	x	x	-	-	-	(x) 	n/a
	U5	Black and white paint layers 1680 decor 	2019	x	x	x	-	-	n/a	- 	X 

* -: no detection, (x): positive but weak signal; ambiguous, x: positive detection, n/a: not applied

**Arabinogalactan proteins

Acknowledgements

We thank Tone M. Olstad, researcher and paintings conservator at the Norwegian Institute for Cultural Heritage Research, for supporting and reading this article. She has been the key person within the ongoing the Sturgeon-Glue Project. Her experience in working with distemper paint has been priceless in understanding its complexity. We are also grateful to Dr. Julia Schultz and the good communication we have had when analysing the paint samples. We express our appreciation to the Directorate for Cultural Heritage for offering us the possibility to research this complex matter in order to improve future understanding of distemper paint. The writing of this article was partly funded by the Norwegian Research Council.

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Biography

Nina Kjølsen Jernæs and ***Anne Apalnes Ørnhøi*** have worked at NIKU since 2008 and many of their undertaken projects have involved consolidation of distemper paint in churches. They are both involved in the ongoing “Sturgeon-glue project”. They have written articles together concerning different paint mediums and challenges connected to consolidation and cleaning of art and interiors. In addition, Ørnhøi is involved in a research project led by NTNU concentrating on monitoring changes in the wood structure that influence overlying distemper paint. Jernæs has worked with changes in indoor climate influencing decorated surfaces, in combination with climate-related hazards to cultural heritage.

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