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CHAPTER

# Beyond the Fire of Attrition: Acid Decay and Forensic Reconstruction

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## Abstract

Digital images of manuscripts are primarily used today in much the same way as hardcopy research surrogates have been used since photography was introduced, allowing researchers to examine a manuscript page repeatedly and in detail without handling the book. This chapter explores the use of forensic musicology in the digital medium as a way of reconstructing lost manuscript content, focusing primarily on the Sadler Partbooks (Oxford, Bodleian Library MSS Mus. e. 1–5) as a case study. It examines the use of various surrogates as an aid to reconstructing a corpus. The chapter is both a case study and an introductory guide for those interested in the intersection of digital retrieval with archival and manuscript research.

**Keywords:** archival research, Tudor, Sadler Partbooks, forensic musicology, manuscript analysis

**Subject:** Musicology and Music History, Music Theory and Analysis, Music

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Digital images of manuscripts are primarily used today in much the same way as hardcopy research surrogates have been used since photography was introduced: they allow us to examine a manuscript page repeatedly and in detail without handling the book. Where previously a researcher might employ a magnifying glass to look closely at a grayscale glossy photograph, the digital image has the advantage of both being in color and, if the resolution is high enough, allowing the user to zoom into a close view of the image on a screen. Most development in the field of delivering digital surrogates of manuscripts is focused on viewing these new RGB images with the greatest ease, speed, and resolution possible online and in linking the images to metadata about the manuscript and page represented rather than providing the user with online tools to improve legibility.[1] The reasons behind this are both practical and historical.

Ultraviolet (UV) and infrared (IR) imaging are still relatively rarely employed even though the cost is now not dissimilar to standard RGB digitization.[2] This is because color and resolution in imaging have improved our ability to read damaged manuscripts significantly compared to what was possible by interacting only with the original source or analog surrogates (microfilms, photographs, Photostats, etc.). Because so much detail can be seen by enlarging a high-resolution RGB image, UV and IR are less often necessary.[3] When digital manipulation tools are used on the RGB masters—even very simple tools—an even greater level of information is visible. Image manipulation is, however, still an activity limited to a few users (and software prices ensure this group remains small); digital surrogates provide us with the opportunity to explore and exploit research materials in ways that were not possible before, but little or no technical development is being focused on online editing tools that can be used in conjunction with the image viewers now being used to disseminate most manuscript collections in the digital medium.[4] Aside from the technical issues, this is largely due to the vast range in the type of damage and the matching range in the needs of the editor. Researchers who master image manipulation can engage in activity hitherto only the province of a conservator and, with creative use of image-processing software, can go significantly further in repairing damage than a conservator could (though there are obvious dangers in editing images in ways that can lead to misreading or misrepresentation).[5]

The Sadler Partbooks (Oxford, Bodleian Library MSS Mus. e. 1–5)[6] have been effectively lost to the research and musicological community for more than half a century due to deterioration and fragility primarily caused by the acidity of the ink used by the original scribes; the ink has burned through the paper in many places, causing some leaves to start to disintegrate and leaving many pages illegible due to the extent of the interference from the writing on the reverse page.[7] Withdrawn from access since the 1960s, this set of five manuscripts was an ideal candidate for digital "rescue", and the Bodleian conservation and reprographics departments undertook to digitize them at high resolution in their entirety so that they could be digitally repaired as part of a larger project exploring the Tudor Partbooks repertory.[8] Among the surviving sets of partbooks, two sets that had been rendered unusable over time were singled out for their importance in terms of repertory and context. As well as the Sadler set, the set copied by John Baldwin,[9] originally six partbooks, was in excellent condition but lacking the Tenor book, and the Newcastle team led by Magnus Williamson reconstructed the missing book from concordant sources and, where no concordances existed, by bringing together experts in stylistic reconstruction of music of the period to recreate the missing voice part.

The Sadler set is one of only a small number of intact partbook sets surviving from this period,[10] comprising five books ranging in extent from sixty-three to seventy-one folios and containing forty-one Latin-texted compositions and one untexted work dating from around 1570–1585. To halt their deterioration the books were disbound and the pages de-acidified and stabilized (some with Japanese tissue overlay) in the 1970s.[11] Even after conservation they were deemed too delicate for handling or rebinding and are now kept in wallets inside boxes. They remain withdrawn from public access, with only a monochrome microfilm taken at the time of conservation available for research access until the recent digital imaging. The images were uploaded to the Digital Image Archive of Medieval Music (DIAMM) online repository at www.diamm.ac.uk and made accessible to the public in 2016. A few images in the microfilm conveyed useful information, but the vast majority defy even the most determined efforts to extract information from them (see Figure 1 for samples and Figure 2 for a graph showing the extent of damage across the books). With the exception of about 10 percent of the pages, the books were therefore effectively lost.

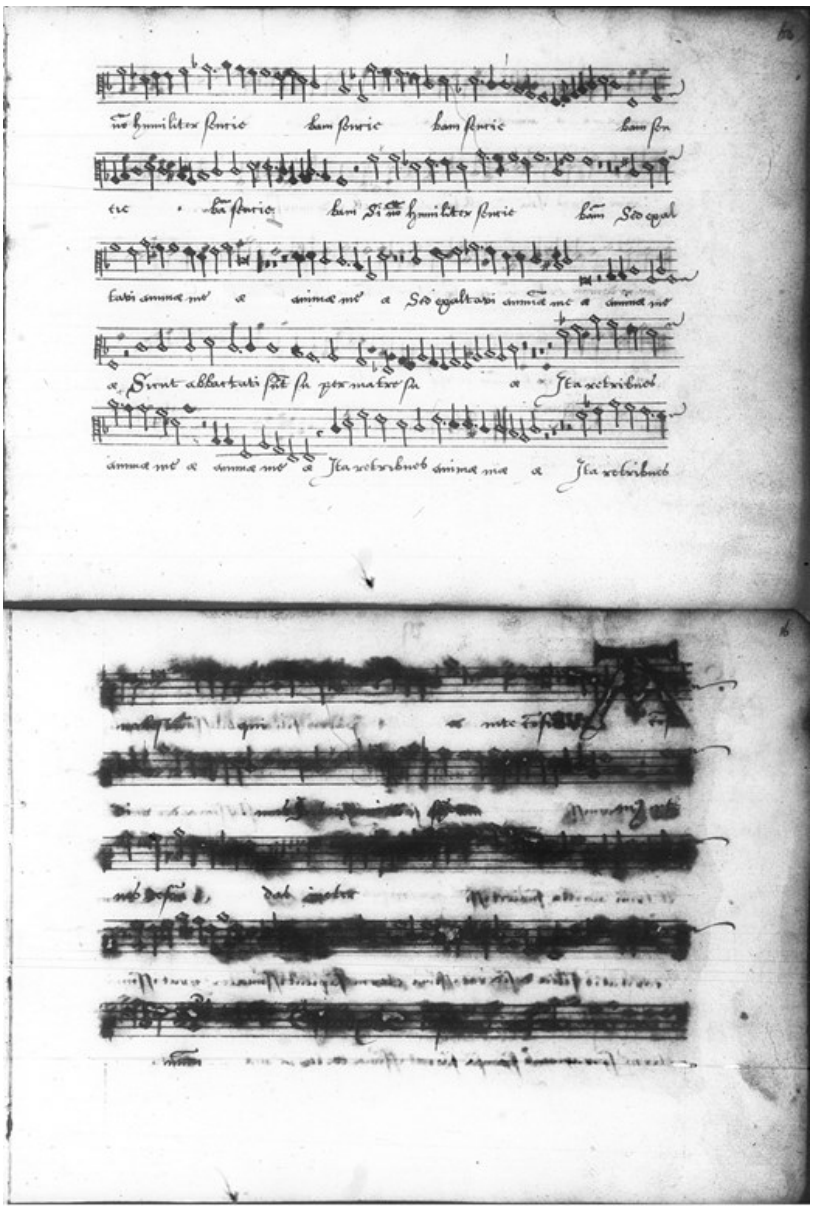

**Figure 1** Scans of the monochrome 1970s microfilm. Top: Mus. e. 3 f. 60r; bottom: Mus. e. 2 f. 16r.

**Figure 2** Graph of damage levels across the partbooks by musical work, rated from 1 (no appreciable damage) to 10 (every area of the page heavily damaged and largely illegible at real size).

The Sadler project set out to repair the damage to the lost books using the new high-resolution color digital images. The extent of the damage was such, however, that common processes such as global level adjustment were largely ineffective, and only a process of "forensic" reconstruction using a variety of sources of information could enable the images to be edited sufficiently to create versions of the leaves that would be fully usable and that could confidently be considered a meaningful representation of the manuscripts.

The Sadler books are important for a number of reasons apart from the fact that the set is intact: they are some of the few manuscripts of this type of music in which the word underlay is carefully positioned under the notes that are sung to those words, an important witness to the way in which the music of this period was performed.[12] There is also abundant evidence here to inform our understanding of how books like this were copied and used, far more so than in many of the other surviving sets: there are frequent corrections, made both during the process of copying and also by different and almost certainly later hands from the original scribes, or by the same hand after copying was complete. There are areas where errors in copying have been scraped or smudged away and rewritten, showing that the text and music were written simultaneously and that most errors were noted during copying. There are performance marks throughout the books that demonstrate not only their use with inexperienced singers (counting marks, underlay alignment marks, and slurs to support word-alignment), but also an afterlife in which they were used as source books: "+" signs used for copying orientation appear in later inks through several works, and there are insertions of accidentals, later layers of corrections, congruence marks, etc. It was therefore important that the ink marks laid down by the scribes were respected as much as possible since any paleographical study of the contents would need the repaired images to support any hypothesis or conclusion about the copyists or manner in which the collection came into existence.

These books are therefore not only witnesses to the repertory they preserve and the persistence and use of pre-Reformation music during and after the Reformation (at the time they were copied the collection was significantly retrospective), but also to copying practices and contemporary performance practice. In addition, overwriting in some areas (a rarity in music sources) suggests the books were compiled using practices related to scribal publishing, where a group of scribes deliberately formed their scripts to look as similar as possible to create a uniform output.[13] Although overwriting was a technique advocated by writing masters as an aid in teaching students to master letter shapes in text writing, this does not seem to have been the purpose here.[14] Although nothing is known of the afterlife of the books in the seventeenth to eighteenth centuries, owners from the early nineteenth century until the books were bought by the Bodleian Library were book collectors rather than musicians, and there is no evidence of textual accretion after the Tudor and early Stuart periods.[15]

Any representation of a manuscript is time-specific: attempting to recreate the way each page in the books looked in the past would produce a result that could not represent the appearance of the books at any time in its life with confidence. The pages seem to have been copied in layers primarily around c. 1585.[16] By the time the last page was copied though, the first page may have aged, and there is evidence that even in their early years some ink had started to show through and interfere with the writing. The decoration, too, seems to have been added in layers. Because of the layered construction and the use of different inks, at any time in the lives of the books some pages would appear more damaged than others, so even if it was possible to recreate a snapshot of the books at a particular time in the past, this would not provide us with a set of images that were paleographically reliable.

To describe the work as "restoration" would therefore be incorrect. Terms used for this type of work—sometimes described as "digital enhancement" or "digital editing"—did not accurately describe the level of intervention of the editors in this case. After demonstrating some prototype samples of editing to conservators in the Bodleian Library, they offered that the process was not "restoration" but rather "reconstruction." This term was surprisingly liberating, since it freed us from the constraints inherent in the terms "restoration" or "enhancement" and clarified to an end-user the extent to which the images had been changed. It also allowed us to extend the work beyond simply making the images readable to repairing all areas of a page that showed

acid damage, something that up to that point had been in question. Should the whole page be edited, or just the areas that are difficult to read?

Lacking an absolute original to which an editor could aspire, all that can be achieved is to repair the damage by reconstructing the paper and notation while remaining as true as possible to the shape and position of the pen strokes as they were first laid down on the paper. This is achieved with the help of multiple sources of evidence. There are many models of how the books *might* have looked today thanks to other contemporary partbook sets and from the few pages in the Sadler books that have not suffered from show-through; this appearance is the baseline of readability to which the editors aspired. The two images from the microfilm in Figure 1 showing the widely disparate condition of leaves demonstrates the wide variation in the extent of the damage caused by the original inks and thus the disparity in the amount of editing required to return each page to legibility.

The history of the books is evident in marks on the paper: water staining and offsets provide evidence of disturbance to the original order of the leaves. It was as important to preserve the evidence of contemporary practices, subsequent use of the books, and non–acid-related damage suffered during their history as it was to recover the musical notes and text underlay, so editorial policies had to ensure the preservation of this "peripheral" non-musical evidence: the work on the images thus needed to remain true to the manuscript in such a way that their original purpose and the way in which they had been compiled and written could be seen and examined as well as the evidence of their history and husbandry.

The reconstruction therefore does not represent the manuscripts as they were at any time in the past, only an idealized version of how they might have looked today had they been prepared with less acidic materials. The process has a corollary in the practice of editing music from this period for modern publication and performance. A modern edition most commonly takes the best readings from all the known sources of a musical work and concatenates them into an idealized version that often does not represent any performance at the time the work was current (since almost all copies include misreadings, variants, or idiosyncrasies of the scribe). Even where a single source is used to make an edition, obvious errors that would render the music unplayable or technically poor are corrected by the editor. Composers themselves apparently recomposed, evidenced by multiple variant copies of many works, so pieces of music evolved until they reached what might be considered a final version either by appearing in print or because of the death of the composer.[17]

The Sadler project intended the reconstruction work on the images to reach and benefit the widest possible public, a readership who could then utilize the books for the purpose and in the manner for which they had originally been intended, returning an original source to usability in the form it was conceived. The books were not originally compiled as display copies or as a collector's archive[18]: they were working books used extensively for performance, and even the quality of the notation indicates aspects of the scribes and copying practices. There would have been no point in simply rebuilding pages by cloning random noteheads so that the images showed the right notes and words on them: that would be better served by a diplomatic transcription. Though cloning would recover the music, it would destroy the information conveyed by the imposition of text on a page by scribes contemporary with its composition, an increasingly important aspect of understanding how to perform this music. A modern edition dispenses with aspects of the early notation with which modern readers are no longer familiar (e.g., parts copied individually rather than in score, imposing meter by adding barlines, and omitting or translating notational signs that no longer have a meaning to us): all of these have an impact on the manner of performance.

The final output for these images is therefore a color print publication which preserves the subtleties of layout and composition that would be lost in an edition or in a monochrome reproduction (Craig-McFeely and Range, 2023). One might ask also why, in a digital age and in a project employing entirely digital processes, one of the planned outputs (alongside web delivery) was a print publication. The answer is partly simple practicality: performers still find it easier to play from paper than from tablets or computer screens. In part this is due to cost (a tablet large enough to read a page of music clearly from a music stand is very expensive) and partly to

the limitations of tablet reproduction: the original must be in a form that fits the tablet. Performers almost always need to mark their copies during rehearsal, so the display needs to be able to do more than simply show the image. Performance issues aside, in the case of partbooks, screen real estate will probably always be a limitation in studying repertories with ease preserved in this format.[19]

Paper output recreates the physicality of the manuscript as an object, something lost in online viewing and one of the reasons "turning the pages" software is so widely used by museums and archives. Even with this software though, the size, shape, and bulk of the book and individual leaves has to be imagined. Those who engage with manuscripts as objects prefer a physical surrogate if access to the manuscript is unavailable since this is the best way to gain a sense of the manuscript as a physical object (and, of course, the user can mark the copy if they choose). As the digital world has opened access to manuscript images, paper facsimiles have taken on a new life, particularly among the wider public who do not have access to manuscripts as researchers.[20] Many professional and amateur music groups now perform from facsimiles of manuscripts since the way in which the music is read and performers interact changes significantly when reading from modern editions.

The reality of time and funding meant that the simple time versus result equation had a major bearing on decisions about methodology and thus the final appearance of the images. Despite a certain level of automation that minimized some aspects of the manual work that was needed to edit the 700 images of the damaged pages of the Sadler books, the work was still unmanageably large for a small team of specialists. The project was extremely fortunate to be able to supplement the in-house team with a large group of volunteers, some editing perhaps one or two images, while others contributed very significant amounts of time and work, making the project viable and facilitating a higher overall quality in the final appearance of the images than would have been possible otherwise.[21] The volunteers contributed not only practically (some creating glossaries of shapes and letter forms used by the scribes that were shared with the wider team, and others assisting in the process of training new volunteers) but also forced the expert team to refine the processes of reconstruction (skill levels with computers were diverse) and the boundaries of what could be achieved. Some of those who had never read music from this period before produced the most accurate restoration work since they had no expectation of meaning or the shapes they were reading. Paleographically, too, observations from the volunteers supported those of the in-house team: since the first recorded descriptions of the books in sale catalogues, the received wisdom was that they had been written by a Northamptonshire schoolmaster and parson, John Sadler,[22] thanks to the inscription "John Sadler" that appeared several times on the front endleaves and in the course of the books. Several of the volunteer editors independently corroborated the observations of the in-house team —having drawn painstakingly around each pen-stroke on a page—that different pages they were working on did not appear to have been written by the same hand, a fact borne out by later paleographical study of the complete corpus of edited images.[23] Toward the end of the project amateur and professional singing and viol groups "proofed" the completed images by playing and singing from them. The project could not have been completed without this extended community.

## Forensic Reconstruction

Though much of the writing—both music and text—was discernible with some effort and could be returned to legibility by careful "cleaning" editing techniques, areas of severe lacing, large holes, or solid dark patches could only be conjectured based on the shape, size, and position of the patches.[24] The process of reconstructing each page therefore became a complex concatenation of different pieces of evidence, both direct (different types of image surrogates) and "circumstantial" (extrapolation and concordancing), to enable the editorial team to reconstruct as true a representation as possible of the original content and construction of each page, not simply the lost music but the orthography and calligraphy of the original scribes; their process of copying, correcting, and recopying; and the interaction of each with other scribes or users of the books.

As it turned out, musicological reconstruction (as for the Baldwin books) was not required: even in places where the damage was so extreme that significant passages of music were lost, the missing notes could be supplied by concordances that were close enough to the Sadler version overall that the missing notes were highly unlikely to have represented a variant reading. The number of concordances indicates the importance of these books to the primary repertory of the period: a more peripheral repertory would have resulted in a similar number of reconstructed notes but would have required a heavier modern editorial hand in determining their pitch and value.

## Direct Evidence

### Master High-Resolution RGB Images

The new digital images were of a resolution and color-depth that image-processing software could differentiate color separation where the naked eye could not, and the images could be enlarged to the extent that very fine detail of the text could be seen that would not have been visible if examining the original leaves. These images were the primary source of information. It was possible to read approximately 85 to 90 percent of the text from these pages, given enough time and with support for questioned readings supplied by indirect sources of evidence such as concordances. The RGB versions of the leaves provided vastly more information than the monochrome microfilm (see Figure 3 for the RGB version[25] of the image shown in the lower part of Figure 1), and, with the greater resolution, it was possible to see the thickness of the ink which had sometimes formed crystals on the surface of the paper, thus facilitating differentiation between the surface ink and the show-through (see Figure 4). Unfortunately where pages had been repaired and stabilized with Chinese paper it was no longer possible to differentiate the layers of writing in this way, making these pages particularly problematic since they were also usually the most damaged.[26]

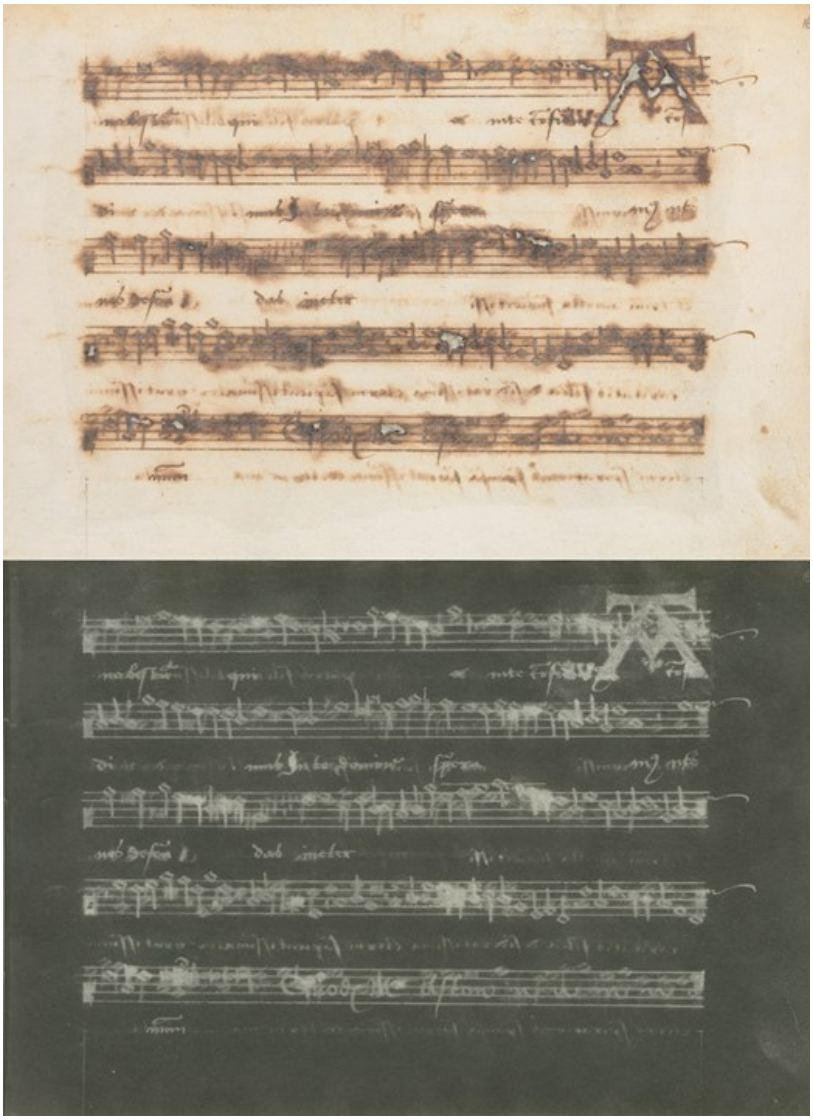

**Figure 3** Mus. e. 2 f. 16r. Master color RGB image taken by the Bodleian Library in 2014 (above), showing considerably more information than the microfilm (image of the same page from the microfilm is shown in Figure 1) and TCM negative Photostat (below), showing the extent of the deterioration in the intervening ninety or so years between the two images.

## TCM Photostats

In the early 1920s, the Carnegie Trust made a grant to the editors of the *Tudor Church Music* (TCM) series to make Photostats of some pages of the Sadler books required for making editions of works in the series. The monochrome negative Photostats survive in Senate House Library in London.[27] These surrogates show the manuscript as it was around a century ago, in a significantly different and usually better state to its current one: the decay is at an earlier stage, so even when show-through is apparent it is easier to differentiate between the surface writing and the reverse ink, even in monochrome. Some of the holes are considerably smaller, but a few areas are more difficult to read as they are obscured by gauze from an early and unrecorded conservation (perhaps undertaken to stabilize the leaves for this reprography). The gauze was evidently lifted in the 1970s, when the manuscripts underwent major conservation prior to microfilming, but the fine grid pattern can still sometimes be seen on the surface of the paper.

Very often, although information could not be obtained from the modern master image, missing or damaged notes could be found in the Photostats, so it was possible to repair notes on the RGB image with absolute confidence as to pitch, position, and shape. By superimposing the scans of the Photostats on the master images

as a layer, editors could draw around the note shapes shown in the Photostat, accurately reconstructing on the master layer the penwork of the original scribe.

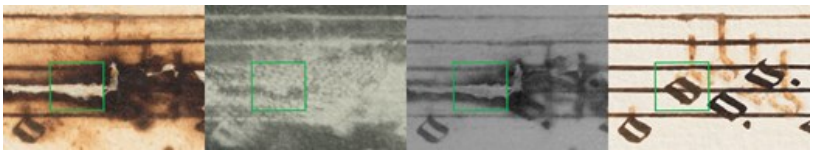

**Figure 4** Mus. e. 3 f.11r (detail). Reading surface notation by close examination. Top: Original RGB master showing surface crystalline deposit. Middle: The same detail with the edges of the original pen strokes outlined. Bottom: "Cleaned" version, which hides the show-through under a pattern-fill created from an undamaged area of the page, leaving the original stave lines and pen strokes untouched, thus retaining original note shapes, positioning, and scribal duct.

Superimposing images was not as straightforward as it sounds because the changes wrought by time and interference between the manuscript and the Photostat prints were manifest: there was both shrinkage and distortion in the manuscript due to the leaves no longer being stretched in a binding, with disintegration of the leaf structure as holes appeared. This was sometimes abetted by the conservation processes, which could not always reliably retain the original shape of the leaves or position of fragmented areas because the leaf was fixed in place by tissue overlay. The Photostats were beginning to deteriorate, with cockling and shrinkage particularly around the edges, adding to the discrepancies between the shapes of the pages as shown in the new digital images and the scans of the Photostats. This meant that simply dropping one image on top of the other did not align notes and other shapes. The superimposed image had to be subtly reshaped (in Photoshop terminology, "warped") to fit exactly over the notes of the master image, and even this process had to be limited by the amount of time available when added to the time needed for reconstructive editing. Rather than attempting to align all the notes on the page perfectly, the alignment was fine-tuned to those areas where the reading was critical.

## Infrared Images

By the time the images had been intensively studied most of the remaining questioned readings concerned missing fragments of paper, leaving only a few places where the paper remained but the RGB and Photostat images were indecipherable. The fragility of the manuscript led the library to put a limit on the number of pages that could be re-photographed under IR conditions, so only pages where readings could not be confirmed in any other way were therefore photographed.[28] The IR images were extremely revealing, not only for the questioned readings, but serendipitously confirming variation in ink types and revealing the pen strokes as they had originally been applied to the paper. The IR results obviated the need to attempt multispectral imaging, though that option was in any case unavailable because of the limitations on access to the original leaves.

The IR images were easier to superimpose because the interval between taking the master images and these surrogates was much shorter, and the digital surrogates were not subject to shrinkage or cockling. It was immediately apparent that the IR images provided a much better view of the original pen strokes than the color images or Photostats, even where the notes had been readable on the RGB images. Although these images are monochrome, the captured information enhanced the separation between show-through and the surface writing, revealing what might be described as the "ghost" of a very early state of the manuscript. As well as improving the show-through, the ink bleed around the pen strokes was eliminated, revealing finer pen-work than even the few undamaged leaves in the Sadler books had suggested. Ink bleed is a result of both the interaction of ink with paper and the natural aging of the documents; it may have started within minutes of the original ink being laid down and could not be wholly attributed to acidity, rather to the choice of materials and

the way in which they interacted. The IR images revealed a subtler and more refined picture of the pen-work than had either the RGB or Photostat images; ideally, a paleographical study of the books should be undertaken with IR images of all the leaves.

### Global Adjustment Versions (with and without Prior Color Selection)

There are types of manipulation that can be applied to digital images that improve their readability (if not their appearance) by separating out colors that are too close for differentiation by the naked eye and increasing the difference until it becomes visible. In many cases, pages that looked at first to be intractably obscure could gain as much as a 60 percent improvement in readability through applying global processes (i.e., adjustments applied to the whole page) such as thresholding, level adjust, color balance or contrast adjust, high-pass filter, etc. to the master images—a process that was only effective because of the high resolution of the masters, which delivered a very high level of color separation. Even so, the results still required painstaking close examination to extrapolate all the notation.

Color selections were ultimately used to automate the removal of the bulk of the show-through from a page image (editing processes are described below), but because the use of pattern fills was destructive, selections had to be conservative to avoid eliminating surface writing that should be retained. However, selections used for evidence could be used to "fade" back specific areas of unwanted staining rather than removing them altogether as an aid in reading prior to reconstruction. The result was strange in appearance (as if areas of the page had been overexposed) and might encompass colors that should not be removed so was not used in the final output, but it could be used where the eye alone was insufficient.

## Circumstantial Evidence

### Extrapolation

In a small number of cases, a note could not be convincingly retrieved precisely from any of the surrogates, but it was possible to deduce both value and pitch from the visible context and the missing note could be reconstructed by cloning one of the correct pitch and value from a cleaner part of the page. In a string of minims (stemmed diamond shapes), for example, a single missing notehead could be deduced in value from positioning and in pitch to some extent from the length of the tail coupled with the elimination of pitches that were visibly clear of notes. An example of a tailless note (either a breve or a semibreve) missing from Aston's *Te Deum* is shown in Figure 5.

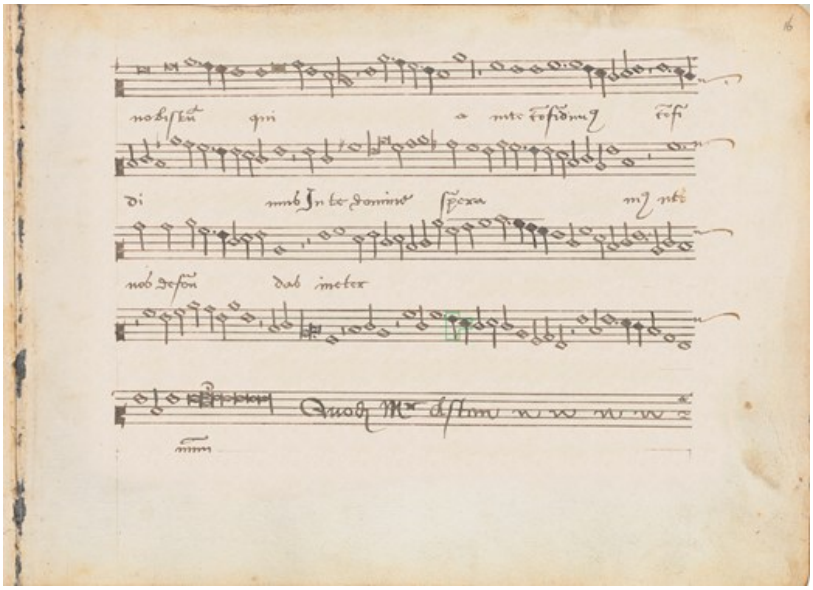

**Figure 5** Mus. e. 4 f.12v (detail of Line 4). The shape of only one note (boxed in the images) could not be reconstructed by referencing any of the surrogates. From left to right: Master RGB image; Photostat (obscured by gauze); infrared image; and reconstructed image including conjectured erasures indicated by the scratched-out stems on the RGB image, remnants visible on the IR image, and the source further along the line of the dittography that had led to the copying error.

The missing note must be on the second stave line up (it is not in either of the vertically adjacent spaces); it has no tail, so it must be a void breve (square note) or semibreve (diamond note)[29]; the context does not allow for a colored (solid black) note.[30] The Photostat contributes nothing to the reading because of the gauze overlay. The IR image confirms the two dotted diamond notes following the boxed note and confirms the absence of vertical downstrokes necessary if the missing note was a breve. It confirms that the note is placed on the second line up, and the visible edges strongly suggest a diamond rather than square shape; the value of the note (and thus its shape) is confirmed by transcription of all parts since any other value renders the polyphony incorrect. The missing note can only therefore be a semibreve (diamond) on the second line up. The reconstruction is effected by cleaning around the shapes of the notes shown in the IR image and cloning the missing note from a matching value close to this part of the page, thus retaining the usage of the scribe who copied this page if not the exact shape of this specific note. Although there is no doubt about the position, value, and pitch of the note, it is boxed to indicate that it has been reconstructed rather than repaired and should therefore be excluded from paleographical consideration of the scribe's work.

## Contemporary Concordances

Contemporary concordances were less reliable sources for information because variations between concordant copies of the same work are not uncommon, and variations in scripts between different collections are often significant. The Baldwin and Dow partbooks—particularly Baldwin—provided readings that were close enough to the readings in the Sadler books that their contribution was particularly valid, although Baldwin is lacking its Tenor book so could not support reconstruction of Mus. e. 4, the Tenor book in the Sadler set.

The primary usefulness of the concordant sources, as for modern editions, was in pointing an editor to the solution to a difficult or dubious reading (for this reason, though, they were only used when all other avenues had been exhausted, to avoid undue influence on the editor); the Baldwin concordances supplied a number of notes that had been lost to disintegration before the time of the Photostats.

Although with circumstantial evidence it was possible to recover the original pitches and values of notes on parts of the page that were missing even in the Photostats, it was not possible to restore the true appearance of

the lost areas of the page, only an approximation, so anything reconstructed in this way is indicated in the completed image by enclosing the inserted material in a green box (which could not be mistaken for anything but an editorial marking on the final images; see Figures 5 and 6 for examples).

## Modern Editions

The Sadler copyists were far from completely accurate: many errors in copying remained uncorrected by the original scribes and users of the books; these errors were not corrected in the reconstructions but were footnoted after determining the correct pitches or note values so that performers attempting to play or sing from the published version of the books would not be derailed by incorrect values or pitches. Without barlines or bar numbers to coordinate parts, a part coming adrift due to a reading error almost always has to result in the piece being restarted from the beginning.

Figure 6 shows the badly damaged leaf shown in Figures 1 and 3 after repair work. At first glance the page is unrecognizable. The main difficulty was with the holes in the page (for which, of course, IR light would not have been helpful). The Photostat showed a significantly less damaged state of this leaf, so all but one complete note and one notehead in line 4 on this page could either be seen on the RGB master (with some effort) or on the Photostat; these are boxed (in green on the color image). The values and pitches of the lost notes were supplied by a close concordance in the Baldwin books—fortunately this voice part is not the one missing from that set.[31]

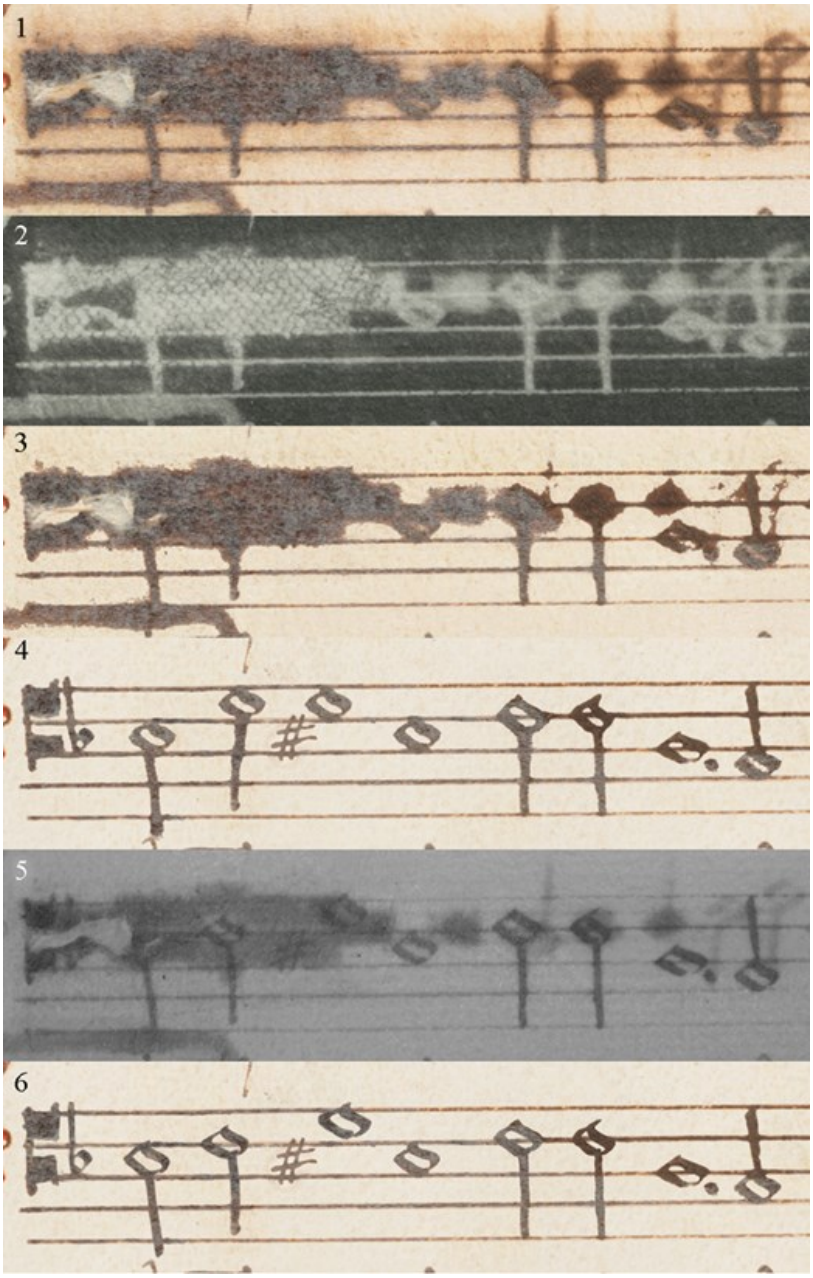


**Figure 6** Mus. e. 2 f. 16r (see also Figures 1 and 3) reconstructed version.

All areas of the reconstruction process had to evolve, from decisions about nomenclature and the overall policy with respect to the original documents to the actual reconstruction techniques used. Although ideally all decisions are based on loyalty to the original, it is difficult, as discussed above, to define in this context what the "original" is.

- Obviously the present state of the manuscripts makes them unreadable, so there is little point in reproducing them in this state except as references for the reconstruction process. Access to the original images for purposes of comparison and checking of paleographical data is provided by the online images for as long as that resource exists.

- The state of the manuscripts at the time of the TCM Photostats shows a much more readable version of the books, but much of the information is still lost and reading the books from these images is laborious —too slow, for example, for performers or those unfamiliar with the style of notation. Some damaged

pages were not included in the Photostat record, so this set of images was incomplete. Reproduction of this set is therefore no more useful than reproduction of the new color images.

- It is not possible to know at what point the acid ink started to have an effect on the reading, but show-through may have been apparent during the period of writing.
- The state of the first folios to be written may not have been exactly the same by the time the last pieces were entered into the books.

The prototype for this level of intervention in the images of a manuscript was work by the author on several leaves of Bologna at the Museo Internazionale e Biblioteca della Musica di Bologna, MS Q. 15 (hereinafter Q15).[32] A handful of the paper leaves in Q15 had suffered significant burn-through due to the acidity of the ink and paper and were unreadable. For the introductory study, I undertook a "restoration" of these eight images, facilitating the first modern transcription of the music they preserved. The Sadler books presented a degree of difficulty in reading similar to that of the damaged leaves of Q15 but a dramatic difference of scale, since instead of just eight page-images in Q15 there were 700 in Sadler that would require significant editing to make them legible.

The work on Q15 was done entirely using cloning, a "live cut-and-paste" of clean areas of the page to repair damaged areas by overwriting them. By successively eliminating (by cloning) marks that were show-through, the surface notes were isolated and subsequently transcribed. The time-consuming process was justified by the small number of images; the end result was usable for the purposes of transcription but not particularly attractive and was reproduced in a monochrome appendix to the commentary, with the unedited images appearing in the color facsimile.

The image processing was done using Adobe's Photoshop software, used by DIAMM since its inception in the late 1990s, when this software offered considerable advantages of functionality over other packages available at the time as well as continuous updates and support for multiple operating platforms and hardware such as graphics tablets that would not have been possible in a custom-designed software.[33] A new version of the image is saved for editing (in Photoshop's proprietary format) with the editing work preserved in layers that can be turned on or off or adjusted to be partially opaque, allowing the editor to make constant reference to the original image (which is preserved as the background base layer) and ensuring that each of the editing processes can be checked, examined, refined, deleted, or duplicated.

Overall, the concept of copying sections of clean paper from the image onto damaged areas is the root of all the editing work on this type of image, but rather than cloning copies of notes to be retained, the method employed here only clones a clean paper pattern to remove information that is unwanted (show-through, etc.), drawing around the pen strokes of the original scribes and leaving them untouched.

Cloning can be done "manually" by selecting a clean part of the page and copying it over something to be removed, but a faster process involves imposing a "blank" layer created from a composite repetition of a section of clean page called (in Photoshop) a *pattern fill*. The layer is masked out, and the editor selectively "paints" this layer onto the underlying image by using a brush tool to bring areas of the layer back to visibility. This speeds up the process considerably because the editor does not need first to locate a clean part of the page from which to copy, nor is the cloning attenuated by the size of the segment of clean paper being cloned. The process can be accelerated by enclosing the editing layer within a further mask layer that contains a mask of the same shape as the stave-lines, preventing the editor from painting over them, so large areas of show-through between notes can be removed very quickly because the stave lines can be ignored when brushing on the pattern fill and only the pen strokes of the scribe have to be avoided. By changing the size and fuzziness of the brush tool, large areas can be "swept" clean or very fine detail can be delineated. Because the work is saved in layers, inaccurate work can be repaired by editing the layer.

With 700 images, removing every unwanted mark on an image manually while at the same time avoiding damage to pen strokes that should remain was seemingly impractical. However, the cost of doing this work by hand was actually lower than the cost of attempting to have a specialist programmer write a piece of software that might do much of the work for us since the results of any automated process would still have to be manually checked and corrected.[34] Photoshop includes a macro editor that allows the user to record a series of color-select/replace actions to create a library of customizable semi-automated processes. This speeded up the early stages of editing and facilitated the fine-tuning and finishing aspects of the work. Six separate color selections were recorded, each selection was then refined by smoothing and feathering, the selection was then used to apply a pattern fill created from a clean area of the page. By keeping the color fills separate, one or more could be turned off after automatic creation to find the optimum combination for each image. In many cases, obscuring information that was required and then returning it to visibility with a mask over the fill layer (which prevents the color fill from showing) was quicker than using a less drastic color fill but having to paint over the remaining unwanted show-through manually while avoiding the edges of pen strokes.

Because the color-fills were based on the rust-colored tone of the show-through, they tended to remove the stave lines (which were drawn with a lighter ink than the music notation and text underlay), and the stave-line mask was made to exclude the stave lines from the color fills.[35] This was relatively easy given that stave lines are for the most part straight, although a single mask could not be created that would work on every page because the hand-ruled staves were too irregular. Creating the mask thus also resulted in a close study of the stave lines. Removing the rusty show-through also eliminated the ink bleed which had made even notes that were not affected by show-through appear fuzzy. Given that the fuzziness was an artifact of the ink type and quality of the paper, the team felt it was not inappropriate to eliminate it as a secondary problem caused by the copyists' materials. This mask also removed later accretions written in a lighter ink, such as performance marks, and these had to be carefully checked and recovered.

The techniques used in this work are described in detail with the visual aid of on-screen demonstration in training videos created for the project volunteers and distributed originally through the project website (www.tudorpartbooks.ac.uk) and more recently on YouTube.[36]

Figure 7 shows a detail of a page at different stages in data recovery leading to a final reading (the text underlay is not shown). At the start of this line of music a large decorative element on the reverse has burned through, obscuring several notes and leaving a hole in the paper repaired by the conservator with a clot of tissue. The first part of the line has been stabilized with tissue overlay, while the latter part is uncovered, and therefore easier to read, but still damaged by show-through. Since readings of tissue-overlaid areas were more difficult than other areas and the note shapes were less easy to define, the "cloudy" effect caused by the tissue has been retained in the final images as a visual aid to evaluating the reliability of the reconstructed notes rather than adjusting the colors of the ink to match the pages where there was no overlay.

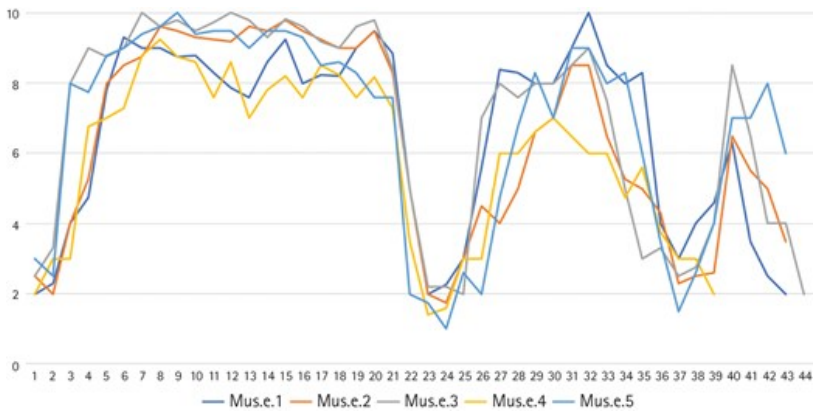


**Figure 7** Mus. e. 3 f. 10v, detail.

1. Master RGB image before editing: Notes at the start of the line are unreadable due to burn-through compounded by tissue overlay, which prevents differentiation in ink color between surface and show-through.

2. Scan of negative Photostat overlaid precisely: The void at the start of the line is slightly smaller, but the burn-through still hides at least three notes, with difficulty in reading compounded by gauze overlay. The head of the antepenultimate note is just discernible as a void.

3. Automated pattern-fill stage on the RGB master: Basic differentiated show-through (the rust tone in color images) has been replaced by a fill made from a clean part of the page; stave lines eliminated by the color selection have been excluded from the fill with a stave-line layer mask. To some extent the loss of the wider tonal gamut makes the text more difficult to read, although it has cleared much of the show-through.

4. First stage of reconstruction work: The number of notes hidden by the burn-through could be established from the syllabic word underlay, stems, and general spacing; note values and pitch are confirmed by context and stemming. The editor believed they could discern the shape of the second note from the left and outlined it accordingly, despite the awkward misalignment with the stem. The "feet" of the sharp are just visible in the original RGB image, and its overall shape and slant could be seen when zoomed in, as could the shapes of the noteheads that were not obscured by the intrusion of the burn-through. At this point concordances and editions are not consulted because those readings might influence the editor into seeing something that is not there, thus losing a variant reading.

5. IR image: There is now a clear reading of shape, pitch, and value for the notes and sharp sign obscured by the burned-through final; all notehead shapes are clarified, particularly position and shape of the dot following the penultimate note.[37]

6. Final reconstruction: This corrects the pitch and position of the second note and the position of third note, and it refines shapes of clef, noteheads, stems, and other signs (achieved by using the aligned IR image as an overlaid template). The notehead formations characteristic of this scribe are now clearly visible. The incorrect pitch of the second note in this detail was the only such error in the entire reconstructed corpus and demonstrates the textual importance of the IR images. The crossbars of the sharp are slightly too long and will be corrected at the next stage of checking.

This final version of the image was checked against contemporary concordances and modern editions of the work to check for any errors made by the editor or the original scribe (copyist errors are footnoted on the published images to facilitate performance). Versioning, layer-naming, and page-specific records of the work done by each editor kept track of individual contributions to the reconstruction; in the final checking phases, any work errors particularly common to any editor could be double-checked.

The degree of intervention necessary in each image to make it practically usable and to meet the need for parity between images meant that a high level of informed decision-making was required in order to achieve an accurate and acceptable result. The images were classified so that each one received a score that indicated to the end-user the extent of damage and therefore the extent of editing. This can be translated into a graphic representation of the levels of damage across the books (the last few works are in four parts and were therefore not copied into the Tenor book, *Mus. e.* 3).

Because the final images created from the master RGBs were to be described as "reconstructed"—with the implication of input from the editor applying specialist knowledge to the repair—it was possible to use the information provided by other surrogates of the manuscript to fill in the lacunae in the modern images; where even the surrogates failed, the lost information could be rebuilt by referencing other sources of the same music (concordances). In a few places, it was possible to determine the pitch of a note but not its value, but these

usually became evident when the individual parts were put together in a score edition. There were places where the damage was so extreme, even in the Photostat, that significant passages of music were lost, but, in each of these cases, the missing notes were supplied by concordances and the inserted notes clearly boxed.

An aspect of the books revealed by the reconstruction work and not anticipated in any way at the outset was that they had not been written by a single scribe (they were first described as the work of John Sadler in sale catalogues—see Burke, 2016—and the assertion was repeated without qualification or question in later scholarly publications). Indeed, a significant number of scribes seem to have been at work in the books. It was therefore important, if not essential, that the work on the images allowed for paleographical examination (and that the original images were available for comparison and consultation). Early reconstruction work in which some notes were cloned rather than being cleaned around was therefore revisited and the cloning of the noteheads removed.

The experience of this project and particularly its size has informed valuable lessons in planning and logistics, not merely in workflow but in the basics of transmitting very large images between geographically dispersed editors. At the outset the work was expected to be the purview of a small team of in-house editors, but expanding it to include volunteers made significant changes to workflow, policies regarding parity of appearance, the extent of editorial intervention, and so on. A similar project in the future should invest more time at the outset in exploring ways to automate even small steps in the process. It was evident that retina-quality screens and graphics tablets advanced the quality and speed of the work (neither of which were available to the team at the start of the project). Changing to retina screens partway through the project significantly improved the quality of the editing and led to some early work being discarded and redone, so attempting to work on existing equipment was a false economy. Graphics tablets are difficult to use at first, but perseverance in adapting from a mouse pays dividends in a much finer and subtler quality of detail work. Tablets would have benefited our volunteers enormously (many enthusiastic volunteers dropped out very early on because they could not manage the fine mouse control required by the editing process), as would full versions of the software rather than cut-down packages.[38]

A large team is essential: there is a limit to the amount of time an editor can work at a screen with the necessary intensity, so there are physical restrictions on how much any individual can achieve. Not only does a large team shorten the working period, creating and maintaining impetus, but the sharing of ideas and techniques creates a fertile development environment. Potential volunteers should be screened to ensure they have the necessary dexterity with mouse or graphics tablet. Inevitably there will be some wastage as volunteers find the work more tedious or frustrating than they expected.

Because of the care with which the Sadler images were edited, they have not only aesthetic and musical value, but also paleographical substance since they elucidate many aspects of the creation and use of the books that could not be seen before; extreme care has been taken to ensure any aspects of the reconstruction that must be disregarded for paleographical purposes have been clearly marked.

The ideal way to disseminate research based on edited images is always to reproduce the original master image alongside the one that has been edited, but this is not possible when dealing with a very large number of images in a print publication or in a journal article where the number of images are limited. Online there are more options, in particular those that provide the ability to view different versions of an image side by side or superimposed. A facility currently not available that would allow users to save their own versions of any image they were viewing online would mean that a variety of different users could offer alternative solutions to problems in reconstruction or restoration. With online research materials providing an increasingly-wider user constituency with access to manuscripts, opening this facility to all users can provide a fresh and often valuable perspective.

Because of the nonstandard nature of manuscript deterioration—even within a single manuscript or across a single leaf—producing scripts or specialist software that are effective even in a limited way across a number of samples is currently impractical, and this is one reason the development of online image-editing tools for this type of work is slow. A simple level-adjust of a complete image (editing the brightness or darkness of an image) can support examination of a damaged leaf, but this is only effective for some types of damage such as fading. In cases of severe or complex damage, a much greater level of interaction and specificity with the detail of the image is required than can be offered currently by online tools.

More subtle and complex editing requires the use of image-processing software; developing a custom application that would support this work is both impractical and unnecessary: commercial cross-platform software will enable any user to do the job and has the advantage of ongoing support and updates, as well as seamless integration with hardware such as graphics tablets. Free image-processing software is supported by open-source developer communities but is generally more unwieldy and thus slower to use, a serious disadvantage in dealing with large image corpora.[39]

The time spent on a task of this sort should not, however, be simply an end in itself. There are aspects of music manuscripts that can be understood by a machine, and one of these is the almost ubiquitous presence of stave lines from some of the earliest surviving manuscripts to the present. By the time polyphony became widely dispersed (even rudimentary polyphony), stave lines pervaded music in mensural notation with only a few tablature notations that do not make use of them. A web search for “staff-line detection” brings up a host of papers and fora in which the various methods for automating this are discussed.[40] Staff-line detection—and then removal—is the first stage in most optical music recognition (OMR) (since individual notes cannot be recognized computationally when they are joined to other notes by lines; they need to have white space surrounding them). The mapping of the staff lines in the Sadler books was saved in a layer that can be used to support machine-learning for more accurate staff-line recognition. The recognition process intended for removal prior to OMR can be repurposed to map out stave lines to automate one of the preparatory processes in digital editing of damaged music documents to mask staves from a pattern fill designed to remove, for example, show-through.

If working fast sacrifices the quality of the result, then it is necessary to look at the gains in the fast process and ask whether the time spent on correcting that process could have been better spent on employing a manual process over which the editor has complete control and that would reveal more. (The staff-removal algorithms used by the music information retrieval (MIR)/OMR community still require each image to be manually checked by a human.) Every page should ideally represent the most readable version of the manuscript possible, not simply a “good enough” version using a blanket process that works for some pages but not others.

The more time humans spend on this task, the more training data can be created for computational models that might be employed to create a process that can be modeled and eventually increasingly automated, but creating the training data needs impetus from the research community to require and use image-editing work for its own sake.

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## Notes

1 Hankinson's open-source Diva.js image viewer (fairly widely used and still under development) hopes to add basic image manipulation tools to the viewer's functionality, but this is relatively low on the list of tools that are gradually being built into the viewer. Development area: https://ddmal.github.io/diva.js/. Functionality currently includes a prototype partbook viewer, various views (page, thumbnail, opening, rotated, etc.), and scrolling update display of page content metadata alongside the images (see http://ddmal.github.io/diva.js/try/ for samples). Overlay of alternative (e.g., UV, IR, digitally manipulated) images is planned for the next release, with online editing tools further down the line.

2 It does, however, require additional handling, which is a conservation issue, but the setup is no different from that required for RGB imaging, and exposure times with single-shot digital capture are not appreciably different, although bracketed exposures are sometimes used to broaden the spectrum of possible results. UV and IR imaging can be managed with UV and IR bandpass filters but is more effective with UV or IR emitters in addition to the filters. In the case of IR, a camera without a built-in IR-blocking filter is required (many high-end manufacturers offer this as an option).

3 A technique using multispectral imaging is described in Andreas Janke, Sebastian Bosch, Oliver Hahn, Ivan Shevchuck, and Claire MacDonald (2014). The article describes the use of multispectral imaging and subsequent pseudo-color superimposition to retrieve lost readings from a palimpsest manuscript.

4 One delivery tool is able to offer global-level adjust to users, which is something of a blunt instrument but useful nevertheless.

5 Ethical issues are discussed in Craig-McFeely, 2020.

6 John Sadler wrote his name and other identifying marks throughout the manuscripts. The complete manuscript images in their unedited form can be seen at https://www.diamm.ac.uk/sets/127/ (accessed July 1, 2019).

7 A number of terms are used to describe this type of damage: "show-through" (in which the writing on the back of the page is visible in a paler color); "bleed-through" (in which the ink starts to bleed through the paper and is difficult to separate in color from the surface ink; "burn-through" (in which the paper appears burned by the ink and may disintegrate altogether). "Lacing" describes the effect of holes burned through between narrow pieces of surviving paper or parchment. There is overlap between show-through and bleed-through depending on perception, and, in this chapter, "show-through" is used to encompass both terms.

8 Tudor Partbooks: The Manuscript legacies of John Baldwin and John Sadler. AHRC-funded research project 2014–2017, www.tudorpartbooks.ac.uk.

9 The Baldwin Partbooks, Oxford, Christ Church MSS Mus. 979–83. https://www.diamm.ac.uk/sources/2348/#/ (accessed July 1, 2019).

10 There are eighteen surviving "sets," only nine of which are intact. Of the remaining nine sets, seven are lacking one book out of four or five and two sets lack three out of five. Oxford, Christ Church Mus. 979–83 "Baldwin" (1580 5/6 surviving); Cambridge, St John's College K.31 and Cambridge University Library Dd.13.27 (1530; 2/5); London, British Library Roy App 74–6 "Lumley" (1550 3/4); Oxford, Bodleian Library Tenbury 1486 and Berkeley private collection motets "Willmott & Braikenridge" (1591; 2/5); Oxford, Bodleian Library Mus. Sch. e.420–2 "Wanley" (1549; 3/4); Oxford, Bodleian Library Tenbury 389 and McGhie private collection partbook (1590, 2/?5); Cambridge, Peterhouse 471–4, "Henrician" 1539–41, 4/5). Later sets include the two Peterhouse Caroline sets that were considerably less complete until a recent discovery of a pile of manuscripts behind some sealed paneling: "Former Caroline Set" MS 47 (1625–40, 7/10); "Latter Caroline Set" MS 42 (1625–40, 7/8). As well as sets of books, twenty-three "orphan" books survive from the Tudor period (some only as a few fragmentary leaves from bindings), many of which may have been witnesses of a larger corpus of lost complete partbook sets, although some were evidently never part of a larger set. All partbook sets are available online at https://www.diamm.ac.uk/sets/268/.

11 Records of the precise date were not kept by the Library at the time.

12 There is extensive literature on word "underlay" (see, e.g., Mateer, 1995, or the collection of essays in Harrán, 1986, which includes the evidence provided by the Sadler books) Vertical alignment is not uncommon, and most of the contemporary partbooks display underlay positioning. The Sadler books are unusual in that the scribes rarely utilize repeat marks to indicate text repetition (://:), and the music spacing is adjusted to accommodate the text more so than in most other sources. The music and text were clearly copied concurrently, evidenced by corrections where the scribe has blotted out errors in both text and music together and written the correction over the top.

13 This was certainly not done to darken faded notes, as at no point in the books has the original writing faded. Although it is not possible to quantify or date how the damage progressed, it appears from 1920s Photostats that the progress of the show-through was reasonably consistent across a leaf, rather than deteriorating in patches, which would be implied if the overwriting was done to improve legibility. The overwriting was not confined to the most damaged pages and appears passim, on leaves of varying condition.

14 Handwriting manuals and copy books are legion; the following are only a sample in which tracing over a model script is advocated: Tagliente, 1524; Erasmus, 1528; de Beauchesne, 1574; Scalzini, 1581. While the scripts evolve, the method of learning to write them generally does not. Overwriting for script-learning purposes in a Tudor music source may have been present in the Hamond Partbooks, London, British Library Add. MSS 30480–4 (c. 1570–1615).

15 Their history is detailed in Burke, 2016.

16 There are four dates written in the body of the books, 1568, 1576, 1580, and 1581, with 1585 written on the front endleaves. These appear to be dates of composition rather than dates of copying.

17 See Milsom, 1988.

18 This has been suggested as the purpose for the exceptionally elegant set compiled by Robert Dow, Oxford, Christ Church Mus. 985–88. See Milsom, 2010. For online images, see https://www.diamm.ac.uk/sets/143/ (accessed July 1, 2019).

19 See Craig-McFeely, 2013.

20 Reports of the death of the paper facsimile have been greatly exaggerated.

21 Volunteers came from very diverse backgrounds ranging from graphic designers to professional caterers, with experience of music ranging from musicologists and talented amateurs used to reading from facsimiles of early sources to individuals who had no experience of reading music but were simply fascinated by the idea of hands-on interaction with documents of this age.

22 The identity of the John Sadler who wrote his name in the books was first proposed by D. G. Mateer, 1979. This was in fact a misidentification, and the books are now known to have been the property of a Norwich Grocer, John Sadler (1534–1592). See (Craig-McFeely and Range, 2020).

23 The matter of scribes is examined in detail in (Craig-McFeely and Range, 2023).

24 In some cases, this could be done with a fair degree of certainty (a) thanks to the relatively predictable musical vocabulary of the time; (b) by transcribing all the parts in score, thus determining the number of missing beats and limiting the

pitches to those that would be concordant with the other parts (as well as those that were horizontally appropriate); and (c) by references to contemporary concordances.

25 Although reproductions in the print version of the present publication are in grayscale, color versions of the figures may be seen in the online version or on DIAMM, www.diamm.ac.uk. A user account is required to view images, but this is free.

26 One hundred eighty-nine pages have been repaired with tissue, most often covering the whole page, but sometimes only covering the most damaged sections.

27 London, Senate House Library, Tudor Church Music Box 48. The exact date of the imaging is unknown; the approximate date comes from identification of the handwriting of a librarian on labeling in the images who retired in the late 1920s. We are immensely grateful to the department of Special Collections in Senate House Library and their administrator, Charles Harrowell, who have preserved these Photostats and kindly allowed me to visit them with a high-resolution scanner to make scans for the reconstruction project. They have also given permission for the scans of the Photostats to be made available online alongside the original and reconstructed images at diamm.ac.uk. Information about the TCM collection may be seen at http://www.senatehouselibrary.ac.uk/our-collections/special-collections/printed-special-collections/tudor-church-music-collection (accessed November 1, 2017).

28 Mus. e. 1: 13r, 13v, 19v, 20v, 22r, 32r; Mus. e. 2: 8r, 8v, 13r, 14r, 18v, 20r, 26v, 29v; Mus. e. 3, 10v, 18v, 20r, 21r, 30r, 31v, 71r; Mus. e. 4: 12r, 12v, 15r, 26r; Mus. e. 5: 10v, 17r, 19v, 44v.

29 There are clearly tails erased above the note: the erasure of the noteheads originally miscopied here having contributed to the damaged area because the paper was scratched thinner and two layers of ink were applied on this side.

30 “Coloration” is the musicological term used to describe notes drawn in black or red among void (or black) notes to change their rhythmic value.

31 Because the two versions of the work are so similar between the two partbook sets, the reconstructed tenor part in the Sadler partbooks can supply the missing tenor part for concordant works in the Baldwin set.

32 The destination for the images was a facsimile published with an introductory study (Bent, 2009); it was awarded the American Musicological Society’s Claude V Palisca prize for 2009.

33 Other platforms and free software now offer similar functionality, though not necessarily with the same ease of user interface.

34 Personal communication with Chris Steele (Managing Director at Marquis Broadcast, summer of 2015): Steele had worked in the film industry creating digital effects and specifically writing automated processes to edit sections of scenes; he provided an insight into commercial options. Unwanted items in shots (such as road traffic signs in period dramas) are dealt with by having humans clone the unwanted item out of every individual frame that showed it. He described cloning costs as a drop in the ocean for a multimillion-dollar production.

35 The mask is preserved in the files because it can be used as training data for automated staff-line removal processes.

36 Laurie Clifford-Frith and Katherine Butler, Digital editing videos uploaded to Tudor Partbooks YouTube Channel. See https://www.youtube.com/@tudorpartbooks4979 (accessed 1 May 2023). These continue to be updated from time to time with revised versions of the original videos and films showing new or more-advanced techniques for experienced Photoshop users). A time-lapse restoration (2 hours 20 minutes reduced to 8 mins) is included, showing the entire process from original image through to finished reconstruction. These have been used, along with images from the DIAMM collection, by the multimedia laboratory of the Department of Cultural Heritage, University of Bologna (www.framelab.unibo.it) for their course in Image Processing and Virtual Restoration, part of the Library and Archive Science Degree.

37 Dot positioning can be crucial both to scribal differentiation and provenance; see Milsom, 2017.

38 Full versions of the software were too expensive to distribute among fifty volunteers, particularly when there was no guarantee a volunteer would end up producing useful work or would stay with the project. Free options for image-editing software suffer from poor user interfaces leading to volunteer fatigue and attrition.

39 GIMP, GNU Image Manipulation Program: https://www.gimp.org/source/. Development areas on github:

https://github.com/snapcrafters/gimp; https://github.com/doctormo/GimpPs; https://github.com/GNOME/gimp; http://seebk.github.io/GIMP-Lensfun/, etc.

40 A selection of recent references indicate the extent to which this topic exercises the OMR community: see Calvo-Zaragoza et al., 2017. This article, available at https://link.springer.com/chapter/10.1007/978-3-319-58838-4_31 (accessed February 13, 2018), provides a host of further references, most of which have the full texts accessible online, linked from that article.