Atmospheric Pollution and Stone Degradation in Nineteenth Century Exeter

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SUMMARY

Over the nineteenth century the spatial pattern of coal use in Exeter changes little, particularly near to the cathedral. Localised sources of pollution, such as the heating of the cathedral itself may, in this context, be important sources of potentially damaging pollutants. By the end of the nineteenth century coal use in Exeter of approximately 33,000 tons is at a similar level to Oxford. Restoration and repair costs vary over the nineteenth century, but seem to bear little relationship to the changes in coal use. Detailed examination of the fabric records suggests that there is no simple, direct relationship between coal use and fabric repair costs. Complicating the relationship are a whole set of complex human systems involved in identification of decay, the style of restoration and management of the repair work.

INTRODUCTION

Studies of contemporary stone weathering have often linked changes in weathering loss to contemporary changes in atmospheric pollution (e.g. Butlin et al., 1992; Jaynes and Cooke, 1987; Inkpen, 1989; BERG, 1989; Webb et al., 1992). Similarly, studies of weathering in the recent past have linked weathering loss to changes in historic atmospheric pollution levels (e.g. Attewell and Taylor, 1988; Cooke et al., 1995; Viles, 1996; Trudgill et al., 1989). The potential role of past pollution environments in determining current rates of degradation, the 'memory effect', is an as yet unquantified factor in most stone decay studies (Smith et al., 1988; Cooke, 1989 and Inkpen, 1991), even if its existence is disputed at least over short timescales (Vleugels et al., 1993). Most studies of the relationship between weathering and historic pollution reconstruct the past environment from surrogate measures. In Cooke et al. (1995), for example, a simple assumption is made that the pollution histories of Wolverhampton and Portsmouth are more alike than that of Swansea. As a result there should be a

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difference between these two sites and Swansea in their weathering losses over the recent past. In this particular case, there is a significant difference in weathering rate over the last 150 years between the industrial Swansea site and the other two urban sites.

More detailed reconstruction of past pollution environments can help to identify not only the presence of a general difference, but clarify temporal and spatial variations in pollution levels and types. Studies such as those by Brimblecombe (1977, 1986) and Hipkins and Watts (1996) draw on various surrogates to develop a finely graduated picture of pollution levels and sources in urban areas over time. Additionally, some studies have tried to link reconstruction of atmospheric pollution environments with indices of stone decay. Camuffo (1993), for example, reconstructed the variability of climate and, hence, the weathering environment experienced by the Trajan Column, erected in 105 A.D. using a variety of different sources. Extreme or unusual natural events were determined by using data on eruptions of Mount Vesuvius. Climate was reconstructed using sources from Roman literature such as Columella, *De Re Rustica* (first century A.D.), the last two centuries of records from the Collegio Romano and implied from the flood records of the Tiber. Possible human influence on the weathering environment was inferred from population changes in Rome since the first century A.D. as well as from the location of industries within Rome over this time period. Combining these sources the appropriate environment for a particular type of biological activity could be inferred. No buildings erected since 1870 had an oxalate patina, hence, this form of biologically induced decay had not been active in Rome after that date. Using a critical population threshold of 150,000-200,000 to indicate a threshold for the occurrence of a lichen toxic atmosphere, Camuffo suggested that this biological activity would not have begun to affect the column until the fifth century A.D.

Viles (1996) reconstructed the pollution environment of Oxford and related its variations to changes in stone decay. Before the arrival of coal by canal in 1790, there was evidence of limited coal use in Oxford, for example, 18 quarters being delivered to Wadham College in 1611. After 1790 the canal gave impetus to the economic nineteenth century development of Oxford. During this period, for example, the population of Oxford rose from 9,500 in 1772 to over 30,000 in 1881. Viles estimates that coal consumption in the city totalled 34,000 tons per year in this period. Despite the dramatic increase in coal use, atmospheric pollution was not seen as a major problem; rather it was bad stone that formed the focus of concern.

Brimblecombe et al. (1992) used fabric records to determine the costs of maintenance and restoration at four cathedrals in the UK, Westminster Abbey, York Minster, Norwich and Exeter Cathedral. They noted that before 1700 fabric records tended to reflect the income for new, additional buildings or for rebuilding rather than the costs of regular maintenance. During the nineteenth century there was widespread enthusiasm for restoration of cathedrals and fabric records reflect this. Likewise they identify changes in architectural style, particularly the revival of Gothic architecture and design after the Catholic Emancipation Act of 1829, as being important in focusing restoration plans. Despite the differences in historic pollution environments of the four places considered the fabric records suggest a similarity in expenditure for virtually all of the nineteenth century. This was a surprise as analysis of sulphur dioxide levels in York from 1700 to 1851 suggested there had been a 3.5 to 8 fold increase in pollution (10 $\mu g/m^3$ to 80 $\mu g/m^3$) which was matched by at least a 10 fold increase in fabric expenditure. This relationship implied that stone decay was extremely sensitive to atmospheric pollution levels.

This study builds up a more detailed picture of the general atmospheric pollution levels in Exeter using similar surrogate data sources. Likewise, this study provides a more detailed analysis of the fabric records of Exeter Cathedral during the nineteenth century to assess the significance of the relationship between atmospheric pollution, and stone decay, the role of architectural trends in restoration work and expenditure and the importance of the human agencies involved in cathedral management.

POPULATION LEVELS IN EXETER

Figures 1 and 2 illustrates the spatial pattern of coal use or wood use in Exeter in 1801 and 1881.[1] Data from 1881 was used as this is the closest census date to the change in detailed recording procedures in the fabric records. The figures are based on the 3 tons of coal or wood used per household or dwelling estimate used by Hipkins and Watts (1996). A household was defined as 6 people based on the average household size from census data of the period. Although the population increased over this period, from just over 17,000 to just under 39,000, there was no dramatic rise. This is reflected in the similar levels of coal use for the city as a whole for both time periods. The pattern of high coal use is the same in both time periods with an increase in the number of areas of high use on the outskirts of the city. Areas of high and low use remain in the same relative relationship between the two time periods (Spearmans Rank Correlation Coefficient of 0.913 statistically significant at $\alpha = 0.01$). The areas immediately around the cathedral used relatively very little coal. Additionally, the large cathedral yard meant that any local pollution from within the city had to traverse a large open space to reach the cathedral. Sulphur production from the southern area of the city is likely to be underestimated using this fuel data as this area was a relatively economically poor area which was provided with low quality coal (Hoskins, 1968). Housing in the southern part of the city is also likely to have been relatively high density, low rise with narrow streets. This would mean that although there would be high sulphur production per unit area, most of it would be released at low levels making transport across the city difficult. The population data suggests that the

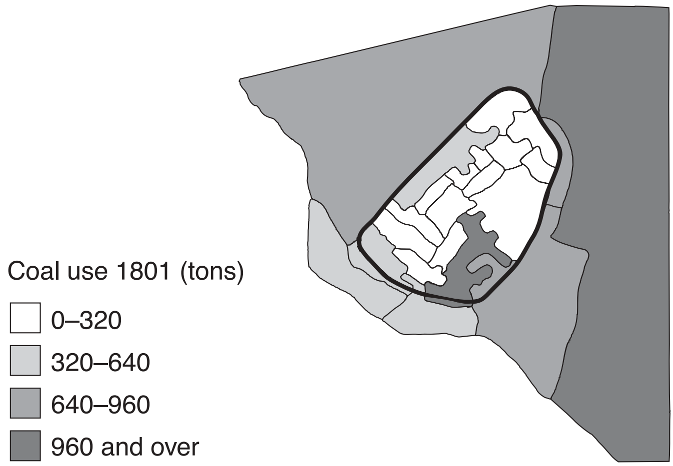

FIGURE 1. Domestic coal use in Exeter 1801

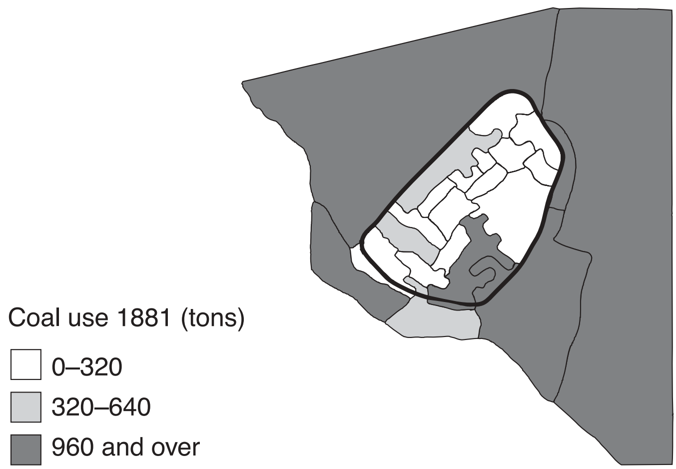

FIGURE 2. Domestic coal use in Exeter 1881

pollution environment of Exeter Cathedral was relatively mild throughout the nineteenth century.

COAL USE IN EXETER

By the mid-nineteenth century the arrival of the railways had complicated the transport of coal to the city from the solely seaborne trade of the eighteenth century. Records of a major user of coal throughout this period, Exeter Gaslight and Coke Company, do provide an indication of how the demand for coal changed. This company was responsible for gaslighting and supply in the whole of Exeter and so its coal use would reflect both increases in population and increases in demand for power and lighting for other uses. Technological changes and increasing efficiency of fuel use mean that the relationship is not prefect however. Figure 3 outlines coal use by this company. There was little heavy industry in Exeter in the nineteenth century suggesting that this company may have been the major coal user in the period. Combining this data with that derived from population (above), coal use in Exeter is relatively low throughout the nineteenth century peaking at less than 15,000 tons per year by the end of the period. If coal use by the general population is added, about 18,000 tons by the end of the period, then Exeter used about 33,000 tons of coal at the end of the

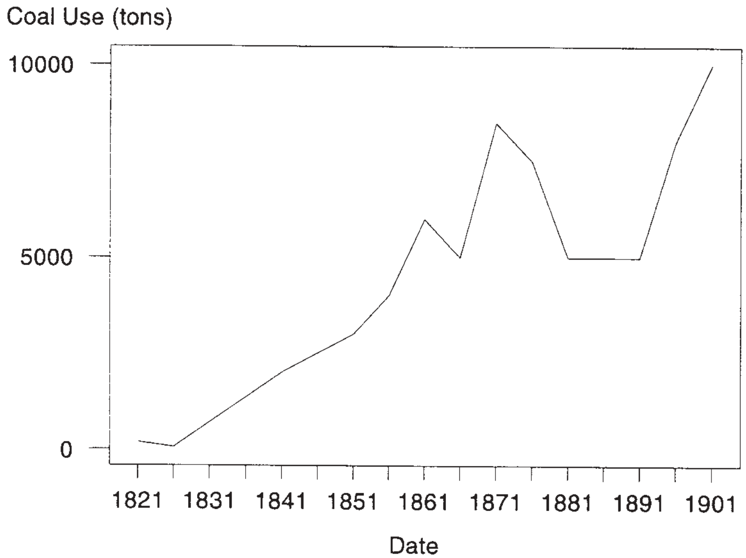

FIGURE 3. Coal use by Exeter Gaslight and Coke Company, 1821-1901

nineteenth century. This figure is very similar to the estimate by Viles (1996) for Oxford of 34,000 tons per year, whilst in contrast London by 1681 was already importing 360,000 tons of coal (Brimblecombe, 1986).

Local use of coal by the cathedral was restricted until after the 1860s when a coal fired heating system was installed in the Chapter House (Figure 4). Although coal use was variable from year to year, peaks of consumption correspond roughly with the periods of restoration work in the 1870s and late 1880s. In addition, the cathedral data highlights the potential differences in local and general pollution environments. The 1880s, for example, are a time of low coal use by the gaslight company, but one of relatively high use by the cathedral. Such local production of pollution may be more important for the decay of stone than more general pollution which may be generated far away from the building and may never reach it.

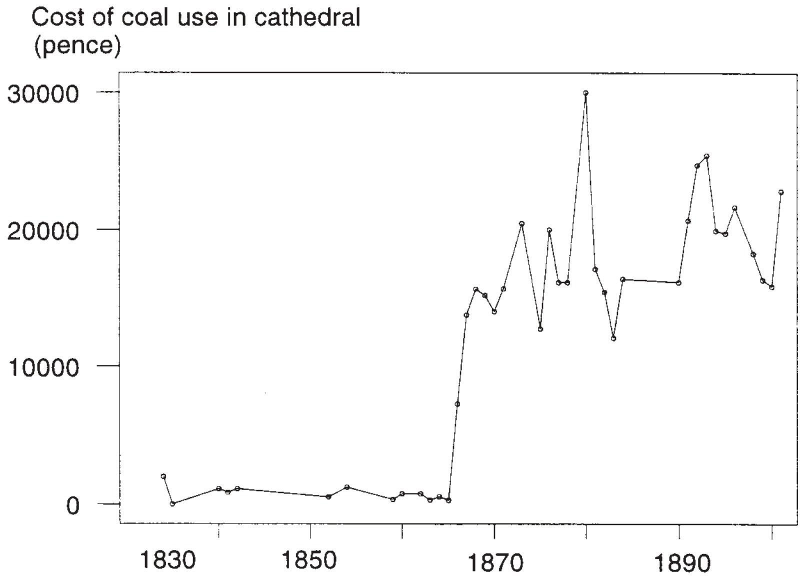

FIGURE 4. Expenditure on coal by Exeter Cathedral, 1830–1901

Both the population and coal data do suggest that the assumption of Brimblecombe et al. (1992) that Exeter was a city with relatively low levels of pollution was valid. In this case the similarity between the fabric expenditure in Exeter and more heavily polluted urban areas such as York and London requires a more detailed examination of the records of expenditure and the manner in which restoration and decay was dealt with.

CATHEDRAL FABRIC RECORDS

The fabric records provide details of repair costs, to whom payment was made, e.g. carpenter, mason or stone mason, and, in most entries, the nature of the work undertaken. Unfortunately, after the mid-1870s this detail is lost as the accounting procedure changed. The detailed records indicate whether work undertaken was inside or outside the cathedral. The fabric records suggests that there are distinct peaks of activity (Figure 5). Three of these peaks are related to documented phases of restoration by different conservators (Eskrine et al., 1988). The 1834 peak results solely from the large capital costs involved in repaving the interior of the cathedral using Purbeck stone. This peak can be disregarded for assessing the impact of weathering processes. The baseline, maintenance costs between peaks is still quite high. There is a decline in expenditure in the 1880s and early 1890s, a period of low coal use by the gaslight company. Such a close relationship between coal use and expenditure need not be causative however. An instantaneous reaction of stonework to changes in pollution level suggests that there are no lags between the two systems. It is more likely, given the 'memory' effect and other lags in the interaction between the systems that there will be an unknown time lag before the impact of any changes in pollution levels are registered as visible effects on stonework.

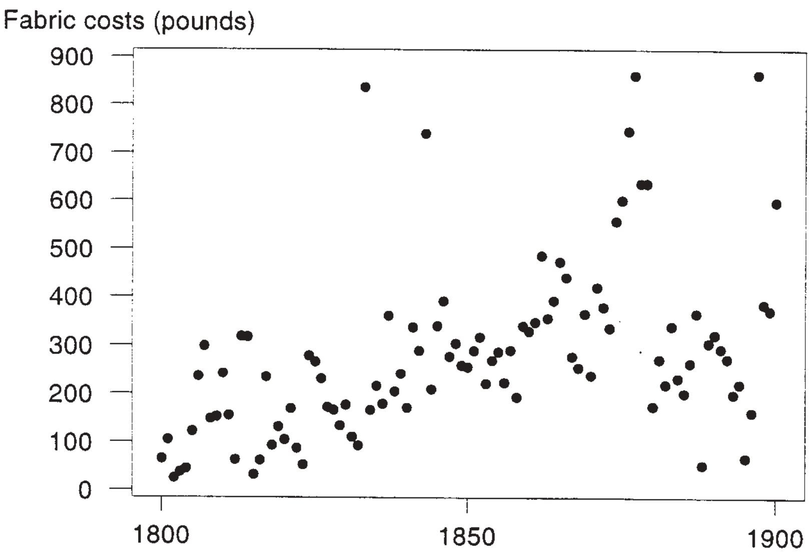

FIGURE 5. Fabric repair costs for Exeter Cathedral, 1800–1900

Disaggregating repair costs by occupation could help in determining if there is a relationship between atmospheric pollution levels and different types of repair work. The tasks of a mason and stone mason may reflect the need to employ different skills. Stone masons would be employed for repairs requiring a high level of skill in working stone, whilst masons would undertake more general repair work and maintenance. It might be expected that certain types of stonework, such as delicate carving, might be more prone to decay by acid deposition as they expose a greater surface area. Different types of stonework could, therefore, have different sensitivities to levels of atmospheric pollution. There is, however, no significant relationship between the costs of stone masons and masons by year over the period of study (Figure 6; Spearman Rank Correlation Coefficient of -0.146). Similarly, there appears to be no correlation between skilled stone masons' costs and coal use. This suggests that if the stone mason was employed to repair delicate stonework or for his expert knowledge, there is no indication that it coincided with periods of high atmospheric pollution. This implies that stone mason costs are not simply linked to pollution levels.

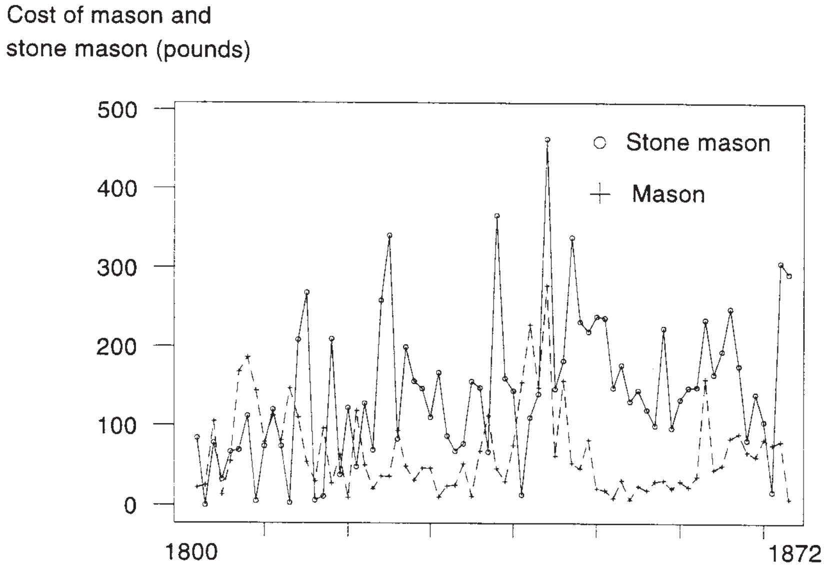

FIGURE 6. Expenditure on stone masons and masons within fabric records, 1800–1872

CONTEXTUALISING STONE DEGRADATION IN EXETER

Stone mason costs are subject to wide fluctuations from year to year which is not reflected in surrogates of atmospheric pollution. Detailed examination of restoration work undertaken by the cathedral in the early part of the nineteenth century could help in understanding why such variability occurred. Most of this restoration work was undertaken by John Kendall, a stone mason trained in the Gothic style (Eskrine et al., 1988). He did not propose the restoration work; this was put forward in the Surveyors Report of 1813. This report starts a separate record book and reflects the level of importance the surveyor attached to this survey and resultant restoration work (Table 1). Conclusions of the survey are entered twice, once as the initial report and the second time as a report specifically aimed at the cathedral authorities urging action on the survey. Within the second report a running total of the number of pinnacles requiring repair is visible in the margin in a different pen. I do not know if this tally is contemporary with the survey, but it is interesting to speculate that this may reflect a member of the cathedral authority keeping a tally on how much work was needed and a rough indication of costs.

Location	*Comments*
Library wall	8 much wasted and all pointed with Roman cement. 8 on north side being most considerably reduced in height.
South side, east end	8 lower tier, one of which new, others pointed much wasted and decayed. 7 upper tier much as those in lower tier.
West end of south tower	7 lower tier, one relatively new, much wasted and considerable parts of top gone on some. 8 upper tier, one relatively new.
North side, west end	6 in upper tier, 3 of which relatively new. 5 in lower tier, 1 of which relatively new. Most in sight.
Northeastern end	9 upper tier. 9 lower tier, but not as bad as those in upper tier.

TABLE 1. Pinnacle repair work 1812-1852. 1813-1814 Surveyor’s report

Although 75 pinnacles were identified for repair only 42 were repaired in the period 1813-1838.[2] The sequence of work undertaken suggests that there was a set of criteria used to determine the ordering of pinnacle repair (Table 2). The initial surveyor’s report and grading of damage was important in determining

Year	Location and Comments
1813	3 new pinnacles, north tower, west end
1818	4 pinnacles on north tower, west end, with new tops only
1821	3 new pinnacles (location unspecified)
1822	1 pinnacle north east end
1823	4 pinnacles, north east side, plus 4 on account
1824	3 pinnacles, 5 as agreed year before
1826	pinnacles north side
1827	4 pinnacles (location unspecified)
1828	4 pinnacles, Lady Chapel
1830	4 pinnacles, south side
1834	2 pinnacles (location unspecified)
1837	1 pinnacle, probably northern location
1838	2 pinnacles, west front

TABLE 2. Pinnacle repair work 1813-1838 (pinnacle work by stone mason 1813-1838)

this order as was the visibility of the damaged pinnacles. The first repairs and replacements, for example, were on the pinnacles most visible from ground level on the west end of the north tower. After these pinnacles those on the northern part of the cathedral were repaired before moving onto the southern end. Often repair work on pinnacles was combined with repair work on windows at the same location. This implies that restoration work was undertaken over a long time period even if a report pointed to the existence of major decay. Staging the work may have helped in raising finance for the repairs or for carrying out the repairs within a long term management plan or both.

The above suggests that certain parts of the stonework, those visible and relatively sensitive to decay, were repaired before other parts of the stonework. Pinnacles in particular seem to have required relatively regular repair, the surveyor noting that some pinnacles requiring urgent attention had only been repaired 30 years earlier. The amount of decay on these features may have been no more severe than on other features, but the visual impact of decay would have ensured their preferential repair. Such decay, however, could only be repaired once it was officially noticed. This required a surveyor's report and a long-term management strategy to pay for repairs. The importance of repair strategies for expenditure on restoration was pointed out by Brimblecombe et al. (1992). The evidence from Exeter appears to confirm that expenditure on restoration depended not only on physical processes causing stone decay, but also upon recognition of the problem by cathedral authorities and the financial resources to undertake restoration work.

CONCLUSION

Within nineteenth century Exeter atmospheric pollution levels show little spatial variation. Local variations in coal use at the cathedral may have more impact upon stone decay than the more general levels of pollution determined from the surrogates. There are temporal changes in levels, but these are relatively small compared to other contemporary urban areas. Restoration and repair costs vary over the nineteenth century and some variation appears to be related to similar trends in coal use. Detailed examination of fabric records, however, suggest that the relationship is not a simple one, with various system lags and other contributing factors intervening. Of particular importance is the staging of repair work by the cathedral authorities. This additional layer of decision-makers means that identification of a direct link between stone decay and atmospheric pollution is not feasible using only fabric records, at least, in the case of this cathedral.

NOTES

The author would like to thank the staff at the Exeter Public Records Office and at Exeter Cathedral Library for their courtesy and assistance in locating and finding the relevant records as well as useful comments from referees.

[1] The map was derived from Hoskins (1968) and provides outlines for the parishes of Exeter. The outer parishes had no boundary in the original figure and so an artificial boundary has been drawn around them. Unfortunately, the original map had no scale or orientation upon it.
[2] For the last nine years of this period John Richards was the stone mason.

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