archaeology international

Hales, J 2014 Bats in Churches: Objective Assessment of Associated Damage Mechanisms. *Archaeology International,* No. 17: pp. 94-108, DOI: http://dx.doi.org/10.5334/ai.1703

RESEARCH ARTICLE

Bats in Churches: Objective Assessment of Associated Damage Mechanisms

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This paper presents the preliminary results of research into the damage mechanisms involved when droppings and urine from insectivorous bats come into contact with a range of materials found within historic churches. It places the research in the wider context of conservation initiatives affecting both bats and historic church buildings in the UK.

Introduction

This research focuses on problems created when large numbers of bats make use of historic churches. At the heart of the research lies a conservation dilemma. The importance of conserving the species of bat native to the British Isles is widely accepted, but for some churches the presence of large numbers of bats has resulted in the deterioration of culturally significant items such as historic monuments, wall paintings, organs, memorial brasses, pews, lecterns, rood screens and fonts. Although we should hope to ensure a sustainable future for both our natural and cultural heritage, it seems that in the case of bats and churches, success in one area sometimes comes at a cost to the other.

The research aims to understand the damage mechanisms involved when bat droppings and urine make contact with historic materials found within the body of a church. It is hoped that improved understanding will make it possible to define damage more reliably, and thereby aid constructive discussion of the problem. It is a further aim of the research to re-assess current mitigation strategies (such as protective coatings) from a more informed perspective with the hope that positive and practical improvements can be suggested.

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Bats in the UK

Bats belong to the second largest order of mammals (Chiroptera) and represent approximately 20 per cent of all classified mammal species. They are the only mammals with true flight ability (as opposed to those that glide), and it is the ability to fly that has enabled them to become one of the most widely distributed groups of mammals in the world (Kunz and Fenton, 2003, 3). All 18 species currently found in the UK are small insectivorous bats ranging in size from the smallest *Pipistrellus pygmaeus* at 35–45 mm (head and body length) to the largest *Nyctalus noctula* at 37–48 mm.

Bats display a wide range of specialist behaviours and physical attributes which reflect the type of insect they prey upon, the niche they occupy, and the environment in which they live, hunt, and breed (Hill and Smith, 1984, Kunz and Fenton, 2003, Mitchell-Jones and Ovenden, 1994, Neuweiler, 2000, Richardson, 2002). Bats in the UK commonly give birth to a single pup per year, which they suckle for a period of six weeks. Juveniles will begin to fly after three weeks but will be unable to hunt and feed themselves until six weeks old. This slow rate of reproduction, coupled with the dependency of the young pups on the mother, is one of the factors that make bat populations very vulnerable to decline (Racey and Entwistle, 2003, 691, Stebbings, 1988, 13). Any disturbance to nursery sites that might cause bats to abandon a roost and their pups, or prevent parents from accessing a roost to feed their young can have a major effect on local populations and the future viability of a breeding population.

As small mammals, bats exploit a number of strategies to mitigate heat loss and promote efficient thermoregulation. Throughout the year they commonly roost in groups as this has the advantage of allowing temperature regulation and energy conservation through clustering together (Neuweiler, 2000, 64). UK bats frequently select roost sites in which they can group themselves in small crevices or cracks thus also providing physical protection. Warm roost sites are required for summer maternity colonies and cooler roost sites with stable temperature and higher humidity are required for periods of hibernation (Kunz and Lumsden, 2003). All UK bats hibernate during the winter when temperatures drop sufficiently that it becomes difficult for them to raise their (already high) metabolic rate in order to maintain body temperature.

Why do bats use churches?

Parkland, gardens, farms, lakes and woodlands are all good foraging environments for bats, and historically bats would have exploited naturally occurring roost sites in holes, tree crevices and caves (Boonman, 2000). In the past two hundred years, deforestation, the growth of modern agricultural practices, and the use of insecticides, coupled with huge urban expansion, has meant that there are fewer naturally occurring roost sites available to bats today (Racey and Entwistle, 2003, 694–696). As bats require different roosts for different purposes, the loss of just one roost can make a wide area unviable for bats, even though other types of roost site may remain within that area.

Thus, increasingly bats have become reliant on traditional agricultural buildings and old churches as roost sites (Howard and Richardson, 2009, 15). These provide ideal conditions of large roof voids, low light conditions, and flight access to and from roost spaces. Traditional timber- frame roof construction provides cracks and crevices not found in modern machine-cut roof timbers, while historic brick and stonework (and commonly the poor state of repair of historic mortar) provide yet more cracks and crevices. However, the trend for barns and farm outbuildings to be converted to residential or modern industrial use has meant that in some landscapes, churches remain one of the few viable roosting options for bats.

In the early 1990's a random sample of 538 churches and chapels in England showed that 142 (26 per cent) showed evidence of bat occupation, 93 per cent of which were historic structures belonging to the Church of England (C of E) (Sargent, 1995, 12). The C of E has responsibility for the largest estate of historic listed buildings in the UK. In addition to its 42 cathedrals, it is responsible for 16,200 churches of which over 12,000 are listed with over 4,800 being listed as 'Grade 1' (English Heritage, 2002, 4). Extrapolating from this data led the *Bats in Churches* report to suggest that a realistic figure for the total number of churches and chapels in England being used by bats as roosts at that date might be 6398. (Sargent, 1995, 13).

Legal protection of bats

In the UK all bat species and their roosts are protected by strict domestic and international legislation. The first piece of protective legislation with a direct bearing on bats in the UK was the *Conservation of Wild Creatures and Wild Plants Act* of 1975 (HMSO, 1975). In 1981, the passing of the *Wildlife and Countryside Act* tightened the legislation in that not only did it afford protection for all

Fig. 1: Left, this marble funerary monument was situated under a bat roost, the staining has been caused by bat droppings and urine in combination. Right, this lectern shows the characteristic white spotting found on wooden surfaces caused by bat urine, the associated reading light is badly corroded.

bats, but it also provided protection for their roosts (HMSO, 1981). Periodic legislation and amendments since (HMSO, 1994, HMSO, 2007) have resulted in further changes in the scope of protection. The following is a summary of how the current legislation relates to bats within the UK:

It is a criminal offence to:

- intentionally kill, injure or handle a bat
- disturb a roosting bat
- destroy or obstruct access to any place used by bats for shelter (regardless of if they are present or not at the time of the act)
- possess a live bat
- possess a dead bat or part thereof
- sell or offer a bat for sale without a licence

(Wildlife and Countryside Act, 1981, The Conservation of Habitats and Species Regulations, 2010).

The effect of this legislation is that only trained and licensed bat workers are permitted to enter a location in which bats are known to be roosting, or to carry out work which otherwise might disturb bats (e.g. bats box checks, hibernation surveys, work involving care of, or direct handling of bats). Maintenance work on buildings containing bat roosts is possible only if a licence has been obtained in advance. Most commonly licences for building works are granted on condition that work should not take place within certain periods of the year (this is dependent on the type of roost and the scale of work involved, but commonly work between April and October is not permitted in order to avoid disturbing maternity roosts).

The Conservation Dilemma

For many years, bats have been thought to be responsible for some types of deterioration to the historic fabric of churches. However, for materials other than wall paintings, for which some research has been undertaken (Paine, 1991), our current understanding of bat related damage extends no further than being able to observe corrosion of metals, pitting of polished stone, white marks on varnished or polished wood surfaces and dark staining on pale coloured porous materials such as alabaster (**Fig. 1**). We do not actually understand why this deterioration has occurred.

This is not just a material issue, there are social implications too. Broadly, the problem affects two different groups: on one side those who wish to protect and conserve bats as an important feature of our natural environment, and on the other those responsible for the churches - from national bodies such as English Heritage and the Church Buildings Council to the parishioners who are responsible for the use and daily care of the buildings. Material damage in church buildings is often conflated with non-material issues, such as the effect bats can have on the church's viability as a place of worship, the burden that bats and their habits place on volunteer cleaners, and the difficulties created when trying to undertake maintenance of a historic structure that is used as a roost by bats (Soady, 2013, BBC, 2011b, BBC, 2011a).

For some churches an inability to resolve bat related issues to the satisfaction of all concerned, has resulted in polarized views and a highly political and emotionally charged situation. Those responsible for the churches and their furnishings argue that damage by bats is significant and widespread, but bat protection groups argue that in many landscapes historic churches offer vital roosting locations, and are key to the viability of many local bat populations.

Another potential area for disagreement is that 'damage' is a poorly defined term even within the heritage sector (Strlič et al., 2013, Ashley-Smith, 1999, 99–119). Different people's perceptions of what constitutes damage can vary widely. When damage is reported, very rarely is the assessment based on any empirical understanding of physical, visual or chemical change within a material. Even within experienced groups of heritage professionals, difference in training, working context and specialism give rise to a surprisingly wide divergence of opinion on the nature of damage, even when the same object or group of objects is being assessed (Taylor, 2005, Taylor, 2009).

Defining an object or material as damaged is the conclusion of a very individual and complicated multivariate analysis. Factors taken into account by an individual (often subconsciously) when assessing 'damage' could include:

- The status and values conferred on the material or object in question
- The perceived extent of physical, visual, chemical change that has occurred
- The degree to which the change has impaired the ability of the material or object to perform its practical function
- The degree to which the change has impaired the material or object aesthetically
- The degree to which the change has impaired the cultural/spiritual significance of the object or material, or has undermined the object's ability to demonstrate its significance.

This list is not exhaustive, but does indicate why two different individuals could agree on the nature of physical, chemical or visual change in a given instance, but might disagree regarding the degree to which that has constituted definable damage.

Methods used and approach to the research

The methods employed in this research are based on experimentation, observation and analysis, with care taken to ensure that the work produced is both objective and reproducible. Work for this project has been designed to provide a data set capable of answering the fundamental questions relating to the deterioration mechanisms responsible for the types of change ('damage') that have been attributed to bats, namely:

- Corrosion of metal surfaces
- Pitting, etching, long term staining of porous surfaces
- Etching of polished surfaces

- Promotion of mould/fungal growth on organic materials

(Paine, 1992, Richardson, 2003, Howard, 2009, 56–57)

The range of material affected by bat droppings and urine in historic churches is broad and therefore presents a challenge to exploring the damage mechanisms involved. Some materials (e.g. marble, alabaster) are porous thus more likely to be affected by the penetration of liquids resulting in dissolution, salt deposition and staining. Soluble salts deposited within porous materials can undergo cycles of dissolution and re-crystalisation that result in the disruption and powdering of surfaces. Non-porous materials such as metals, will be less affected by these mechanisms but will be very susceptible to corrosion promoted by the presence of electrolyte solutions. It is not only the range of materials involved that creates difficulties, it is also likely that bat droppings and urine deposited in isolation on a surface will react differently to droppings and urine in combination.

Due to the complexity of the problem, experimental work has been designed so that standardized tests and experiments can allow multiple variables to be analysed both in isolation, as well as in combination. Although the use of synthetic/surrogate materials representing bat droppings and urine would introduce less variability to experimental work, it was decided that fresh bat droppings and urine from live bats living in a natural environment and eating a natural diet should be used wherever possible.

Experimental work in the first part of this research (and reported on here) has consisted of:

- Urine collection from live bats in order to determine pH (acidity or alkalinity), urea concentration, and sodium, potassium and chloride ion concentration.
- Experiments to establish the role of urea crystals in the deterioration of porous materials
- Design of test materials and their exposure to bat droppings and urine for subsequent analysis

Case studies

If it could not be demonstrated that the deterioration shown in experimental work was comparable to that observed *in situ* in churches the research would be of limited value. For this reason case study churches were incorporated into the research design to provide context for the experimental work. In addition to fulfilling this role the churches provided an opportunity to assess the practicality and efficacy of any mitigation and cleaning practices being employed by parishioners.

Two suitable case-study churches were identified with the assistance of the Church Buildings Council. The churches were chosen on the basis that they had bat roosts and significant bat activity, and had employed mitigation strategies in an attempt to ameliorate the effects of bat droppings and urine.

St Nicholas Church, Stanford on Avon in Northamptonshire is a Grade I Listed building built between 1300 and 1350AD. In addition to an historic organ, baptismal font and woodwork, it has a number of important historic monuments currently suffering damage as a result of a large *Pipistrellus pygmaeus* (Soprano Pipistrelle) maternity roost. Holy Trinity Collegiate Church, Tattershall in Lincolnshire, is a Grade I listed building dating to between 1472 and 1500AD. It is a large church with medieval stained glass and an important collection of brasses. The church is currently used by three species of bat: *Myotis daubentonii* (Daubenton's bat), *Myotis nattereri* (Natterer's bat), and *Pipistrellus pipistrellus* (Common Pipistrelle).

Bat species used in this research

The experimental work undertaken to date has focused primarily on those species of bat most commonly found using church buildings in the UK. The *Bats in Churches Project*, (Sargent, 1995, 12) reported that four species of bat are commonly found roosting in churches, of which the following three are widely distributed (BCT, 2006) thus most likely to produce data broadly relevant to churches throughout the UK:

- *Pipistrellus pygmaeus* (Soprano pipistrelle)
- *Plecotus auritus* (Brown long-eared bat)
- *Myotis nattereri* (Natterer's bat)

Choice of representative test materials for use in experimental work

To provide consistency and comparability of results modern materials were selected to represent the historic fixtures and furnishings in churches. This allows for a more robust experimental approach, additionally modern materials offer greater opportunity to represent a range of compositions within a single material type e.g. the different alloy compositions that might be found in monumental brasses. This 'replicate first' approach can be used to inform later work on original historic materials, thus ensuring a better understanding of the basic mechanisms involved.

A review of the materials traditionally used in the manufacture of historically significant objects, furniture or decorative features within churches produced the following list of broad material categories:

- Metals and metal alloys
- Wood (sometimes covered in polish or other coating)
- Stone
- Textiles
- Wall plaster
- Polychrome surfaces
- Glass

In selecting material to investigate, priority was placed on those materials that were most commonly exposed to bat dropping and urine. The following criteria were used to determine which materials would be studied:

- Is it commonly found in a horizontal plane when *in situ,* thus likely to suffer a high rate of deposition of droppings and urine?
- Is it commonly used in a way that would prevent it being easily moved from its position within a church building?
- Can the material be accurately represented in experimental work using a manageable number of modern sample materials?

The list of test materials ultimately selected for experimental work is given in **Table 1**.

Data generated

Table 2 provides a summary of the different stages of the project showing the connection between the research goals, the experimental methods used to achieve these goals, and the basic data sets gathered.

Preliminary results

Work on this project is still in progress, but some preliminary results are reported in the following section.

Bat urine collection and analysis

Understanding of deterioration mechanisms related to bat urine must begin with knowledge of its chemistry. Damage mechanisms are likely to be governed by pH, ion concentration, urea concentration, as well as by any material left after the liquid fraction of urine has evaporated. Unfortunately, there is little reliable information available relating to the urine composition of UK bat species. To gather reliable data, quantities of bat urine from multiple bats of different species were obtained and analysed.

The analysis focused on:

- urea concentration
- Sodium (Na) ion concentration,
- Potassium (K) ion concentration
- Chloride (Cl) ion concentration

Test material	Representative of
Lead/tin alloy 94/4 (remainder trace elements)	organ pipes
Lead/tin alloy 42/51 (remainder trace elements)	organ pipes
Lead/tin alloy 29/66 (remainder trace elements)	organ pipes
Copper/zinc alloy 90/10 alpha (Gilding metal CW501L)	Memorial brasses, church plate, lecterns, architectural fittings
Copper/zinc alloy 70/30 alpha (cartridge brass CW505L)	Memorial brasses, church plate, lecterns, architectural fittings
Copper/zinc alloy 63/37 alpha (common brass CW508L)	Memorial brasses, church plate, lecterns, architectural fittings
Copper/zinc alloy 59/39/2pb alpha/beta (engraving brass – modern CW608N)	Memorial brasses, church plate, lecterns, architectural fittings
Alabaster	Funerary monuments
Marble	Funerary monuments, architectural elements
Granite	Memorial slabs, funerary monuments, flooring, architectural elements
Oak (untreated, waxed, or coated with shellac)	Pews, rood screens, fonts, choir stalls, pulpits, lecterns, architectural elements
Pitch Pine (untreated, waxed, or coated with shellac)	Pews, pulpits, lecterns

(Note: CW numbers for copper alloys refer to British Standard numbers for the specified alloy).

Table 1: Final selection of test materials chosen.

- pH

Apart from the measurement of pH, all the analyses were carried out by the Diagnostic Laboratories, of the Clinical Services Division of the Royal Veterinary College, using an *IL ILab 600* clinical chemistry analyser. Na, K and Cl ion concentrations were measured by ion selective electrodes (ISE), and urea concentration was measured spectrophotometrically at 340nm. Urea analysis was based on end-point analysis and an enzyme-coupled urease/GLDH methodology.

Urine analysis required a minimum of 150 µl of urine for one attempt at all four tests. In order to allow for waste during pipetting into the analyser, 200 µl was ideally required. UK bats do not produce this volume of urine individually, commonly producing in the region of only 20 µl per micturition (Shackelford and Caire, 1993). Therefore a method of urine collection based on pipetting multiple fresh urine samples from the surface of a non absorbent material placed in the enclosures of captive bats was devised (these are healthy bats recovering from injury). The approach had the advantage that it could be carried out by licensed bat workers on my behalf, allowed urine to be collected from multiple bats, and would allow a sufficient volume of urine for analysis to be collected. In addition to these logistical advantages, the method of collection also meant that the samples analysed were in effect a 'species average' composition, and therefore the risk of collecting urine from an

Experimental work	Data set generated	Research questions answered
Urine collection from live bats in order to determine, pH, urea concentration etc.	Species specific pH data, urea concentration and K, Na and Cl ion concentration	Species specific understanding of what bat urine is chemically, including urea concentration and pH. Informed understanding of mechanisms of deterioration.
Experimental work to determine effect of deposition rate, pH and urea concentration of aqueous solutions on sample materials	Observations from experimental work	Is there any interaction between bat droppings and urine and those materials commonly found within a church building that would result in chemical, physical or visual change? If so, what is the nature of the interaction and what are the mechanisms involved?
Experimental work to establish the role of urea crystals in the deterioration of porous materials	ESEM and SEM micrograph data showing effect of urea crystalisation on porous materials	If physical, chemical or visual change does occur, is the effect impermanent or superficial, or significant and permanent?
Exposure of test materials to bat droppings and urine for subsequent analysis	Exemplar data set showing quantifiable, physical chemical and visual change on a range of materials	Are the observable interactions (if any) between bat droppings and urine, and those materials commonly found within a church building different for different species of bat?
Exposure of test materials with protective coatings to bat droppings and urine for subsequent analysis	Exemplar data set to show efficacy of surface coatings and proof of reproducibility of method (when compared with data from earlier sample boards)	Better understanding of the potential for mitigation strategies involving coatings (currently coatings are not used)
Assessment of current mitigation strategies in light of research findings	Critical assessment of current practice in light of my research findings.	How effective are currently recommended and adopted mitigation practices in preventing any observable interaction between bat urine and droppings and those materials commonly found within a church building? How practical and viable are these mitigation practices in real terms ?

Table 2: Table showing the relationship between the experimental work undertaken for this project, the data it will generate, and the research questions that will be answered using that data.

atypical animal or an animal in poor health was mitigated.

Urine was successfully collected from the following species of bat in sufficient quantities to enable quantitative analysis to be undertaken.

- *Myotis Nattereri*

Species	Urinary Sodium mmol/l	Urinary Potassium mmol/l	Urinary Chloride mmol/l	Urinary Urea mmol/l
Myotis Nattereri	283	143.4	65	1841
Nyctalus noctula	274	113.9	86	1777
***Pipistrellus* Spp.**	431	243	214	3120
Plecotus auritus	464	228	181	2419

Table 3: Table showing quantitative analysis of urine from four different species of bat. Results are given in mmol/l for urinary sodium, potassium, chloride and urea.

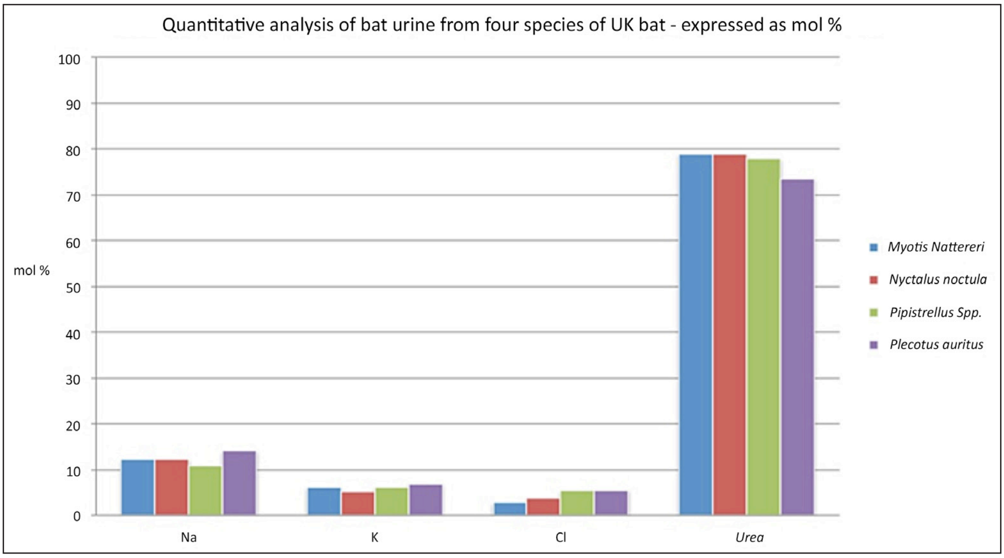

Fig. 2: Graph showing quantitative analysis of urine from four different species of bat converted to relative molar percentages for each species.

- *Nyctalus noctula*
- *Pipistrellus* Spp.
- *Plecotus auritus*

Urine associated with bat droppings was collected separately from uncontaminated urine. Only uncontaminated urine was used for analysis.

Results of the quantitative analysis undertaken on the four different urine samples can be found in **Table 3**.

Table 3 shows that there is a greater quantity of solute in the urine of *pipistrellus* spp. and *Plecotus auritus* as compared to the other species examined. However, by expressing the concentration of the solute in each sample as molar percentages (i.e. expressing the different analytes as quantities relative to each other) (**Fig. 2**) it can be seen that the components of the bat urine analysed show a good degree of consistency across the four species, with little to no variance beyond the calculated standard deviation. What this means, is that urine composition is broadly consistent across all four species, yet the concentration of the urine is not.

What is most striking about the data is that the concentration of the urine is inversely

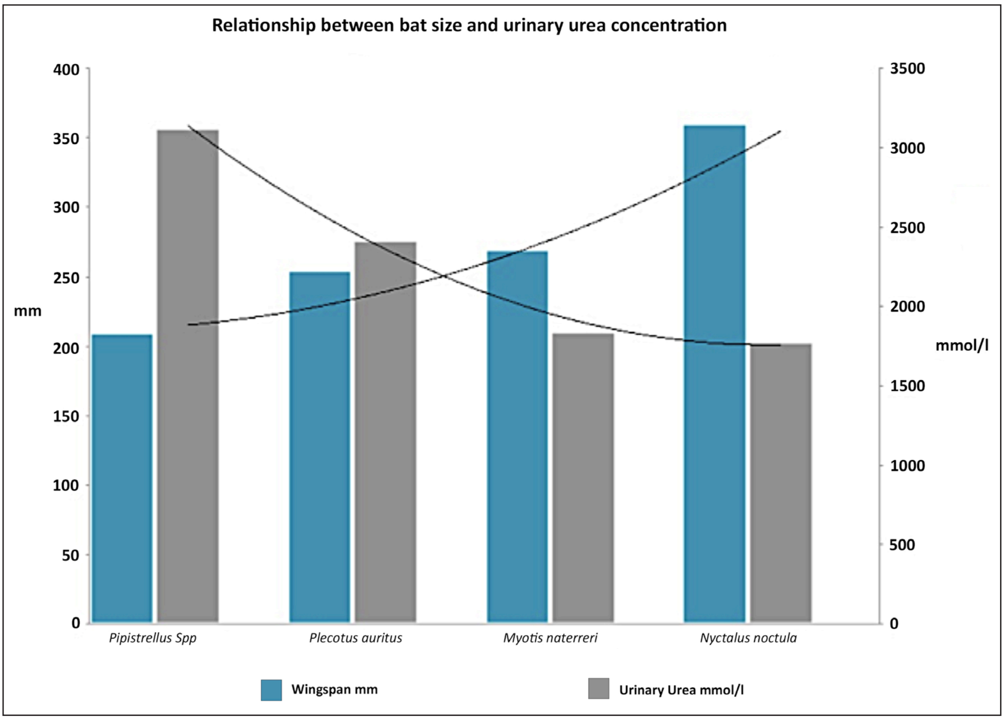

Fig. 3: Graph showing the inversely proportional relationship between bat size (represented by wingspan in mm) and urea concentration in mmol/l. To further highlight the relationship, polynomial trend lines are shown for both wingspan and urinary urea.

proportional to the size of the bat, with larger bats producing more dilute urine. **Fig. 3** shows the relationship between bat size (represented by wingspan) and urea concentration - the relationship between the two parameters can clearly be seen. If the solutes detected are found to play a significant role in deterioration mechanisms, then clearly their relative abundance in the urine of different species of bat will be a factor affecting the levels of deterioration that might be expected from roosts of different species.

Bat urine pH measurement

pH readings were obtained in sufficient numbers to allow urine pH ranges and median values to be determined for five species of bat (due to the smaller quantities of urine required for pH testing, it was possible for pH data to be collected for *Eptesicus serotinus* [serotine bat] in addition to the four species listed above). A combined total of 73 individual pH readings were recorded (**Fig. 4**). pH measurement was conducted on my behalf by licensed bat workers, measurements were taken from fresh urine collected as before from captive bats.

As can be seen, pH ranges for all species tested are broadly similar with a total range for all readings between pH 5.3 - 6.8. Technically speaking all these values fall within a pH range that would be described as acidic, however to provide some context, bottled drinking water sold in the U.K. has a pH that ranges from 4.2 – 8.7 depending on source (Buckscc, 2005) and de-ionised water used in conservation laboratories commonly has a pH of 5.5. Therefore, while the pH of bat urine is acidic, it is only mildly so. Although it should be noted that long term exposure to mildly acidic solutions can be problematic for some materials (for example calcareous stone), my findings do not

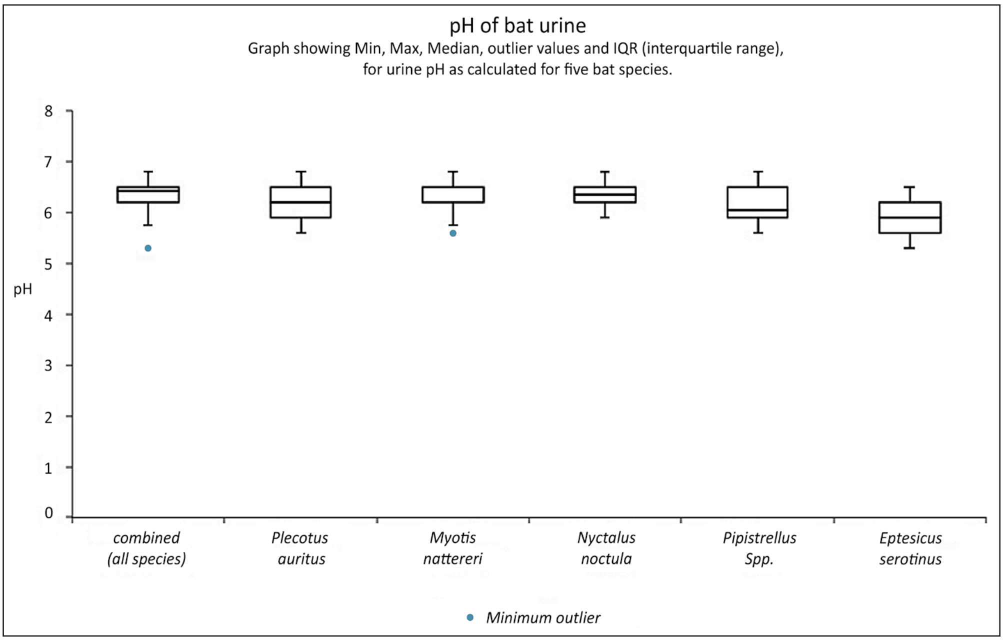

Fig. 4: Median Dq plot showing urine pH ranges obtained for five UK bat species. The graph is a "box and whisker" plot. The "whiskers" show the minimum and maximum pH values recorded for each species, the interquartile range (Q_3-Q_1) shows the distribution of the middle 50% of the data points and is represented by the "box", the median value shown by the horizontal line appearing inside.

support the popular perception that it is the highly acidic nature of bat urine that is the significant and major factor in deterioration mechanisms.

Establishing the role of urea crystals in the deterioration of porous materials

In order to assess the role urea crystals might play in deterioration of porous materials, the deliquescent nature of urea was examined. Using a partial pressure chamber and a cryo-stage in an Environmental Scanning Electron Microscope (ESEM) the relative humidity (RH) value at which the dissolution/crystallization of urea takes place was first established. By monitoring urea crystals in real time as environmental parameters were adjusted it was determined that urea will crystalise when the RH falls below 68% and will deliquesce (become liquid by absorbing moisture from the atmosphere) at an RH of 70%. For porous materials on which urine has been repeatedly deposited, fluctuating RH across the range of 68–70% could therefore result in cyclic damage due to super saturated solutions of urea forming within their pore structure and subsequent subflorescence/efflorescence of urea crystals.

While it may appear that this boundary zone is high, RH values of above 70% are regularly experienced in the cool interiors of church buildings and in microclimates created at the surface of materials that are significantly cooler than the ambient air temperature e.g. stone floors, brass memorial slabs and monuments. Currently the case study churches are being used for temperature measurement and microclimate studies of monuments and other surfaces in order to establish how regularly RH levels might be expected to cross the critical boundary zone.

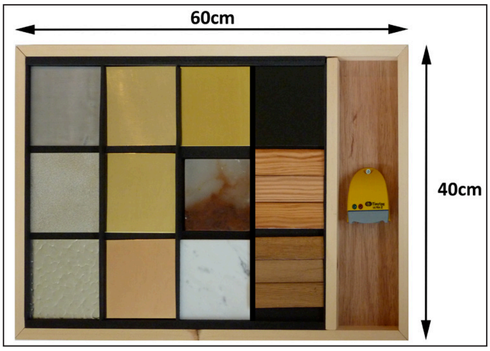

Fig. 5: Sample board prior to deployment and positioning of protective elements to partly cover the test samples, and showing the data logger.

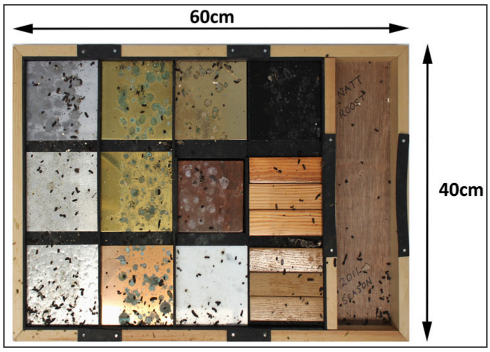

Fig. 6: Phase 1 Sample board after retrieval, the effect of bat droppings and urine on the test materials is readily apparent.

Exposure of test materials to bat droppings and urine – Sample boards phase 1 and 2

In order to assess the effects of urine and droppings on the different test materials, sample boards containing the chosen test materials were placed in known and active bat roosts, and exposed to droppings and urine from bats eating a natural diet and living in a natural environment. Single-species roost sites were chosen in order to obtain data that could be used to compare the effects of droppings and urine from different species.

The sample boards consisted of wooden trays 60cm x 40cm holding prepared samples of 10cm x 10cm each (**Fig. 5**). The design allowed for samples to be partly covered so that a section of their surface was protected thus providing a control specific to each individual test material. Each tray carried a data logger used to record relative humidity (RH) and temperature for the duration of the exposure period. This was considered important as temperature and RH would likely play a role in corrosion cycles, rates of reaction and the effect of salt crystalisation within porous substrates.

The boards were designed to be easy to place in roost sites by licensed bat workers. The three roost sites were inhabited by the species which were the focus of this study (*Pipistrellus pygmaeus* [Soprano pipistrelle], *Plecotus auritus* [Brown long-eared bat], *Myotis nattereri* [Natterer's bat]). A fourth roost site was identified for *Plecotus auritus* so that a second set of data could be gathered for this species, but with the variable of a different geographical location since results might be affected by local diet or local climate. Phase 1 boards were deployed from April 2011 until November 2011, a period of time relating to those months in a one-year cycle when bats are active. In the following year (phase 2 - April 2012 to November 2012) a further 4 boards were deployed, but this time with selected protective coatings applied to areas of the test materials.

This aspect of the work represents a two-year cycle of experimental work, and has generated a dataset of 84 different sample surfaces on which subsequent analysis can now take place. While a full analysis of the test samples has yet to be undertaken, there are some interesting preliminary results. Of foremost importance is the fact that the deterioration seen on the test samples is directly comparable to that observed *in situ,* for example in the case study churches, with corrosion of metal surfaces, staining of porous materials, and the distinctive white spotting resulting from urine deposition on organic coatings (such as polishes) all seen on the test samples (**Fig. 6**). From initial observations it can also be seen that investigation should focus not only on the effects of urine and droppings individually, but also on their effects in combination as it appears that this can affect both the type of corrosion seen on metal surfaces and the staining observed on porous materials.

Further research

The role that urea plays in the deterioration mechanisms of both porous and non-porous materials is an area that will continue to be explored. Further experimental work will involve applying urea solutions (of equivalent concentration to the urea in UK bat urine) to marble, alabaster and limestone samples. The samples will be subjected to a cycling relative humidity environment that frequently crosses the dissolution/crystallization boundary, scanning electron micrographs will be taken before and after to establish the effect on the samples. The potential for urea crystals deposited on metal surfaces to absorb moisture from the atmosphere and change phase (from solid to liquid) over repeated cycles will also be explored in relation to the promotion of localised corrosion.

Test materials previously exposed to bat droppings and urine (sample boards - phase 1 and 2 described above) will be examined to determine the extent and nature of chemical, physical or visual change that has occurred. The efficacy of the selected protective coatings will also be assessed. Full analysis will involve the following methods:

- Photography
- Microscopy
- Scanning electron micrographs of surfaces and cross sectioned samples
- Qualitative analysis of corrosion products and surface deposits using FTIR, XRD and EDX

FTIR – Fourier Transform Infrared Spectroscopy
XRD – X-Ray Diffraction
EDX – Energy Dispersive X-Ray analysis

Finally, experimental data will be reviewed in relation to the two case study churches, St Nicholas Church, Stanford on Avon and Holy Trinity Collegiate Church, Tattershall. This important part of the project will serve to place the research into a real world context, and will provide the opportunity for mitigation strategies currently employed by these (and other) churches to be assessed in light of the research findings.

Conservation as mediation

This research project has been a collaborative venture from the outset. In order to fully understand the nature of the problems associated with bats in churches it was important to engage openly with individuals and stakeholder groups from all sides of the debate. Not only was collaboration required to gain an understanding of this complex issue, but on a practical level much of the work required the active assistance of licensed bat workers, local bat groups, church parishioners and incumbents. An interesting and unexpected result has been the achievement of a form of mediation between individuals on different sides of the debate. I have been able to talk to representatives of different groups about their concerns, and because I have shown that I am approaching this research with an open mind and without a fixed agenda, I have been able to enlist their help and support. Representatives of each group are now persuaded that a real understanding of the damage will be beneficial to all parties concerned and will help to develop acceptable solutions to the problem. This positive development has allowed for much more constructive discussion to take place, with the focus shifting from conflicts of interest, to an approach based on mitigation and problem solving.

Conclusion

The research is currently at an exciting stage and has already highlighted misconceptions in our current understanding of the problem, areas requiring further investigation and new areas for investigation not previously considered. While the work is still in progress the experimental approach has been shown to be successful, having generated robust data that will inform and shape the future of the project and, more importantly, our understanding of the damage mechanisms involved when bat droppings and urine affect historic materials.

Acknowledgments

I would like to thank Andrew Argyrakis, then Conservation Officer at the Church Buildings Council for bringing this research topic to my attention, and for helping to secure funding from the Pilgrim Trust, to whom I am very grateful. This grant allowed for the purchase of experimental materials and equipment, and paid for travel expenses and training courses without which the project would not have been possible.

It is primarily via the Bat Conservation Trust (BCT), and in particular Dr. Karen Haysom, the organisation's Head of Science, that I was introduced to many of the regional bat groups that have helped with this research. Without their support the project would have made very little progress and would have been much less well informed. I would like to thank Shirley Thompson of Kent Bat Group and Nick Kelly of North Bucks Bat Group for their assistance with locating suitable roost sites for deposition experiments, and for placing and retrieving boards on my behalf – this research could not have been done without them. I am grateful to Judith Wiggins, David Mullenger and Ian Nixon for their kind assistance in providing access and information relating to the case study churches used. Thanks also go to Roger Bishop of the Clinical Services Division at the Royal Veterinary College for carrying out the urine analysis, and to Karen Larkin and Amanda Millar for collecting the bat urine.

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How to cite this article: Hales, J 2014 Bats in Churches: Objective Assessment of Associated Damage Mechanisms. *Archaeology International,* No. 17: pp. 94-108, DOI: http://dx.doi.org/10.5334/ai.1703

Published: 23 October 2014

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