Experimental Studies on the Impact of Bird Excreta on Architectural Metals

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Fig. 1. Bourke Street mall, Melbourne, Australia, showing soiling of building ledges caused by perching pigeons. All photographs by the author.

Communal wisdom has it that bird droppings corrode architectural elements and outdoor sculpture made of metal. But does the experimental evidence stack up?

Metals were (and are) widely used for many purposes in architecture: structural, such as iron framing and girders; protective, such as roofing, guttering, capping of ledges and cornices, and balustrades; and decorative, as in the case of roof decorations, finials, and the like. Metals also figure prominently as a material in outdoor statuary. The metals used range from iron and steel to various other metals (copper, bronze, and brass, as well as zinc, aluminum, lead, etc. Like all other building materials, they are subject to a range of environmental decay processes, one of which is birds and their excreta.

This paper reviews knowledge regarding the processes of environmental decay of architectural metals and statuary caused by birds. While the literature contains numerous examples asserting a causal link between bird excreta and the corrosion of architectural metals, there are few experimental studies that examine these effects.

This paper summarizes the factors that influence the components of bird excreta (especially that of pigeons), since they have a bearing on the impact that excreta may have on architectural metals. The final part of the paper reviews and evaluates the few extant experimental studies that have been carried out on this topic.

Fig. 2. Passage Vendome, Paris 3e, France, showing soiling of buildings caused by nesting pigeons. Note the inefficacy of the spikes.

Birds as Agents of Environmental Decay

In urban settings, perching and roosting birds defecate on architectural elements of buildings and other structures such as bridges and overpasses. The excreta not only cause aesthetically unpleasing soiling but have been implicated in the decay of the architectural fabric (Figs. 1 and 2).[1] Excreta have also been causal to the dispersal of organisms that are harmful to humans.[2] For a number of commensal bird species, urban environments provide suitable substitute habitats because of the lack of or low levels of predation; the availability of building cavities (building ledges, overhangs, bridge structures, etc.) that simulate natural perching and nesting spaces; and a ready food supply during winter.[3]

Of global concern are primarily feral pigeons (*Columba livia domestica*), house sparrows (*Passer domesticus*), and starlings (*Sturnus vulgaris*), as well as, to a lesser degree, ducks (Anatidae), and swallows or martins (Hirundinidae). In coastal and riverine settings, various species of gulls (Laridae) play a major role. In a supra-regional context, other birds need to be considered, such as crows and ravens (Corvidae) in Europe and North America; monk parakeets (*Myiopsitta monachus*) in the Americas; the common myna (*Sturnus tristis*) in southeast Asia and Australia; and cockatoos (Cacatuidae) and ibis (*Threskiornis* spp.) in Australia. These birds contribute to direct damage by nest building, as well as through the accumulation of their excreta.

Bird excreta, or "guano," is a combination of urine and fecal matter. Unlike in mammals, for example, excreta in birds do not occur as discrete entities of solid and liquid waste. In some bird species, the urine and fecal matter are mixed, and in others, there is a distinctly visible urinary (white) and fecal (brown or green) portion.[4] The whitish part of bird excreta is an aqueous suspension of uricite crystals (the end product of amino-acid metabolism), which are largely insoluble under normal environmental conditions.[5] The brown or green part is the fecal matter, coated with a thin layer of urea and uric acids, often coated with mucus. When pigeon excreta are dissolved by rain, these crystals are redeposited and may form white staining.[6]

Non-crystallized uric acid ($C_5H_4N_4O_3$) has been associated with the decay of structural and ornamental sandstone; paint finishes; and metals in outdoor sculpture, gutters, and composite roofs.[7] Phosphoric acid from pigeon excreta has been attributed to damage of architectural marble in Venice.[8] Recent work has also focused on the influences of urine- and feces-derived soluble salts on masonry, as deposited by humans and their pets, as well as birds.[9] Soluble salts have been documented to leach from rainfall-liquefied bird excreta onto the stone.[10]

In addition, there are secondary effects to the deposition of bird excreta, such as the colonization of the bird excreta by ammonia-, nitrite-, and sulphur-oxydizing bacteria, which produce nitrous, nitric, and sulphuric acids as their waste products and thus aid the biodeterioration of surfaces.[11] Excreta also provide nutrients to lichen and mosses, which in turn cause additional biodeterioration.[12]

While decay has been attributed to long-term effects of bird excreta, a systematic review of the literature found little substantiated evidence that bird excreta causes a direct impact on the fabric of buildings such as marble, limestone, or sandstone.[13] This finding is supported by recent experimentation.[14] It appears that most of documented impact is secondary rather than direct, such as through the retention of moisture, the introduction of soluble salts, and the introduction of nutrients that facilitate fungal and lichen growth.

Yet, among heritage professionals and building managers, pigeon excreta have been claimed to cause unspecified chemical attack of metals generally, and copper alloys specifically, particularly in outdoor sculpture, gutters, and composite roofs.[15] Many of these claims, however, are generic, lacking specific evidence that pigeon excreta is the cause. Early studies argued that the immediate effect of pigeon excreta on building materials was extremely small, but the impact on metals of any kind was severe. A 1932 study by Alois Kieslinger, for example, summarized the state of knowledge, primarily informed by communication with municipal building authorities in several German and Austrian towns. He noted that roofing iron and both copper- and zinc-coated iron, as well as other iron fittings, corroded rapidly when covered with pigeon excreta.[16] The causalities of this remained largely unexplored. These assumptions are not limited to pigeons. A 1988 study by Kees Vermeer, Damian Power and John Smith reported that a roof inspector concluded that nesting gulls cause the deterioration of metal roofs through chemical erosion caused by defecation and by water damage resulting from the blockage of drainage pipes by feathers and nest materials.[17]

The impact of bird excreta on metal outdoor statuary, on the other hand, is a common theme in heritage reports. Bird excreta have been referred to as being "toxic to…fragile bronze surfaces."[18] They also "react with the bronze and corrode it."[19] It is also reputed to be "releas[ing] organic acids that can accelerate corrosion."[20] On occasion comments have been more specific, such as excreta have "a high degree of acidity and can damage the structure and can damage copper alloys either by direct reaction with the components of urine (pH can range from 5 to 8) or as a result of fungal growth (which can lower the pH from 7 to less than 4)." [21]

Despite these claims, the direct impact of bird excreta on metals used as architectural elements and outdoor sculpture has not been systematically evaluated experimentally to date.[22] The majority of studies examining the patina and corrosion products of copper and bronze address aspects of atmospheric pollution, mainly by sulphur-dioxide (SO_2) and the resulting sulphuric acid (H_2SO_4), rather than any direct impact of bird excreta. Increased levels of acidity (atmospheric or otherwise) are known to convert the insoluble cuprite (Cu_2O) into other copper-oxide compounds that are much more prone to erosion.[23] A 1994 study by Andrew Lins and Tracy Power noted the role of pH in the decay products of outdoor bronze exposed to atmospheric pollutants, with the more aggressive low-pH environments forming strong corrosion crusts.[24] Some papers examining the patina and corrosion products on outdoor statuary and copper roofing note that bird excreta appear to cause concentrations of phosphates on the corrosion surfaces of bronze statuary.[25] While this suggests that phosphoric acid may be deposited in the excreta, the extent of the impact is uncertain. The authors of a 1997 study, Grant Skennerton, Jason Nairn, and Andrej Atrens noted their view that phosphate and nitrate compounds on incidental bird excreta did not influence the degree of atmospheric corrosion of their test samples.[26]

This paper is part of a wider examination of how commensal birds, particularly pigeons, use Australian cities, and the effects of non-accumulative (single-dropping) pigeon feces on heritage structures.[27] The primary focus is three major species: feral pigeons, gulls, and common mynas, which have been observed to favor narrow building ledges, as well as point sources (heads of statues, finials, crosses, etc.) as vantage points during perching (Fig. 3).[28] The remainder of this paper summarizes and evaluates the state of knowledge of the direct impact of bird excreta on the conservation of metals used in architecture and outdoor statuary.

Fig. 3. State Library of Victoria, Melbourne, Australia, statue of Jeanne d'Arc by Emmanuel Fremiet, purchased in France in 1906 and erected in 1907. Statues form vantage points for pigeons and silver gulls during perching.

Urban Birds and the Nature of Their Excreta

Feral pigeons (*Columba livia domestica*) are regarded as a major urban pest. The built environment of urban areas sufficiently resembles the original habitat of the rock dove (*Columba livia*), in that it provides a very suitable synanthropic habitat for feral pigeons, which are descended from rock doves. The success of feral pigeons in urban settings has been attributed to a range of factors, including the lack or low levels of predation; the ready availability of building ledges, overhangs, bridge structures, etc., that simulate natural spaces for nesting, roosting, and perching; the relative non-specificity of nesting materials required; lack of cold-stress in winter due to urban heat domes; and a ready food supply during winter. Additionally, urban bird populations use not only the natural food sources provided by nearby farmlands, as well as by urban parks and private gardens, but also the "waste foods" (spillage of human food) and "volunteer foods" (intentional feeding, usually seeds and bread) offered by the human environment (Fig. 4). The feral-pigeon population in an urban community, for example, is directly related to the amount of food present.[29]

Physiological studies have shown that there is a direct relationship between the diet of birds and the quantity, nature, and composition of their excreta. Experimental assessment of the digestive system of the feral pigeon has documented an average passage rate of foods between 5.3 and 8.6 hours, depending on the nature of marker used. In general, food is collected and stored in the crop, and then gradually digested during periods of non-foraging, when the pigeons often congregate in communal roosts. It appears that much

Fig. 4. Porte des Vanves, Paris 14e, France, pigeons scavenging for waste foods.

of the previous day's intake is digested during that period and then excreted (Figs. 5 and 6). Not surprisingly, both the frequency of excretion and the total mass of excreta is related to the volume of food consumed.[30] A single pigeon reputedly can generate 9 to 28 pounds of excreta per year.[31]

A review of the literature showed that the acidity of pigeon excreta is dependent on a range of physiological and metabolic factors before voiding and a range of climatological (humidity) and biological factors (e.g., bacteria and fungi) after voiding.[32] Normal urine in birds is made up of uric-acid precipitates and crystals (uric-acid dihydrate), as well as various salts. Physiological factors that can influence the acidity of excreta are the bird's age and sex, and, for females, whether they are in the egg-laying stage. While significant, the observed differences are of a smaller magnitude on fecal pH than the influence of diet. Natural, grain, and pulse-based foods (peas, beans, etc.) are less acidic (by an order of 2 pH increments) than human, processed foods, such as the typical diet of urban-waste foods, comprised of white bread and French fries. Moreover, the documented high individualities of the birds and their food preferences, as well as the variable nature of accessible food sources, result in a high variability of the fecal pH such that no two pigeons' excreta are the same.[33]

Once voided, the excreta are subject to environmental factors that become more pronounced over time. Setting aside direct leaching due to precipitation, any uric acid remaining in voided excreta will be continually degraded by aerobic and anaerobic bacteria if exposed to moisture but may crystallize to less soluble forms under dry conditions. In their 20-day 2017 experiment, Dirk Spennemann, Melissa Pike, and Maggie Watson found that samples of pigeon excreta stored at room temperature (21°C) initially became more acidic (pH 5.40±0.12) compared to fresh excreta at pH 6.0±0.15, which can be attributed to bacterial action. The pH then returned to near-original levels by day eight (pH 6.02±0.17) and rose sharply on days nine to 11, with the pH eventually plateauing at 8.66±0.11. This rise was directly correlated with the colonization of the samples by mold.[34] Other studies also correlated increased pH with the presence of mold.[35] Bacterial and fungal acidity would also be regulated by relative humidity and temperature.

Given these observations, it is evident that any bird excreta used in an experiment to determine its effects on a substance should, at the very minimum, be described in terms of freshness and pH. Ideally this should be further specified in terms of the relative contribution of uric, nitric, and phosphoric acids, as well as the species of bird that excreted the droppings.

Experimental Studies Investigating the Effect of Pigeon Excreta on Metals

A systematic review of the impact of bird excreta on building structures found only three of 95 studies that were specifically executed to assess experimentally the impact of bird excreta on metals.[36] These are reviewed below.

Thomas Adam and Peter Grübl examined the impact of bird excreta on a range of building materials. They created four circular silicone receptacles (diameter 35 mm) on each of the test surfaces and filled them with fresh excreta of pigeons fed with a mixed-grain diet. The excreta were removed after 7, 28, 50, and 70 days. To accelerate decay, as well as the growth of bacteria and fungi, on the moist excreta, the samples were suspended above water in closed plastic containers (close to 100% humidity) and stored in a warming cabinet at 86ºF (30°C). The pH of the excreta ranged from 5.5 to 5.8 at the start to 5.7 to 5.9 at the end of the experiment. The presence of soluble salts in the excreta was acknowledged, but salinity was not measured. The experimental design included no controls to account for the effects of oxygen exclusion on the covered surfaces. There appeared to be no impact of the excreta on quarzitic sandstone, granite, travertine, concrete mortar, natural and clear-coated pine, or two kinds of brick. Seemingly dramatic impact, however, was noted on the metals tested: copper, painted steel, galvanized steel, and bronze.[37]

Upon review of the experimental setup, however, it is obvious that at least some, if not most, of the observed oxidization was caused by anaerobic galvanic corrosion. Experimentation with sterile fine sand, sterile soil, or some sterile organic paste, instead of pigeon excreta, might have yielded a very similar, if not the same outcome given the unquantified presence of soluble salts in the excreta. Adam and Grübl's study is further flawed by the lack of controls, as well as the lack of replicates.

Moreover, the findings have little applicability to real-life situations, as the experiment was conducted at 100 percent humidity, which does not occur for a prolonged period in environments where urban birds exist. Temperature and humidity as UV radiation (sunlight) have direct influences on the viability of bacterial and fungal colonies, which are known to modify the pH. To better reflect real-life conditions while at the same time excluding some external influences, experiments should be set up in enclosed boxes with built-in misting devices that allow the dispensing of set amounts of moisture.[38]

Elena Bernardi, Derek J. Bowden, Peter Brimblecombe, H. Kenneally, and Luciano Morselli tested the effects of uric acid and actual bird excreta on the corrosion of copper and bronze. Aqueous pastes (of unknown definition) were tested with an admixture of uric acid, uric acid with sodium nitrate, and uric acid with potassium dihydrogen phosphate (to simulate the influences of nitrate and phosphates in actual bird excreta). The sample collection of real bird excreta was done with pliers on a clean surface in a private garden, where feed was spread to attract birds. The authors considered that the use of real bird excreta would ensure that "greater amounts of uric acid [were] in contact with the surface." The aqueous pastes were applied as drops, with 5 mm-diameter exposure areas. To accelerate decay, the samples were suspended in closed plastic containers with close to 100-percent humidity and stored in a warming cabinet at 25°C. The researchers found that pure uric acid had a much greater effect on the copper samples. After a few days, the samples with real excreta developed mold. As the authors speculated, this would have altered the action of uric acid, and that part of the experiment was therefore terminated.[39]

Fig. 5. Grain silo, Holbrook, Australia, showing accumulation of pigeon excreta at a nighttime roost.

Fig. 6. Westfield Parramatta shopping center carpark, Parramatta, Australia, showing accumulation of pigeon excreta at a nest site.

Upon review of the experimental setup, it is obvious that the experiment has some shortcomings. The mode of collecting the actual excreta samples resulted in no control over the bird species that voided the excreta (as multiple species may have contributed) nor any indication of their diet. The authors tested only for the presence of uric acid but not its concentration or the overall acidity. The comments made regarding the Adam and Grübl experiment above regarding the exposure to 100 percent humidity also apply to this experiment. Finally, the experimental design included no replicates or controls to account for corrosion due to the experimental conditions.

On a different note, the fact that the samples with real excreta developed mold should not be construed as a cause for termination. Microbic action in excreta is a factor that occurs in the real world and that affects the pH of the excreta.[40] In the ideal world, if so desired, the effects of the development of mold can be tested by subjecting a subsample of the excreta to Gamma radiation, which destroys most spores and retards the germination of the surviving spores.

Adrian Vasiliu and Daniela Buruiana examined the corrosion of various metals and alloys (copper, bronze, brass, galvanized iron), which had been immersed for two months in a suspension of dried pigeon excreta dissolved in water (300 g dried excreta in 200 ml of water). The primary acidity of one of the four suspensions was 7.42 (the others are not stated). The samples were each immersed in a separate suspension, ensuring that no contact, and hence no galvanic corrosion, occurred between the samples. A weight loss was observed in all samples, with galvanized iron corroding the fastest (mass loss after 60 days was 0.05%) and brass the least (0.01%).[41]

Methodologically, the study is flawed, as the excreta used were of unknown age and stage of leaching, and the contributing diet was also unknown. A diverse range of objects of various shapes and sizes was submerged in the experiment, and they were of differing ages (new to old), as well as different alloys (actual composition not stated) and different types of galvanized iron (galvanization method not specified). Also, it appears that the samples were not cleaned prior to experimentation; thus pre-existing contamination (by soluble salts, for example) cannot be excluded. The samples were suspended in open containers, with the experimental set making no provision for the evaporation loss, and, therefore possible changes in acid concentration. Finally, the experimental design included no controls to account for corrosion due to the experimental conditions (e.g., plain water control).

Evaluation

The validity of each study as a proxy for real-life decay phenomena was scored as percent of the number of criteria (11) that were met. The criteria were derived from a review of factors that influence the composition and behavior of the excreta, as well the factors that influence corrosion in general. The criteria used for the assessment of the experiments were the origin of the excreta (the diet contributing to the feces, degree of freshness, and the species, if known), the pH and salinity (ideally the nature and concentration of the soluble salts), excreta preparation (e.g., is the concentration stated?), test-sample substrate preparation, appropriate methodological setup, and the use of replicates and controls. None of the studies achieved a full score. A common shortcoming in the three studies was the lack of controls to account for decay caused by the experimental setup, as well as the experimental design that appears to have prejudiced outcomes irrespective of the addition of bird excreta.

Implications for Future Work

The current state of knowledge of the actual short- and long-term effects of bird excreta on historic architectural metals and statuary is far from satisfactory. While effects of acids on mobilization and modification of various copper oxides and the formation of corrosion crusts have been established, the actual role played by pigeon excreta remains unclear. As indicated in the introduction above, real-life situations include a plethora of variables that will influence the preservation of architectural metals and statuary. Experimental studies can assess only a limited number of these. This review has highlighted a range of factors that need to be considered. Future experiments will need to account for the effects of the following:

- Oxygen-excluding covering of metal surfaces by moist substances/pastes compared to non-covered areas and the presumably additional effects of the excreta (i.e., set up a control with a sterile paste made from fine wet sand and agar and set up a control without any application)
- Differential acidity levels derived from the diet of the birds
- Differential acidity levels dependent on the age of the excreta and acidity-modifying effects of mold and bacterial action
- Different proportions of uric, nitric/nitrous, and phosphoric acid in the fresh excreta, and changes to these proportions due to bacterial action
- Effects of temperature and humidity on excreta and the implications for the effects of mold and bacterial action (desiccation, leaching, etc.).

Finally, all experiments should ideally be executed with five or more replicates to ensure statistical reliability of the experiments as conducted.

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