



Dietary habits of urban pigeons (*Columba livia*) and implications of excreta pH – a review

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ABSTRACT

Pigeons are considered to be urban pests, causing untold damage to buildings and potentially impacting the health of humans who come into contact with them or their faeces. Pigeon faecal matter has been implicated in both health impacts and building damage, with the acidity of the excreta playing an important role.


Purpose of the Review. This paper is a wide-ranging review of the chemical processes of excreta in the pigeon to aid our understanding of the potential problems of pigeons to buildings and human amenity in the urban space. The natural pH of pigeons is shown to vary based on the bird's and age as well as reproductive stage.

Key findings of the review. The influences of the altered diet between the rock dove (the wild progenitor of the feral pigeon) and the feral pigeon are detailed, indicating that the human-based diet of urban pigeons most likely causes the feral pigeon excreta to be more acidic than the rock dove excreta. This higher acidity is due in part to diet, but also to potential increases in faecal and/or uric acid volumes due to the low quality of human-based diets. Again, this area of interest is highly data deficient due to the few number of studies and unspecified dietary intake before pH measurement.

Implications of the review. Humans are increasingly concerned about pigeon populations (and presumably their accumulated faeces) in the urban space, and control comprises a large part of the interaction between humans and feral pigeons. This review provides a greater understanding of feral pigeons and the true effects of their excreta.

KEYWORDS

Columba livia; pH; Foraging; Diet; Excreta

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INTRODUCTION

Feral pigeons (*Columba livia* f. *urbana* Gmelin, 1789) are descended from rock doves (*Columba livia*), a Eurasian species which roosts and nest on natural cliffs (Larson et al. 1999; Stringham et al. 2012). The diet of rock doves has been found to consist of mostly seeds, primarily sourced from grassland settings (Murton & Westwood 1966; Little 1994). Human land modification, in the form of managed rural landscapes (with the accompanying abundance of grain sources) and the development of urban agglomerations with tall structures (church towers, multi-storey buildings, etc.) has provided the rock dove with an eminently suitable synanthropic habitat (Hetmański et al. 2011). Today, the feral pigeons have become regarded as a major urban pest (Schuster et al. 1989; Gavris 2011). Initially they were regarded as welcome additions to the urban landscapes (Haag-Wackernagel 2003; Jerolmack 2008), as evidenced by the numerous early twentieth century pictorial postcards of people feeding pigeons (Spennemann 2017), but soon

they turned into problem animals (for an early example see Anonymous 1901). Bird excreta, especially from pigeons, are deemed a major problem for property owners, mainly due to the soiling of facades and internal spaces (Mansfield 1990), as well as public health authorities, as they have been identified as vectors for a number of pathogens (carrying virus, bacteria, fungi, protozoa and parasites) that can be harmful to humans and domestic animals (Cerri et al. 1989; Haag-Wackernagel & Moch 2004; Haag-Wackernagel & Spiewak 2004; Haag-Wackernagel 2004, 2006; Moriarty 2008). Property owners have engaged in a diverse range of often costly repellent techniques to rid themselves of these nuisance birds (Alderson 1991; Howard et al. 1991; Slater 1998; Stevens et al. 1998; Cook et al. 2008; Haag-Wackernagel & Geigenfeind 2008; Duarte et al. 2011; Riddell 2011; Seamans & Blackwell 2011; Jenni-Eiermann et al. 2014; Stock & Haag-Wackernagel 2014). While the mechanical, chemical and acoustic repellent methods appear to be of dubious efficacy, and trapping and poisoning pose issues of social

acceptability, as well as ecological efficacy (Kösters et al. 1991; Magnino et al. 2009), the most effective method appears to be the denial of food (Przybylska et al. 2012; Senar et al. 2017).

From a public health perspective, pigeon excreta have been documented as vectors for *Chlamydia psittaci*, *Chlamydia abortus*, *Cryptococcus neoformans*, *Trichophyton gallinae*, various microsporidia as well as *Salmonella*. *Chlamydia psittaci*, which causes psittacosis in humans, was detected in the faeces of most feral pigeon populations (Heddema et al. 2006; Magnino et al. 2009). Recent studies also isolated *Chlamydia abortus*, which causes abortion and foetal death in mammals, including humans (Sachse et al. 2012). *Cryptococcus neoformans*, is an opportunistic fungus that thrives on bird excrement (Hubalek 1975; Caicedo et al. 1999; Abegg et al. 2006; Cermeño et al. 2006). In humans, it mainly infects the lungs by inhalation of aerosolized basidiospores (Buchanan & Murphy 1998). In immunocompromised patients, it can cause fungal meningitis and encephalitis (Buchanan & Murphy 1998). Salmonellosis is common among pigeons (Granville 1973; Dutta et al. 2013) and transmission from pigeons to humans has been reported (Cena et al. 1989). Transmission of various microsporidia (parasitic fungi) has also been noted (Bart et al. 2008).

Among heritage professionals and building managers, pigeon excreta have been claimed to cause unspecified chemical attack on wood (Leucci et al. 2013), metals (Spennemann & Look 2006), and architectural stone (Murton et al. 1972b). Bird droppings are known to contain salts; phosphoric, nitric and uric acids. Acid deposited on the surface of materials from any source reacts with susceptible components and corrodes or dissolves the surface of the material (Channon 2004; Doehne & Price 2010). The greater the acidity of the deposited substance, that is, the lower the pH, the greater the impact observed on susceptible materials. Uric acid has been associated with the decay of structurally and ornamentally used sandstone (Bridaham 1971; Del Monte & Sabbioni 1986; Slater 1998; Heltai 2013; Ali et al. 2014; El-Gohary 2015); limestone and marble (Hempel & Moncrieff 1972; Mitchell 2014); metals in outdoor sculpture (Vasilii & Buruiana 2010); gutters (Newark and Sherwood District Council 2001); composite roofs (Doroudiani & Omidian 2010); and paint finishes (Doroudiani & Omidian 2010; Mitchell 2014).

This review summarises our current understanding of the factors that influence the pH in pigeon excreta. While it is primarily intended to inform a number of studies examining the effects of non-accumulative pigeon faeces on sandstone heritage buildings (Pike et al. 2016a; Spennemann & Watson 2017b; Spennemann et al. 2017) and architectural metals (Spennemann & Watson 2017a), it also has direct application and relevance to the public health arena, in particular with regard to the survival of *Cryptococcus neoformans*. The high acidity of pigeon excreta provides ideal living conditions for *Cryptococcus neoformans*, which cannot survive in alkaline conditions (Jinks & Yee 1968; Abegg et al. 2006).

1. URBAN PIGEONS

The built environment of urban areas has a close enough resemblance to the original habitat of the rock dove (*Columba livia*), that is, natural cliffs (Larson et al. 1999); it provides a very suitable synanthropic habitat for feral pigeons (*Columba livia* f. *urbana*) (Rose et al. 2006). The success of feral pigeons in urban settings has been attributed to a range of factors, including the lack or low levels of predation (Sol et al. 1998); the ready availability of building ledges, overhangs, bridge structures and so on, that simulate natural spaces for nesting (Savard & Falls 1981; Hetmański et al. 2011; Przybylska et al. 2012), roosting (Sacchi et al. 2002; Ali et al. 2013) and perching (Pike et al. 2016b); the relative non-specificity of nesting materials required (Goodwin 1960; le Roux et al. 2013); lack of cold-stress in winter due to urban heat domes (Dobeic et al. 2011); a ready food supply during winter (Jokimaki & Suhonen 1998); and the ability of pigeons to utilise the high protein content of human food sources (Ciminari et al. 2005).

Unlike their wild ancestors and co-specifics (Baldaccini et al. 2009), feral pigeons in urban settings are capable of breeding all year round (subject to food availability and climate), with most reproduction occurring in late spring and summer (Dunmore & Davis 1963; Riddle 1971; Hakkinen et al. 1973; Murton et al. 1974; Dilks 1975; Johnston 1984; Johnston & Janiga 1995; Hetmański 2004; Hetmański & Wołk 2005; le Roux et al. 2013). Feral pigeons form breeding pairs that have an average clutch size of two eggs. The duration of incubation is around 18 days, with fledging occurring 28–32 days after hatching (Dilks 1975; Johnston & Janiga 1995; Vatnick & Foertsch 1998). Clutch intervals are influenced by a number of factors, including environmental conditions (hours of daylight, temperature), colony size and size of territory (Hetmański & Wołk 2005; Hetmański & Barkowska 2007; Hetmański & Barkowska 2008).

Feral pigeons now occur in high densities in many cities. Reported are, *inter alia*, densities of 4–5 pigeons/ha in inner city Amsterdam (Buijs & Van Wijnen 2001); 4.5 pigeons/ha (summer) and 6.8 pigeons/ha (winter) in Wellington (NZ) (Ryan 2011); 8.1 pigeons/ha in Padua (Amoruso et al. 2014); 8.4 pigeons/ha in Basel (Haag-Wackernagel 1995); 9.4–9.5 pigeons/ha in Barcelona (Uribe et al. 1984; Sol & Senar 1992); 13.6 in Poznan (Przybylska et al. 2012); to 20.8 pigeons/ha in inner city Milan (Sacchi et al. 2002). Densities are known to fluctuate inter-annually (Amoruso et al. 2014) as well as seasonally (Ryan 2011; Ali et al. 2013). Moreover, studies have shown that population densities are higher in the city centres than at the periphery (Uribe et al. 1984) or in suburbia (Ferman et al. 2010), with the nature of micro-habitat as one of the determinants (Przybylska et al. 2012). The density of feral pigeon populations in an urban community appears to be directly related to the amount of available food (intentional feeding, spillage, organic waste) (Sol et al. 2000; Buijs & Van Wijnen 2001; Morand-Ferron et al. 2009; Przybylska et al. 2012; Senar et al. 2017) which is also related to the size of human population (Hetmański et al. 2011). A large quantity of energy requirements of the feral

pigeons is provided by edible waste in public areas (Jokimaki & Suhonen 1998; Buijs & Van Wijnen 2001). Feral pigeons, adapted to urban environments, tend to have stable flocks (Lefebvre 1985), with juveniles dispersing only marginally. Young birds leaving their natal colonies usually relocate to colonies within the built-area, eschewing those on urban edges and rural areas (Hetmański 2007).

As granivores, rock doves (*Columba livia*) do not require complex foraging skills but must forage intensively. While the natural diet of rock doves has been found to consist of mostly seeds (Murton & Westwood 1966; Little 1994), this species is particularly able to adjust and source food from urban settings and managed rural landscapes (Little 1994; Soldatini et al. 2006; Silva & Medeiros 2008). Feral pigeons, on the other hand, are considered not to be strictly granivores, as they include other sources of protein in their diet such as small invertebrates, insects and protein-rich human food (Lefebvre & Giraldeau 1984; Jokimaki & Suhonen 1998). The less natural diet available to pigeons in urban centres, however, results in extensive malnutrition (Dobeic et al. 2011) such that feeding pigeons with grain and bread is considered animal cruelty in some countries (e.g., Switzerland, see Kösters et al. 1991).

As pigeons are able to store large quantities of food in their crops and need only a few minutes to fill the crop (Johnston & Janiga 1995; Sol et al. 1998), they are eminently suited to exploit ephemeral, abundant food sources, including those provided by the public (Murton & Westwood 1966). Because of the social composition of feral pigeons, and their tendency to visit many foraging sites each day (Lefebvre & Giraldeau 1984), individual pigeons are able to monitor potential food sources and have highly individualised diets (Inman et al. 1987) that maximise their position within the flock (Giraldeau & Lefebvre 1985).

2. HOW OFTEN AND WHEN DO PIGEONS DEFECATE?

Pigeons often use communal roosts during non-foraging (loafing) time periods and digest majority of their food stored in the crop while resting during the dark periods, primarily to maintain their thermocontrol through shivering (Johnston & Janiga 1995; Rashotte et al. 1997; Laurila et al. 2003). It appears that during such a period, much of the previous days intake is digested and then excreted (Rashotte et al. 1997). Experimental assessment of the digestive system of the pigeon has shown that the average passage rate of foods is between 5.3 and 8.6 hours, depending on the nature of marker used (Hatt 2002; Sales & Janssens 2003b). The total daily mass of excreta is related to the volume of food consumed (Rashotte et al. 1997), ranging from 11 g to 26 g within a 24-hour period (Hempel & Moncrieff 1972; Laurila et al. 2003; Spennemann et al. 2017). Individual voiding volume is between 0.5 to 1.5 g (Laurila et al. 2003).

A single pigeon reputedly can generate 4–12 kg of excrement per annum (Kösters et al. 1991; Stock & Haag-Wackernagel 2014). Not surprisingly, both the frequency of excretion and the total mass of excreta is related to the volume of food consumed (Rashotte et al. 1997). Experimental studies of individual pigeons showed (for a 24 hour period) the following mass of excreta: 12 g (Hempel & Moncrieff 1972); 20.1–25.6 g (depending on feeding regime) (Laurila et al. 2003); 11.4 g (commercial seed-based maintenance diet, pers. obs.); 0.1 mL to 1.2 mL depending on the diet and age of bird (Pike 2016). Importantly, the quality of diet may have a direct impact on the quantity of faeces – birds that are eating low-quality diets compensate by increasing intake of food. This ‘quality versus quantity’ link between diet and faecal amounts was demonstrated in starlings that were fed low quality (high fibre, low fat, low kilojoule) or high quality (low fibre, high fat, high kilojoule) diets. Birds that ate low-quality diets excreted more faecal matter than those fed high quality diets (Geluso & Hayes 1999).

Temperature, as well as time of feeding, has been shown to influence the mass and timing of excreta deposition (Jarema et al. 1995). In an experimental setting, caged birds (kept at 5°C and at 22°C) were fed either in the morning or the evening. Birds fed in the morning maintained an hourly excreta mass of about 1 g and 0.5 to 0.8 g during the dark phase and about 1 g during the light phase. In the hour after the commencement of the light phase, however, the birds kept at 22°C showed a marked spike in excreta deposition (about 2.5±1 g), while the birds kept at 5°C remained at the 0.8 g level. Birds maintained on an evening feeding pulse showed a gradual increase in excretal discharge from 0.8 to about 1.7 g during the night, followed by a drop to 1 g (for birds kept at 5°C) and 0.5 g (at 22°C) (Laurila et al. 2003).

Short term, in the form of perching, longer term in the form of roosting and long term in the form of nesting. All three forms result in the deposition of excreta. More than other bird species, feral pigeons, which are highly opportunistic flock feeders (Murton & Westwood 1966), exhibit a behaviour of short term resting in the form of perching on elevated spots. Pigeons have a producer/scrounger dynamic which means certain birds have the skill to find food, while some are watching for signs that others have found food and then kleptoparasitise (Giraldeau & Lefebvre 1987). Feral pigeons and other common birds are known to defecate before taking off (Caro 2005) as part of the fit-for-flight hypothesis (Van der Veen & Sivars 2000). Since pigeons are social birds, they tend to aggregate in communal roost sites that are protected from the elements. Roosting sites tend to be spaces that are protected from the elements such as bridges, underpasses, parking garages, attics and other roof spaces, bell towers and the like. Perches, on the other hand, tend to be parapets, window ledges, cornices and other architectural elements (Pike et al. 2016b). As these sites are being used for a considerable period of time by a large number of birds with the same birds returning to the same roosts (Murton et al. 1972a), the accumulation of droppings can be significant. Examples are on record where such deposits

exceeded a depth of 1 m (County Clean 2015). From a property management perspective, pigeons are known to have three different modes of resting.

3. THE INFLUENCE OF PIGEON DIET ON THE PH OF EXCRETA

Avian excreta size and chemical composition are highly influenced by their diet (Geluso & Hayes 1999). Therefore, the food habits of the feral urban pigeon are likely to warrant investigation to determine changes in faecal chemistry that may lead to impacts on the urban built environment.

3.1. Pigeon diet

Pigeons are known to exhibit idiosyncratic food habits with a resultant inter-individual variability among pigeons (Brown 1969; Moon & Zeigler 1979; Giraldeau & Lefebvre 1985; Shettleworth 1987; Biedermann et al. 2012). Experiments with various seeds, simulating a natural diet, showed inter-individual variability among pigeons, but noted that while peas, millet and grain were preferred, but hard-shelled maize was spurned (Brown 1969; Moon & Zeigler 1979); but see the contrary data (Plowright & Redmond 1996; Plowright et al. 2004). Grain size was a factor in a number of studies with both too large (Shettleworth 1987) and too small units being rejected (Biedermann et al. 2012). Competition by other pigeons made individuals less choosy (Plowright & Redmond 1996; Plowright et al. 2004). As covered above, the wild progenitors of feral pigeons, the rock dove, are strictly granivorous, while feral pigeons are omnivores (Lefebvre & Giraldeau 1984; Jokimaki & Suhonen 1998).

Observations of urban pigeon populations regularly indicate the birds' reliance on 'waste foods' (spillage of human food) and 'volunteer foods' (intentional feeding, usually seeds and bread) (Sol et al. 1998), few studies have been carried out that consider the effects of the altered diet in urban environments. Murton and Westwood examined the crop contents of both feral pigeons and rock doves over a twelve-month period and found that the main foods of the urban pigeons were bread, cake and currants (Murton & Westwood 1966). After examining the ecology of feral pigeons in London, Goodwin suggested that feral pigeons had become completely dependent on humans for food, where most pigeons were eating 'artificial' food given or discarded by humans, most of which was bread (Goodwin 1960). Biedermann, Garlick and Blaisdell fed laboratory pigeons, which had been maintained on a standard diet of commercial pellets and sorghum, to a number of novel foods, in particular (pre-packaged) bread crumbs, sunflower hearts, popping corn, split peas, dried mealworms, and granulated peanuts (Biedermann et al. 2012). The birds preferred foods high in fatty acids such as sunflower hearts and granulated peanuts, over carbohydrate-rich foods such as popping corn and sorghum. Food particle size was also a consideration with ground breadcrumbs, the smallest grain size being the least preferred (Biedermann et al. 2012). Studies in Spain have

shown that volunteer food attracted a greater number of individuals than waste food (Sol et al. 1998), with both a greater flock size and an increased percentage of birds feeding.

4. CHEMISTRY OF PIGEON EXCRETA

Traditionally, pigeon excrement was one of the natural mordants used in tannery processes in many parts of the world (e.g., Iran, Amirkhani et al. 2009; Bengal, Chandra 1904; Morocco, Holt 1914; Nigeria, Lamb 1981; England, Thompson 1981) with a long history ('Leather Act', 1563; Maniatis 2011). Hides were placed in lime pits to depilate them, then washed and then finally placed in 'grainers' for 'bating', pits filled with warm suspensions of pigeon's dung, hen's dung or dog's dung (Desmond 1801; Swan 1821). The tanning industry described pigeon excrement as 'rich in organic matter and phosphoric acid. It also contains uric acid, which through "putrid fermentation" turns into ammonia-rich compounds' (Gansser & Jettmar 1920). It was noted early that aged pigeon dung contained much less ammonia (in the form of ammonium carbonate, $[\text{NH}_4]_2\text{CO}_3$) (Loudon 1831). This is caused by ammonium oxidizing bacteria, which excrete nitrous (HNO_2) and nitric acid (HNO_3) (Fernandes 2006; Wei et al. 2013). The bacterial action of the fermented pigeon dung with its weak acidity allows for gentle delimiting of the hides, making them supple (NIIR Board of Consultants & Engineers 2011).

The first formal analyses of the chemical composition of pigeon excrement date to the eighteenth and nineteenth century, driven by the need to understand its capabilities as manure as well as a bating solution for tanning. At the end of the nineteenth century, better analytical methods were brought to bear by Macadam (1888) and Schulze (1895), and later by Grimme (1931). Since the analyses of chemical composition of pigeon excrement is rare, the older studies are reproduced herein. As pigeon excreta when voided from the body is water (75.7%–79.2%, depending on feeding regimen) (Laurila et al. 2003; Huang & Lavenburg 2011), the older analyses of semi-dried pigeon dung will need to be interpreted *cum grano salis* (Table 1). Normal urine in birds is made up of uric acid precipitates and crystals (uric acid dihydrate) as well as various salts (Folk 1970; Poulson & McNabb 1970) (Lonsdale & Sutor 1971). The amount of uric acid in a pigeon's excreta ranges from 2.5 to 12.6 mg/dL. Uric acid crystals (normally inert) dissolve easily in sodium hydroxide (a base) (Harr 2002). The different methodologies and analytical technologies notwithstanding, the available chemical analyses of pigeon excreta show a large variation (Table 1). Formal analyses are surprisingly few.

A number of more recent studies mention the chemical composition of pigeon excreta (Yousif & Mubarak 2009). Many of these studies do not contribute to our knowledgebase as either the origin (i.e., bird species) of the excreta or the diet of the pigeons voiding the excreta is unknown. This is essential information in light of correlations between the volume of food consumed and the mass of excreta voided (Rashotte et al. 1997), the age of excreta and microbial and fungal ac-

Table 1. Early chemical analyses (in %) of pigeon dung

Element	Element	Macadam (1888)		Schulze (1895)	Grimme (1931)
Water	H ₂ O	56.08	58.32	21.00 (3.80–40.00)	50.50
Organic matter		18.35	26.50		30.50
Crude ash					17.50
Ammonia (nitrogen)	NH ₃	1.21	1.75	2.53 (1.47–5.04)	1.75
Phosphate	P	2.69	2.54		
Calcium carbonate & C. sulphate	CaCO ₃ / CaSO ₄	3.08	1.75		
Phosphoric acid	H ₃ PO ₄			1.79 (1.00–2.77)	1.79
Potassium oxide	K ₂ O				1.00
Calcium oxide	CaO				1.65
Potash				1.46 (0.71–2.57)	
Alkaline salts		0.82	1.99		
Silica and sand		17.92	7.00		
N		1	1	40	?

tion (Spennemann et al. 2017) and between the pigeons' diet and the pH of the excreta (Spennemann et al. 2017). One study worth noting (Table 2) attempts to understand the chemical impact of pigeons on highway structures (Huang & Lavenburg 2011).

5. FACTORS INFLUENCING THE ACIDITY OF EXCRETA

Limited data on pigeon intestinal and excreta pH have been published. Early experiments showed a direct correlation between quantity and nature of nutrition and the resultant uric acid excretion (Fisher 1935a, 1935b). It was also recognised early on that the pH varies throughout the whole intestinal tract of birds (Herpol & van Grembergen 1967). Other studies suggest that for pigeons, neither the volume of food (McNabb & Poulson 1970), nor the levels of protein in the diet (McNabb et al. 1973) appear to have an influence on the concentration of uric acid in the urine. Pigeons with a high protein diet, however, produce a four-fold higher volume of urine (McNabb et al. 1973).

On the other hand, the concentration of uric acid in the excreta is related to the overall water intake by pigeons (Lumeij 1987). Among chickens, variations in pH has been observed between male and female (6.4 vs. 5.3) (Ariyoshi & Morimoto 1956), as well as between egg-laying (5.3) and non-

laying birds (7.6). During the egg-laying phase, when calcium is being deposited on the shell, the excretal pH is lower than when the egg is laid or no calcium is being deposited on the shell (Prashad & Edwards 1973; Sturkie 1976).

Experimental studies showed that the uric acid concentration in bird urine is higher than when mixed with faeces in the cloaca. Anderson and Brain showed that 68% of the urate present in urine is degraded in the lower intestine in Gambell's quail (*Callipepla gambelii*) (Anderson & Brain 1985), with caecal anaerobic bacteria being held responsible (Barnes 1972; Mead 1989). The resulting degraded products are ammonia (NH₃), fatty acids and CO₂ (Karasawa 1989; Singer 2003). Long noted that the pH of voided excreta of many bird species was on average one unit more alkaline than that of urine itself, possibly exacerbated by the loss of CO₂ (Long 1982). It can be posited that the effect of caecal anaerobic bacteria will continue after voiding.

Svihus et al. (2013) showed that bacterial action in the caeca of domestic poultry affects the fermentability of fibres and by implication, alters the concentration of uric and other acids that are voided in the excreta. Diet may influence animal urine pH (Burton 1980) and also the nitrate content in pigeon excreta (Sales & Janssens 2003a, 2003b). Experimental studies found that pigeon diets with a high gelatinisation of the constituent starches (i.e., cooking) resulted in excreta with a higher pH than an identical diet modified to have a lower gelatinisation (Abd El-Khalek et al. 2011). While this study is in-

Table 2. Chemical composition of two sets of pigeon excreta (Huang & Lavenburg 2011).

Element	Bridge (n=16)		Farm (n=9)	
	Avg±SD	Range	Avg±SD	Range
C	36.93±17.84	(5.15–63.40)	48.75±22.08	(0–72.51)
O	30.36±11.08	(3.69–49.54)	38.02±14.20	(22.21–70.97)
N	21.17±8.96	(11.79–29.65)	33.58	(33.58–33.58)
Ag	19.72±22.29	(5.15–45.38)		
S	10.52±10.61	(0.62–26.29)	0.42±0.16	(0.25–0.56)
Pd	7.96		12.31	
Au	7.36±4.12	(4.45–10.27)	13.02	
Ca	6.54±10.21	(0.19–30.54)	1.97±1.58	(0.61–4.67)
Si	5.67±7.72	(0.4–18.98)		
F	5.14±2.95	(1.74–8.92)		
K	3.70±10.19	(0.3–37.59)	4.80±3.07	(2.24–11.39)
P	3.29±4.09	(0.21–12.30)	2.36±2.35	(0.27–6.36)
Cl	2.94±2.47	(0.77–8.80)	0.61±0.16	(0.39–0.8)
Mg	1.50±3.44	(0.19–10.66)	1.54±1.39	(0.29–3.55)
Na	1.37±0.80	(0.43–2.45)		
Ti	1.21			
Al	0.95±0.99	(0.22–2.99)		
Fe	0.54			

dicative only, as the differences were not statistically significant, it nonetheless suggests that processed foods (cooked human discards) may induce a higher pH than unprocessed, natural diets, such as grass seeds. Therefore, any pH data of excreta without accompanying dietary information are insufficient to draw conclusions. A number of studies mention the pH data in pigeon excreta (Caicedo et al. 1996; Vasiliu & Buruiana 2010; Huang & Lavenburg 2011; Spennemann et al. 2017). Table 3 compiles the data for pigeon excreta derived from known diets, while Table 4 summarises studies where pigeon excreta derived from unknown diets. Available data on the pH in excreta of bird species other than pigeons and chickens have been compiled elsewhere (Spennemann & Watson 2016). The difference in pH between diets can be as much as 2 pH units within a single

species. Variations in excreta pH caused by dietary variations have also been observed among species other than pigeons and chicken. For example, Kalmar et al. (2010) showed that the pH of excreta voided by the African grey parrots (*Psittacus erithacus*) ranged from 5.6 for a seed mixture to 7.9 for a diet of extruded pellets. Kear (1963) examining the excreta of geese and swans found that the pH of excreta voided by the Greylag Goose (*Anser anser*) ranged from 5.5 for a diet of winter wheat or Merse grass to 8.5 for a diet of shoots of swede turnips. The primary cause for the variation in pH seems to be the different amounts of uric acid in the excreta. Domestic ducks (*Anas platyrhynchos domesticus*) which were fed experimental diets of varied protein content and grain/pulse mixes (soybean and

Table 3. Measured pH in pigeon excreta: known diets

pH	Diet	Sample Origin	Location	Sampling Method	Dilution excreta/RO water	Source
5.5–5.8	Mixed grain	Unspecified, caged	Darmstadt, Germany	fresh	unknown	(Adam & Gröbl 2004)
5.5–6.9	Witte Molen® Pigeon Feed (maize grits, barley, wheat, red and white sorghum, safflower, green peas, yellow peas, vetches)	61 individuals	Netherlands	fresh urine only	unknown	(Halsema et al. 1988)
5.58±0.34	White bread, deep-fried potato chips ('French fries')	Individual birds (3 adults, 2 juveniles)	Albury, NSW	fresh	1:3	(Spennemann et al. 2017)
6.0±0.15	50% dun peas, 50% wheat	Racing pigeon coop	Albury, NSW	fresh	1:2	(Spennemann et al. 2017)
6.39±1.03	Food scraps (bread, meat, pasta, tomato sauce, fruit [oranges and apples])	Individual birds (3 adults, 2 juveniles)	Albury, NSW	fresh	1:3	(Spennemann et al. 2017)
6.40±0.48	Cracked wheat, cracked sorghum, hulled oats, rape seed, canary seed, white French millet, Panorama/Red Panicum/Japanese millet	Individual birds (3 adults, 2 juveniles)	Albury, NSW	fresh	1:3	(Spennemann et al. 2017)
6.54	Puregrain® European Supreme POP (Small Yellow Corn, Canada Peas, Whole Wheat, Austrian Peas, Red Milo, White Kafir, Oat Groats, Mineral Oil)	Bird farm	Bear, DE	semi-fresh	unknown	(Huang & Lavenburg 2011)
6.76±0.12	Cracked corn plus mixed seeds	2 adults (4 measurements each)	Connecticut, USA	fresh urine only	unknown	(McNabb & Poulson 1970)
7.03±0.56	Avigrain® Pigeon Mix (wheat, sorghum, corn, dun peas and/or safflower)	Individual birds (3 adults, 2 juveniles)	Albury, NSW	fresh	1:3	(Spennemann et al. 2017)
7.39±0.27	Cereal grains (wheat, barley, and/or sorghum), rice bran, pollard, bran, soybean meal, limestone, dicalcium phosphate, canola oil, essential amino acids including lysine and methionine, Coprice layer trace mineral and vitamin premix, salt.	Individual birds (3 adults, 2 juveniles)	Albury, NSW	fresh	1:3	(Spennemann et al. 2017)

corn or millet) showed significant variation in the uric acids in their excreta (Adeola & Rogler 1994).

5.1. After voiding

Once voided, excreta are subject to environmental and biological factors that become more pronounced over time. Any uric acid remaining in voided excreta will be continually degraded by aerobic and anaerobic bacteria if exposed to moisture (Lindboom 1984), but may crystallise to less soluble forms under dry conditions. Faecal bacteria may survive even the harshest of conditions (Hartz et al. 2008) and continue to degrade the faecal matter outside the body. Finally, faecal matter is considered to be an excellent substrate for fungi, bacteria, lichen and mosses (García-Rowe & Saiz-Jimenez 1991), not to mention

the invertebrate activity, which can also continue physical and chemical changes once the excreta are voided. For example, in their twenty-day experiment, Spennemann et al. (2017) 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), but returned to near original levels by day eight (pH 6.02±0.17). On days nine to eleven, the pH rose sharply, eventually plateauing out at 8.66±0.11. This rise was directly correlated with the colonisation of the samples by mould. Other studies also observed an increase in pH after the excreta matured (among poultry, Jinks & Yee 1968), which also appeared correlated with the presence of mould (Cermeño et al. 2006).

Table 4. Measured pH in pigeon excreta: unspecified diets

pH	Diet	Sample Origin	Location	Sampling Method	Dilution excreta/RO water	Source
5.4	Unspecified	Tannery	Fez, Morocco	Rehydrated	Unknown	(Elharchli et al. 2012)
5.5	Unspecified	Various roost sites	Santiago de Cali, Colombia	Semi-fresh	Unknown	(Caicedo et al. 1996)
6.0±0.02	Unspecified	Farm	Omdurman, Sudan	Unknown	Unknown	(Yousif & Mubarak 2009)
6.0–6.6	Unspecified	Four urban buildings	Pittsburgh, USA	Unknown	Unknown	(Jinks & Yee 1968)
6.4-7.9	Rural area	Church tower	Popice, CSSR	Dried	Small amount	(Hubalek 1975)
6.71	Unspecified	Roost underneath Bridge	Wilmington, DE	Unknown	Unknown	(Huang & Lavenburg 2011)
7.0 (6–8)	Unspecified	Various roost sites	Bolivar, Venezuela	Rehydrated	1:10	(Cermeño et al. 2006)
7.42	Unspecified	Various roost sites	Galati County, Romania	Dried	300g/200ml	(Vasiliu & Buruiana 2010)
8.5	Unspecified	Various roost sites	Santiago de Cali, Colombia	Semi-fresh	Unknown	(Caicedo et al. 1996)

6. CONCLUSIONS

The classic concept of the role of pigeons and their accumulated excreta in the urban environment is deceptively simple: faeces are considered variously ‘bad’, ‘harmful’ and ‘dangerous’. There is little evidence to suggest that other than potential public health issues and general aesthetics of soiling, pigeons are damaging the urban environment.

This paper has reviewed and summarised the current knowledge of various physiological and metabolic factors that influence the acidity of excreta in feral pigeons. Physiological factors that can influence 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 faecal pH than the influence of diet. Natural, grain and pulse-based foods are less acidic (by an order of 2 pH incre-

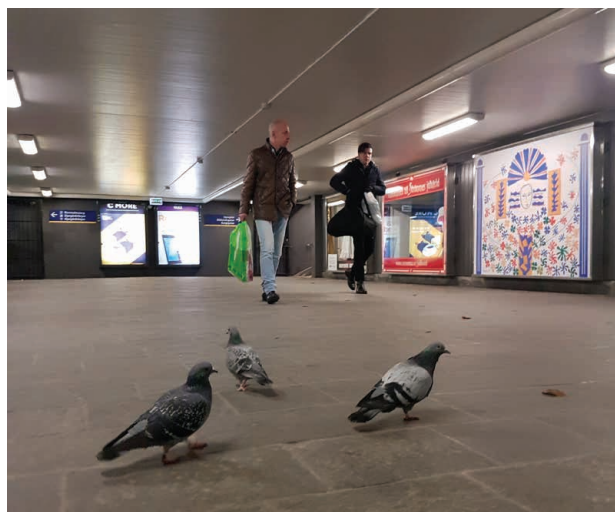


Figure 1. Feral pigeons one level below ground (Tunnelbana Station Centralen, Stockholm) (Photo Dirk HR Spennemann December 2016)



Figure 2. Feral pigeons feeding on discarded human food (Porte de Vanves, 14ème arrondissement, Paris) (Photo Dirk HR Spennemann January 2017)



Figure 3. Feral pigeons and domestic sparrows feeding on animal food spillage (Central Park, New York) (Photo Dirk HR Spennemann January 2017)



Figure 4. Volunteer food (bread) offered to feral pigeons by a member of the public (Battery Point, New York) (Photo Dirk HR Spennemann January 2017)



Figure 5. Feral pigeons feeding waiting for spillage of human food (South Kensington, London) (Photo Dirk HR Spennemann January 2017)



Figure 6. Feral pigeons feeding on volunteer food (Bermondsey Markets, London) (Photo Dirk HR Spennemann January 2017)

ments) than human, processed foods. The documented high individuality of the birds, their food preferences, as well as the variable nature of accessible food sources results in a high variability of the faecal pH. Once voided, the external factors, such as leaching by rainwater as well as colonisation by bacteria and fungi, change the acidity levels. This too is not uniform but dependent on relative humidity, temperature and available sources of fungal spores.

This review also indicates that the chemistry of pigeon excreta is highly complex and if property managers, or citizens in general, wish to avoid potential aesthetic and chemical damages to their properties, an individualistic understanding of the diet of local birds is necessary. Silva and Medeiros (2008) indicate that humans are increasingly concerned about pigeon populations (and presumably their accumulated faeces) in the urban space, and in response (Senar et al. 2017), demonstrate that food control is key to population reduction. A greater understanding of the chemical responses of urban spaces to faeces, both recently voided and accumulated, is necessary to complete the picture of the effects of feral pigeons.



Figure 7. Feral pigeons nesting in the carpark and associated soiling nesting and roosting (Westfield Shopping Centre, Parramatta, NSW) (Photo Dirk HR Spennemann July 2015)



Figure 8. Feral pigeons nesting despite pigeon spikes (Passage Vendôme, 3ème arrondissement, Paris) (Photo Dirk HR Spennemann January 2016)

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