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Birds documenting the Anthropocene: Stratigraphy of plastic in urban bird nests

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The amount of plastics produced annually continues to grow. Of all the plastics ever produced, 79% is still with us, as they remain in landfills or in the natural environment (Geyer et al., 2017). The disruption driven by our collective human activities on Earth may result in a new geological epoch: the Anthropocene (Crutzen & Stoermer, 2021). This contemporary period in the geological history of planet Earth is defined by the impact humans have on our natural world and is already a firmly established term in environmental sciences. Plastic may be used as a global marker for the Anthropocene, which allows plastic items to be used as "index fossils" to date with accuracy sediment layers within the Anthropocene epoch (Corcoran et al., 2017), especially using the expiration date printed or stamped on food packaging or perishable products in general as a back-dating tool (Cau et al., 2019; Hoffmann & Reicherter, 2014). Single-use plastic food and drink packages now dominate plastic production (Geyer et al., 2017; Williams & Rangel-Buitrago, 2022) and consequently are the categories of litter most often encountered in Dutch freshwater systems (Boonstra & de Winter, 2019, p. 19). As these types of packaging are so widely present as litter, the material has also been adopted by birds to build their nests. Building with artificial materials is widespread (Jagiello et al., 2023), and a broad range of items may become part of a bird nest, even materials that are meant to deter birds (Hiemstra et al., 2023a). Food and drink packages have been documented as nest material in a wide variety of birds (Appendix S1: Section S1), one of which is the common coot (*Fulica atra*; Hiemstra, Gravendeel, et al., 2021). An urban population of the latter species in Leiden, The Netherlands, proved to be one of the first bird populations for which *all* nests contained plastic (Hiemstra, Gravendeel, et al., 2021). The common coot is a wetland bird that in The Netherlands originally built its nests of plant materials which rapidly decay, so coots normally construct a new nest every year (Gadsby, 1978; Jedlikowski & Polak, 2019). However, as plastics and other artificial, more durable materials are used for nest construction, new behavior, namely, the reuse of nests from previous years, may appear. This, in turn, may create a history of multiple years of nest use, reuse, and reconstruction to be studied using the stratigraphy of dateable plastic debris in the nest.

To document such a history of reuse, we collected common coot (*F. atra*) nests in the city center of Amsterdam, The Netherlands, on 22 September 2021 (after the end of the breeding season, when all nests were abandoned). Before collecting, each nest was checked for the presence of nidicoles like smooth newts (*Lissotriton vulgaris*), which may hibernate in waterfowl nests (Van Der Goot et al., 2022). If none was detected, nests were collected by hand, stored in large sturdy plastic bags, and brought to the lab for further analysis. There, the nests were deconstructed and split into piles of natural and artificial items, which was easy to do as nest material either consisted of "twigs" or "macroplastics," like near complete items of packaging. Each artificial item was subjected to a thorough examination with particular emphasis on identifying information that could serve as dating criteria. Specifically, items featuring packaging details like production dates, expiration dates, or copyright registration years were retained for further analysis (Cau et al., 2019). We interpreted all expiration dates as EU dates, instead of the US notation, as they were most likely locally bought. We discovered two nests that displayed a particularly rich stratigraphy, which we report upon in this paper. To prove the validity of the plastic nest stratigraphies, we screened archived Google Street View images for obtaining historical insights into nest occupancy. This allowed us to track nest site activity over time, and link those visual observations of the nest to the expiry dates of the plastic nesting material.

The most striking common coot nest was found underneath the dock of the Oude Turfmarkt, at the Rokin (52.368192° N, 4.893292° E). This nest, further referred to as the Rokin nest, was built on top of a disused foundation pile, the top of which is just above water level (Figure 1A–C). The metal tube is slightly longer than the pile, and creates a hollow space of around 20-cm deep which, over the years, has been filled with nesting material from successive generations of nest site reuse by birds. During deconstruction of this nest, 635 artificial items were counted; 206 items were food-related, of which 32 (5%) showed an expiry date. From these dateable items, a picture emerges of what happened at this nesting site over the past 30 years. As the nest was located at a dock for tour boats, which were constantly mooring, the nest could not be deconstructed layer by layer in chronological order. Yet while collecting, we observed recent top layers of facemasks and the deepest layers of nest material showed plastic dating back to the early 1990s. The timeline in Figure 1D shows the dateable pieces of nest material which were found in the nest, grouped by year, and indicating presumed breeding (attempts). A descriptive list of nest items is presented in Appendix S1: Section S2 (together with a more in-depth site description) and all dateable pieces of plastic were deposited in the collection of Museon-Omniversum, The Hague, The Netherlands, with registration number 239120. The older nest material could be linked to visual observations of nesting attempts thanks to photos in Google Street View in which the nest site is visible. Coots were indeed nesting in the years corresponding to the expiration dates found in the nest (Appendix S1: Section S3).

Another nest from Amsterdam also shows clear signs of reuse. The nest from Onbekendegracht (52.36242° N, 4.90474° E) had 40 dateable plastics, of which 22 were from 2019. However, on top of the nest were facemasks woven into the structure: personal protection equipment related to the COVID-19 pandemic, which had not started during the breeding season of 2019. The timeline in Figure 2 shows the dateable pieces of nest material which were found in the nest, again grouped by year, indicating presumed breeding (attempts). This nest is also visible on Google Street View, and photos from 2021 clearly show the addition of a new layer on top of the old nest, also with what appears to be plastic (Appendix S1: Section S4). A descriptive list of nest items is presented in Appendix S1: Section S5 (together with a more in-depth site description), and these dateable plastics have also been deposited in the collection of Museon-Omniversum, The Hague, The Netherlands, with registration number 239121.

Besides these two nests, another 13 nests from Amsterdam included plastic material with expiry dates from multiple time periods. Some nests contain material dated prior to the year that they were collected (Appendix S1: Section S6), which could be the result of reuse. In addition, we found nests built in 2021 for which the plastic items do not indicate reuse, as all dates are from the year of collection, or later (Appendix S1: Section S7).

Here, we describe constituents of nests of the common coot from the canals of Amsterdam, The Netherlands, which are being reused, a behavior that is enabled because of repurposing of artificial materials as nest components. Half of the Dutch coots are year-round residents (Daalder, 2017), which facilitates embarking on earlier breeding attempts. The Rokin nest summarized 30 years of nest activity, reflected in 10 presumed breeding attempts of a species which normally does not reuse its nest (Gadsby, 1978; Jedlikowski & Polak, 2019). As far as we know, these are the first bird nests that could be dated thanks to expiration dates of the plastic litter used as nesting material, validated by corresponding Google Street View images. Here, we will further discuss these stratigraphically layered bird nests, both from ecological and geological perspectives.

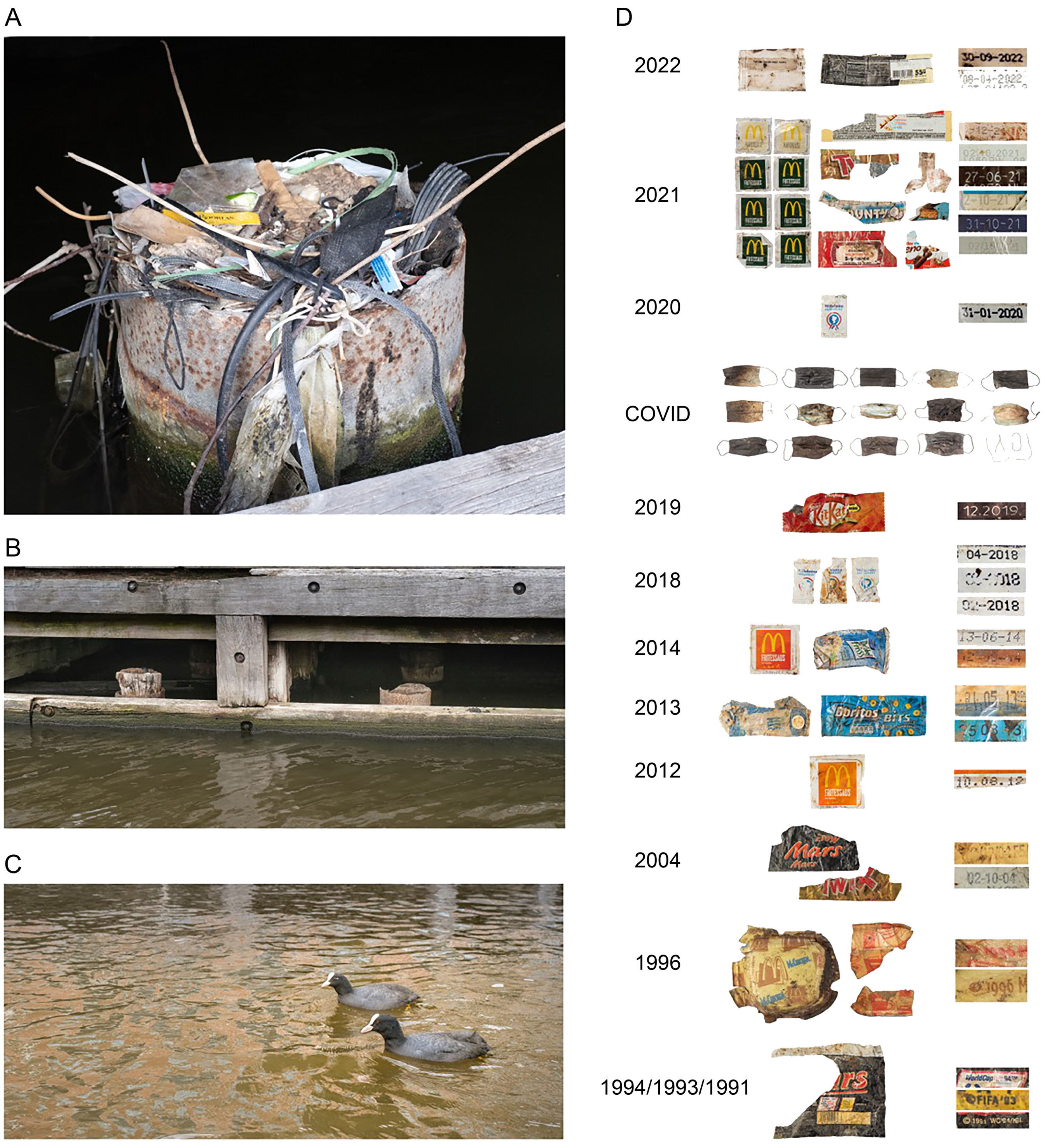

FIGURE 1 (A) Nest location at Rokin, Amsterdam, before its collection at the end of the breeding season. (B) Two foundation piles, the hollow pipe in which the Rokin nest was built on the right. (C) Common coot architects of the focal nest in front of the dock of the Oude Turfmarkt. (D) Dateable plastic from the Rokin nest made by common coots in Amsterdam, The Netherlands, deposited in the collection of Museon-Omniversum, The Hague, The Netherlands, with registration number 239120. Photographs: Auke-Florian Hiemstra.

Coots normally build nests for just one breeding season (Gadsby, 1978; Jedlikowski & Polak, 2019). As the plants they naturally use as building material decay rapidly, constant repair is needed to sustain the structure. This disadvantage of natural materials makes long-term use of the same nest impossible, or energetically maladaptive, as nest upkeep stops after the chicks have fledged. However, building with artificial and durable

FIGURE 2 Dateable plastic from the Onbekendegracht nest made by common coots, Amsterdam, The Netherlands, which have been deposited in the collection of Museon-Omniversum, The Hague, The Netherlands, with registration number 239121. Photographs: Auke-Florian Hiemstra.

material like plastic may enable reuse of earlier nests. Even the oldest pieces of nest material from the Rokin nest did not show any signs of wear or degradation, so a well-constructed nest made from artificial material may support birds for a long time. As half of the Dutch coots are year-round residents (Daalder, 2018), they may add some new material on top of the nest, but the base of the construction had already been built. Reuse of nests may result in evolutionary advantages. It reduces the search effort for nest material and could lessen building time, in favor of time to defend territories or advance breeding periods. It is unclear to us if nest reuse is stimulated because of such benefits, or because of the scarcity of good urban nest sites like stern platforms of boats, car tires used as dock fender, or artificial nesting platforms. Even though we collected the base of the nest on the Onbekendegracht, on that exact spot, a new nest was built again the following year). However, there may also be disadvantages to nest reuse, such as increased chances of an ectoparasite infestation or a greater risk of predation (Hiemstra et al., 2023b), as urban coots may be preyed upon by, for example, dogs, cats, rats, herons, gulls, and pikes (Daalder, 2017).

Interestingly, the base of the Rokin nest could be dated back to the start of the 1990s, around the time that the first coots started to breed in the city center of Amsterdam (this first occurred at Kattenburg in 1989) (Daalder, 2017; Van Groen & Kooijmans, 2022). The base of the Rokin nest must have been constructed by one of the first coots that entered the center of Amsterdam, as the oldest piece of litter found could be dated to 1991–1994. Following the work of Minias et al. (2018) on coots and urbanization, these first coots in Amsterdam may have been behaviorally and physiologically preadapted to urban life due to phenotype sorting, were extremely plastic in their behavior, or both. By switching from reed to using plastic litter as nesting material, coots may have unlocked the inner city as a breeding area, which was otherwise unsuitable, as the Rokin nesting site lacks natural vegetated banks. Of all the 23 species of waterbirds from Amsterdam, only grebes (*Podiceps cristatus*) and coots nest in the city center, as these species are more flexible in their nest site selection and are capable of building with plastic (Van Groen & Kooijmans, 2022, p. 52).

Artificial nest material allows birds to reuse earlier nests, if those are still available. Rijkers (unpublished thesis) revealed that 43 of the 112 observed coot nests from Amsterdam were removed during the breeding season of 2022 (38.4%), even though the removal of nests is forbidden by national regulations. Most nests were presumably removed by people, as the nests were constructed on, for example, boats, which consequently cannot be used for the duration of the breeding season. Temporary availability of anthropogenic nest localities has thus been defined as an environmental trap (Reynolds et al., 2019). However, once an undisturbed nest site is found that enables long-term reuse, this place may be referred to as an "ecological magnet" (Hickey, 1942). Such nests may be dated using different methods. Gyrfalcons (*Falco rusticolus*) in Greenland deposited stratified accumulations of guano, which can accumulate up to 1.5-m thick (Burnham et al., 2009). Radiocarbon dating revealed some of these nests to date back to 2740–2360 years ago. Similar studies carbon dated solidified stomach oil deposits, peat moss deposits, and bone and feather samples (Emslie et al., 2007; Gaston & Donaldson, 1995; Hiller et al., 1988). The use of plastic litter in nests, as a back-dating tool for animals building with artificial material, may be a new instrument in the toolkit of the urban ecologist and prove to be a cheap and fast way to learn about the history of a nest site.

Layer upon layer, with every new breeding attempt, an accumulation of plastic litter in stratigraphic order is laid down, which forms a historical time series. The serial deposits, constructed out of artificial material, may not only document the history of a bird nest, but also reflect the history of our Anthropocene Epoch. Following Zalasiewicz et al. (2014, 2016), we refer to this accumulation as a technostratigraphy, as this contemporary deposit is built up of human artifacts. Geologically speaking, the plastic objects may be regarded as *ichnofossils* (Barnosky, 2013), being future human trace fossils, specifically distinguished as *technofossils*, the remains of the technosphere (Haff, 2013). Compared with the biosphere, where almost everything breaks down, the technosphere recycles very little. From all the plastic waste ever produced, only 9% has been recycled (Geyer et al., 2017). While there has been an explosive human population growth, there has also been an orders-of-magnitude increase in the production of human artifacts (Zalasiewicz et al., 2014, 2016). Technofossils will have the capacity to characterize the sedimentary deposits in which they are found. Single-use packages, in particular, may be regarded as feeding traces, *pascerichnia*, which could act as very precise index fossils, referring to the year and date of advised consumption, thus reflecting a nearly exact moment within the Anthropocene.

Due to globalization, and the spread of artifacts around the world, remains of products of brands like McDonalds that produce a vast amount of technofossils all around the world, will classify as a very consistent marker. McDonalds is one of the most polluting companies (Ahmed, 2023), and almost half of the datable products in our Rokin nest were made by this brand. COVID-19 facemasks, which are often seen in bird nests

(Hiemstra, Rambonnet, et al., 2021), have also been suggested as a specific marker for the pandemic years (Weber & Lechthaler, 2021). In the Rokin nest 14 facemasks were present, next to four loose elastic bands originating from such a mask. Based on expiration date analysis, the base of the nest from Onbekendegracht was constructed in 2019, so pre-COVID-19, but it had four facemasks on top when it was collected in 2021. These new top layers help to protect older layers as burial is required for long-term preservation, limiting surface exposure and photodegradation of the plastic (Zalasiewicz et al., 2014). The metal pipe, in which the Rokin nest was built, further secured the stratigraphical structure, preserving a time series as a cylindrical section of a core sample.

While technofossils can be used for “ultrahigh resolution geological dating” (Zalasiewicz et al., 2014, 2016) and the printed text on plastic seems to be very durable (Appendix S1: Section S8), expiration dates do vary, and some products may have a longer shelf life than others. This is reflected by the fact that we discovered 2022 ($n = 13$), 2023 ($n = 4$), and 2024 ($n = 1$) dates on packages in nests that were collected in 2021 (Appendix S1: Sections S3 and S4). Depending on the perishability of a product type, a more fine-tuned time window could be constructed. A package of fresh milk (expiration date 21 May 2013) found in the Rokin nest, or a “ripe avocado” packaging (expiration date 25 May 2021) from the Looiersgracht nest, are very precise markers. Yet a non-food item like a packaged condom found in the Blauwbrug nest, or nonperishable, shelf-stable products, could result in less precise dating, which may be a year or a few years off. The Rokin nest, for example, shows peppermint packaging with an expiration date of 31 January 2020. However, this piece of nest material will probably be from an earlier nest attempt, and not reflect the 2020 breeding season. Furthermore, pieces of older plastic may resurface due to bottom disturbance after being buried for some years. This may explain incidental findings of historic plastic in layers of modern plastics. As an example, we found a bag of paprika chips in the nest located at the Oudezijds Achterburgwal in Amsterdam from the brand “Zakje Smis,” which did not show an expiration date yet dates to the 70s according to its outdated product name.

Expiration dates have previously been used to date seafloor macro litter (Cau et al., 2019) and to reconstruct Anthropocene extreme flood events (Hoffmann & Reicherter, 2014). Jagiello et al. (2023) hypothesized that bird nests which are used over repeated seasons may appear to be built out of more artificial than natural material, due to a variation in the persistence of different nest items. Such a surplus of sheets of artificial material may actually prove to be a useful back-dating tool for ecologists. Future research may shed light on the differences between predation risk and fledging success of urban nests compared with more natural sites, with a special emphasis on the pros and cons of nest reuse.

AUTHOR CONTRIBUTIONS

Auke-Florian Hiemstra carried out the fieldwork, conceived the presented idea, and wrote the first draft of the manuscript. All authors discussed the findings and contributed to the final manuscript. Both Barbara Gravendeel and Menno Schilthuizen supervised the project.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The nest material on which this study is based is deposited in the scientific collection of Museon-Omniversum, The Hague, The Netherlands, and retrievable with registration numbers 239120 and 239121.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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