Ingested solid pollutants in White Stork *Ciconia ciconia* in Aragón, Spain

Contaminantes sólidos ingeridos por la cigüeña blanca *Ciconia ciconia* en Aragón, España

Chabier González[1], Ignacio de Blas[2,3], Lluís Luján[2,3]

[1]La Alfranca Wildlife Rescue Center, Government of Aragón, Pastriz (Zaragoza), Spain
[2]Departamento de Patología Animal, Facultad de Veterinaria, Universidad de Zaragoza, Zaragoza, Spain
[3]Instituto Agroalimentario de Aragón-IA2, Universidad de Zaragoza, Zaragoza, Spain

Corresponding author:
Chabier González
La Alfranca Wildlife Rescue Center
Finca de La Alfranca, s/n, 50195 Pastriz (Zaragoza)
Email: chabiergo@gmail.com

Page-header title: Solid pollutants in White Stork

Key words: Rubber, silicone, plastic, landfills, impaction, landbirds, plasticosis

Number of words in text: 4320

Research paper

ORCID
Chabier González: 0009-0008-5883-4135
Ignacio de Blas: 0000-0002-1204-4356
Lluís Luján: 0000-0002-2053-9842

Author contribution:
Study conception: CG, LL. Methodology: CG. Formal analysis: IdB. Investigation: data/evidence collection: CG. Writing/manuscript preparation: writing the initial draft, critical review, commentary or revision, visualization/data presentation: CG, IdB. LL. Supervision: IdB, LL. Project administration: LL.

SUMMARY

The aim of this work was to study the presence and importance of solid pollutants found in the digestive system of White Stork *Ciconia ciconia* in Aragón, North-Eastern Spain. Necropsies of a total of 1,550 white storks were carried out. A total of 1,045 presented digestive contents. Solid contents found in the oesophagus, proventriculus and ventriculus were identified by their nature and shape and classified in twelve categories, according to the origin of the material. Volume of these materials was measured and classified into three categories as Low, Medium and High, when compared to the maximum volume found in a normal white stork pellet. Solid pollutants were found in 342 birds out of 1,045 examined digestive contents (32.7 %). In 142 of these cases (41.5%), two or more categories of solid pollutants were observed in the same animal. Rubber bands were the most frequently found pollutant as they were detected in 200 (19.1%) ventriculi. Silicone was found in 66 (6.3 %) ventriculi. All other materials were found in a much less frequency. Impaction linked to very high levels of rubber bands (>200 ml) was detected in five cases. Digestive obstruction only represented 0.9 % of the cases but 6.3 % of the examined digestive contents showed a High volume of solid pollutants. The occurrence of solid pollutants in the digestive did not differ with sex or age. The presence of these materials in the digestive system of white storks was found associated to dump foraging and could be also related to massive intake of rubber bands that are sometimes abandoned in cropfields. This is an important environmental problem affecting white storks that need better dump managements, improved agricultural practices and an improvement of the environmental awareness by the general population.

RESUMEN

El objetivo de este trabajo fue estudiar la presencia e importancia de los contaminantes sólidos encontrados en el sistema digestivo de la Cigüeña Blanca *Ciconia ciconia* en Aragón, Noreste de España. Se realizaron necropsias a un total de 1.550 cigüeñas blancas y un total de 1.045 presentaban contenido digestivo. Los contenidos sólidos encontrados en el esófago, proventrículo y ventrículo se identificaron por su naturaleza y forma y se clasificaron en doce categorías, según el origen del material. Se midió el volumen de estos materiales y se clasificó en tres categorías: bajo, medio y alto, en comparación con el volumen máximo encontrado en una egagrópila normal de cigüeña blanca. Se encontraron contaminantes sólidos en 342 aves de un total de 1.045 contenidos digestivos examinados (32,7%). En 142 de estos casos (41,5%), se observaron dos o más categorías de contaminantes sólidos en el mismo animal. Las gomas elásticas fueron el contaminante más frecuentemente encontrado, ya que se detectaron en 200 (19,1%) ventrículos. La silicona se encontró en 66 (6,3%) ventrículos. Todos los demás materiales se encontraron en una frecuencia mucho menor. La impactación ligada a niveles muy elevados de gomas (>200 ml) se detectó en cinco casos. La obstrucción digestiva sólo representó el 0,9% de los casos, pero el 6,3% del contenido digestivo examinado presentaba un volumen elevado de contaminantes sólidos. La presencia de contaminantes sólidos en el digestivo no difirió ni en cuanto a la edad ni al sexo. La presencia de estos materiales en el aparato digestivo de cigüeñas blancas se encontró asociada a la búsqueda de alimento en vertederos, y podría también estar relacionada con la ingesta masiva de gomas que son a veces abandonadas en campos de cultivo. Este es un importante problema medioambiental que afecta a las cigüeñas blancas y que requiere una mejor gestión de los vertederos, una mejora de las prácticas agrícolas y una mayor concienciación medioambiental por parte de la población.

INTRODUCTION

Anthropogenic pollution is increasingly widespread in all ecosystems around the world, negatively affecting many organisms such as birds (Richard *et al.* 2021). Among the anthropogenic pollutants, plastics are highly relevant due to their massive use and persistence. Indeed, plastic pollution is one of the main environmental problems in the planet and a major cause of concern, as huge amounts of these long-lasting debris accumulate both in land and sea environments (UNEP, 2018). The increase in plastic waste has been very important during the last decades and it is already affecting all types of ecosystems and animals (Pilapitiya & Ratnayake 2024). Ingestion of plastic fragments is one of the multiple consequences of plastic waste accumulation, being especially important in animals living in marine ecosystems (Stubbins *et al*., 2021). Severe effects of swallowed plastics have been described in sea birds (Shaw & Day, 1994; Blight & Burger, 1997), such as the Laysan Albatross *Phoebastria immutabilis*, whose feeding habits make it a species highly susceptible to plastic ingestion and subsequent damage (Pettit *et al.*, 1981; Fry *et al.*, 1987; Sileo *et al.*, 1990). Recently, the term plasticosis has been coined to describe the pathologic changes caused by ingested plastic in the digestive tract of the Flesh-footed Shearwater *Ardenna carneipes* (Charlton-Howard et al., 2023). Reports on plastic ingestion are biased towards marine birds, while few studies deal with land and freshwater birds. The white stork, as one of the most terrestrial freshwater bird is a good model to analyse the incidence of ingestion of solid pollutants including plastics because they use antropized habitat for breeding and foraging. Indeed, previous studies have focused on plastic ingestion by white storks although they generally deal with a limited number of samples (Peris 2003, Nicastro *et al*. 2018, Cano-Povedano *et al*. 2023, Bjedov et al. 2024).

The White Stork is a species very well adapted to anthropic habitats, with nesting, roosting and feeding mainly occurring in highly humanized areas. In Spain, white storks often use landfills as an important source of food. Indeed, landfills are major winter feeding areas not only for resident storks, but also for wintering North-European birds. Actually, both Iberian and North-European white storks have in general substituted Spanish landfills for their former wintering grounds in the Sahel (Africa) (Bécares *et al.*, 2019). This adaptation has been a great advantage for storks and it is one of the causes for the population increase observed during the last decades (Molina & del Moral, 2005, Bécares *et al.*, 2019). However, feeding in landfills imply exposure to a massive amount of pieces of plastic, rubber, metal, glass and other long-lasting pollutants that end up in the organic waste dumps, where storks and other birds search for food (Peris, 2003; Nicastro *et al.*, 2018). Moreover, plastic and other debris are carried by wind, rain water streams or sewage to the water bodies that constitute another important food source for storks. Finally, abandoned plastic and rubber gear is fairly common in the cropfields that are also major stork feeding grounds. Actually, Mansfield et al. (2024) underline the importance of white storks as bio-indicators of plastic pollution. There are a few previous studies about solid pollutants in the white stork, either focusing on the relationship with landfills (Peris, 2003), specific pollutants found in pellets (Henry *et al.*, 2011), or anthropogenic debris in nests (Jagiello *et al.*, 2018). However, a comprehensive study on ingested solid pollutants and their effects on digestive obstruction in the white stork is still missing (Cano-Povedano *et al.*, 2023, Mansfield *et al*. 2024, Bjedov *et al.*, 2024).

Since 1996, the daily work performed at La Alfranca Wildlife Rescue Centre (Centro de Recuperación de Fauna Silvestre de La Alfranca, CRFSA) has clearly showed that the white stork is by far the most affected species most affected by the ingestion of plastic and other solid pollutants: the finding of ingested solid, non-digestible material in other species is merely accidental, as indicated by data obtained from digestive contents found in three species of raptors commonly seen eating in landfills (Black kite *Milvus* *migrans*, Red kite *Milvus milvus* and Griffon vulture *Gyps fulvus*) during the same period of time (Table 1). Therefore, a scientific study that determines the real impact of this problem is urgently needed. The objectives of this study are i) to determine the nature and origin of these pollutants. ii) To evaluate the direct effects of ingested solid pollutants in the white stork and, specifically, the digestive tract obstruction due to the accumulation of these contaminants, that is the only clinical condition we have observed along the study and iii) to determine the prevalence of this problem and its possible relationship with age, sex, season or feeding habitat, expecting a higher presence and/or abundance of contaminants in the digestive tract of younger birds due to their less foraging experience and in the digestive tract of storks that feed in less natural places due to the higher presence of contaminants in them.

MATERIAL AND METHODS

Study area, sample size and collection of data

This study was performed with white storks found in Aragón, an autonomous region that covers an area of 47,720 km^2 in north eastern Spain (Fig. 1). Aragón contains most of the European terrestrial ecosystems including the arid scrub lands of the Ebro Valley, the alpine habitats of the high Pyrenees, pine and evergreen oak forests, riparian woods, Atlantic humid forests, high moors or endorheic lagoons, among others.

Data used in this study was obtained from the data base of the CRFSA, the main official facility attending wildlife in Aragón. All protected animal species found injured, ill, orphan or dead in this region are carried to the CRFSA. The aim of this centre is not only the rehabilitation and release of individuals, but also the study of the main causes of mortality affecting protected species. Therefore, dead animals are also admitted and subjected to full post mortem examination. Every animal is registered individually and all possible data are collected (finding circumstances, health status, analysis, treatments, evolution, release and when dead, necropsy findings). Between 1997 and 2019, more than 33,000 animals were admitted to the CRFSA, 3,098 White storks among them. A total of 1,550 of these White storks were admitted dead and only 1,045 presented digestive contents. Only 107 of them were marked, making a study based on individual marking impossible. For these 1045 birds we wrote down the following information:

i) Causes of admission. They were classified into the following categories (Table S1): collision, electrocution, fallen from nest, road kill, string entanglement (strangulation by ropes, normally affecting limbs, mainly in growing nestlings), weather (storms, lightning, wind, hail, etc.), intoxication (deliberate or not), digestive obstruction (always by solid pollutants), predation, traps (accidental or intentional), trapped in building, gunshot, starvation (when it was not due to a pathological cause), disease (both infectious and parasitic, not induced by wound contamination) and chick (nestlings collected from nest without pathologies). Case resolution included admitted dead, dead during admission and treatment, euthanized and released.

ii) Sex. It was determined by gonadal inspection when possible.

iii) Age of the storks was classified in four groups, according to development and moult pattern (Blasco-Zumeta and Heinze, 2023): nestling, fledgling, immature and adult. Fledging were storks from first flights until the end of the first calendar year. Immature were storks in their second calendar year. Adult were considered the rest of animals from the end of these second year, onwards. Distinction between nestling and fledgling is important for our aims because nestlings passively receive food carried by their parents and they are likely prone to accumulate non-digestible items. Fledglings and immatures, less experienced than adults, might be also risk groups. We decided not to include a subadult group and consider every stork older than 2 years in the adult group because third and sometimes even second year white storks behave as adults and they are already able to breed. Moreover, distinguishing between subadults and adults is only possible in spring and not in all individuals. As white storks were received along the year, it was considered more appropriate to include just a category.

iv) Foraging ground. To determine the foraging ground is an important issue to identify riskier locations. Foraging ground was defined as the place where the bird had been mainly foraging and it was determined by the food items admixed with solid pollutants. Therefore, the material that accompanies the solid contaminants was taken as the closest plausible approximation to the environment where they came from. For example, when a mass of rubber bands was only accompanied by fragments of invertebrates and/or mammalian hair, there was greater possibility that it had been ingested in crop fields. On the contrary, when the associated food was made up of remains of meat from domestic animals, often cooked, it was most likely it had been eaten in a landfill. Hence, cropfield foraging was inferred by the presence of Orthoptera, Coleoptera, voles *Microtus duodecimcostatus* and other terrestrial preys. On the other hand, discarded human food was evidence for landfill feeding and water foraging by the presence of fish, amphibians, crayfish and other aquatic animals. To our understanding this is the best proxy, although this approach is far from perfect.

Only digestive contents found in the oesophagus, proventriculus and ventriculus were registered, as solid contains do not normally transit down the gut. Ingested preys were identified visually by morphological traits, with naked eye or using a hand lens when required. Non-identifiable remains of digested food were washed with water, treated either by flotation, sedimentation or sieving (using a 0.5 mm sieve) and finally examined with naked eye, hand loupe and/or binocular loupe. Vertebrate, crustacean, insects and gastropod remains were identified up to the species level if enough diagnostic fragments were present. In other cases, invertebrates were only identified up to the order level. In order to measure solid pollutants, volume was chosen between other measurements as the only clinical problem observed linked to these materials was physical obstruction of the digestive tract, and the possibility of obstruction was directly related with volume. Several materials such as rubber bands, silicone strips, cotton sausage strings and strands or fragments of nylon ropes (see below) are prone to become entangled, forming a single mass that is impossible to expel, which led us to take into account the total volume of solid pollutants. Volume of solid pollutants found in a single bird was measured by water displacement, i.e.; solid pollutants were packed tightly in a plastic bag, air manually extracted and pack was maintained under water with the help of a clamp. Volume of displaced water was measured with a 50 ml syringe. We undertook a survey to determine the maximum volume of a physiological white stork pellet in eight nests. We collected 100 pellets for which the maximum recorded volume was 54 ml, which was taken as a reference, as it was a perfectly normal, solid pollutant-free pellet, expelled by a healthy, near fledged stork. Consequently, three groups within each category were established regarding the volume of solid pollutants, in relationship with the normal reference: Low, if the volume was less than 25% (<13.5 ml), Medium, if the volume was between 25-50% (13.5-27 ml) and High, if the volume was higher than 50% (27 ml).

Solid pollutants found during necropsy procedures were identified by their nature and shape and classified in ten categories. In the case of plastics, recommendations made by Hartmann et al. (2019) were followed (Table S2).

A) Plastics:

Following classification stablished by Hartmann et al (2019), all the plastic materials found in this work were solid, insoluble polymeres. Shape, colour and elasticity were highly variable.

1. Rubber items. They were made of synthetic or natural (latex) rubber and they were divided according to shape in: a) Rubber bands, showing a cylindrical or fiber shape. b) Rubber pieces. A broad diversity of rubber items, other than bands, with irregular or laminar shapes. Distinction between both shape categories is important, because bands tend to entangle making up obstructive masses.

2. Silicone. Mostly window caulking, silicone tubes and other pieces, mostly cylindrical or fibre shaped.

3. Inelastic plastic. Two categories were defined according to shape and therefore, capability of entanglement: a) bag fragments and hard plastic pieces. They were solid plastics with a laminar or irregular shape and they were termed simply “plastic”. b) Nylon cords. Baling twines. They were plastics with a fibre shape.

B) Non plastic materials

1. Glass. Mostly glass fragments or remains of broken bottles.

2. Aluminium and other metals. Mostly aluminium sausage staples, used in food industry

3. Vegetal cords. Cords made of cotton threads, used to tie several types of sausages. They are often found in landfills, still attached to food remains. Hemp cords were also found.

4. Ceramic. Floor tiles from demolitions.

5. Paper. Sanitary towels and packing paper.

6. Bamboo skewers. Sticks of manufactured wood for roasting meat.

7. Fabric. Fabric bands and clothing strips.

During the period of the study, 13 white storks were admitted alive and diagnosed as suffering from ventricular impaction by plastic. Seven of them required surgery and volumes of solid pollutants recovered ranged between 180 and 480 ml. Three of these animals were released to the wild and the other 4 died due to advanced cachexia. Six storks did not require surgery, as the volume of solid pollutants was <65 ml. Birds were feed with one-day chickens and mice, a diet rich in non-digestible material (feather or hair). Four of them soon expelled a variable amount of plastic content and were released and the other two died. None of the 13 storks showed clinical signs indicating toxicity linked to the ingested material.

Statistical methods

Categorical variables were described as absolute and relative (%) frequencies. The association between two categorical variables was checked using the Pearson's Chi-square test when less than 20% of expected values were lower than 5, and in other case Likelihood Ratio test was applied. The alpha error was set up at 0.050 and statistical analysis were carried out using IBM SPSS 26.0 for Windows.

RESULTS

The frequencies for each cause of admission regarding the 1,045 storks included in this work are shown in Supplementary material, Table S1. Remarkably, collision and electrocution represented 46.8 and 23.7 % of the total, respectively.

Irrespective the cause of admission, pollutants were found in 342 birds out of 1,045 examined digestive contents (32.7 %). In 142 of these cases (41.5%), two or more categories of solid pollutants were observed in the same animal. Results on solid pollutants ordered by categories and frequencies are presented in Fig. 2 and are described below.

Plastic

Rubber items. On the one hand, rubber bands were found in 200 (19.1%) ventriculi, mainly at low and medium volumes (Fig.2). Impaction linked to very high levels of rubber bands (>200 ml) was detected in five cases. Rubber bands contributed to impaction in further two cases, when they appeared admixed with nylon strings and other rubber pieces in the ventriculus. In some cases, rubber bands occupied the proventricle and lower oesophagus (Fig. 3). Rubber bands included a broad variety of sizes (Fig. 4). On the other hand, a broad diversity of rubber pieces was found in 41 (3.9 %) stork gizzards (Fig. 2). These include items such as condoms, rubber belts, coffee machine rubbers, sheets, torn balloons and other objects. In two cases rubber items were the primary cause of impaction, one of them due to massive ingestion of condoms located in the gizzard and in the other case due to two foam water soakers present in the proventriculus.

Silicone. It was found in 66 (6.3 %) ventriculi, mainly at low volumes (Fig. 2). The most frequent silicon item in stork stomachs were strips of discarded window caulking, although silicone tubes and long pieces were also found.

Inelastic plastic. Pieces of inelastic plastic were found in 42 (4.0 %) ventriculi, mainly at small volume (Fig. 2). Soft plastics consisted in garbage bag fragments, other plastic bag pieces, whole greengrocer's bags and hard plastic pieces. Hard plastic pieces were mainly polyhedric flat fragments (<2 mm thick and ≤30 mm long), always ingested in low numbers (≤10 items). Only one stork had a high content of plastic, occupying proventriculus and ventriculus. In addition, nylon cords were also found. They were always represented as baling twines, and they were discovered in the gizzard of two birds, at low volumes. This material is far more dangerous when used for nest lining as a total of 175 nestlings suffered severe limb strangulation by discarded baling twines (Fig. 2).

Non plastic

Glass. Glass chips were found in 49 (4.7 %) gizzards, having exclusively low volumes (Fig. 2). Most of the glass chips were small fragments (<25 mm) of bottle remains. Often, glass chips acquired an arrowhead shape but none of the gizzards showed macroscopic lesions that could be attributed to them.

Aluminium/metals. Metals were found in 29 (2.8 %) gizzards, mainly at low volumes (Fig. 2). Aluminium was the most frequently ingested metal (23 out of 29) and always consisted in sausage staples, attached to cotton cords and sausage remnants.

Vegetal cords. They were found in 29 (2.8 %) stomachs, mainly at low and medium volumes (Fig. 2).

Ceramic. It was found in 15 stomachs (1.4 %), always at low volumes. All the items were chips of floor tiles (Fig. 2).

Paper. It was only found in 4 (0.4 %) stomachs, mainly at low volumes (Fig. 2).

Bamboo skewers. Manufactured wood that can cause dramatic lesions although it is not a pollutant on itself. Four storks died after having swallowed these sticks, in all cases with some meat still attached. The skewers caused a piercing of the stomach wall and reach a variety of distant organs or structures with bacterial seeding along their pathway.

Fabric. It was only found in 3 (0.3 %) birds, two of them at high volumes (Fig. 2).

Despite the fact that solid pollutants were found in 32.7% of sampled storks, digestive obstruction as primary cause of admission only represented 0.9 % of the cases. There were no differences between sexes concerning frequencies of solid pollutants in the ventriculus (X^2=11.604; degrees of freedom (df)=6; p=0.071). Sexes were similarly represented in the whole sample but among adult storks there was an overrepresentation of males vs females (65.3 and 31.3 %, respectively). Regarding frequencies of solid pollutants by age, there were no significant differences according to the likelihood-ratio test (LR=15.472; df=12; p=0.217; Fig. 5) but among High level frequencies, nestlings and fledglings duplicated values when compared with immature and adult animals (X^2=8.083; degrees of freedom (df)=3; p=0.044).

Regarding foraging ground, landfills revealed significantly less individuals than expected without solid pollutants and significantly higher frequencies of solid pollutants in all level categories (X^2=161.403; df=6; p<0.001; Fig. 6), with an approximate value of 20 % for all of them (Fig. 6). On the other hand, both water and crop fields showed a marked decrease in frequency of solid pollutants from Low to High levels. Regarding frequencies of solid pollutants by month, the frequency of birds with a high level of solid pollutants is significantly higher in June-July and the period from October to January (LR=57.234; df=33; p=0.006; Fig. 7).

DISCUSSION

This work represents the largest survey to date on solid pollutants ingested by white storks as it includes the study of 1,045 digestive contents from a total of 1,550 necropsies. Results demonstrate the ingestion of a huge variety of human-made objects, linked to the different foraging grounds where storks use to feed. These results seem to indicate a low level of food selectivity from storks when they are confronted with some human made materials and also poor management of residues by humans (Henry *et al.*, 2011).

We measured the volume of solid pollutants because the only relevant problem observed after ingestion of solid pollutants was digestive obstruction. This was further confirmed by the clinical data obtained from alive white storks. No signs of intoxication by any components were detected although this was not an objective of this work. Once plastics were removed, animals recovered without further complications. The analysis of pellets has been used to assess the presence of anthropogenic particles in the environment (Bjedov et al., 2024) but it is not useful to know the volume of material ingested by the bird, as this material can be released in several pellets along different days (C. González, personal observation). Furthermore, mortality in storks was primarily attributed to collisions and electrocution, with intestinal obstruction appearing to pose minimal threat to the species.

Digestive obstruction depends on size (transversal section) of the pellet which is directly related to the volume. Actually, all masses within the ventriculus end as ellipsoids due to gastric muscular movements. Solid pollutants were present in almost one third (32.7 %) of the birds and 41.5 % of them presented two or more different solid, non-digestible materials. Rubber bands were present in almost 20 % of all contents and they were the most relevant item found in stork gizzards by far. Actually, the following five categories together would be similar in importance to rubber bands. In addition, more than 10 % of birds presented medium or high volumes of rubber bands, a condition that can lead to gizzard impaction and cachexia, something that was detected in at least five birds in our study. Rubber bands are often found on the ground. For instance, anchor rubber bands are often used in agriculture procedures to guide the growing of young trees and other type of rubber bands are also used for a large variety of crops. These items are often discharged in the fields after use and storks might interpret these artefacts as invertebrates (slugs, earth worms) and small vertebrates (voles, snakes). Silicone was the second more important category both in frequency and in volume and its presence denotes foraging in landfills as the origin is mostly discarded window caulking. The shape and elasticity of these items make them very similar to stork preys such as worms or snakes.

Moreover, these properties of silicone favours entanglement in the ventriculus, both with itself and/or rubber bands. Other rubber pieces were less important in terms of frequency but reached remarkable volumes in 2 % of the birds. These items included a huge variety of shapes and sizes, all of them resembling stork preys. Other group of solid pollutants were constituted by materials such as aluminium staples, cotton cords and bamboo skewers that were actually attached to food stuffs such as salami and meat. The frequency of these materials was not very important but the clinical consequences were very serious. For instance, four storks died by the perforation caused by ingested bamboo skewers that could affect internal structures or communicate with the exterior. Finally, glass, plastic, ceramic and paper were always present in very low quantities and likely, they were attached to other food items and ingested accidentally.

Neither the sex nor the age of individuals affected the probability of ingestion of solid pollutants. This might indicate a poor food selection even by parents feeding their offspring (Antczak *et al.*, 2002: Chenchouni *et al.*, 2015).

However, nestlings and fledglings showed solid pollutants with higher volume than more-aged birds, which suggests poorer food selectivity by breeding individuals for their chicks and by recently emancipated fledglings. The foraging ground affected the presence and frequency of high contents of solid pollutants, being the highest in landfills and the lowest in crop fields and water. These results are not surprising, as landfills contain many more solid pollutants than any other location. The highest frequency of solid pollutants was observed during two periods along the year: from October to January and in June-July. The latter might be related to the end of the breeding period, perhaps due to non-trained foraging by fledglings, whereas the former could be explained by the use of dumpfills by the high number of wintering white storks in the Iberian Peninsula.

The reason why this species is more prone to ingesting non-target items compared to other birds is the way white storks select their prey. Unlike herons or raptors of similar sizes, storks can rely on very small invertebrates for food (Alonso *et al.*, 1991; Pinowska et al., 1991; Chenchouni *et al.*, 2015), taking them with rapid bill grabbing and swallowing a big amount of insects (i.e., one cm long *Carabidae* beetles) in a few minutes (Pinowski *et al.*, 1991). This habit could not allow storks to select their prey accurately and many rubber pollutants could be interpreted as long-bodied animals such as worms, snakes or slugs. If the pollutant is present in low quantities or frequencies, an accidental ingestion cannot be ruled out. However, the high quantities of some of the pollutants (i.e., rubber bands) found alone in some ventricles likely indicate a deliberate choice after being mistaken with prey (Henry et al., 2011). Authors have observed white stork rejecting vegetal items (algae, other plants and vegetal garbage), even when they are attached to real preys. In addition, very low quantities of vegetal remains are found during necropsy procedures (C. González, personal observations), likely accidentally ingested.

There are several studies about solid pollutants focused on the white stork but they are either limited to its relationship with landfills (Peris, 2003), focussed on specific pollutants (rubber bands) mainly found in pellets in a limited number of necropsies (Henry et al., 2011), or only studying anthropogenic debris in nests (Jagiello et al., 2018). Recently, several degrees of proventricular fibrosis have been described in fledglings of Flesh-footed Shearwaters, correlated with plastic ingestion in the digestive tract (Charlton-Howard et al., 2023). In our cases, no gross lesions were detected in the digestive tract, even in the most affected specimens and no samples were taken for histopathology. However, the presence of proventricular fibrosis or any other pathological condition will be microscopically investigated in the future in other individual cases.

The white stork is one of the few terrestrial avian species known to be affected by the ingestion of solid pollutants, which are probably mistaken with food when ingested.

The accumulation of a type or several types of materials can lead to massive presence of pollutants in the ventriculus and proventriculus, that can cause a diversity of digestive problems. By far, rubber bands are the most frequently found contaminant, followed by silicone remnants. This is likely due to dump foraging but also to massive intake of rubber bands abandoned in cropfields. This is a unique problem that needs specific attention regarding dump management, agricultural practices and an increase of environmental awareness by the general population.

ACKNOWLEDGEMENTS

We are very grateful to Dr. Jeremy Brock for scientific and English review of the manuscript.

REFERENCES

Alonso, J.C., Alonso, J.A. & Carrascal, L.M. (1991). Habitat selection by foraging white storks, *Ciconia ciconia* during breeding season. *Canadian Journal of Zoology*, 69: 1957–1962.

Antczak, M., Konwerski, S., Grobelny, S. & Tryjanowski, P. (2002). The food composition of immature and non-breeding white storks in Poland. *Waterbirds*, 25: 424–428.

Bécares, J., Blas, J., López-López, P., Schulz, H., Torres-Medina, F., Flack, A., Enggist, P., Höfle, U., Bermejo, A. & de la Puente, J. (2019). Migración y ecología espacial de la cigüeña blanca en España. Monografía 5 del programa Migra. SEO/BirdLife. Madrid. DOI: 10.31170/0071.

Bjedov, D., Mikuška, A., Gvozdić, V., Glavaš, P., Gradečak, D., & Sudarić Bogojević, M. (2024). White Stork Pellets: Non-Invasive Solution to Monitor Anthropogenic Particle Pollution. *Toxics*, 12, 236.

Blasco-Zumeta, J. & Heinze, G.M. (2023). Identification Atlas of the Continental Birds of Southwestern Europe. Tundra Ediciones, pp: 46-47. ISBN: 978-84-19624-38-3.

Blight, L.K. & Burger, A.E. (1997). Occurrence of plastic particles in seabirds from the Eastern North Pacific. *Marine Pollution Bulletin*, 34: 323–325.

Cano-Povedano, J., López-Calderón, C., Sánchez, M.I., Hortas, F., Cañuelo-Jurado, B., Martín-Vélez, V., Ros, M., Cózar, A., Green A.J. (2023). Biovectoring of plastic by white storks from a landfill to a complex of salt ponds and marshes. *Marine Pollution Bulletin*, 197: 115773.

Chenchouni, H., Bachir, A.S. & AlRashidi, M. (2015). Trophic niche and feeding strategy of the white stork (*Ciconia ciconia*) during different phases of the breeding season. *Avian Biology Research*, 9: 1–13.

Charlton-Howard, H.S., Bond, A.L., Rivers-Auty, J. & Lavers, J.L. (2023). 'Plasticosis': characterising macro- and microplastic-associated fibrosis in seabird tissues. *Journal of Hazardous Materials*, 450: 131090.

Fry, M.D., Fefer, S.I. & Sileo, L. (1987). Ingestion of plastic debris by Laysan albatrosses and wedge-tailed shearwaters in the Hawaiian Islands. *Marine Pollution Bulletin*, 18: 339–343.

Hartmann, N.B., Hüffer, T., Thompshon, R.C., Hassell¨ov, M., Verschoor, A., Daugaard, A. E., Rist, S., Karlsson, T., Brenholt, N., Cole, M., Herrling, N.P., Hess, M.C., Ivleva, H. P., Lusher, A.L., Wagner, M., 2019. Are we speaking the same language? Recommendations for a definition and categorization framework for plastic debris. Environ. Sci. Technol. 53 (3), 1039–1047. https://doi.org/10.1021/acs.est.8b05297.

Henry, P., Wey, G. & Balança, G. (2011). Rubber band ingestion by a rubbish dump dweller, the White Stork (*Ciconia ciconia*). *Waterbirds*, 34: 504-508.

Jagiello, Z., Dylewski, L., Winiarska, D., Zolnierowicz, K. & Tobolka, M. (2018). Factors determining the occurrence of anthropogenic materials in nests of the white stork *Ciconia ciconia*. *Environmental Science and Pollution Research*, 25: 14726–14733.

Mansfield, I., Reynolds, S. J., Lynch, I., Matthews, T. J., & Sadler, J. P. (2024). Birds as bioindicators of plastic pollution in terrestrial and freshwater environments: A 30-year review. Environmental Pollution, 123790.

Molina, B. & del Moral, J. C. (2005). La cigüeña blanca en España. VI Censo Internacional (2004). SEO/BirdLife. Madrid.

Nicastro, K.R., Lo Savio, R., McQuaid, C.D., Madeira, P., Valbusa, U., Azevedo, F., Casero, M., Lourenço, C. & Zardi, G.I. (2018). Plastic ingestion in aquatic-associated bird species in southern Portugal. *Marine Pollution Bulletin*, 126: 413-418.

Peris, S. (2003). Feeding in urban refuse dumps: Ingestion of plastic objects by the White Stork (*Ciconia ciconia*). *Ardeola: International Journal of Ornithology*, 50: 81-84.

Pettit, T.N., Grant, G.S. & Whittow, G.C. (1981). Ingestion of plastics by Laysan Albatross. *The Auk*, 98: 839–841.

Pilapitiya, P.G.C.N.T., Ratnayake A.S. (2024). The world of plastic waste: A review. *Cleaner Materials*, 11: 100220.

Pinowska, B., Buchholz, L., Grobelny, S., Stachowiak, P., Pinowski. J. (1991). Skipjacks Elateridae, weevils Curculionidae, orthopterans Orthoptera and earwigs Dermaptera in the food of white stork *Ciconia ciconia* (L) from the Mazurian Lakeland. *Studia Naturae Seria A*, 37: 87–106.

Pinowski J, Pinowska B, de Graaf R, Visser J, Dziurdzik B (1991) Influence of feeding habitat on prey capture rate and diet composition of white stork *Ciconia ciconia* (L.). *Studia Naturae Seria A*, 37: 59–85.

Richard, F.J., Southern, I., Gigauri, M., Bellini, G., Rojas, O., Runde, A. (2021). Warning on nine pollutants and their effects on avian communities. *Global Ecology and Conservation*, 32: e01898.

Shaw, D.G. & Day, R.H. (1994). Colour and form-dependent loss of plastic micro-debris from the North Pacific Ocean. *Marine Pollution Bulletin*, 28: 39–43.

Sileo, L., Sievert, P.R. & Samuel, M.D. (1990). Causes of mortality of albatross chicks at Midway Atoll. *Journal of Wildlife Diseases*, 26: 329–338.

Stubbins, A., Law, K.L., Muñoz, S.E., Bianchi, T.S., Zhu, L. (2021). Plastics in the Earth system. *Science*, 373: 51–55.

UNEP (2018). Single-use plastics: A Roadmap for Sustainability. Available at URL: https://www.unep.org/resources/report/single-use-plastics-roadmap-sustainability

Table 1

Frequencies of solid pollutants in other scavengers examined between 1997-2019

Species	**n***	**Frequency**	**Type of pollutants**	**Volumes**
Black kite (*Milvus migrans*)	237	10 (4.2%)	Meat stuff or envelopes Tiny diverse fragments	< 1 ml
Red kite (*Milvus milvus*)	432	3 (0.7%)	Meat envelopes	< 1 ml
Griffon vulture (*Gyps fulvus*)	8756	106 (1.2%)	Meat stuff or envelopes Tiny diverse fragments	< 5 ml

*n: Digestive contents examined

FIGURES

Fig. 1. Geographic location of Aragón in the Iberian Peninsula (in dark grey color)

Fig. 1. Localización geográfica de Aragón en la península ibérica (en color gris oscuro)

Fig. 2. Percentages of solid pollutants (plastic and non-plastic) found in 1045 digestive contents from white stork, by categories.

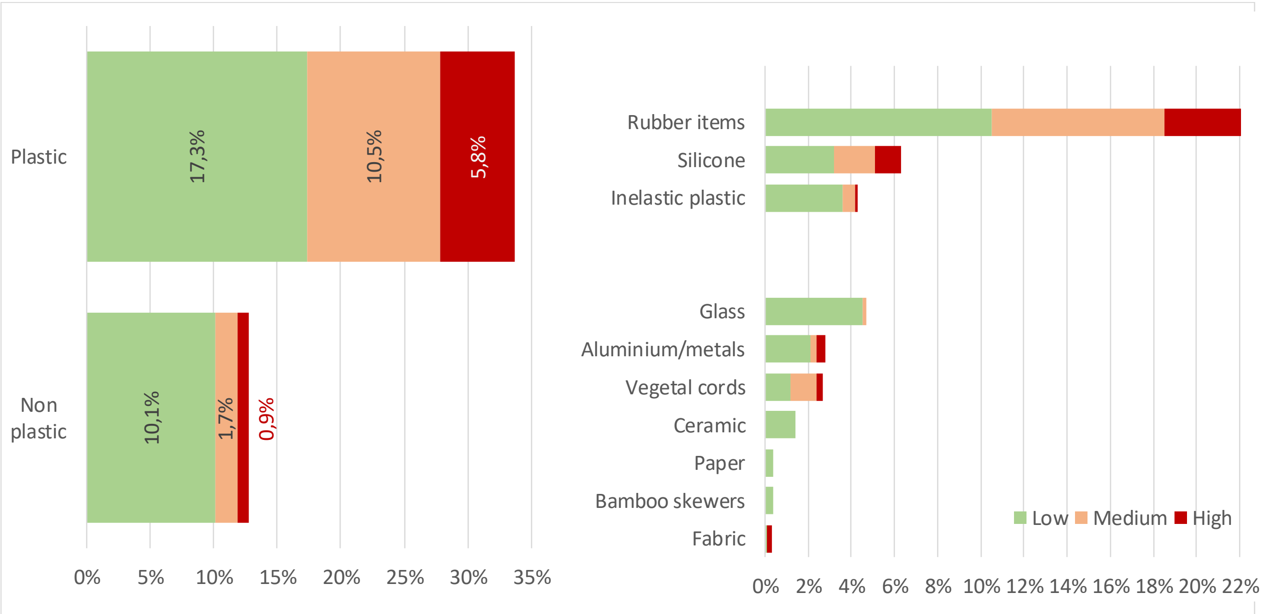


Fig. 2. Porcentajes de contaminantes sólidos (plástico y no plástico) hallados en 1045 contenidos digestivos de cigüeñas comunes, por categorías.

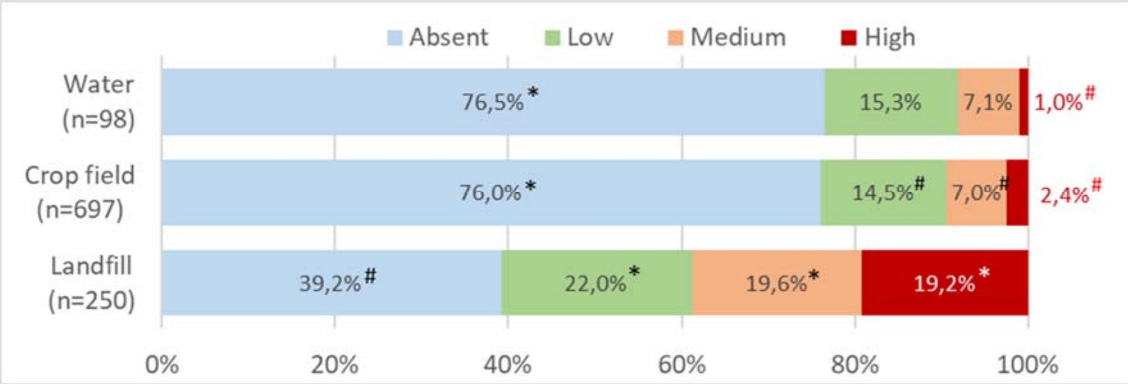
Fig. 3. A. White stork, ventriculus. Massive accumulation of rubber bands, an artifact used in agricultural procedures. The total volume of this mass was 185 ml. A Louisiana crayfish *Procambarus clarkii* can be observed in the proventriculus, on the left. **B.** White stork. Partial contains of the ventriculus seen in A, after cleaning.

Fig. 3. A. Ventrículo de cigüeña común. Acumulación masiva de gomas de embalar, un material utilizado en tareas agrícolas. El volumen total de esta masa fue de 185 ml. Un cangrejo rojo americano *Procambarus clarkii* se observa en el proventrículo, a la izquierda. **B.** Cigüeña común. Contenido parcial del ventrículo expuesto en A, tras su limpieza.

Fig. 4. Percentage of solid pollutants in white stork by age.

Fig. 4. Porcentaje de contaminantes sólidos en cigüeña común por edades.

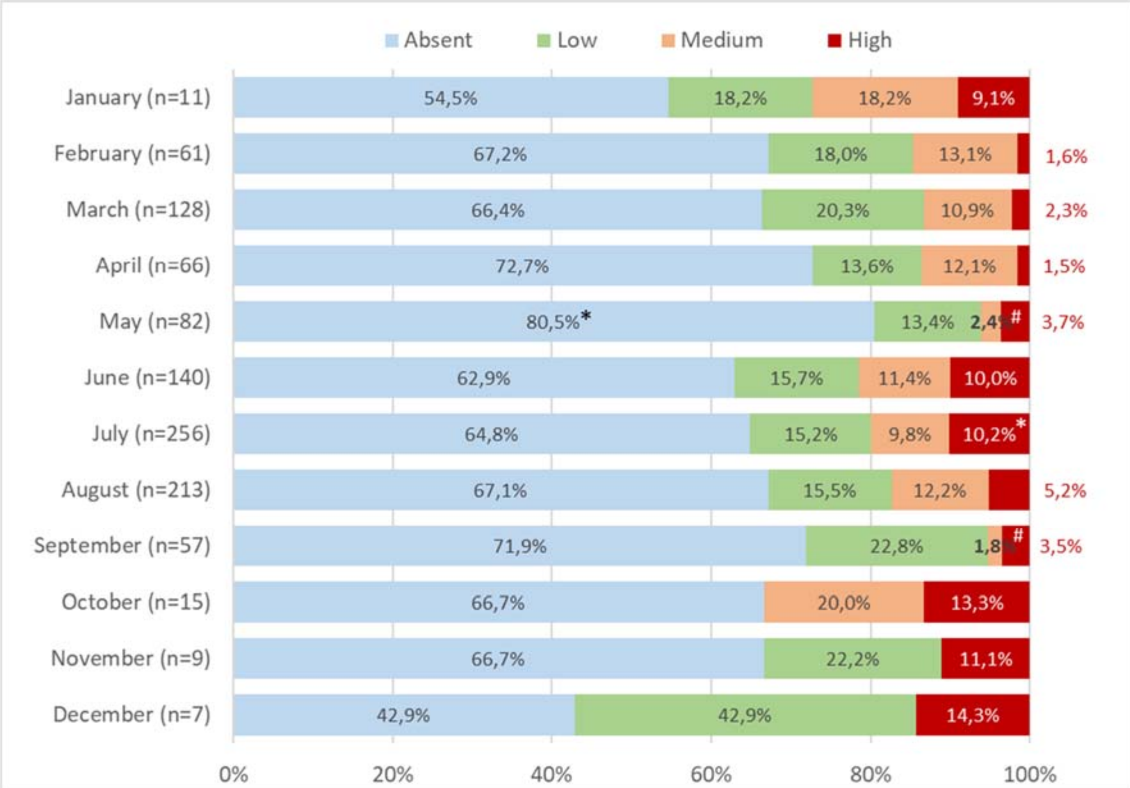
Fig. 5. Percentage of solid pollutants in white stork by foraging ground (inferred by food items).



*Statistically significant higher value within a frequency
#Statistically significant lower value within a frequency
*#Pearson's chi-squared test ($p<0.001$)

Fig. 5. Porcentaje de contaminantes sólidos en cigüeña común por hábitat de alimentación (deducido a partir de componentes de la ingesta).

Fig. 6. Percentage of solid pollutants in white stork by month.



*Statistically significant higher value

#Statistically significant lower value

Likelihood-ratio test (p=0.006)

Fig. 6. Porcentaje de contaminantes sólidos en cigüeña común por meses.

SUPPLEMENTARY ELECTRONIC MATERIAL (APPENDIX 1)

Ingested solid pollutants in White Stork *Ciconia ciconia* in Aragón, Spain

Contaminantes sólidos ingeridos por la cigüeña blanca *Ciconia ciconia* en Aragón, España

Chabier González[1], Ignacio de Blas[2,3], Lluís Luján[2,3]

[1]La Alfranca Wildlife Rescue Center, Government of Aragón, Pastriz, Zaragoza, Spain
[2]Departamento de Patología Animal, Facultad de Veterinaria, Universidad de Zaragoza, Zaragoza, Spain
[3]Instituto Agroalimentario de Aragón-IA2, Universidad de Zaragoza, Zaragoza, Spain

Corresponding author: Chabier González (chabiergo@gmail.com)

Table S1
Causes of admission for the storks included in this work

Cause of admission	**n**	**%**
Collision	489	46.8
Electrocution	248	23.7
Fallen from nest	100	9.6
Road kill	87	8.3
String entanglement	49	4.7
Weather	18	1.7
Intoxication	9	0.9
Digestive obstruction	9	0.9
Predation	9	0.9
Traps	7	0.7
Trapped in building	6	0.6
Gunshot	5	0.5
Starvation	4	0.4
Disease	4	0.4
Chick	1	0.1
Total	**1,045**	**100**

Table S2

Categories of solid pollutants found in 1045 digestive contents from white stork and their absolute frequencies. Low, Medium and High refer to the distribution of frequencies within a category, with reference to the maximum volume of a white stork pellet, considered at 54 ml.

Materials	**Solid content**	**Frequency**	**%**	**Low**	**Medium**	**High**
Plastic						
	Rubber items	241	23.00	10.5	8.0	4.5
	Silicone	66	6.30	3.2	1.9	1.2
	Inelastic plastic	44	4.20	3.6	0.6	0.1
Non-Plastic						
	Glass	49	4.70	4.5	0.2	-
	Aluminium/metals	29	2.80	2.1	0.3	0.4
	Vegetal cords	29	2.80	1.2	1.2	0.3
	Ceramic	15	1.40	1.4	-	-
	Paper	4	0.40	0.4	-	-
	Bamboo skewers	4	0.40	0.4	-	-
	Fabric	3	0.30	0.1	-	0.2