

UNIVERSIDAD DE COSTA RICA
SISTEMA DE ESTUDIOS DE POSGRADO

TÍTULO: USO DE MATERIAL ARTIFICIAL PARA LA CONSTRUCCIÓN DE NIDOS DE
AVES: POTENCIALES CONSECUENCIAS SOBRE EL ÉXITO REPRODUCTIVO DE
TURDUS GRAYI (PASSERIFORMES: TURDIDAE)

Tesis sometida a la consideración de la Comisión del Programa de Estudios de Posgrado en
Biología para optar al grado y título de Maestría Académica en Biología

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TABLA DE CONTENIDOS

Dedicatoria y agradecimientos	ii
Hoja de aceptación	iii
Resumen	vii
Lista de cuadros.....	viii
Lista de figuras	x
Licencia de publicación.....	xii
Introducción general.....	1
Capítulo 1. Human waste used as nesting materials affects thermoregulation in birds	11
Resumen	11
Introducción	12
Métodos	14

Análisis estadístico.....	15
Resultados	17
Discusión	17
Referencias	22

Capítulo 2. A potential consequence for reproductive success in urban birds: anthropogenic nest materials reduce nest survival

Resumen	36
Introducción	37
Métodos.....	40
Análisis estadístico.....	43
Resultados	45
Discusión.....	46
Referencias	49

Capítulo 3. Careful with your waste: Urbanization increases artificial materials in bird nests

Resumen	58
Introducción	59
Métodos.....	62
Análisis estadístico.....	64

Resultados 65

Discusión 65

Referencias 70

RESUMEN

El exponencial aumento en la población humana ha generado una rápida expansión de las zonas urbanas. El aumento en el área de las ciudades produce que algunas especies entren en contacto directo con nuevos recursos generados por los humanos. Estos recursos pueden estar relacionados con alimentación o materiales para construir madrigueras o nidos. Algunas especies de aves que habitan ciudades, incorporan material artificial en sus nidos. La incorporación de este tipo de materiales podría estar relacionada con la creciente disponibilidad del material producto del aumento en las áreas urbanas, sin embargo las consecuencias de esto aún son poco claras. La incorporación de material artificial podría tener consecuencias para el éxito reproductivo de las especies que incorporan el material, principalmente con efectos sobre la depredación y la termorregulación de los nidos. Con la presente investigación de tesis, determiné potenciales consecuencias del uso de materiales artificiales en la construcción de nidos sobre el éxito reproductivo de *Turdus grayi*: Turdidae, el ave nacional costarricense. Determiné que el uso de materiales artificiales aumenta el enfriamiento y disminuye la supervivencia de los nidos. Además el nivel de urbanización del sitio en donde se construye un nido, influye sobre la diversidad de materiales artificiales incorporados en los nidos ya que los nidos construidos en lugares con mayor urbanización, tienen más tipos de materiales artificiales. Las consecuencias del uso de materiales artificiales sobre nidos de las aves son diversas, sin embargo con esta investigación ofrezco evidencia sobre consecuencias negativas que podrían afectar las poblaciones de aves en zonas urbanas.

LISTA DE CUADROS

Capítulo 1

Table 1. Artificial materials found in the 46 studied nests of the clay-colored thrush and the number of nests with each type of material 29

Table 2. Generalized linear models (family Gaussian) ranked according to the lowest AICc value explaining cooling slope in clay-colored thrush nests in simulations without the female at the nest (cotton ball was not used after heating). Principal components are shown as internal (i) and external (e). Bold model represents the best model that explains nest cooling 31

Table 3. Generalized linear models (family Gaussian) ranked according to the lowest AICc value explaining cooling slope in clay-colored thrush nests in simulations with presence of female at the nest (cotton ball used after heating). Principal components are shown as internal (i) and external (e). Bold models represent best models that explain nest cooling 32

Capítulo 2

Nest survival models explaining nest daily survival rate in clay-colored thrush's nests ranked according to AICc values (Proportion = exposed artificial materials area/total exposed nest area, PC = principal component) 57

Capítulo 3

Table 1. Number of nests of the clay-colored thrush (*Turdus grayi*) with artificial material, and proportion of nests with each of the materials listed..... 77

Table 2. Zero inflated generalized linear mixed models (family negative binomial) ranked according to the lowest AICc value explaining the richness of artificial material in clay-colored thrush's nests. Bold text indicates the model that best explain the richness in artificial material types

..... 78

LISTA DE FIGURAS

Capítulo 1

Figure 1. Nests of the clay-colored thrush (*Turdus grayi*) with a total weight of 118 g, and materials separated in artificial, adobe, and natural A) when artificial material mass is high (13.4 g), and B) when artificial material mass is low (0.1 g) 33

Figure 2. Nest cooling ($^{\circ}\text{C}/\text{min}$) according to the adobe mass in simulated female absence at the nest of the clay-colored thrush (*Turdus grayi*)..... 34

Figure 3. Nest cooling ($^{\circ}\text{C}/\text{min}$) according to A) artificial material mass, B) adobe mass, C) natural mass, and D) internal principal components (PC1 = camera area, PC2 = base depth) in simulated female presence at the nest of the clay-colored thrush (*Turdus grayi*) 35

Capítulo 2

Figure 1. Clay (left) and natural (right) eggs of the clay-colored thrush for comparative purposes 54

Figure 2. Map of the University of Costa Rica main campus gridded in quadrats of 60 m side. The dashed line shows the campus perimeter, grey area represents buildings, roads and parking lots, and white area represents forest patches and gardens. Black dots represents an unpredated nest, and white dots represent a predated nest of the clay-colored thrush 55

Figure 3. Predicted nest daily survival rate (continuous line) with 95% confidence limits (dashed lines) and proportion between nest's artificial materials exposed area and total nest area (“Proportion”)..... 56

Capítulo 3

Figure 1. Relationship between artificial material richness and gray area (ha) in a) 100 m radius circular plot, b) 200 m ring c) 400 m ring and d) 400 m radius circular plot. Each point represents one clay-colored thrush's nest..... 79

Figure 2. Artificial material richness mean (\pm EE) in nests of clay-colored thrush by urbanization level. Rural and suburban differs from urban level. Letters indicate differences among groups for urbanization level (Tuckey test)..... 80

Figure 3. Clay-colored thrush's nests with artificial materials. Downer photos show artificial materials in upper nests' structure (Cam= nest camera, Par= Nest walls)..... 81



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INTRODUCCIÓN GENERAL

El crecimiento de la población humana y sus actividades asociadas producen consecuencias directas o indirectas sobre casi cualquier ecosistema del planeta (Liu 2001). El desarrollo urbano asociado al crecimiento poblacional, es un agente modificador del paisaje natural que genera cambios en la dinámica de los ecosistemas donde sucede y en zonas con conexión directa o indirecta a estas (Clergeau et al. 2001). Debido a las consecuencias del aumento del área urbanizada durante los últimos años, nuevas interacciones entre animales y ecosistemas urbanos han empezado a ser descritas, principalmente en grupos como artrópodos, mamíferos y aves (Rizali et al. 2008, Gedeon et al. 2010, Rousseau et al. 2015).

La gran modificación del paisaje en las zonas urbanas actuales, produjo que los espacios urbanos llegaron a ser zonas únicamente habitadas por un reducido número de especies habituadas a convivir con humanos (Ditchkoff et al. 2006). Sin embargo, estas áreas están siendo aprovechadas por un mayor número de especies de lo esperado, las cuales estaban asociadas con bordes de bosque o áreas rurales (Ditchkoff et al. 2006). Aquellos individuos que se establecen en sitios urbanos parecen desarrollar la capacidad de explotar los nuevos recursos de origen antropogénico (ej., alimento o materiales sintéticos para la construcción de nidos o madrigueras) que el ecosistema urbano les ofrece (McKinney 2002, Audet et al. 2015).

El efecto producido por el desarrollo urbano sobre las comunidades de aves es variado (Kuranov 2009, Jackson et al. 2013). Por ejemplo, con la expansión del área urbanizada hacia zonas naturales, la riqueza de especies de las áreas afectadas y zonas cercanas ha disminuido (Gagné et al. 2016). Además, se han descrito cambios en el comportamiento de las especies, por ejemplo habituación a la presencia de humanos (Cavalli et al. 2016) o aprovechamiento de recursos antropogénicos como alimento y materiales para la construcción de nidos (Máthé & Batáry 2015, Biddle et al. 2016).

El uso de materiales artificiales en la construcción de nidos ha sido el foco de estudio de algunas investigaciones relacionadas con aves que viven en o cerca de ambientes urbanos (Kuranov 2009, Surgey et al. 2012). En algunas especies de aves, el uso de materiales artificiales en la construcción de sus nidos es común (Doerr 2010, Sergio et al. 2011), sin embargo poco se conoce sobre los posibles efectos de la incorporación de estos materiales en el éxito reproductivo de las especies. Algunas investigaciones se han enfocado en describir el uso de materiales artificiales en nidos de aves que anidan cerca de la costa, materiales que se han acumulado en zonas costeras por efecto de las actividades humanas (Hartwig et al. 2007, Votier et al. 2011, Buxton et al. 2013). Por ejemplo, en la gaviota *Rissa tridactyla* (Laridae), se encontró un aumento en la proporción de nidos con material artificial a través del tiempo, situación posiblemente relacionada con el aumento de basura plástica en las costas donde se realizó la investigación (Hartwig et al. 2007). En un estudio realizado en varias especies de la familia Procellariidae (*Pterodroma macroptera*, *Puffinus carneipes*, *Puffinus gavia*, *Puffinus assimilis*, *Pterodroma pycrofti*, *Puffinus griseus*), las cuales anidan en acantilados cerca de la costa, se documentó la presencia de fragmentos de plástico en los nidos. En este caso, los autores también describen una posible relación positiva entre la cantidad de plástico en la zona y el uso de este material en los nidos (Buxton et al. 2013).

Las consecuencias del uso de material plástico en aves han descritas poco descritas en la literatura. Sin embargo, un estudio en el alcatraz común *Morus bassanus* (Sulidae) reporta una potencial asociación entre el uso de material plástico en nidos y muerte de individuos principalmente por enredo de cuerdas plásticas alrededor del cuello (Votier et al. 2011). El uso de material plástico podría comportarse como un agente de selección ya que aunque algunos individuos llegan a morir por problemas en la manipulación del material, si la mayor cantidad de individuos que lo utilizan no tienen consecuencias negativas se volverían más exitosos y por ende se fijaría el comportamiento. Además, los investigadores demuestran un uso frecuente de cuerdas sintéticas, posiblemente debido a que la mayor parte del material plástico encontrado en el sitio de estudio presenta esta forma. Esta situación

concuerta con otros estudios en donde también se demuestra la utilización de este tipo de material sintético en nidos de aves playeras (Hartwig et al. 2007, Buxton et al. 2013).

En zonas agrícolas, en un estudio realizado con nidos del alcaudón real *Lanius excubitor* (Laniidae), se encontró un alto uso de material plástico blanco en la construcción de sus nidos (294 nidos de un total de 317 estudiados) (Antczak et al. 2010). Los investigadores describen un aumento en el uso del material a través del tiempo, posiblemente relacionado con un aumento en el uso de fibras plásticas en el mismo periodo, en actividades agrícolas. También relacionado con la disponibilidad del material en el medio, se encontró que el uso de material artificial en la construcción de nidos del bulbul chino *Pycnonotus sinensis* (Pycnonotidae), está relacionado con la disponibilidad de los mismos en el ambiente, lo que a su vez podría estar relacionado con el grado de alteración del sitio, ya que en sitios más alterados el material artificial es más abundante (Wang et al. 2009). Con esto se logró demostrar que esta especie es capaz de ajustar el uso de estos materiales a la mayor disponibilidad dada por el grado de urbanización.

Hasta ahora los datos de las investigaciones parecen demostrar que el uso de materiales artificiales podría ser una característica sólo de algunas especies, las cuales podrían coexistir en espacios alterados con especies que no utilicen del todo este tipo de material (obs. pers). En Inglaterra, en cuatro especies de aves de la familia Paridae (*Parus major*, *Periparus ater*, *Poecile palustris* y *Cyanistes caeruleus*) se estudió la utilización de materiales artificiales para construir nidos y se encontró que el uso de este material varió entre especies (Surgey et al. 2012). Por ejemplo, *P. major* incorpora materiales artificiales en más nidos que las otras especies y que *P. palustris* utiliza en baja frecuencia el material. Las especies estudiadas podrían estar incorporando el material por composición y forma, ya que no se encontró preferencia por algún color. Se comprobó que en la mayoría de los casos la utilización del material artificial está relacionada con la cercanía de este al sitio de percha del nido. Para estas especies, el uso del material artificial parece ser oportunista, ya que un cuarto de los nidos estudiados lo tenían.

Pocos trabajos describen las consecuencias del uso de material artificial sobre el éxito reproductivo de las especies que incorporan estos a sus nidos. Sin embargo, algunos estudios ofrecen evidencia que sugiere algunas potenciales consecuencias de este comportamiento. Por ejemplo en *L. excubitor* el uso del material plástico en los nidos podría brindar protección adicional a los huevos contra las condiciones atmosféricas adversas, ya que esta especie anida al inicio de la primavera cuando las temperaturas aún podrían ser bajas (Antczak et al. 2010). Además, se sugiere que el material artificial es más fácil de manipular que aquellos de origen natural con similar forma y tamaño, lo que sumado al aumento en la abundancia de este recurso supone un menor gasto energético en la búsqueda y manipulación de material para la construcción del nido (Antczak et al. 2010). Sin embargo, la evidencia directa para probar estas hipótesis es escasa y se requiere más investigación.

El uso de material artificial se ha reportado en un grupo pequeño de especies poco relacionadas filogenéticamente (Sergio et al. 2011, Doerr & Endler 2015). El uso de material artificial parece ser una cualidad facultativa para las especies que han podido aprovechar estos recursos, ya que como se ha demostrado en varios grupos, la utilización de este material depende de la cercanía, disponibilidad y el tipo de material en el ambiente donde se lleva a cabo la construcción del nido (Townsend & Barker 2014). Sin embargo, las consecuencias del uso de materiales artificiales en aves aún son poco claras y sólo para algunas especies que los incorporan en sus nidos, se ofrece evidencia indirecta de potenciales consecuencias positivas, negativas o neutras (Antczak et al. 2010, Votier et al. 2011).

En aves constructoras de nidos, el éxito reproductivo está estrechamente relacionado con las características de la estructura y de los materiales con los que se lleva a cabo la construcción del nido (Gładalski et al. 2016). El uso de materiales artificiales en la construcción del nido de aquellas especies que lo utilizan, podría estar relacionado con variables poco estudiadas hasta ahora como el riesgo de depredación y la termorregulación de la estructura. En sitios urbanos, la depredación de nidos es una de las presiones selectivas más influyentes sobre el éxito reproductivo de las aves (Jokimäki & Huhta 2000, Borgmann & Rodewald 2004, Lima 2009). La incorporación de materiales artificiales podría tener

consecuencias sobre la detectabilidad de la estructura, lo que a su vez podría influenciar el riesgo de depredación de los nidos.

Con respecto a la termorregulación, se ha probado que las propiedades térmicas y la ubicación de los materiales tienen un rol determinante en la retención de calor de los nidos, aún cuando únicamente se incorporen materiales naturales (Hilton et al. 2004). Esto sugiere una potencial presión en la selección de los materiales y una posible influencia sobre el éxito reproductivo relacionado con los materiales que se incorporen en la estructura. Con respecto a materiales artificiales, por ejemplo el polietileno (material común en la fabricación de plásticos) presenta mayor retención de calor que materiales de origen natural (Gaur & Wunderlich 1981), sugiriendo que su incorporación en nidos podría tener algún efecto sobre las características térmicas de la estructura. Este polímero es común en nidos de aves que incorporan material artificial (obs. pers.).

Entender las implicaciones de la incorporación de materiales artificiales en la construcción de nidos de aves, ayudará a dilucidar cómo ese comportamiento podría influir en el estado de las poblaciones de las especies de aves que lo hacen. Además, brindará información sobre los procesos adaptativos de especies de aves que logran ajustarse a las transformaciones del ambiente hecha por los humanos. Por todo esto, con la presente investigación de tesis identifiqué posibles consecuencias del uso de materiales artificiales en la construcción de nidos, sobre el éxito reproductivo del yigüirro (*Turdus grayi*: Turdidae). El yigüirro, es una de esas especies que han logrado adaptarse a estas transformaciones. Esta ave tiene una distribución amplia en el país, que va desde zonas urbanas y suburbanas hasta bordes de bosque y bosques de poca edad (Stiles & Skutch 1989). El yigüirro incorpora una amplia gama de materiales en la construcción de sus nidos como alambres de cobre, filtros de cigarrillos y cuerdas de nylon. (obs. pers.), sin embargo las consecuencias de esto no han sido descritas aún.

El objetivo general de esta investigación es determinar si el uso de materiales artificiales en la construcción de nidos afecta el éxito reproductivo de los nidos de las aves.

Los objetivos específicos de esta investigación son: (1) Determinar si el uso de materiales artificiales afecta la termorregulación de los nidos de *T. grayi*. Es conocido que el tipo de material usado para la construcción del nido, influye en la tasa de enfriamiento de los huevos dentro de la estructura (Hilton et al. 2004). Por esto, la incorporación de material artificial podría influir en la termorregulación de la estructura. Es posible que la incorporación de material artificial provoque mayor porosidad en los nidos, causando que estos pierdan calor más rápidamente (Rohwer & Law 2010). Sin embargo, otros materiales podrían disminuir la pérdida de calor cuando se compara con materiales naturales, por lo que la tasa de pérdida de calor podría estar relacionada con el tipo y la cantidad de material artificial utilizado en la construcción (Gaur & Wunderlich 1981). (2) Determinar si la incorporación de materiales artificiales en el nido, influye sobre la depredación de los huevos por depredadores visuales. Para depredadores visuales con una imagen de búsqueda basada en nidos, espero que la incorporación de material artificial influya sobre la tasa de depredación de las estructuras. Es posible que la incorporación de material artificial, rompa la imagen de búsqueda de los depredadores visuales y estos ataquen en menor medida aquellos nidos que incorporen este tipo de materiales. Sin embargo, es posible que la incorporación de material artificial en el nido, haga a la estructura más contrastante con su entorno, aumentando la detectabilidad y la tasa de depredación de estos. (3) Determinar si el nivel de urbanización de la localidad donde el nido fue construido se correlaciona con la cantidad y diversidad de materiales artificiales que incorporan los yigüirros al nido. Debido a que sitios urbanizados presentan una mayor cantidad de residuos sólidos sin coleccionar (Programa Estado de la Nación 2018), mi predicción es que nidos provenientes de sitios con mayor nivel de urbanización, presenten mayor cantidad y diversidad de materiales artificiales.

REFERENCIAS

- Antczak, M, M Hromada, P Czechowski, J Tabor, P Zablocki, J Grzybek & P Tryjanowski (2010) A new material for old solutions-the case of plastic string used in Great Grey Shrike nests. *Acta Ethologica* 13: 87–91.
- Audet, J-N, S Ducatez & L Lefebvre (2015) The town bird and the country bird: problem solving and immunocompetence vary with urbanization. *Behavioral Ecology* 27: 637–644.
- Biddle, LE, AM Goodman & DC Deeming (2016) Geographical effects on the mass and dimensions of finch (Fringillidae, Passeriformes) and thrush (Turdidae, Passeriformes) nests. *Avian Biology Research* 9: 13–21.
- Borgmann, KL & AD Rodewald (2004) Nest predation in an urbanizing landscape: The role of exotic shrubs. *Ecological Applications* 14: 1757–1765.
- Buxton, RT, CA Currey, POB Lyver & CJ Jones (2013) Incidence of plastic fragments among burrow-nesting seabird colonies on offshore islands in northern New Zealand. *Marine Pollution Bulletin* 74: 420–424.
- Cavalli, M, A V. Baladrón, JP Isacch, LM Biondi & MS Bó (2016) Differential risk perception of rural and urban Burrowing Owls exposed to humans and dogs. *Behavioural Processes* 124: 60–65.
- Clergeau, P, J Jukimaki & J-PL Savard (2001) Are urban bird communities influenced by the bird diversity of adjacent landscapes ? *Journal of Applied Ecology* 38: 1122–1134.
- Ditchkoff, SS, ST Saalfeld & CJ Gibson (2006) Animal behavior in urban ecosystems: Modifications due to human-induced stress. *Urban Ecosystems* 9: 5–12.
- Doerr, NR (2010) Does decoration theft lead to an honest relationship between male quality and signal size in great bowerbirds? *Animal Behaviour* 79: 747–755.
- Doerr, NR & JA Endler (2015) Illusions vary because of the types of decorations at bowers,

not male skill at arranging them, in great bowerbirds. *Animal Behaviour* 99: 73–82.

- Gagné, SA, PJ Sherman, KK Singh & RK Meentemeyer (2016) The effect of human population size on the breeding bird diversity of urban regions. *Biodiversity and Conservation* 25: 653–671.
- Gaur, U & B Wunderlich (1981) Heat capacity and other thermodynamic properties of linear macromolecules. II. Polyethylene. *Journal of Physical and Chemical Reference Data* 10: 119–152.
- Gedeon, CI, G Markó, I Németh, V Nyitrai & V Altbäcker (2010) Nest material selection affects nest insulation quality for the European ground squirrel (*Spermophilus citellus*). *Journal of Mammalogy* 91: 636–641.
- Gładalski, M, M Bańbura, A Kaliński, M Markowski, J Skwarska, J Wawrzyniak, P Zieliński, I Cyżewska & J Bańbura (2016) Effects of nest characteristics on reproductive performance in Blue Tits *Cyanistes caeruleus* and Great Tits *Parus major*. *Avian Biology Research* 9: 37–43.
- Hartwig, E, T Clemens & M Heckroth (2007) Plastic debris as nesting material in a Kittiwake (*Rissa tridactyla*) colony at the Jammerbugt, Northwest Denmark. *Marine Pollution Bulletin* 54: 595–597.
- Hilton, GM, MiH Hansell, GD Ruxton, JM Reid & P Monaghan (2004) Using artificial nests to test importance of nesting material and nest shelter for incubation energetics. *The Auk* 121: 777–787.
- Jackson, AK, JP Froneberger & DA Cristol (2013) Habitat near nest boxes correlated with fate of eastern bluebird fledglings in an urban landscape. *Urban Ecosystems* 16: 367–376.
- Jokimäki, J & E Huhta (2000) Artificial nest predation and abundance of birds along an urban gradient. *Condor* 102: 838–847.

- Kuranov, BD (2009) Nest biology of urban populations of cavity-nesting birds. *Contemporary Problems of Ecology* 2: 240–247.
- Lima, SL (2009) Predators and the breeding bird: Behavioral and reproductive flexibility under the risk of predation. *Biological Reviews* 84: 485–513.
- Liu, J (2001) Integrating ecology with human demography, behavior, and socioeconomics: Needs and approaches. *Ecological Modelling* 140: 1–8.
- Máthé, O & P Batáry (2015) Insectivorous and open-cup nester bird species suffer the most from urbanization. *Bird Study* 62: 78–86.
- McKinney, ML (2002) Urbanization, biodiversity, and conservation. *BioScience* 52: 883–890.
- Programa Estado de la Nacion (2018) Estado de la Nación en Desarrollo Humano Sostenible. Pavas, Costa Rica.
- Rizali, A, MM Bos, D Buchori, S Yamane & CH Schulze (2008) Ants in tropical urban habitats: the myrmecofauna in a densely populated area of bogor, West Java, Indonesia. *Journal of Biosciences* 15: 77–84.
- Rohwer, VG & JSY Law (2010) Geographic variation in nests of yellow warblers breeding in Churchill, Manitoba, and Elgin, Ontario. *Condor* 112: 596–604.
- Rousseau, JS, JPL Savard & R Titman (2015) Shrub-nesting birds in urban habitats: their abundance and association with vegetation. *Urban Ecosystems* 18: 871–884.
- Sergio, F, J Blas, G Blanco, A Tanferna, L López, JA Lemus & F Hiraldo (2011) Raptor nest decorations are a reliable threat against conspecifics. *Science* 331: 327–330.
- Stiles, FG & AF Skutch (1989) Guía de aves de Costa Rica. Editorial INBio, Santo Domingo, Heredia.
- Surgey, J, CR Feu, DC Deeming, ST Condor & N May (2012) Opportunistic use of a wool-

- like artificial material as lining of tit (Paridae) nests. *The Condor* 114: 385–392.
- Townsend, AK & CM Barker (2014) Plastic and the nest entanglement of urban and agricultural crows. *PLoS ONE* 9: 1–5.
- Votier, SC, K Archibald, G Morgan & L Morgan (2011) The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Marine Pollution Bulletin* 62: 168–172.
- Wang, Y, S Chen, RB Blair, P Jiang & P Ding (2009) Nest composition adjustments by Chinese bulbuls *Pycnonotus sinensis* in an urbanized landscape of Hangzhou (E China). *Acta Ornithologica* 44: 185–192.

CAPÍTULO 1

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Human waste used as nesting material affects thermoregulation in birds

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ABSTRACT

Bird nests are constructed to minimize the negative effects of some parasites and predators, and to maintain an appropriate microclimate for eggs and chicks development. The internal microclimate of nests largely depends on the materials used in their construction; as different material have varying influences on the temperature inside the nest camera and the isolation of nest walls. In urban environments, the availability of natural materials for nest building decreases, and the availability of artificial materials increases. Artificial materials are used by birds that nest within or close to cities, and those materials may have consequences in adults and nestlings, such as increasing mortality in adults by entanglement with plastic strings or nestlings by plastic ingestion. However there is much information that we do not yet know on nest thermal consequences about artificial materials used in nesting. In this work we conducted an experiment to measure the effect of artificial materials included as part of nest structure, in nest thermoregulation. We measured the cooling of nests of the clay-colored thrush (*Turdus grayi*) with different mass of artificial materials used by birds to construct their nest walls. We determined that the nest cooling is

affected by artificial materials mass only when females are incubating. We specifically found that when the mass of artificial materials increases, nest cooling also increase. Artificial materials possibly reduce nest compactness and heat retention when compared with natural materials. We provide evidence that artificial materials increase the cooling effect in bird nesting, though the consequences of bird reproduction are yet unknown.

KEY WORDS: nest cooling, nest porosity, urbanization, urban nesting, artificial materials consequence

The rapid increase in human population has caused the replacement of agricultural and natural ecosystems by urban areas to provide home and work for people (Gomes et al., 2019; Montoya-Tangarife et al., 2017). Urbanization produces the reduction, modification, and fragmentation of natural habitats within or close to cities due to the fast expansion of urban landscapes (McKinney, 2006; Wu et al., 2011). This results in the loss of natural elements, which are commonly replaced by artificial structures and different man-made materials (Kaza et al., 2018). These modifications on natural ecosystems result in the drastic reduction of population of many native species of arthropods (Lagucki et al., 2017), reptiles (Andrade, 2019), amphibians (Hamer and McDonnell, 2008), mammals (Villaseñor et al., 2014), and birds (Hensley et al., 2019) due to the reduction in food sources, freshwater, or nesting resources (Beninde et al., 2015).

Some bird species that have colonized urban habitats use new resources available in urbanized ecosystems to feed or to build their nests (Katlam et al., 2018; Suárez-Rodríguez et al., 2017). For example, the rufous-tailed hummingbird (*Amazilia tzacatl*) and the rufous-collared sparrow (*Zonotrichia capensis*) respectively use feeders with sugar water or seeds and invest less energy in food searching (Reynolds et al., 2017); similarly, the large-billed crow (*Corvus macrorhynchos*) use discarded human solid food to feed (Katlam et al., 2018). Many urban species use artificial materials available in urban ecosystems to build their nests. This is the case of the great grey shrike (*Lanius excubitor*) that uses plastic

material to construct the nests in agricultural landscapes in Poland (Antczak et al., 2010). Other species, such as the Chinese bulbuls (*Pycnonotus sinensis*) use different proportions of artificial materials in cities where natural materials are scarce; they afterwards use more artificial materials than in rural areas (Wang et al., 2009).

The selection of nest materials could have consequences on bird reproduction success (Charmantier et al., 2008; Mainwaring et al., 2016). Nest materials may reduce the negative effects of parasites, and create an appropriate microclimate for eggs and chicks development (Mainwaring et al., 2014). For example, house finches (*Haemorhous mexicanus*) use cigarette butts as part of the nest structure, which reduce parasites inside the nest camera, and improving the breeding success (Suárez-Rodríguez et al., 2013), but it is also known that the same cigarette butts have a potential genotoxic effect (Suárez-Rodríguez and García, 2014). Negative effects of using artificial materials are known for several species. For instance, chicks and adults of the American crow (*Corvus brachyrhynchos*) have died entangled in plastic fragments and strings used in their nest construction (Townsend and Barker, 2014).

Nest temperature is determinant in its success because there is a small range of temperatures with optimal conditions for embryo development, and small changes in incubation temperature could lead to negative consequences in chicks development (DuRant et al., 2013; Ospina et al., 2018). Since thermal properties of the nest are influenced by materials therein (Gedeon et al., 2010), and many urban dwellers use artificial materials for nest construction, it is expected that thermal properties of nests in those birds are changing with growing urbanization. However, to our best knowledge, the consequences of using artificial materials for nest construction on the thermal properties of nests are unknown. In this context, the objective of this study is to examine how the use of artificial materials affects the thermal properties of nests of the clay-colored thrush (*Turdus grayi*). This species is a common habitant of urban and rural habitats and normally uses natural material for nest building, in altered habitats it often uses a variable amount of artificial materials. Such flexibility in the use of alternative material in their nest makes the

clay-colored thrush an ideal model to understand the thermal consequences of the reduction of natural materials for nest construction. Considering that natural materials used in nest construction influence heat retention (Hilton et al., 2004), we expect that the incorporation of plastic material increase heat retention since it is well known that plastics retain more heat than natural materials (Gaur and Wunderlich, 1981).

MATERIAL AND METHODS

Nest measurements

We used 46 clay-colored thrush nests collected and deposited at Museo de Zoología, Universidad de Costa Rica (MZUCR) between 2012-2018. All nests were collected within a narrow range of elevation (mean [SD] = 1020 [318] m a. s. l.). In each nest we measured the following eight dimensions: (1) nest length (nest longest distance), (2) nest width (perpendicular to nest length), (3) camera length (camera longest distance), (4) camera width (perpendicular to camera length), (5) nest height (distance from the top to bottom of the nest), (6) camera height (height from camera to nest top), (7) nest base depth (distance from the camera to nest base), and (8) nest wall thickness (mean thickness of four cross points between nest camera and nest outer layer). All measurements were collected in mm (± 0.1 mm). Additionally, we quantified the mass of three types of material used by birds to build their nests, by destroying the nest and separating each material (Fig. 1). The materials were classified in artificial materials (e.g. plastic, synthetic cotton, metal), natural materials (e.g. dry roots, twigs, hair), and adobe (the mixture of mud and natural materials as dry leaves, twigs, or hair) (Fig. 1).

Nest cooling measures

We conducted an experiment in a climate controlled room (20°C and 30% environmental humidity). We used 20°C as our baseline temperature because is close to the mean temperature in the collecting sites. In each trial, we used the same three common

quail (*Coturnix coturnix*) eggs filled with high temperature silicone (Loctite®) to emulate a mean clutch size of the study species. We selected this silicone type to avoid heat retention and egg deformations when heating. We measured temperature inside the nest camera using an iButton® data logger (Embedded Data Systems, Mod DS1921H-F5#), placed in the middle of the camera. We heated both eggs and nests from 20°C until they reach 40°C (± 0.1) using a 250 W light bulb. We choose 40°C because this is the highest temperature reported for passerine incubation (DuRant et al., 2013). After heating the nest, we let the nest and eggs cool for 10 min, because it is an expected time that nest remains unattended (Sánchez et al., 2018). We conducted two trials per nest, one only with eggs to simulate when incubating female leaves the nest for self-maintenance activities and another trial with the eggs and a cotton ball covering all nest camera to simulate the effect of a female incubating. During all the experiment, eggs and nests were always stored in the climate controlled room. We used the same 20 g cotton ball for all nests to avoid differences in nest cooling resulted from the cotton, and the size of the nest camera was similar in all nests (length: 92.12 [7.92] mm, width: 83.6 [9.08] mm), so the cotton ball fit well in all nests. To estimate nest cooling, we calculated the slope of the regression line between the nest temperature and the time after heating during 10 min.

Statistical analysis

For the nest measurements, we conducted two principal component analyses, one for external dimensions of the nest and another for internal dimensions to combine measures into two multivariate response variables, using varimax rotation on the correlation matrix in each case. In the analysis conducted for external dimensions (nest length, width, height, and base depth), the first two components had eigenvalues greater than 1.0, and together explained 80.2% of the variance of the four original variables. The first component explained 42.3% of the variance and showed a positive correlation with nest length ($r = 0.59$; we present here correlation coefficients between factor 1 and the raw variables) and nest width ($r = 0.68$), but a weak negative correlation with nest height ($r = -0.35$) and nest base depth ($r = -0.24$). We named this first rotated component "nest area" (ePC1), since

nests that received a high score had a higher nest area. The second rotated component explained 37.9% of the variance and showed a strong positive correlation with nest height ($r = 0.60$) and nest base depth ($r = 0.66$), but a weak positive correlation with nest length ($r = 0.40$) and nest width ($r = 0.19$). We, therefore, named this variable "nest height" (ePC2), since nests that received a high score for this second principal component were more height.

In the analysis conducted with internal dimensions (camera length, width, height, and nest wall thickness), the first two components had eigenvalues greater than 1.0, and together explained 72.3% of the variance in the original four dimensional variables. The first component explained 47.1% of the variance and showed a positive correlation with camera length ($r = 0.53$), camera width ($r = 0.60$) and a negative correlation with nest wall thickness ($r = -0.53$), but a weak positive correlation with camera height ($r = 0.27$). We named this first component "camera area" (iPC1), therefore nests that received a high score had a higher camera area and a lower wall thickness. The second component explained 25.2% of the variance and showed a positive correlation with camera height ($r = 0.89$), but a weak negative positive correlation with camera length ($r = -0.40$), camera width ($r = 0.11$) and nest walls thickness ($r = 0.18$). We, therefore, named this variable "camera height"(iPC2), since nests with high scores for this second principal component had higher cameras.

We conducted several General Linear Models (GLMs) with a Gaussian error distribution, to its second order interactions; to test the effect of the mass of artificial materials, adobe and natural materials, as well as the principal components of nest dimensions, on the slope of nest cooling, either with the simulation of the female presence and without the female in the nest. Because residuals deviated from Gaussian distribution, the dependent variable was transformed with square root in data set that simulated female presence. After all GLM analyses, we used the Akaike information criterion to select the best set of models that explain better the nest cooling, and the best models were the ones

with the lowest ΔAICc value (Burnham and Anderson, 2002; Richards, 2005). We used R statistical language version 3.6.0 (R Core Team, 2019) for all statistical analyses.

RESULTS

The nests included in this study had 27 different types of artificial materials. From the 46 nests analyzed, 33 had sewing threads, 25 plastic broom fibers, and 25 polyester cotton as the most common artificial materials (Table 1). All nests had artificial materials (Table 1), and artificial materials mass varies between 0.1 g and 17.5 g (mean = 2.3 g), and the percentage of the mass of artificial materials to the total nest mass varied between 0 and 30.8% (Fig. 1).

In trials with nests that included only eggs (without the cotton ball) the mass of adobe influenced nest cooling (Table 2). When adobe mass increased, nest cooling decreased so nest lost heat slower ($t = 2.07$, $p = 0.04$; Fig. 2). In those trials with nests that included eggs and simulated females (cotton ball) artificial materials mass, adobe mass, natural mass, camera area (iPC1) and base depth (iPC2) influenced nest cooling (Table 3). We decided to use the models that have artificial materials mass separated from the one with the internal principal components because of AIC values differences from first ranked model are less than 2, and the reduced number of parameters (k) in both cases. When artificial materials mass increase, nest cooling also increase so nest got cold faster ($t = -2.2$, $p = 0.03$, Fig. 3). Nest with a bigger camera area cooled more slowly than nests with a smaller camera area ($t = 2.28$, $p = 0.03$; Fig. 3). Although camera depth ($t = 1.66$, $p = 0.1$), natural mass ($t = -0.84$, $p = 0.41$) and adobe mass ($t = -0.89$, $p = 0.41$) were included in models with lower AIC values, those relations were not significant.

DISCUSSION

Our study showed that clay-colored thrushes use a wide range of artificial materials to build their nests. The artificial materials most frequently used for nest building were sewing threads, plastic broom fibers, and plastic cotton, which are thrown to ground by people during daily activities. The plastic is a very common trash of human activities (Hartwig et al., 2007; Katlam et al., 2018; Kaza et al., 2018) and also a common material used for nest building by several birds species around the world (Antczak et al., 2010; Townsend and Barker, 2014; Wang et al., 2009; Witteveen et al., 2017). This type of material may have negative consequences in nestlings or adults produced by ingestion, entanglement, or modification of nest microenvironment, reducing individuals reproductive success (Jagiello et al., 2018; Mee et al., 2007). For example, in the California condor (*Gymnogyps californianus*) ingestion of plastic junk was the primary cause of nestlings mortality after ingestion (Mee et al., 2007). In the kelp gull (*Larus dominicanus*) adults and chicks die as they entangled in fishing lines (Witteveen et al., 2017). Additionally, the nest microenvironment (the chemical and physical conditions inside nest camera), could be altered by plastic materials, which may reduce the occurrence of natural substances that modulate bacteria and parasite populations inside nests (Ruiz-Castellano et al., 2016). For example, fresh plant materials in nests are associated with a reduction of parasites and bacteria abundance (Dubiec et al., 2013), then if plastics replace vegetal material, it is possible that parasites and bacterial population increases, reducing nestling survival (Cantarero et al., 2013).

We found that artificial materials mass increased nest cooling, but only when the simulated female is incubating the nest. Artificial materials have different physical characteristics from those of natural materials used for nest building (Mikulčić et al., 2019), because density is higher in certain artificial materials (e.g. metal nails and glass) than in natural materials (e.g. wood twigs and roots; Pandita et al. 2014; Yang and Li 2012), and this condition makes this type of artificial materials less flexible and harder to manipulate for nest construction. Conversely, other artificial materials (e.g. sewing threads and plastic cotton) that are less dense than natural materials (e.g. small roots and leaves; Jhanji et al.,

2015), may reduce the thermal isolation of the nest because of the additional space in material's structure, compare to natural materials. Incorporation of artificial materials with those characteristics, as we found in nests of clay-colored thrushes nests, may reduce compactness and produce additional porosity in nests walls, decreasing camera isolation due to the heat dissipation through nest wall orifices, with the result that nest get cold faster (Deeming and Biddle, 2015).

The use of artificial materials in nesting may have negative consequences in adult females and their offspring. Females may need to increase incubation effort to maintain an optimal range of temperature for embryo development (DuRant et al., 2013), causing for example, an increase of its metabolic rate to produce more heat and maintain eggs in optimal development temperature (Cresswell et al., 2004; Vleck, 1981). Another possibility is that females invest more time in incubation and less time in self-maintenance activities (e.g. feeding), causing negative health consequences over adults (Williams, 2015). Moreover, if the offspring development occurs at suboptimal temperatures, nestlings could exhibit a reduction in its body size and survival, as found in the American robin (*Turdus migratorius*; Ospina et al., 2018).

Artificial materials did not influence nest temperature during the simulated female absence. During time that females leave their nests unattended, nest cooling is expected to mainly depends on the difference between the nest and the environmental temperature, as described for the Carolina chickadees (*Poecile carolinensis*; Walters et al., 2016). This situation reduces the effect of nest walls for nest isolation during female absence, because heat dissipate through the open nest camera, and potential nest walls porosity caused by artificial materials is not an important factor for heat dissipation in this context. In the absence of incubating females, nest walls have little influence in nest isolation, and the isolation is provided mainly by the base of the nest, as described for the common blackbird (*Turdus merula*) and the song thrush (*Turdus philomelos*) (Biddle et al., 2018). Nest walls provide a slight effect in thermal dynamics of the nest during female absence, at least in the

described thrush species, and that explains our results because the presence of artificial materials is not an important factor for nest cooling during a female absence.

In the clay-colored thrush, the adobe was thought to be a structural component of nests (Skutch, 1960), however, we found that also adobe increases nest isolation in the absence of the female. A greater mass of adobe, decrease the cooling rate of nests, because the adobe increases heat retention in the nest (Hilton et al., 2004). This pattern has been reported also for the rufous hornero (*Furnarius rufus*), a species that build nests only with adobe (Shibuya et al., 2015). Probably the adobe, that is a material used for several bird species in nest building (e.g. the common blackbird, the song thrush, and the barn swallow *Hirundo rustica*), is selected to increase the nest isolation more than a pure structural material, but this assumption needs to be tested to contrast both functions.

We also found that nest dimensions affect nest cooling rate, because wider, and longer nest cameras had a lower cooling, but only when a female was incubating. Nest dimensions play an important role in nest thermal characteristics because wider cameras provide better isolation for nest temperature, as found in birds (Crossman et al., 2011) and some rodent species (Lynch, 1980; Muul, 1974; Shump, 1978). For example, the American robin and the prairie warbler (*Setophaga discolor*) built wider and larger cameras in colder habitats because they retain heat better than smaller nests (Crossman et al., 2011; Rohwer and Law, 2010).

Humans activities have profound impacts for wildlife that inhabits inside or nearby to human settlements. In this study, we showed a consequence of human induced reduction and modification of original ecosystems because these changes are driving urban birds to use artificial materials instead of less available natural material (Reynolds et al., 2019). The inclusion of anthropogenic materials, such as plastic, in nest structure, affects the nest isolation because a greater mass of artificial materials produces a faster cooling and this may have negative consequences in urban birds' reproduction, but this need to be tested.

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References

- Andrade, A. C.** (2019). Metropolitan lizards? Urbanization gradient and the density of lagartixas (*Tropidurus hispidus*) in a tropical city. *Ecol. Evol.* **10**, 1–11.
- Antczak, M., Hromada, M., Czechowski, P., Tabor, J., Zablocki, P., Grzybek, J. and Tryjanowski, P.** (2010). A new material for old solutions-the case of plastic string used in Great Grey Shrike nests. *Acta Ethol.* **13**, 87–91.
- Beninde, J., Veith, M. and Hochkirch, A.** (2015). Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecol. Lett.* **18**, 581–592.
- Biddle, L. E., Goodman, A. M. and Deeming, D. C.** (2018). Infrared thermography provides insight into the thermal properties of bird nests. *J. Therm. Biol.* **76**, 95–100.
- Burnham, K. P. and Anderson, D. R.** (2002). *Model Selection and Inference: A Practical Information-theoretic Approach*. 2nd ed. New York: Springer-Verlag.
- Cantarero, A., López-Arrabé, J., Rodríguez-García, V., González-Braojos, S., Ruiz-De-Castañeda, R., Redondo, A. J. and Moreno, J.** (2013). Factors affecting the presence and abundance of generalist ectoparasites in nests of three sympatric hole-nesting bird species. *Acta Ornithol.* **48**, 39–54.
- Charmantier, A., McCleery, R. H., Cole, L. R., Perrins, C., Kruuk, L. E. B. and Sheldon, B. C.** (2008). Adaptive phenotypic plasticity in response to climate change in a wild bird population. *Science.* **320**, 800–803.
- Cresswell, W., Holt, S., Reid, J. M., Whitfield, D. P., Mellanby, R. J., Norton, D. and Waldron, S.** (2004). The energetic costs of egg heating constrain incubation attendance but do not determine daily energy expenditure in the pectoral sandpiper. *Behav. Ecol.* **15**, 498–507.

- Crossman, C. A., Rohwer, V. G. and Martin, P. R.** (2011). Variation in the structure of bird nests between northern Manitoba and Southeastern Ontario. *PLoS One* **6**, e19086.
- Deeming, D. C. and Biddle, L. E.** (2015). Thermal properties of bird nests depend on air-gaps between the materials. *Acta Ornithol.* **50**, 121–125.
- Dubiec, A., Gózdź, I. and Mazgajski, T. D.** (2013). Green plant material in avian nests. *Avian Biol. Res.* **6**, 133–146.
- DuRant, S. E., Hopkins, W. A., Hepp, G. R. and Walters, J. R.** (2013). Ecological, evolutionary, and conservation implications of incubation temperature-dependent phenotypes in birds. *Biol. Rev.* **88**, 499–509.
- Gaur, U. and Wunderlich, B.** (1981). Heat capacity and other thermodynamic properties of linear macromolecules. II. Polyethylene. *J. Physiscal Chem. Ref. Data* **10**, 119–152.
- Gedeon, C. I., Markó, G., Németh, I., Nyitrai, V. and Altbäcker, V.** (2010). Nest material selection affects nest insulation quality for the European ground squirrel (*Spermophilus citellus*). *J. Mammal.* **91**, 636–641.
- Gomes, E., Abrantes, P., Banos, A., Rocha, J. and Buxton, M.** (2019). Farming under urban pressure: Farmers' land use and land cover change intentions. *Appl. Geogr.* **102**, 58–70.
- Hamer, A. J. and McDonnell, M. J.** (2008). Amphibian ecology and conservation in the urbanising world: A review. *Biol. Conserv.* **141**, 2432–2449.
- Hartwig, E., Clemens, T. and Heckroth, M.** (2007). Plastic debris as nesting material in a Kittiwake (*Rissa tridactyla*) colony at the Jammerbugt, Northwest Denmark. *Mar. Pollut. Bull.* **54**, 595–597.
- Hensley, C. B., Trisos, C. H., Warren, P. S., MacFarland, J., Blumenshine, S., Reece, J. and Katti, M.** (2019). Effects of urbanization on native bird species in three

southwestern US cities. *Front. Ecol. Evol.* **7**, 1–10.

Hilton, G. M., Hansell, Mi. H., Ruxton, G. D., Reid, J. M. and Monaghan, P. (2004).

Using artificial nests to test importance of nesting material and nest shelter for incubation energetics. *Auk* **121**, 777–787.

Jagiello, Z. A., Dylewski, Ł., Winiarska, D., Zolnierowicz, K. M. and Tobolka, M.

(2018). Factors determining the occurrence of anthropogenic materials in nests of the white stork *Ciconia ciconia*. *Environ. Sci. Pollut. Res.* **25**, 14726–14733.

Jhanji, Y., Gupta, D. and Kothari, V. K. (2015). Thermo-physiological properties of

polyester–cotton plated fabrics in relation to fibre linear density and yarn type. *Fash. Text.* **2**, 1–14.

Katlam, G., Prasad, S., Aggarwal, M. and Kumar, R. (2018). Trash on the menu:

patterns of animal visitation and foraging behaviour at garbage dumps. *Curr. Sci.* **115**, 2322–2326.

Kaza, S., Yao, L., Bhada-Tata, P. and Van Woerden, F. (2018). *What a waste 2.0: a*

global snapshot of solid waste management to 2050. Urban Development Series. World Bank. Washington, DC.

Lagucki, E., Burdine, J. D. and McCluney, K. E. (2017). Urbanization alters

communities of flying arthropods in parks and gardens of a medium-sized city. *PeerJ* **5**, e3620.

Lynch, C. B. (1980). Response to divergent selection for nesting behavior in *Mus*

musculus. *Genetics* **96**, 757–765.

Mainwaring, M. C., Hartley, I. R., Lambrechts, M. M. and Deeming, D. C. (2014). The

design and function of birds' nests. *Ecol. Evol.* **4**, 3909–3928.

Mainwaring, M. C., Barber, I., Deeming, D. C., Pike, D. A., Roznik, E. A. and Hartley,

- I. R.** (2016). Climate change and nesting behaviour in vertebrates: a review of the ecological threats and potential for adaptive responses. *Biol. Rev.* **92**, 1991–2002.
- McKinney, M. L.** (2006). Urbanization as a major cause of biotic homogenization. *Biol. Conserv.* **127**, 247–260.
- Mee, A., Rideout, B. A., Hamber, J. A., Todd, J. N., Austin, G., Clark, M. and Wallace, M. P.** (2007). Junk ingestion and nestling mortality in a reintroduced population of California Condors *Gymnogyps californianus*. *Bird Conserv. Int.* **17**, 119–130.
- Mikulčić, H., Jin, Q., Stančin, H., Wang, X., Li, S., Tan, H. and Duić, N.** (2019). Thermogravimetric analysis investigation of polyurethane plastic thermal properties under different atmospheric conditions. *J. Sustain. Dev. Energy, Water Environ. Syst.* **7**, 355–367.
- Montoya-Tangarife, C., De La Barrera, F., Salazar, A. and Inostroza, L.** (2017). Monitoring the effects of land cover change on the supply of ecosystem services in an urban region: A study of Santiago-Valparaíso, Chile. *PLoS One* **12**, 1–22.
- Muul, I.** (1974). Geographic variation in the nesting habits of *Glaucomys volans*. *J. Mammal.* **55**, 840–844.
- Ospina, E. A., Merrill, L. and Benson, T. J.** (2018). Incubation temperature impacts nestling growth and survival in an open-cup nesting passerine. *Ecol. Evol.* **8**, 3270–3279.
- Pandita, S. D., Yuan, X., Manan, M. A., Lau, C. H., Subramanian, A. S. and Wei, J.** (2014). Evaluation of jute/glass hybrid composite sandwich: Water resistance, impact properties and life cycle assessment. *J. Reinf. Plast. Compos.* **33**, 14–25.
- R Core Team** (2019). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R->

project.org/.

- Reynolds, S. J., Galbraith, J. A., Smith, J. A. and Jones, D. N.** (2017). Garden bird feeding: Insights and prospects from a north-south comparison of this global urban phenomenon. *Front. Ecol. Evol.* **5**, 1–15.
- Reynolds, S. J., Ibáñez-Álamo, J. D., Sumasgutner, P. and Mainwaring, M. C.** (2019). Urbanisation and nest building in birds: a review of threats and opportunities. *J. Ornithol.* **160**, 841–860.
- Richards, S. A.** (2005). Testing ecological theory using the information-theoretic approach: Examples and cautionary results. *Ecology* **86**, 2805–2814.
- Rohwer, V. G. and Law, J. S. Y.** (2010). Geographic variation in nests of yellow warblers breeding in Churchill, Manitoba, and Elgin, Ontario. *Condor* **112**, 596–604.
- Ruiz-Castellano, C., Tomás, G., Ruiz-Rodríguez, M., Martín-Gálvez, D. and Soler, J. J.** (2016). Nest material shapes eggs bacterial environment. *PLoS One* **11**, 1–21.
- Sánchez, N. V., Vargas-Castro, L. E. and Barrantes, G.** (2018). Nestling feeding, nest success, and notes of parental care in the Clay-colored Thrush (*Turdus grayi*): the role of females and males. *Wilson J. Ornithol.* **130**, 437–444.
- Shibuya, F. L. S., Braga, T. V. and Roper, J. J.** (2015). The Rufous Hornero (*Furnarius rufus*) nest as an incubation chamber. *J. Therm. Biol.* **47**, 7–12.
- Shump, K. A.** (1978). Ecological importance of nest construction in the hispid cotton rat (*Sigmodon hispidus*). *Am. Midl. Nat.* **100**, 103–115.
- Skutch, A. F.** (1960). *Life Histories of Central American Birds. Part II. Families Vireonidae, Sylviidae Turdidae, Troglodytidae, Paridae, Corvidae, Hirundinidae and Tyrannidae.* Berkeley, California: Cooper Ornithological Society.
- Suárez-Rodríguez, M. and García, C. M.** (2014). There is no such a thing as a free

cigarette; lining nests with discarded butts brings short-term benefits, but causes toxic damage. *J. Evol. Biol.* **27**, 2719–2726.

Suárez-Rodríguez, M., López-Rull, I. and Garcia, C. M. (2013). Incorporation of cigarette butts into nests reduces nest ectoparasite load in urban birds: new ingredients for an old recipe? *Biol. Lett.* **9**, 20120931.

Suárez-Rodríguez, M., Montero-Montoya, R. D. and Macías Garcia, C. (2017). Anthropogenic nest materials may increase breeding costs for urban birds. *Front. Ecol. Evol.* **5**, 1–10.

Townsend, A. K. and Barker, C. M. (2014). Plastic and the nest entanglement of urban and agricultural crows. *PLoS One* **9**, 1–5.

Villaseñor, N. R., Driscoll, D. A., Escobar, M. A. H., Gibbons, P. and Lindenmayer, D. B. (2014). Urbanization impacts on mammals across urban-forest edges and a predictive model of edge effects. *PLoS One* **9**, 1–12.

Vleck, M. (1981). Energetic cost of incubation in the zebra finch. *Condor* **83**, 229–237.

Walters, L. A., Webber, J. A., Jones, B. A. and Volker, C. L. (2016). Taking a break: the relationship between ambient temperature and nest attendance patterns of incubating Carolina chickadees (*Poecile carolinensis*). *Wilson J. Ornithol.* **128**, 719–726.

Wang, Y., Chen, S., Blair, R. B., Jiang, P. and Ding, P. (2009). Nest composition adjustments by Chinese Bulbuls *Pycnonotus sinensis* in an urbanized landscape of Hangzhou (E China). *Acta Ornithol.* **44**, 185–192.

Williams, J. B. (2015). *The energetic costs of incubation. In Nests, Eggs, and Incubation: New Ideas About Avian Reproduction (ed. D. C. Deeming and S. Reynolds), pp 152-170.* United Kingdom: Oxford University Press.

- Witteveen, M., Brown, M. and Ryan, P. G.** (2017). Anthropogenic debris in the nests of kelp gulls in South Africa. *Mar. Pollut. Bull.* **114**, 699–704.
- Wu, J., Jenerette, G. D., Buyantuyev, A. and Redman, C. L.** (2011). Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States. *Ecol. Complex.* **8**, 1–8.
- Yang, W. and Li, Y.** (2012). Sound absorption performance of natural fibers and their composites. *Sci. China Technol. Sci.* **55**, 2278–2283.

Table 1. Artificial materials found in the 46 studied nests of the clay-colored thrush and the number of nests with each type of material.

Artificial material	Number of nests
Electric wire	1
Silicon fragment	1
Metallic staple	1
Plastic mesh	1
Cloth closures	1
Concrete	2
Sponge	2
Fishing lines	2
Metal fragments	2
Plastic tie	3
Dental floss	3
Plastic thread	4
Polystyrene	4
Glass	4
Metal thread	5
Construction nails	5
Cigarette butts	5
Plastic fragments	5
Cloth fragments	6
Paint	7
Paper	20
Sack fibers	21
Cotton laces	21
Candy wrappers	23
Plastic cotton	25

Plastic broom fibers	26
Sewing threads	33

Table 2. Generalized linear models (family Gaussian) ranked according to the lowest AICc value explaining cooling slope in clay-colored thrush nests in simulations without the female at the nest (cotton ball was not used after heating). Principal components are shown as internal (i) and external (e). Bold model represents the best model that explains nest cooling.

Model	K	AICc	Δ AICc
Adobe	1	-39.3	0.0
Artificial + adobe	2	-37.1	2.2
Adobe + natural	2	-37.1	2.2
Null	1	-37.0	2.3
Adobe + nest area + nest height (ePC2)	3	-36.5	2.8
Camera area (iPC1) + camera depth (iPC2)	1	-36.0	3.3
Adobe + camera area (iPC1) + camera depth (iPC2)	3	-35.8	3.5
Natural	1	-35.2	4.1
Base height (ePC2)	1	-35.2	4.1
Camera area (iPC1)	1	-35.0	4.3
Nest area (ePC1)	1	-35.0	4.3
Artificial	1	-35.0	4.3
Artificial + natural + adobe	3	-34.8	4.5
Camera area (iPC1) + camera depth (iPC2)	2	-33.8	5.5
Artificial + natural + adobe	2	-33.0	6.3
Nest area (ePC1) + nest height (ePC2)	2	-33.0	6.3
Natural + camera area (iPC1) + camera depth (iPC2)	3	-31.6	7.7
Artificial + camera area (iPC1) + camera depth (iPC2)	3	-31.5	7.8
Natural + nest area (ePC1) + nest height (ePC2)	3	-30.8	8.5
Artificial + nest area (ePC1) + nest height (ePC2)	3	-30.7	8.6
Camera area (iPC1) + camera depth (iPC2) + nest area (ePC1) + nest height (ePC2)	4	-29.3	10.0
Full	6	-28.1	11.2

Table 3. Generalized linear models (family Gaussian) ranked according to the lowest AIC_c value explaining cooling slope in clay-colored thrush nests in simulations with presence of female at the nest (cotton ball used after heating). Principal components are shown as internal (i) and external (e). Bold models represent best models that explain nest cooling.

Model	K	AIC _c	ΔAIC _c
Artificial + camera area (iPC1) + nest depth (iPC2)	3	-64.87	0.00
Camera area (iPC1) + base depth (iPC2)	2	-64.77	0.10
Camera area (iPC1)	1	-64.10	0.77
Artificial	1	-63.95	0.92
Adobe + camera area (iPC1) + base depth (iPC2)	3	-63.24	1.63
Natural + camera area (iPC1) + base depth (iPC2)	3	-63.25	1.64
Artificial + adobe	2	-62.22	2.66
Artificial + natural	2	-61.78	3.09
Base depth (iPC2)	1	-61.70	3.18
Null	1	-61.14	3.73
Camera area (iPC1) + base depth (iPC2) + nest area (ePC1) + nest height (ePC2)	4	-60.32	4.55
Full	6	-60.02	4.85
Artificial + natural + adobe	3	-59.92	4.95
Artificial + nest area (ePC1) + nest height (ePC2)	3	-59.53	5.35
Nest area (ePC1)	1	-59.43	5.44
Adobe	1	-59.37	5.50
Natural	1	-59.14	5.73
Nest height (ePC2)	1	-59.14	5.73
Nest area (ePC1) + nest height (ePC2)	2	-57.24	7.63
Adobe + natural	2	-57.18	7.69
Adobe + nest area (ePC1) + nest height (ePC2)	3	-55.65	9.22
Natural + nest area (ePC1) + nest height (ePC2)	3	-54.96	9.91



Figure 1. Nests of the clay-colored thrush (*Turdus grayi*) with a total weight of 118 g, and materials separated in artificial, adobe, and natural A) when artificial material mass is high (13.4 g), and B) when artificial material mass is low (0.1 g).

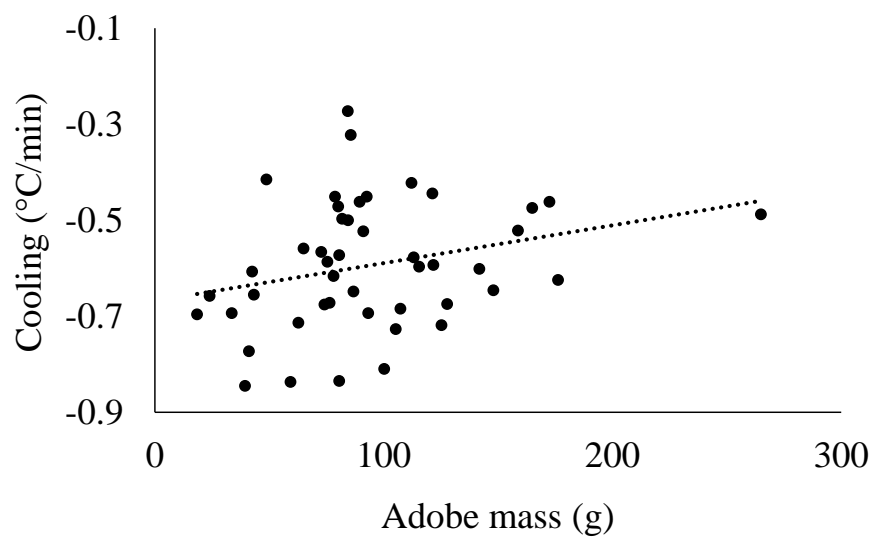


Figure 2. Nest cooling (°C/min) according to the adobe mass in simulated female absence at the nest of the clay-colored thrush (*Turdus grayi*).

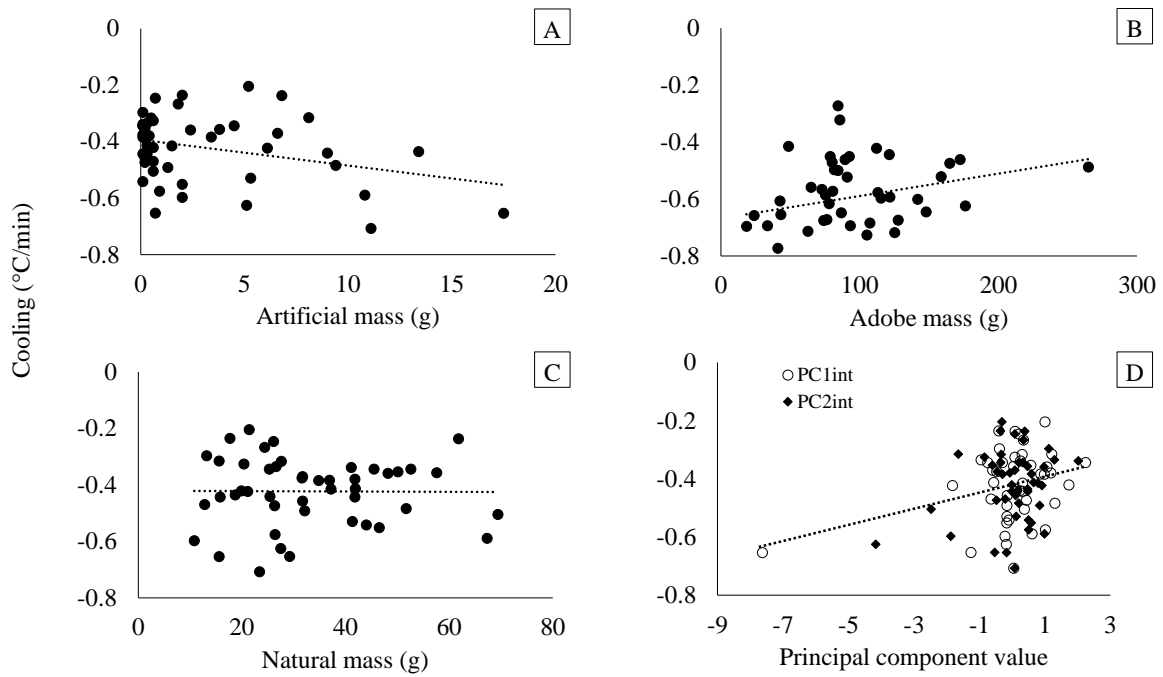


Figure 3. Nest cooling ($^{\circ}\text{C}/\text{min}$) according to A) artificial material mass, B) adobe mass, C) natural mass, and D) internal principal components (PC1 = camera area, PC2 = base depth) in simulated female presence at the nest of the clay-colored thrush (*Turdus grayi*).

CAPÍTULO 2

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**A potential consequence for reproductive success in urban birds:
anthropogenic nest materials reduce nest survival**

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Abstract—Urban bird dwellers survive and reproduce in highly urbanized ecosystems with a reduced amount of natural resources for nesting. Some individuals adjust to these novel circumstances by changing natural nesting materials for artificial materials, and thus making nests more conspicuous in the environment, from a human perspective. Consequences of using of artificial materials in nesting remain poorly understood, especially from a nest-predator perspective. For this reason, we studied if exposed artificial

materials on bird nest affects daily survival rate in a common dweller species, the clay-colored thrush. We used 28 previously collected nests with different amounts of artificial materials in the outer layers, and placed them with three clay eggs on the main campus of the Universidad de Costa Rica, Costa Rica. During 12 days within the reproductive season of the clay-colored thrush, we monitored the survival of nests using trap cameras located in front of each nest. We evaluated nest survival using the program MARK and found that nest survival decreased with the proportion of exposed artificial materials in the nest. We also found that 50% of nests were predated and the principal predators were conspecifics. Some conspecific individuals collected materials from the experimental nests after eggs were predated. Artificial materials used in the outer layer of nests make them more susceptible to predation. The use of artificial materials could reduce reproductive success and population size in urban clay-colored thrush.

Key words: artificial materials, MARK, nest daily survival rate, nesting success, nest's urban predators, urban ecosystems

Introduction

Urbanization is considered the main driver of global landscape modification (Powers and Jetz 2019), leading to fast homogenization, and fragmentation of original aquatic and terrestrial ecosystems (Blair 1996, McKinney 2006, Biamonte et al. 2011). This process affects many aspects of wildlife, having consequences on

species richness (McKinney 2002) or changes in behavior (Audet et al. 2015). For example, flying arthropods communities have experienced a dramatic loss of diversity, especially in areas close to human settlements (Ibáñez-Álamo et al. 2017). Conversely, perception of predation risk is altered in urban habitats, for instance, individuals of the vervet monkey (*Chlorocebus pygerythrus*) delay more its escape in urban than rural ecosystems because they habituate to non-lethal interactions with people in cities

In urban dwellers, species that reproduce inside or close to urban settlements, not only species richness and predation risk perception has been adapted to urban conditions but so have reproductive behaviors. For example, in the eastern wood-pewee (*Contopus virens*), individuals have increased the minimum frequency of their song as the traffic noise of the city increased (Gentry et al. 2018). Also, birds change natural perches for nesting because trees or shrubs are limited or eliminated from cities and, consequently, they use anthropogenic structures. For example, in Chicago city, the peregrine falcon (*Falco peregrinus*) uses mainly buildings as nest perches (Caballero et al. 2016), and in Lowicz, Poland, the white stork (*Ciconia ciconia*) uses electric posts as nest perch in areas with high population densities (Janiszewski et al. 2015).

Human settlements produce resources that birds use for food or as nest perch, but human daily also activities produce artificial materials, that birds use to build their nests (Jagiello et al. 2019). The increase in solid waste availability in the

environment is a resource that urban dwellers exploit to persist in rural and urban ecosystems. For example, the great grey shrike (*Lanius excubitor*) uses plastic as nesting material in agricultural landscapes in Poland (Antczak et al. 2010). Chinese bulbuls (*Pycnonotus sinensis*), a species that nests from urban to rural or less altered habitats, modifies its nest composition according to the urbanization level of the area it inhabits, adding more artificial materials in cities than in rural areas (Wang et al. 2009). Moreover, the house finch (*Haemorhous mexicanus*), that originally inhabits agricultural ecosystems, now is a common habitant of urban centers in Mexico, and it is common to find artificial materials like cigarette butts, in nests located in cities (Suárez-Rodríguez and García 2014).

The artificial materials that birds used in the outer layer of their nests often produce a drastic contrast against the brownish natural materials that those species usually use in natural conditions (Sergio et al. 2011). For example, the clay-colored thrush (*Turdus grayi*) uses red plastic ropes, green cloth fragments, and white plastic fragments (unpubl. data). Additionally, urbanization reduces predator diversity and most of the remaining predators exhibit opportunistic behaviors (e.g., predated unattended nests) and a generalist diet (Rodewald and Kearns 2011), a situation that makes nests an attractive source of food.

The incorporation of artificial materials could influence predation probability in nests, particularly for visual predators with a nest searching image, as the red-backed shrike (*Lanius collurio*) (Němec et al. 2015). Here, we tested if

artificial materials in the outer layer of the nest influence bird reproduction success through an increase in nest predation. We specifically tested if exposed artificial materials on the outer layer of nests affected daily survival rate in nests of the clay-colored thrush. This species is a common bird dweller that use a great variety of artificial materials in nest construction, and some of them exposed on the outer layer. Therefore, we predict that nests that have exposed artificial materials in the outer layer will decrease its nest survival because exposed artificial materials make nests more contrasting or visible in the environment, detectability will increase, and consequently those nest will be more predated than those that only included natural materials.

Materials and methods

We conducted this research from 14 May to 26 June 2019 at the main Campus of University of Costa Rica (UCR), in San José province (9°56'N, 84°03'W, 1200 m a.s.l.). The daily temperature in the area was between 17°C and 28°C, and a the monthly precipitation mean was 172 mm during study period (Instituto Meteorológico Nacional 2019). The area had a mosaic of constructed areas (e.g. buildings, parking lots, and roads) and green areas (e.g. parks, soccer field, and small natural reserves). The campus is transited for approximately 3000 people daily, during the experiment date.

Study species

The clay-colored thrush (*Turdus grayi*) is a common species in agricultural fields, pastures, and rural and urban areas in Costa Rica (Stiles and Skutch 1989). Its breeding season occurs from March to June, and build an open cup nest with natural and anthropogenic material, on natural perches or buildings (Stiles and Skutch 1989, Sánchez et al. 2018). Females build the nest, using plant and artificial material, mud in the intermediate layer, and roots and leaf rachises on the outer layer of the structure (Stiles and Skutch 1989). On average, females lay three light-turquoise and brown dotted eggs per nest, however, the number of eggs varies between 2 and 4 (Sánchez et al. 2018). Common predators in the study site includes brown jays (*Cyanocorax morio*), Montezuma oropendolas (*Psarocolius montezuma*), and blue-crowned motmots (*Momotus momota*), but mainly great-tailed grackles (*Quiscalus mexicanus*), variegated squirrels (*Sciurus variegatoides*), and domestic cats (*Felis catus*) (Sánchez et al. 2018).

Nest measurements

To evaluate if the area of exposed artificial materials influences the survival rate of the nests, we placed in trees previously collected clay-colored thrush nests with different amount of exposed artificial materials, and three clay eggs to emulate a mean clutch. We used 28 nests with different area of exposed anthropogenic materials, stored at Museo de Zoología, Universidad de Costa Rica (MZUCR). First, we obtained the following eight measurements to quantify nest dimensions: (1) nest length (nest longest side), (2) nest width (perpendicular to nest length), (3)

camera length (camera longest side), (4) camera width (perpendicular to camera length), (5) nest height (distance from the top to bottom of the nest), (6) camera height (height from camera to nest top), (7) nest base depth (distance from camera to nest base), and (8) nest walls thickness (mean thickness of four cross points between nest camera and nest outer layer). Nest variables were measured to the nearest mm.

To quantify exposed artificial materials, we took four pictures for each nest side and one photo from the above nest, and used Android's app Image Meter Pro to measure the exposed total nest area and the exposed area made with artificial materials per nest. We defined artificial materials as all materials that are not originally available in the environment. We then calculated the proportion of the total nest area covered by artificial material.

Experiment settings

We placed 28 nests in trees between 5 - 6 m above ground to emulate the height range at which birds build their nests. We separated nests in three rounds, one of eight nests and two of ten nests and never placed more than ten nests simultaneously to reduce a possible nest density effect on nest predation, produced as consequence of our experiment. In each nest, we placed three clay eggs with very similar color and size of clay-colored thrush eggs (Fig. 1), and a trap camera in front of the nest (Bushnell® Trophy Cam HD Aggressor; interval = 5 s, capture = 2 photos, sensor level = Auto) for a daily recording without human direct presence.

We used odorless, non-toxic clay (Acrilex®) to avoid odor cues that can attract predators.

To choose trees, we divided total area of the campus (31.5 ha) into 90 quadrats of 60 m side and randomly used 28 of these quadrats. We then place one nest per quadrat, and never used two consecutive squares in the same round (Fig. 2). We left each nest for twelve days on the campus, because is an expected incubation time for the clay-colored thrush (Dyrz 1983), and then collected nests and clay eggs. For each nest, we use trap cam photos and clay eggs to register predation events, and predator identification (White and Burnham 1999). We defined a nest as predated if at the end of the twelve-day period, no eggs were found inside the nest or the remaining eggs had been damaged.

Statistical analysis

To characterize nest dimensions, we conducted two principal component analyses (PCA), the first included the external dimensions (nest length, width, height, and nest base depth), and the second the internal dimensions of the nest (camera length, width and height, and nest wall thickness) using varimax rotation on the correlation matrix. The PCAs allowed us to characterize each nests with a reduced number of multivariate variables. In the analysis conducted for external dimensions, the first two components had eigenvalues greater than 1.0, and together explained 84.4% of the variance of the original four variables. The first component that explained 50.1% of the variance showed a relatively strong positive correlation with nest

height ($r = 0.63$; we present correlation coefficients between factor 1 and the raw variables) and nest base depth ($r = 0.56$), but a weak positive correlation with nest length ($r = 0.35$) and nest width ($r = 0.41$). We named this first component "nest height", since nests with high scores had a higher nest heights. The second component explained 34.34% of the variance and showed a strong positive correlation with nest length ($r = 0.61$) and nest width ($r = 0.57$), but weak and negative correlations with nest height ($r = -0.31$) and nest base depth ($r = -0.45$). We therefore named this component "nest area", because nests with high scores for this second principal component had a higher nest area.

In the analysis conducted for internal dimensions, the first two rotated components had eigenvalues greater than 1.0, and both explained 72.2% of the variance in the original four dimensional variables. The first rotated component explained 41.6% of the variance and showed a strong negative correlation with camera length ($r = -0.66$), a positive correlation with camera depth ($r = 0.65$), but a weak positive correlation with camera width ($r = 0.01$) and wall thickness ($r = 0.38$). We named this first rotated component "camera size", where nests that received a high score had a lower camera length and a higher camera depth. The second component explained 30.6% of the variance and showed a strong positive correlation with camera width ($r = 0.78$) and a negative correlation with wall thickness ($r = -0.56$), but a weak negative correlation with camera length ($r = -0.03$) and a positive correlation with camera depth ($r = 0.27$). We therefore named this

component "camera width", since nests with high score for this second principal component had wider cameras but thinner walls.

We applied a nest survival model using the proportion of nest area exposed with artificial materials, and principal components of nest dimension measures as independent variables, and the nest daily survival rate as a dependent variable. We used the Akaike information criterion to select the best model, and the best model was that with the lowest $\Delta AICc$ value (Burnham and Anderson 2002, Richards 2005). For the PCA we used R (R Core Team 2019) and for the survival modeling we used the program MARK 9.0 (White and Burnham 1999).

Results

The main exposed artificial materials located in the external layer of the nests used in the experiment were artificial cotton and cotton laces; which were present in 10 of 28 nests. The proportion of exposed nest area with artificial materials varied between 0% and 32%.

Fourteen nests were predated (one or all eggs were bitten or removed from the nest) by common opossum (*Didelphis marsupialis*, n = 1), domestic cat (n = 1), great-tailed grackle (n = 1), great kiskadee (*Pitangus sulphuratus*; n = 1), and clay-colored thrush (n = 8); we could not identify predators of remaining predated nests. The nest survival rate decreased as the amount of artificial material in the outer layer of the nest covered a larger proportion (estimate = 0.85, SE = 0.03, 95% CI =

0.76, 0.91; Fig. 3; Table 1); but none of the models that included nest dimensions (internal or external) influenced the nest survival rate (Table 1).

Discussion

Predation is the main cause of bird's nest failure (Hollander et al. 2015), and has played an important role in the evolution of clutch size, and nesting strategies (Lack 1946, Skutch 1985, Dillon and Conway 2018). In general, bird nest predation carried out by generalist heterospecific predators of a wide range of taxa. However, we found that 57% of the nests of the clay-colored thrush were predated by conspecifics, while 43% were predated by heterospecific predators. Botero-Delgadillo et al. (2015) obtained a similar result but for a cavity nesting species in which nesting places are strongly limited, so conspecifics compete for nesting sites and attack other nests in cavities when were unattended. In this study, clay-colored thrushes attack nests of conspecifics to throw eggs to the ground and probably to collect materials for their own nests, a behavior that has been reported in other species (Belles-Isles and Picman 1986, Wang et al. 2018). We were unable to identify individuals, so that the identity and sex of conspecifics remain unknown.

The clay-colored thrush is a territorial species whose males defend territories aggressively from other males (Sánchez et al. 2018). Therefore it is likely that the individuals, which were recorded attacking nests, were males defending territorial resources (Belles-Isles and Picman 1986), or females disarming nests to avoid

competition for food or to use nesting materials. However, there is little evidence of female's role in territorial defense or competition with other females in the Clay-colored thrush (Dyrz 1983, Fedy and Stutchbury 2005, Sánchez et al. 2018). Though, in high-density populations, competition for resources such as food or nest perches and materials may be more aggressive (Real et al. 2017). It is also possible that individuals attacking nests were both males and females defending either territories or resources for nesting, because the clay-colored thrush population at UCR reaches up to 100 individuals (3.2 ind/ha), a high-density population for this species (Dyrz 1983).

Our results suggest that artificial materials do not break the searching image of the predator and rather could attract predators to the nests. Bird urban dwellers had adjusted some of their behaviors to successfully adapt to urban ecosystems (e.g., use of garbage as food or nesting materials) (Antczak et al. 2010, Stofberg et al. 2019). This behavioral flexibility could lead urban predators to identify a nest even if nest's structure is modified with artificial materials, making nests more contrasting and conspicuous, or less cryptic. Another possibility is that urban predators learn a novel searching image, and they may search first where nests include artificial materials, a common nest pattern in urban habitats for some species (Bateman et al. 2017). We recorded a conspecific individual taking away a yellow wool yarn on its first approach to the nest. This suggests that artificial materials on nests could attract not only predator but another clay-colored thrush,

which results in nest failure because individuals throw eggs to the ground and disarm nest.

This study showed that artificial materials used in nests by the clay-colored thrush, had negative consequences in reproductive success because artificial materials make nests more attractive for potential predators and conspecifics. This study also suggests that nesting behaviors are altered in urban ecosystems possibly due to human activities, so active solid waste management is required to conserve bird wildlife in cities. Our results also highlight the importance of preserve natural habitats in urbanized ecosystems to provide materials for nesting. In many ways, human pollution is altering original ecological traits, but in birds, the great availability of artificial materials in human settlements is leading to an unpredictable population destiny because of the consequences of the use of those materials by some individuals.

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References

- Antczak, M., Hromada, M., Czechowski, P., Tabor, J., Zablocki, P., Grzybek, J. and Tryjanowski, P. 2010. A new material for old solutions-the case of plastic string used in Great Grey Shrike nests. - *Acta Ethol.* 13: 87–91.
- Audet, J.-N., Ducatez, S. and Lefebvre, L. 2015. The town bird and the country bird: problem solving and immunocompetence vary with urbanization. - *Behav. Ecol.* 27: 637–644.
- Bateman, P. W., Fleming, P. A. and Wolfe, A. K. 2017. A different kind of ecological modelling: the use of clay model organisms to explore predator–prey interactions in vertebrates. - *J. Zool.* 301: 251–262.
- Belles-Isles, J.-C. and Picman, J. 1986. House wren nest-destroying behavior. - *Condor* 88: 190–193.
- Biamonte, E., Sandoval, L., Chacón, E. and Barrantes, G. 2011. Effect of urbanization on the avifauna in a tropical metropolitan area. - *Landsc. Ecol.* 26: 183–194.
- Blair, R. B. 1996. Land use and avian species diversity along an urban gradient. - *Ecol. Appl.* 6: 506–519.
- Botero-Delgadillo, E., Poblete, Y. and Vásquez, R. A. 2015. Nestling mortality as a consequence of interspecific competition between secondary cavity nesters in the sub-Antarctic forests of Chile. - *Wilson J. Ornithol.* 127: 131–134.

- Burnham, K. P. and Anderson, D. R. 2002. Model selection and Inference: a practical information-theoretic approach. - Springer-Verlag.
- Caballero, I. C., Bates, J. M., Hennen, M. and Ashley, M. 2016. Sex in the city: Breeding behavior of urban peregrine falcons in the Midwestern US. - PLoS One 11: 1–16.
- Dillon, K. G. and Conway, C. J. 2018. Nest predation risk explains variation in avian clutch size. - Behav. Ecol. 29: 301–311.
- Dyrce, A. 1983. Breeding ecology of the Clay-coloured robin *Turdus grayi* in lowland Panama. - Ibis. 125: 287–304.
- Fedy, B. C. and Stutchbury, B. J. M. 2005. Territory defence in tropical birds: Are females as aggressive as males? - Behav. Ecol. Sociobiol. 58: 414–422.
- Gentry, K. E., McKenna, M. F. and Luther, D. A. 2018. Evidence of suboscine song plasticity in response to traffic noise fluctuations and temporary road closures. - Bioacoustics 27: 165–181.
- Hollander, F. A., Van Dyck, H., Martin, G. S. and Titeux, N. 2015. Nest predation deviates from nest predator abundance in an ecologically trapped bird. - PLoS One 10: 1–19.
- Ibáñez-Álamo, J. D., Rubio, E., Benedetti, Y. and Morelli, F. 2017. Global loss of avian evolutionary uniqueness in urban areas. - Glob. Chang. Biol. 23: 2990–2998.
- Instituto Meteorológico Nacional 2019. Consulta de datos meteorológicos. Accessed in: <https://www.imn.ac.cr>.

- Jagiello, Z., Dylewski, Ł., Tobolka, M. and Aguirre, J. I. 2019. Life in a polluted world: a global review of anthropogenic materials in bird nests. - *Environ. Pollut.* 251: 717–722.
- Janiszewski, T., Minias, P. and Wojciechowski, Z. 2015. Selective forces responsible for transition to nesting on electricity poles in the white stork *Ciconia ciconia*. - *Ardea* 103: 39–50.
- Lack, D. 1946. The significance of clutch-size. - *Ibis*. 89: 302–352.
- McKinney, M. L. 2002. Urbanization, biodiversity, and conservation. - *Bioscience* 52: 883–890.
- McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. - *Biol. Conserv.* 127: 247–260.
- Němec, M., Syrová, M., Dokoupilová, L., Veselý, P., Šmilauer, P., Landová, E., Lišková, S. and Fuchs, R. 2015. Surface texture and priming play important roles in predator recognition by the red-backed shrike in field experiments. - *Anim. Cogn.* 18: 259–268.
- Powers, R. P. and Jetz, W. 2019. Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. - *Nat. Clim. Chang.* 9: 323–329.
- R Core Team 2019. R: A language and environment for statistical computing. - R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

- Real, E., Oro, D., Martínez-Abraín, A., Igual, J. M., Bertolero, A., Bosch, M. and Tavecchia, G. 2017. Predictable anthropogenic food subsidies, density-dependence and socio-economic factors influence breeding investment in a generalist seabird. - *J. Avian Biol.* 48: 1462–1470.
- Richards, S. A. 2005. Testing ecological theory using the information-theoretic approach: Examples and cautionary results. - *Ecology* 86: 2805–2814.
- Rodewald, A. D. and Kearns, L. J. 2011. Shifts in dominant nest predators along a rural-to-urban landscape gradient. - *Condor* 113: 899–906.
- Sánchez, N. V., Vargas-Castro, L. E. and Barrantes, G. 2018. Nestling feeding, nest success, and notes of parental care in the Clay-colored Thrush (*Turdus grayi*): the role of females and males. - *Wilson J. Ornithol.* 130: 437–444.
- Sergio, F., Blas, J., Blanco, G., Tanferna, A., López, L., Lemus, J. A. and Hiraldo, F. 2011. Raptor nest decorations are a reliable threat against conspecifics. - *Science*. 331: 327–330.
- Skutch, A. F. 1985. Clutch size, nesting success, and predation on nests of neotropical birds reviewed. - *Ornithol. Monogr.* 36: 575–594.
- Stiles, F. G. and Skutch, A. F. 1989. *Guía de aves de Costa Rica*. - Editorial INBio.
- Stofberg, M., Cunningham, S. J., Sumasgutner, P. and Amar, A. 2019. Juggling a “junk-food” diet: responses of an urban bird to fluctuating anthropogenic-food availability. -

Urban Ecosyst. 22: 1019–1026.

Suárez-Rodríguez, M. and García, C. M. 2014. There is no such a thing as a free cigarette; lining nests with discarded butts brings short-term benefits, but causes toxic damage. - J. Evol. Biol. 27: 2719–2726.

Wang, Y., Chen, S., Blair, R. B., Jiang, P. and Ding, P. 2009. Nest composition adjustments by Chinese Bulbuls *Pycnonotus sinensis* in an urbanized landscape of Hangzhou (E China). - Acta Ornithol. 44: 185–192.

Wang, L., Cheng, S. J., Hsu, Y. C. and Liang, W. 2018. Nest-dismantling behavior of yellow-bellied prinia in mainland and island populations. - Acta Ethol. 21: 35–41.

White, G. and Burnham, K. 1999. Program MARK: survival estimation from populations of marked animals. - Bird Study 46: 120–138.



Figure 1. Clay (left) and natural (right) eggs of the clay-colored thrush for comparative purposes.



Figure 2. Map of the University of Costa Rica main campus gridded in quadrats of 60 m side. The dashed line shows the campus perimeter, grey area represents buildings, roads and parking lots, and white area represents forest patches and gardens. Black dots represents an unpredated nest, and white dots represent a predated nest of the clay-colored thrush.

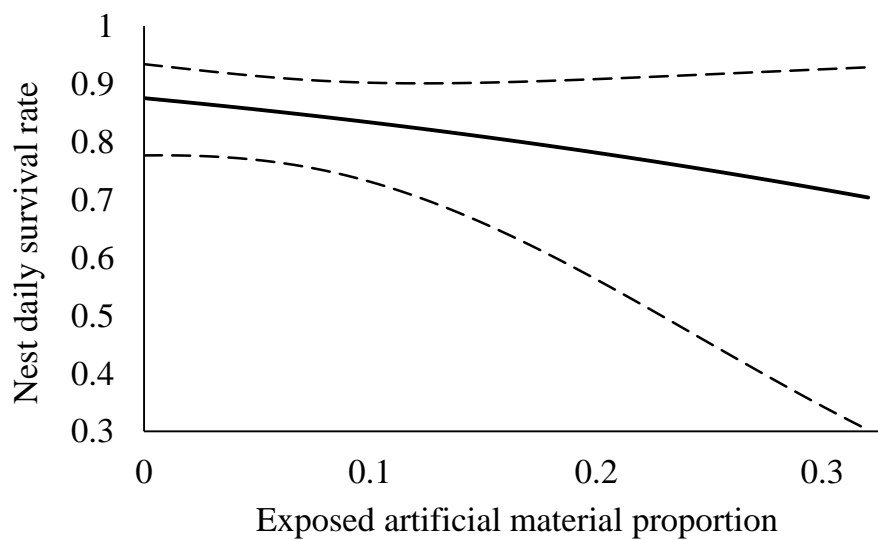


Figure 3. Predicted nest daily survival rate (continuous line) with 95% confidence limits (dashed lines) and proportion between nest's artificial materials exposed area and total nest area ("Proportion").

Table 1. Nest survival models explaining nest daily survival rate in clay-colored thrush's nests ranked according to AICc values (Proportion = exposed artificial materials area/total exposed nest area, PC = principal component).

Model	K	AICc	Δ AICc
Proportion	1	82.54	0
External dimensions (PCs)	2	85.2	2.65
Internal dimensions (PCs)	2	86.46	3.92
Proportion + External dimensions (PCs)	3	86.48	3.94
Proportion + Internal dimensions (PCs)	3	86.72	4.18

CAPÍTULO 3

Formato para la revista: Urban Ecosystems

Careful with your waste: Urbanization increases artificial material in bird nests

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ABSTRACT

Human population is experiencing an unprecedentedly fast growth, producing likely irreversible changes in natural ecosystems. As urbanization expands and human population increases, the amount of solid waste also becomes more abundant in every place people inhabit. Some birds use artificial materials to build their nests but the relationship between the availability of such materials and birds' use remain unclear. To test if urbanization affects the presence of artificial material in nests, we registered the types and frequency of artificial materials in nests of the clay-colored Thrush (*Turdus grayi*) collected in sites with different levels of urbanization. We disassembled 78 nests found along an urban gradient

and found that almost 80% of nests included at least one type of artificial material. Cotton threads and plastic broom fibers were the most common artificial materials in nests. We found more types of artificial materials in more urbanized areas. The large availability of anthropogenic materials in the environment, the reduction in availability of natural materials, and the behavioral flexibility of some individuals to use new nesting materials are the more likely reasons to use artificial materials for nest construction. This study showed a positive correlation between the number of different types of artificial material in nests and its abundance in urban areas. We found an innovative adjustment of the use of nest materials, and its relation with available materials in the environment.

KEY WORDS: man-made materials, plastic, bird nesting, waste, pollution, cities wildlife

INTRODUCTION

Recent projection indicate that by the end of 2050 the human population would increase at least 20% with approximately 70% of people living in urban areas (United Nations, Department of Economic and Social Affairs 2019a). Urbanization expansion as a cause of human growth is causing a worldwide changing of natural and semi-natural ecosystems (e.g. agricultural fields, pastures) (Biamonte et al. 2011), leading to the reduction, modification, and fragmentation of natural habitats within or close to cities (McKinney 2006; Wu et al. 2011). In addition to habitat loss (Powers and Jetz 2019), these changes decrease natural food availability (Onrust et al. 2019), and modify the foraging habits of animals exposed to urbanization (Caryl et al. 2016).

Urbanization results in negative effects on diversity of arthropods (Lagucki et al. 2017), reptiles (Andrade 2019), amphibians (Hamer and McDonnell 2008), mammals (Villaseñor et al. 2014), and birds (Hensley et al. 2019) due to a reduction in the availability of food, freshwater, or suitable habitats, which limits survival and reproduction of several species (Beninde et al. 2015). Nevertheless, some native and introduced species are adapting to urban environments and are increasing or maintaining viable populations in urban areas or their surrounding (Guénard et al. 2015). For example, the Peregrine Falcon (*Falco peregrinus*) is colonizing and nesting in urban habitats (e.g., Chicago city), where the species maintain relatively large populations (Caballero et al. 2016). However, for most bird species the factors favoring urban colonization are barely beginning to be understood.

Urban bird colonization occurs in species that can exploit anthropogenic resources such as food or materials for nesting (McKinney 2002). Nevertheless, some behavior flexibility is required to adapt to urban ecosystems, such as diet modifications (Stofberg et al. 2019), changes in acoustic communication to cope with noisy environments (Redondo et al. 2013; Gentry et al. 2018), modification of predator risk perception associated to human coexistence (Cavalli et al. 2016), and adjustment in nesting behaviors (Klett-Mingo et al. 2016). A common response to urbanization related to nesting is to use artificial perches for nest building instead of the natural ones (Wang et al. 2015), as well as, the use of artificial materials, produced as garbage by human activities, for nesting (Antczak et al. 2010). For example, the white stork (*Ciconia ciconia*), which nests over trees in natural areas, is using electric posts as nesting perches in regions with a high individual density (Janiszewski et al.

2015). Similarly, Chinese bulbuls (*Pycnonotus sinensis*) increase the use of artificial materials in nest construction when this kind of materials are more available in urban areas (Wang et al. 2009).

Bird nesting is an energetically expensive activity that requires a variety of resources in a synchronized moment, for example, food for adults and chicks, perches and materials for nest construction (Mainwaring and Hartley 2013). Compared with natural or rural areas, in urban centers the availability of persistent perches (e.g. buildings or posts) and garbage increases, but natural perches and food resources decreases. For instance, trees and shrubs used by birds as food or nesting resources (e.g. perch or nesting materials) are less common in urban areas (McKinney 2006). An increasing number of bird species that inhabit cities are changing to use those urban resources; for example, they are nesting in artificial structures (Caballero et al. 2016), feeding from the garbage (Katlam et al. 2018), and incorporating plastic and artificially colored wool fibers in nest construction (Antczak et al. 2010; Surgey et al. 2012). However, there is little information on the consequences of using such resources for adults or chicks health and survival for most bird species in urban areas. Nevertheless, it is known that chicks of the American crow (*Corvus brachyrhynchos*) die entangled with anthropogenic materials incorporated to the nests by their parents (Townsend and Barker 2014); similarly, adults of the northern gannet (*Morus bassanus*) also die entangled with fishing lines incorporated in their nests (Votier et al. 2011).

Usually, urbanized locations accumulate an increasing amount of uncollected solid waste (Programa Estado de la Nacion 2018), and some of this garbage is available as

artificial materials for nest construction. However, there is little information of the responses of nesting birds to a greater exposure to artificial materials in ecosystems with a reduced natural materials (Jagiello et al. 2019). To test if urbanization affects the richness of artificial material in bird nests, we study the different types of artificial materials used by the clay-colored Thrush (*Turdus grayi*) for nest building along an urbanization gradient. We expected that nests constructed in highly urbanized areas will have more types of artificial material, if individuals use them according to their abundance, such as reported in Chinese bulbuls (Wang et al. 2009). We selected the clay-colored thrush as our study species because it is a common species in urban and rural locations in Costa Rica, built nests on accessible perches where they can be collected, and use a great diversity of artificial materials in its nests.

METHODS

Study species. The clay-colored Thrush (*Turdus grayi*) is a common species in crops, pastures, and rural and urban areas in Costa Rica (Stiles and Skutch 1989). The species breeding season occurs from March to June, and females build an open cup nest, using plant material, mud in the intermediate layer, roots and parts of leaves on the outside of the structure (Stiles and Skutch 1989), and usually artificial materials in all layers (pers. obs.). Nests are built on natural or human made perches (Stiles and Skutch 1989).

Urbanization and measurements of nest materials. To determine if the urbanization level influences the use of different artificial materials in the clay-colored Thrush, we used the nest collection maintained in the Museo de Zoología at Universidad de Costa Rica (MZUCR). To measure the level of urbanization, we recorded the geographical coordinates of each nest and using Google Earth Pro (version 7.3.2.5776) and made circular plots of 100 m (eye altitude 350 m), 200 m (eye altitude 650 m), and 400 m (eye altitude 1300 m) radius, around each nest location. Within each plot, we quantified the gray area (e.g., buildings and roads) and green area (e.g., parks and forests). We used the historical photos of Google Earth to match the date of the photo with the nest collection date. Nests were collected between 2010 and 2018.

Additionally, we registered other two variables to achieve another effects associated with artificial materials availability. First, we obtained the number of garbage collection days per week in the area where the nest was collected, we consider this variable as a proxy to the availability of garbage in the environment. We obtain this information by consulting to the local government of each nest collection locality about the periodicity of garbage collection. Second, to consider the regional variation in the urbanization level, we categorized the area in a 5 x 5 km plot, centered in the nest collection locality point. We used three categories: “rural” if less than 20% of the plot was covered by urban elements (buildings or asphalt roads) and remaining area was compound by grassland, plantations or young successional vegetation, “suburban” if between 20% and 60% of the plot was compound by urban elements, and “urban” if more than 60% of the plot was compound by

urban elements. This approach allowed us to analyze if local (i.e., 100 m, 200 m, and 400 m circular plots) and regional (i.e. 5 x 5 km plot) landscape features influence the use of artificial materials. For example, if a nest was surrounded by urban elements inside the 400 m plot, but outside of the plot there was a rural or natural landscape (a common pattern of rural areas in studied sites), individuals could use the artificial materials provided by the human settlement inside the plot or the natural material outside of it.

Finally, we disassembled all nests to quantify the artificial material richness, and to categorize each material by type based on the main component and structure of each element. Subsequently, we defined richness as the number of different artificial materials that a nest had. All categories are listed in Table 1, and all disassembled nests remain in the nest collection at MZUCR.

Statistical analysis. We tested the effect of urbanization in artificial material richness using a zero inflated generalized linear mixed model (GLMM), with a negative binomial error distribution (Zuur et al. 2009). We used the urbanized area within the 100 m circular plot (“100 m”), the urbanized area within the ring between 200 and 100 m circular plots (“200 m ring”), the urbanized area within the ring between 400 m and 200 m circular plots (“400 m ring”), and the urbanization level as independent factors, and artificial materials richness per nest as dependent variable. Because garbage collecting days depends on the local government, we considered the number of collecting garbage days/week as a random factor, and used the Akaike information criterion to select the model that best explains the richness of artificial material per nest (Burnham and Anderson 2002; Richards 2005). All

tested models are described in table 2. We used R statistical software version 3.6.0 (R Core Team 2019) for all statistical analyses.

RESULTS

In total, we disassembled 78 nests, from which 61 showed at least one type of artificial material as part of the nest structure. We found 27 types of different artificial materials, of which being cotton threads and plastic broom fibers were the most common (Table 1).

The gray area within a 100 m circular plot, 200 m ring, 400 m ring, and urbanization level influenced nest artificial materials richness (Table 2). We decided to use the model with the gray areas separated from the one with urbanization level because of AIC values differences from first ranked model are less than 2, and the reduced number of parameters (k) in both cases. Nest artificial material richness increased with gray area in 100 m circular plot ($Z = 2.52$, $p = 0.01$) and in 400 m ring ($Z = 2.14$, $p = 0.03$), and had a little change in 200 m ring with the same pattern ($Z = -1.96$, $p = 0.05$; Fig. 1). Artificial materials richness in nests was higher in urban areas than in suburban and rural areas ($Z = 2.48$, $p = 0.01$), but richness in nests build in suburban and rural was similar ($Z = 0.80$, $p = 0.43$; Fig. 2).

DISCUSSION

Human activities have affected almost all natural ecosystems on Earth, with drastic and often irreversible negative consequences for wildlife (Silva et al. 2014; Powers and Jetz 2019). In this study, we found that most nests of clay-colored thrush had at least one type of artificial material in its structure, even in rural locations. Similar results were obtained for nests of the American crow, a species that also nest in rural and urban ecosystems (Townsend and Barker 2014). In both species, the most common artificial materials found in nests were those that people probably throw to ground during daily activities such as sewing threads, plastic broom fibers, and plastic cotton. These materials could have negative consequences for chicks or adults survival, as adults of the American crow often get entangled in synthetic strings (Townsend and Barker 2014), a material with similar characteristics to the cotton thread we frequently found in clay-colored thrush's nests.

In approximately 50% of all clay-colored Thrush's nests, we found plastic broom fibers and in at least three nests it was a component of nest camera (Fig. 3). Plastic fibers of all types are a very common thrash of human activities (Hartwig et al. 2007; Katlam et al. 2018; Kaza et al. 2018) and thus, could become available as nest material for several bird species in the world, as we found for this species. Plastic fibers potentially have negative consequences on nestlings or adults due to ingestion, entanglement, or modification of nest microenvironment, reducing species' reproductive success. For example, in the California condor (*Gymnogyps californianus*) ingestion of plastic junk was the primary cause of nest failure, because nestlings died after ingestion (Mee et al. 2007). Adults and chicks of the kelp gull (*Larus dominicanus*) entangled and die by asphyxia in fishing lines (Witteveen et

al. 2017), and this consequence is common in many species that nest in cities close to the sea (Votier et al. 2011). In addition, nest microenvironment (the chemical and physical conditions inside nest camera), could be altered by plastic materials because nest materials modulate bacteria and parasites population in nests (Ruiz-Castellano et al. 2016). For example, fresh plant materials in nests are related to a reduction of parasites abundance (Dubiec et al. 2013), then if plastic substitute vegetal material it is possible that parasites population increase reducing nestling's survival (Cantarero et al. 2013).

We found differences in the richness of nests' artificial materials between urban areas and suburban and rural areas. Urban areas have more types of artificial materials use for birds to construct their nests because those areas house most of the human population (United Nations, Department of Economic and Social Affairs 2019b), and waste production increases with human population due to an inappropriate waste management (Kaza et al. 2018). On the contrary, availability of natural materials decreases rapidly in urban areas due to the elimination of natural cover (Beninde et al. 2015; Hui et al. 2017); making more likely the use of artificial materials for nesting by some bird species. The richness in artificial material used in nests was similar in rural and suburban areas, and both had lower richness than urban areas possibly because density of human populations is lower, and consequently the amount of solid waste available in the environment is also smaller, but natural materials are more abundant due to larger extensions of natural vegetation. These results support our prediction that the use of artificial material in nests of the clay-colored

thrush correlates with waste abundance in the environment, both in a local or in a regional scale.

To our knowledge, there is little evidence of the consequences of using artificial materials for nest construction. If the use of artificial material in nests affects reproductive success of birds, its use could, in conjunction to other factors, determine the local extinction of populations in urban areas. However, if the use of artificial material increases fitness, birds that are behaviorally flexible to incorporate new artificial material in their nests, would have a greater probability of population persistence.

In this research, we provide evidence that the use of artificial material for nest construction correlates with the level of urbanization of the habitats used by the clay-colored thrush. Materials commonly used by nesting birds are those that people discard every day, likely unaware of the use birds gives to such material (e.g., cotton thread). We also offer evidence of a consequence produced by the human reduction and modification of original ecosystems because this phenomenon is forcing urban birds to use artificial materials instead of less available natural ones, so strategies to preserve natural resources in urban cores are urgently needed to avoid environmental contamination and its impact on wildlife. There is also needed a greater responsibility by people to correct waste disposal and avoid unnecessary consumption in order to avoid consequences over bird nesting and urban wildlife. Efforts should be driven to decrease the amount of available artificial materials in all ecosystems and to preserve urban birds and wildlife.

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REFERENCES

- Andrade AC (2019) Metropolitan lizards? Urbanization gradient and the density of lagartixas (*Tropidurus hispidus*) in a tropical city. *Ecol Evol* 10:1–11.
<https://doi.org/10.1002/ece3.5518>
- Antczak M, Hromada M, Czechowski P, et al (2010) A new material for old solutions-the case of plastic string used in Great Grey Shrike nests. *Acta Ethol* 13:87–91.
<https://doi.org/10.1007/s10211-010-0077-2>
- Beninde J, Veith M, Hochkirch A (2015) Biodiversity in cities needs space: A meta-analysis of factors determining intra-urban biodiversity variation. *Ecol. Lett.* 18:581–592
- Biamonte E, Sandoval L, Chacón E, Barrantes G (2011) Effect of urbanization on the avifauna in a tropical metropolitan area. *Landsc Ecol* 26:183–194.
<https://doi.org/10.1007/s10980-010-9564-0>
- Burnham KP, Anderson DR (2002) *Model selection and Inference: a practical information-theoretic approach*, 2nd edn. Springer-Verlag, New York
- Caballero IC, Bates JM, Hennen M, Ashley M (2016) Sex in the city: Breeding behavior of urban peregrine falcons in the Midwestern US. *PLoS One* 11:1–16.
<https://doi.org/10.1371/journal.pone.0159054>
- Cantarero A, López-Arrabé J, Rodríguez-García V, et al (2013) Factors affecting the presence and abundance of generalist ectoparasites in nests of three sympatric hole-

nesting bird species. *Acta Ornithol* 48:39–54.

<https://doi.org/10.3161/000164513x669982>

Caryl FM, Lumsden LF, van der Ree R, Wintle BA (2016) Functional responses of insectivorous bats to increasing housing density support “land-sparing” rather than “land-sharing” urban growth strategies. *J Appl Ecol* 53:191–201.

<https://doi.org/10.1111/1365-2664.12549>

Cavalli M, Baladrón A V., Isacch JP, et al (2016) Differential risk perception of rural and urban Burrowing Owls exposed to humans and dogs. *Behav Processes* 124:60–65.

<https://doi.org/10.1016/j.beproc.2015.12.006>

Dubiec A, Gózdź I, Mazgajski TD (2013) Green plant material in avian nests. *Avian Biol Res* 6:133–146. <https://doi.org/10.3184/175815513X13615363233558>

Gentry KE, McKenna MF, Luther DA (2018) Evidence of suboscine song plasticity in response to traffic noise fluctuations and temporary road closures. *Bioacoustics* 27:165–181. <https://doi.org/10.1080/09524622.2017.1303645>

Guénard B, Cardinal-De Casas A, Dunn RR (2015) High diversity in an urban habitat: are some animal assemblages resilient to long-term anthropogenic change? *Urban Ecosyst* 18:449–463. <https://doi.org/10.1007/s11252-014-0406-8>

Hamer AJ, McDonnell MJ (2008) Amphibian ecology and conservation in the urbanising world: A review. *Biol Conserv* 141:2432–2449.

<https://doi.org/10.1016/j.biocon.2008.07.020>

Hartwig E, Clemens T, Heckroth M (2007) Plastic debris as nesting material in a Kittiwake (*Rissa tridactyla*) colony at the Jammerbugt, Northwest Denmark. *Mar Pollut Bull* 54:595–597. <https://doi.org/10.1016/j.marpolbul.2007.01.027>

Hensley CB, Trisos CH, Warren PS, et al (2019) Effects of urbanization on native bird species in three southwestern US cities. *Front Ecol Evol* 7:1–10.
<https://doi.org/10.3389/fevo.2019.00071>

Hui C, Richardson DM, Visser V (2017) Ranking of invasive spread through urban green areas in the world's 100 most populous cities. *Biol Invasions* 19:3527–3539.
<https://doi.org/10.1007/s10530-017-1584-0>

Jagiello Z, Dylewski Ł, Tobolka M, Aguirre JI (2019) Life in a polluted world: a global review of anthropogenic materials in bird nests. *Environ Pollut* 251:717–722.
<https://doi.org/10.1016/j.envpol.2019.05.028>

Janiszewski T, Minias P, Wojciechowski Z (2015) Selective forces responsible for transition to nesting on electricity poles in the white stork *Ciconia ciconia*. *Ardea* 103:39–50. <https://doi.org/10.5253/arde.v103i1.a4>

Katlam G, Prasad S, Aggarwal M, Kumar R (2018) Trash on the menu: patterns of animal visitation and foraging behaviour at garbage dumps. *Curr Sci* 115:2322–2326.
<https://doi.org/10.18520/cs/v115/i12/2322-2326>

- Kaza S, Yao L, Bhada-Tata P, Van Woerden F (2018) What a waste 2.0: a global snapshot of solid waste management to 2050. Urban Development Series., World Bank. Washington, DC
- Klett-Mingo JI, Pavón I, Gil D (2016) Great tits, *Parus major*, increase vigilance time and reduce feeding effort during peaks of aircraft noise. Anim Behav 115:29–34.
<https://doi.org/10.1016/j.anbehav.2016.02.021>
- Lagucki E, Burdine JD, McCluney KE (2017) Urbanization alters communities of flying arthropods in parks and gardens of a medium-sized city. PeerJ 5:e3620.
<https://doi.org/10.7717/peerj.3620>
- Mainwaring MC, Hartley IR (2013) The energetic costs of nest building in birds. Avian Biol. Res. 6:12–17
- McKinney ML (2002) Urbanization, biodiversity, and conservation. Bioscience 52:883–890. [https://doi.org/10.1641/0006-3568\(2002\)052\[0883:UBAC\]2.0.CO;2](https://doi.org/10.1641/0006-3568(2002)052[0883:UBAC]2.0.CO;2)
- McKinney ML (2006) Urbanization as a major cause of biotic homogenization. Biol Conserv 127:247–260. <https://doi.org/10.1016/j.biocon.2005.09.005>
- Mee A, Rideout BA, Hamber JA, et al (2007) Junk ingestion and nestling mortality in a reintroduced population of California Condors *Gymnogyps californianus*. Bird Conserv Int 17:119–130. <https://doi.org/10.1017/S095927090700069X>
- Onrust J, Wymenga E, Piersma T, Olf H (2019) Earthworm activity and availability for

meadow birds is restricted in intensively managed grasslands. *J Appl Ecol* 56:1333–1342. <https://doi.org/10.1111/1365-2664.13356>

Powers RP, Jetz W (2019) Global habitat loss and extinction risk of terrestrial vertebrates under future land-use-change scenarios. *Nat Clim Chang* 9:323–329. <https://doi.org/10.1038/s41558-019-0406-z>

Programa Estado de la Nacion (2018) Estado de la Nación en Desarrollo Humano Sostenible. Pavas, Costa Rica

R Core Team (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL <https://www.R-project.org/>.

Redondo P, Barrantes G, Sandoval L (2013) Urban noise influences vocalization structure in the House Wren *Troglodytes aedon*. *Ibis* 155:621–625. <https://doi.org/10.1111/ibi.12053>

Richards SA (2005) Testing ecological theory using the information-theoretic approach: Examples and cautionary results. *Ecology* 86:2805–2814. <https://doi.org/10.1890/05-0074>

Ruiz-Castellano C, Tomás G, Ruiz-Rodríguez M, et al (2016) Nest material shapes eggs bacterial environment. *PLoS One* 11:1–21. <https://doi.org/10.1371/journal.pone.0148894>

- Silva A Da, Samplonius JM, Schlicht E, et al (2014) Artificial night lighting rather than traffic noise affects the daily timing of dawn and dusk singing in common European songbirds. *Behav Ecol* 25:1037–1047. <https://doi.org/10.1093/beheco/aru103>
- Stiles FG, Skutch AF (1989) *Guía de aves de Costa Rica*. Editorial INBio, Santo Domingo, Heredia
- Stofberg M, Cunningham SJ, Sumasgutner P, Amar A (2019) Juggling a “junk-food” diet: responses of an urban bird to fluctuating anthropogenic-food availability. *Urban Ecosyst* 22:1019–1026. <https://doi.org/10.1007/s11252-019-00885-3>
- Surgey J, Feu CR, Deeming DC, et al (2012) Opportunistic use of a wool-like artificial material as lining of tit (*Paridae*) nests. *Condor* 114:385–392. <https://doi.org/10.1525/cond.2012.110111>
- Townsend AK, Barker CM (2014) Plastic and the nest entanglement of urban and agricultural crows. *PLoS One* 9:1–5. <https://doi.org/10.1371/journal.pone.0088806>
- United Nations, Department of Economic and Social Affairs PD (2019a) *World urbanization prospects: the 2018 revision*. United Nations, New York
- United Nations, Department of Economic and Social Affairs PD (2019b) *World Population Prospects 2019: Highlights*. United Nations, New York
- Villaseñor NR, Driscoll DA, Escobar MAH, et al (2014) Urbanization impacts on mammals across urban-forest edges and a predictive model of edge effects. *PLoS One*

9:1–12. <https://doi.org/10.1371/journal.pone.0097036>

Votier SC, Archibald K, Morgan G, Morgan L (2011) The use of plastic debris as nesting material by a colonial seabird and associated entanglement mortality. *Mar Pollut Bull* 62:168–172. <https://doi.org/10.1016/j.marpolbul.2010.11.009>

Wang Y, Chen S, Blair RB, et al (2009) Nest composition adjustments by Chinese Bulbuls *Pycnonotus sinensis* in an urbanized landscape of Hangzhou (E China). *Acta Ornithol* 44:185–192. <https://doi.org/10.3161/000164509X482768>

Wang Y, Huang Q, Lan S, et al (2015) Common blackbirds *Turdus merula* use anthropogenic structures as nesting sites in an urbanized landscape. *Curr Zool* 61:435–443. <https://doi.org/10.1093/czoolo/61.3.435>

Witteveen M, Brown M, Ryan PG (2017) Anthropogenic debris in the nests of kelp gulls in South Africa. *Mar Pollut Bull* 114:699–704. <https://doi.org/10.1016/j.marpolbul.2016.10.052>

Wu J, Jenerette GD, Buyantuyev A, Redman CL (2011) Quantifying spatiotemporal patterns of urbanization: The case of the two fastest growing metropolitan regions in the United States. *Ecol Complex* 8:1–8. <https://doi.org/10.1016/j.ecocom.2010.03.002>

Zuur AF, Ieno EN, Saveliev AA, Smith GM (2009) Mixed effects models and extensions in ecology with R. Springer Science, New York

TABLES AND FIGURES

Table 1 Number of nests of the clay-colored thrush (*Turdus grayi*) with artificial material, and proportion of nests with each of the materials listed.

Artificial material	Nests	Proportion
Electric wire	1	1.28%
Silicon fragment	1	1.28%
Metallic staple	1	1.28%
Plastic mesh	1	1.28%
Cloth closures	1	1.28%
Plastic tie	3	3.85%
Dental floss	3	3.85%
Plastic thread	5	6.41%
Construction nails	5	6.41%
Sponge	5	6.41%
Polystyrene	5	6.41%
Cigarette butts	5	6.41%
Fishing lines	5	6.41%
Metal fragments	5	6.41%
Concrete	6	7.69%
Glass	6	7.69%
Metal thread	7	8.97%
Solid plastic fragments	10	12.82%
Cloth fragments	11	14.10%
Paint	13	16.67%
Paper	29	37.18%
Sack fibers	31	39.74%
Cotton laces	33	42.31%
Candy wrappers	35	44.87%
Plastic cotton	38	48.72%
Plastic broom fibers	42	53.85%
Cotton threads	51	65.38%
Nests Total	78	

Table 2 Zero inflated generalized linear mixed models (family negative binomial) ranked according to the lowest AICc value explaining the richness of artificial material in clay-colored thrush's nests. Bold text indicates the model that best explain the richness in artificial material types.

Model	K	AICc	Δ AICc
100 m + urbanization level	2	370,5	0,0
100 m + 200 m ring + 400 m ring	3	370,5	0,1
100 m + 200 m ring + 400 m ring + urbanization level	4	371,5	1,1
Urbanization level	1	371,7	1,3
200 m ring + urbanization level	2	373,7	3,2
400 m ring + urbanization level	2	373,7	3,2
100 m	1	373,9	3,4
400 m ring	1	374,6	4,1
Null	1	379,6	9,1
200 m ring	1	380,0	9,5

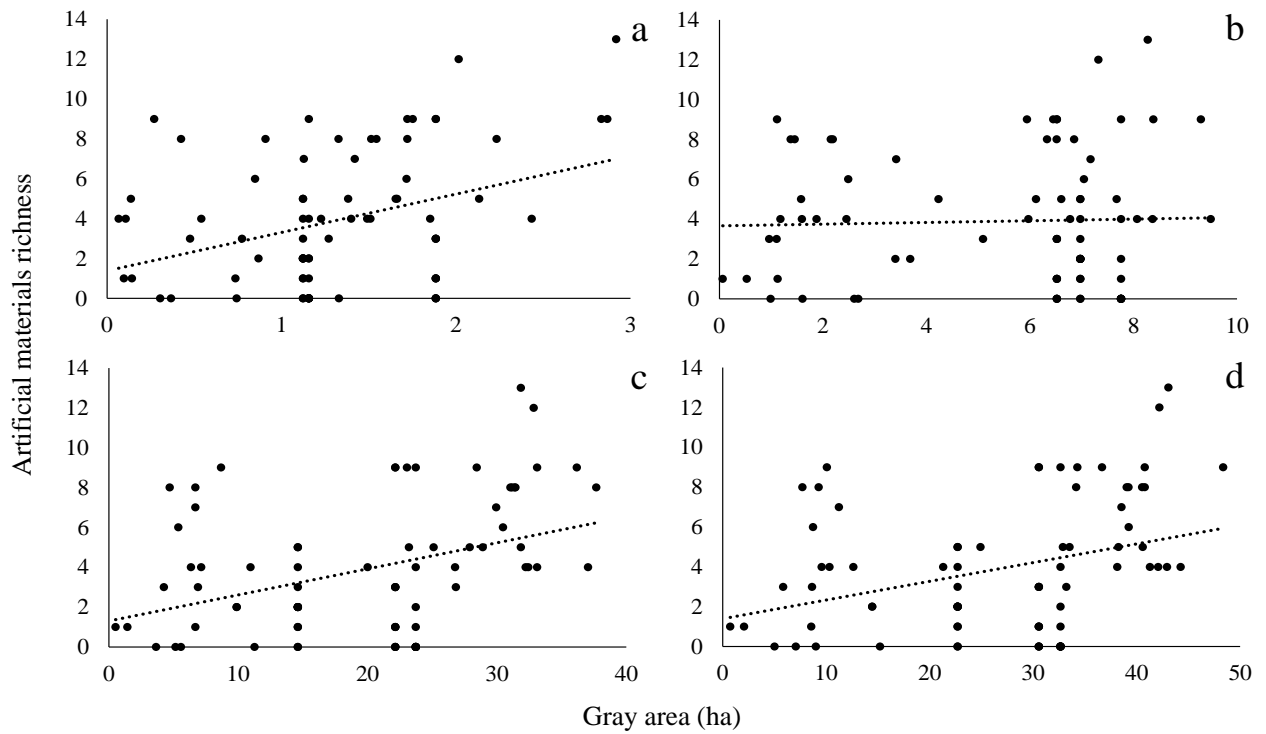


Figure 1 Relationship between artificial material richness and gray area (ha) in a) 100 m radius circular plot, b) 200 m ring c) 400 m ring and d) 400 m radius circular plot. Each point represents one clay-colored thrush's nest.

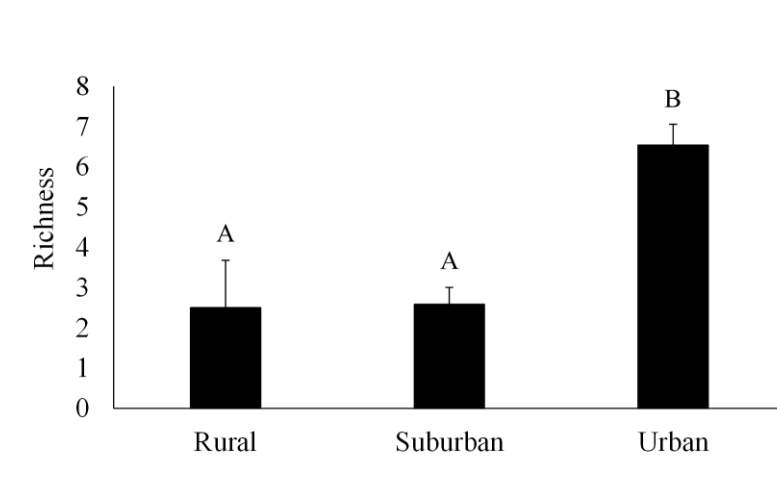


Figure 2 Artificial material richness mean (\pm EE) in nests of clay-colored thrush by urbanization level. Rural and suburban differs from urban level. Letters indicate differences among groups for urbanization level (Tuckey test).



Figure 3 Clay-colored thrush's nests with artificial materials. Downer photos show artificial materials in upper nests' structure (Cam= nest camera, Par= Nest walls).