Experimental protocol to repel opossums (*Didelphis marsupialis*) through an artisanal odor repellent device

*Protocolo experimental para ahuyentar zarigüeyas (*Didelphis marsupialis*) mediante un dispositivo artesanal de olor repelente*

*Protocolo experimental para repelir gambás (*Didelphis marsupialis*) por meio de um dispositivo artesanal de odor repelente*

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Abstract

Background: The human-opossum (*Didelphis marsupialis*) conflict has increased during the last decades mainly due to natural habitat loss and mediated by the opossum’s generalist and opportunistic habits. **Objective:** A potential solution to reduce this conflict is to discourage the opossum’s presence in human settlements without affecting the welfare of both parts. With this purpose we developed an artisanal odor device with three different chemicals: citronella, ammonia and creolin, and tested their effectiveness to drive away opossums. **Methods:** We first attracted local opossums using fruits or canned sardines as bait in two areas, an urban natural park (n = 2 sites), and in a peri-urban forest reserve (n = 4 sites), both in Envigado, Antioquia, Colombia. Posteriorly we installed the odor device with one of three chemicals on each site and for two weeks. The cycle was repeated with all chemicals in all sites. The number of opossums per night was recorded daily using camera-traps with bait and bait+chemical. **Results:** We found that ammonia and creolin were associated to fewer opossums/night, even when the sites were still baited, and that citronella did not decrease the presence of opossums/night when added to the baited sites. In addition, the number of opossums per night was higher in the urban park relative to the forest reserve. **Conclusion:** We suggest to further test the repellent effect of ammonia and creolin on real human-opossum conflict scenarios, however caution is warranted given its irritant, flammable, and corrosive properties.

**Keywords:** aversive conditioning; deterrent; *Didelphis marsupialis*; human-opossum conflict; odors; opossums; repellents; urban wildlife; wildlife; wildlife management.

Resumen

**Antecedentes:** el conflicto humano-zarigüeya (*Didelphis marsupialis*) se ha acrecentado en las últimas décadas debido principalmente a la pérdida de hábitats naturales y mediado además por los hábitos generalistas y oportunistas de las zarigüeyas. **Objetivo:** una posible solución para disminuir este conflicto es desalentar la presencia de zarigüeyas en áreas habitadas por humanos, sin afectar el bienestar de las partes. Con este objetivo nosotras
desarrollamos un dispositivo artesanal de olor con tres químicos diferentes: citronela, amoníaco, y creolina, y probamos su efectividad para ahuyentar las zarigüeyas. **Métodos:** inicialmente cebamos con frutas o sardinas enlatadas para atraer las zarigüeyas locales en dos áreas, un parque natural urbano (n = 2 sitios), y una reserva forestal peri-urbana (n = 4 sitios), ambas en Envigado, Antioquia, Colombia. Posteriormente instalamos el dispositivo con uno de los tres químicos en cada sitio durante dos semanas. El ciclo se repitió con los tres químicos en todos los sitios. El número de zarigüeyas/noche fue registrado diariamente con cámara-trampas con cebo y con cebo + químico. **Resultados:** encontramos que el amoníaco y la creolina estuvieron asociados con un menor registro de zarigüeyas/noche, aun cuando los sitios aún tenían cebo. Por otro lado, cuando se adicionó citronela, el número de zarigüeyas/noche no disminuyó. Adicionalmente, el número de zarigüeyas/noche registradas en el parque urbano fue mayor relativo a la reserva forestal peri-urbana. **Conclusión:** sugerimos evaluar el efecto ahuyentador del amoníaco y la creolina en ambientes de conflictos humano-zarigüeyas reales, tomando precauciones en su manipulación dadas sus propiedades irritantes, corrosivas e inflamables.

**Palabras clave:** Conflicto humano-zarigüeya; condicionamiento aversivo; *Didelphis marsupialis*; disuasores; fauna silvestre urbana; manejo de fauna silvestre; olores, repelentes; zarigüeyas.

**Resumen**

**Antecedentes:** el conflicto humano-gambá (*Didelphis marsupialis*) ha aumentado durante las últimas décadas debido principalmente a la pérdida de hábitat natural y ha sido mediado por hábitos generalistas y oportunistas del gambá. **Objetivo:** una solución potencial para reducir este conflicto es desencadenar la presencia de gambás en asentamientos humanos sin afectar el bienestar de ambas partes. Con este objetivo, desarrollamos un dispositivo artesanal de olor con tres diferentes productos químicos: citronela, amoníaco y creolina, y probamos su eficacia para afastar gambás. **Métodos:** inicialmente atraímos gambás locales usando frutas o sardinas en lata como isca en dos áreas, un parque natural urbano (n = 2 locais) y una reserva forestal periurbana (n = 4 locais), ambos en Envigado, Antioquia, Colômbia.
Posteriormente, instalamos o dispositivo de odor usando um dos três produtos químicos em cada local durante duas semanas. O ciclo foi repetido com todos os três produtos químicos em todos os locais. O número de gambás/noite foi registrado diariamente usando câmera-armadilhas com isca e isca+produto químico. **Resultados:** verificamos que a amônia e a creolina estiveram associadas ao menor número de gambás/noite, mesmo quando os locais ainda estavam iscados, e que a citronela não diminuiu a presença de gambás/noite quando adicionada aos locais iscados. Além disso, o número de gambás/noite foi maior no parque urbano em relação à reserva florestal. **Conclusão:** sugerimos avaliar o efeito repelente da amônia e da creolina em cenários reais de conflito entre humanos e gambás; no entanto, deve-se ter cuidado devido às suas propriedades irritantes, inflamáveis e corrosivas.

**Palavras-chave:** conflito homem-gambá; condicionamento aversivo; *Didelphis marsupialis*; dissuasivo; vida selvagem urbana; manejo da vida selvagem; odores, repelentes; gambás.

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**Introduction**

Human-wildlife conflict can be defined as a state of hostility or fight, in which either one part has an adverse effect on the other (Redpath *et al.*, 2015). In the metropolitan area of the Antioquia department (Colombia) the human-opossum conflict is a current concern (Delgado, 2007) as reported by Fundación Zarigüeya (FUNDZAR), a Colombian NGO that works for the opossums’ welfare. From 2018 to 2020 FUNDZAR received 3,008 opossum-related calls from citizens asking for help. From this total, 62.6% were road-kills, 14.9% were dog or cat attacks, 10.1% were hard-objects hitting, and 9.7% orphaned opossums (F. Flórez, director FUNDZAR, personal communication, June 15, 2021).

The common opossum (*Didelphis marsupialis*, Didelphidae) is a neotropical mammal distributed from Mexico to Argentina. They have a highly unrestrictive and opportunistic diet, are skillful in arboreal and terrestrial environments, and have a high reproductive potential of up to 10 young twice a year (McManus, 1970; Flórez-Oliveros and Vivas-Serna, 2020). These characteristics have conferred it an ecological success to exploit a wide variety of habitat types (McManus, 1970; Sunquist *et al.*, 1987; Vaughan and Hawkins, 1999). On
the other side, Antioquia has a high deforestation associated to pasture establishment, urban expansion, and wildland fires (González-Caro and Vásquez, 2017). These conditions are difficult to manage, and the human-opossum conflict may worsen (Rueda et al., 2013) if no practical solutions are implemented at least to discourage their encounters.

Several repellent methods have been proposed to mitigate wildlife-human conflicts, including acoustic, visual, odor, electric and irritant systems (Mason, 1998; Gerisoli and Pereira, 2020). Electrical fencing, trip alarms, and warning calls have also been used, however these were expensive and not viable in the long term (O’Connell-Rodwell et al., 2000). Other methods, such as burning animal feces with ground chillies to produce a noxious smoke, were more effective and inexpensive (Osborn and Parker, 2002). Plant oils are also used as olfactory repellents and wolf urine as anti-predator response to repel deer, however, these were not effective perhaps due to a rapid habituation (Elmeros et al., 2011).

To our knowledge no odor repellents have been systematically tested on opossums, thus herein we tested three chemicals, citronella, ammonia, and creolin, as potential odor repellents. We set camera-traps to estimate the frequency of opossum’s reactions to these repellents in two localities of Envigado, and report the wildlife observed at these sites to contribute to the local species richness knowledge.

Materials and Methods

This study was approved by the Committee on Ethics in Animal Research of the University of Antioquia (Act 114, December 5th, 2017).

Study sites

We chose six sites in two localities to test for the effectiveness of three chemicals as odor repellents on opossums in the municipality of Envigado, department of Antioquia, Colombia. Four sites were located at the peri-urban natural forest, La Morena (Morena 1, 2, 3, 4), and
two sites at the urban park La Heliodora (Heliodora 1, 2). La Morena Ecologic Reserve is a peri-urban forest with 37 hectares located at vereda El Escobero at 2,200 m.a.s.l., while La Heliodora is an urban park with 24 hectares at an elevation of 1575 m.a.s.l. (Alcaldía de Envigado, 2016). We chose four sites in La Morena and only two sites in La Heliodora because the later has a higher number of visitants, day and night, and there was a potential risk of losing the equipment. We installed one camera-trap per site (three Bushnell Trophy Cam Essential 12mp, two Bushnell Trophy Cam Hd Aggesso 14mp, and a Cuddeback 20mp IR plus) which were set to record 20-seconds videos with 10-seconds intervals, and with a high level of movement sensitivity. The camera-traps recorded the presence of opossums (or any species) from April to October 2018, although the total number of sampling days slightly varied on the sites due to rough environmental conditions.

*Chemicals and chemical odor devices*

Three chemicals were used in this study: citronella, ammonia, and creolin. Citronella (CAS registry number 8000-29-1) is a water-insoluble oil extracted from an aromatic plant, *Cymbopogon nardus* (density 0.85 g/mL). It has a light-yellow color, citric smell, and is efficient as insect repellent (Sharma *et al*., 2019). Ammonia or ammonium hydroxide (CAS registry number 7664-41-7) is a solution of NH₃ in water (24-28%), colorless, highly irritant, and water-soluble. Citronella and ammonia were bought from local chemical retail stores, e.g., Quimicos JM S.A., and Protokimica. Creolin (CAS registry number 12751-04-1) is a natural disinfectant and an over-the-counter product mainly composed of phenol (17%). It is commonly used as antiseptic to clean wounds, bathrooms, and barns at low concentrations, although in higher concentrations can cause severe toxicity (Vearrier *et al*., 2015). This chemical was purchase from different labs, but all had the same phenol concentration, e.g., Fenolgan® produced by Fenolgan laboratory, or Especifico® distributed by Rotam Agro Colombia.

Six devices were elaborated by hand and with low-cost materials to contain the chemicals. These consisted of five-gallon plastic containers (40 cm diameter, 50 cm high), with four 2
cm holes below the lid. Then a foam strip (100 × 4 × 4 cm) was wrapped inside the container, and then the liquid chemicals were added until the foam strip was covered. The liquid chemical was added so its gases spread out of the container through the holes.

Experimental design

All sites were initially baited with fruit (ripe mango or plantain wrapped in a piece of veil and hanged from a tree) or canned sardines to habituate the resident opossums for approximately three to four months. Immediately afterwards, the chemical devices were installed besides the bait, one device per site for two weeks. A new cycle started by removing the device and baiting again for two weeks, and then adding a second chemical for two weeks again. Each of these cycles were repeated on each site only changing the chemical used until all three chemicals were tested on each site. First, we added the citronella, then the ammonia, and lastly the creolin (Table 1). The cameras were recording the activity of each site permanently, and every 14 days they were checked to retrieve the videos and identify the wildlife species visiting the sites. Site Morena 1 was chosen as a control site and the device installed there had no chemical inside. The control site was used to test that the container itself did not affect the frequency of opossums observed.

Table 1. Experimental design used in this study indicating the treatment (only bait or bait+chemical) used on each site.

| Site (bait) | Treatment (days of each cycle) |
|-------------|--------------------------------|
| Morena 1 =  | bait (92 d)                    |
| Control site| bait+empty container (14 d)    |
| (fruit)     |      | bait (20 d)                    |
|             |      | bait+empty container (16 d)    |
|             |      | bait (13 d)                    |
|             |      | bait+empty container (14 d)    |
| Heliodora 1 | bait (95 d)                    |
| (fruit)     |      | bait + citronella (14 d)       |
|             |      | night + ammonia (16 d)         |
|             |      | night + creolin (14 d)         |
Heliodora 2  
(sardines)  
bait  (95 d)  
bait + citronella (14 d)  
bait  (20 d)  
bait + ammonia (16 d)  
bait  (13 d)  
bait + creolin (14 d)

Morena 2  
(fruit)  
bait  (117 d)  
bait + citronella (14 d)  
bait  (20 d)  
bait + ammonia (16 d)  
bait  (13 d)  
bait + creolin (14 d)

Morena 3  
(fruit)  
bait  (103 d)  
bait + citronella (14 d)  
bait  (20 d)  
bait + ammonia (16 d)  
bait  (13 d)  
bait + creolin (14 d)

Morena 4  
(sardines)  
bait  (113 d)  
bait + citronella (14 d)  
bait  (20 d)  
bait + ammonia (16 d)  
bait  (13 d)  
bait + creolin (14 d)

The number in parenthesis indicate the duration of each cycle. d: days.

Data analysis

There were nights with several videos obtained at different times, however it was not possible to differentiate if it was the same or a different individual as many videos were recorded within 60 min at the same site. Thus, to be conservative we counted only the number of nights with opossum records (and nights without opossum records) regardless of the nightly number of videos obtained. The capture success was calculated by dividing the number of nights that opossums were recorded by the number of camera trap-nights and multiplying the result by 100 (Srbek-Araujo and Chiarello 2013). Fisher’s exact tests of independence were used to test the null hypothesis that the proportion of opossums/night (number of nights with opossum / number of nights without opossums) without the chemical (citronella, ammonia, or creolin) is not different than the proportion of opossums with the chemical. This null hypothesis would indicate that the chemical did not repel the opossums. P values below 0.05 were considered significant to reject the Ho and accept the alternative hypothesis that the proportions varied, i.e., that the chemical repelled the opossums. Fisher's exact test is more accurate than the Chi-square test when the expected numbers are small, i.e., when sample
size is less than 20 in a $2 \times 2$ contingency table (McCrum-Gardner 2008). Fisher´s exact tests were done using the function fisher.test in package stats version 4.0.2 in R environment.

**Results**

**Repellent effectiveness**

In this study we compared the proportion of opossums recorded (nights with opossums / nights without opossums) using bait alone vs. bait plus one of the three different chemicals expecting to drive the opossums away. The proportions were statistically different with ammonia and creolin, but not with citronella, at some sites (Table 2). Specifically, we found that there were less opossums when ammonia was added at Heliodora 2 and overall (counting all sites together; $p<0.0008$ and $p<0.0007$, respectively); and there were less opossums when creolin was added at Morena 4 and overall ($p<0.0003$ and $p<0.0113$, respectively). Citronella showed no effect on the presence or absence of opossums at either of the sites tested nor overall ($p>0.05$ all sites and overall).

The results were significant in spite that other factors also affected the proportion of opossums recorded, i.e., the sampling site and the bait used. There were more opossums at the urban park La Heliodora (n = 43, in two sites) than at the peri-urban forest La Morena (n = 17, in three sites) when bait alone was used ($p<0.0001$). Also, overall, there were 38% more opossums captured when sardines were used as bait (21 opossums/187 nights) compared to fruits (14 opossums/331 nights; $p<0.007$).

**Opossums’ nocturnal activity**

Although the chemical devices were let in place from May to October 2018, the cameras stayed in place longer, until February 2019. In this way we obtained a total of 244 videos recording opossums at five sites (Heliodora 1 and 2, and Morena 1, 2 and 4). The activity peak of opossums was recorded by midnight at both sites, the urban park, and the peri-urban forest, starting by 18:00 hours and ending by 8:00 (Figure 1). Although there seems to be a
tendency to start the activity earlier in the afternoon and finish later in the morning at the urban site, we found no statistical difference in the frequency distributions between both sites (p = 0.297).
Table 2. Number of days with opossums/number of days without opossums discriminated by site and treatment (bait or bait+chemical).

| Site          | Bait          | Bait + Citronella | p       | Interpretation       | Bait            | Bait + Ammonia | p       | Interpretation       | Bait            | Bait + Creolin | p       | Interpretation       |
|---------------|---------------|-------------------|---------|----------------------|-----------------|----------------|---------|----------------------|-----------------|----------------|---------|----------------------|
| Control site  | 8/109         | 0/14              | 0.599   | No effect as expected| 1/19            | 0/16           | 1       | No effect as expected| 1/12            | 0/14           | 0.481   | No effect as expected|
| Heliodora 1   | 10/85         | 0/14              | 0.355   | No effect            | 3/17            | 0/16           | 0.238   | No effect            | 1/12            | 0/14           | 0.481   | No effect            |
| Heliodora 2   | 16/79         | 4/10              | 0.284   | No effect            | 10/10           | 0/16           | **0.001** | Repellent effect*   | 3/10            | 3/11           | 1       | No effect            |
| Morena 2      | 4/113         | 0/14              | 1       | No effect            | 0/20            | 0/16           | 1       | NA                   | 0/13            | 0/14           | 1       | NA                   |
| Morena 3      | 0/133         | 0/14              | 1       | NA                   | 0/20            | 0/16           | 1       | NA                   | 0/12            | 0/15           | 1       | NA                   |
| Morena 4      | 5/108         | 0/14              | 1       | No effect            | 0/20            | 0/16           | 1       | NA                   | 8/4             | 0/15           | **0.000** | Repellent effect    |
| Overall       | 35/518        | 4/66              | 1       | No effect            | 13/87           | 0/80           | **0.001** | Repellent effect    | 12/51           | 3/69           | **0.011** | Repellent effect    |

Bold p values reject the null hypothesis and suggests the chemical had a repellent effect, e.g.: *Ammonia decreased the number of days with opossums (from 10 to 0) and increased the number of days without opossums (from 10 to 16). NA = not possible to test the potential repelling effect of the chemical because there were no opossums to repel.
Figure 1. Nocturnal activity of opossums recorded at the urban park La Heliodora and the peri-urban forest La Morena.

Wildlife species richness

During this study we recorded a higher species richness at the peri-urban forest La Morena than at the urban park La Heliodora (pooling results from all sites within each one). This is, we recorded 9 different species of mammals of medium and large body size (including *Dasypus novemcinctus*, *Potos flavus*, *Eira barbara*, *Mustela frenata*, *Cerdocyon thous*, and *Herpailurus yagouaroundi*), and 9 birds at La Morena At the urban park we recorded 3 mammals of smaller body size (*Notosciurus granatensis* and *Cerdocyon thous*) and 3 birds (Table 3). Opossums were observed at all sites, La Heliodora urban park and at La Morena peri-urban forest (except at Morena 3), and they were always among the top three species more common at both sites. However, and as expected, opossums were more common at the urban park than at the peri-urban natural forest. This is, we recorded opossums in 42 nights using 324 camera trap-nights at Heliodora urban park (capture success = 12.96%), compared
to 30 nights using 768 camera trap-nights at la Morena (capture success = 3.9%). The real number of opossums were probably higher given that we counted only the number of nights with at least one video record, not opossums’ records to avoid counting the same individual several times.

**Table 3.** Wildlife species richness recorded during this study at the peri-urban natural forest La Morena and the urban park La Heliodora, Envigado, Antioquia, Colombia.

| Species                      | Local common name (in Spanish) | Observation records | Capture success |
|------------------------------|--------------------------------|---------------------|-----------------|
| Ortalis columbiana           | Guacharaca colombiana          | 12                  | 6.2%            |
| Didelphis marsupialis        | Zarigüeya común               | 10                  | 5.2%            |
| Eira barbara                 | Hurón mayor                   | 4                   | 2.1%            |
| Leptotila verreauxi          | Paloma rabiblanca             | 4                   | 2.1%            |
| Cercocyon thous              | Perro de monte                | 3                   | 1.5%            |
| Notosciurus granatensis      | Ardilla de cola roja          | 3                   | 1.5%            |
| Catharces aura               | Gallinazo de cabeza roja      | 2                   | 1.0%            |
| Chamaepetes goudotii         | Pava maraquera                | 2                   | 1.0%            |
| Sylvilagus nicefori          | Conejo de bosque              | 2                   | 1.0%            |
| **Total**                    |                                | 42                  |                 |

| Species                      | Local common name (in Spanish) | Observation records | Capture success |
|------------------------------|--------------------------------|---------------------|-----------------|
| Didelphis marsupialis        | Zarigüeya común               | 4                   | 2.1%            |
| Cercocyon thous              | Zorro cangrejero              | 3                   | 1.5%            |
| Notosciurus granatensis      | Ardilla de cola roja          | 3                   | 1.5%            |
| Dasypus novemcinctus         | Armadillo de nueve bandas     | 2                   | 1.0%            |
| Potos flavus                 | Perro de monte                | 2                   | 1.0%            |
| Eira barbara                 | Hurón mayor                   | 1                   | 0.5%            |
| Leptotila verreauxi          | Paloma rabiblanca             | 1                   | 0.5%            |
| Ortalis columbiana           | Guacharaca colombiana         | 1                   | 0.5%            |
| **Total**                    |                                | 17                  |                 |

| Species                      | Local common name (in Spanish) | Observation records | Capture success |
|------------------------------|--------------------------------|---------------------|-----------------|
| Leptotila verreauxi          | Paloma rabiblanca             | 16                  | 8.4%            |
| Chamaepetes goudotii         | Pava maraquera                | 15                  | 7.9%            |
| Notosciurus granatensis      | Ardilla de cola roja          | 14                  | 7.4%            |
| Especies no identificadas    | Not applicable                | 6                   | 3.2%            |
| Rhynchortyx cinctus          | Perdiz selvática              | 3                   | 1.6%            |
| Dasypus novemcinctus         | Armadillo de nueve bandas     | 2                   | 1.1%            |
| Species                        | Common Name              | Count | Percentage |
|-------------------------------|--------------------------|-------|------------|
| Momotus aequatorialis         | Barranquero              | 2     | 1.1%       |
| Cercocyon thous               | Zorro cangrejero         | 1     | 0.5%       |
| Eira barbara                  | Hurón mayor              | 1     | 0.5%       |
| Ortalis columbiana            | Guacharaca colombiana    | 1     | 0.5%       |
| **Total**                     |                          | 45    |            |

Morena 4 (sampling nights = 190, April 24 to October 27, 2018)

| Species                        | Common Name              | Count | Percentage |
|-------------------------------|--------------------------|-------|------------|
| Chamaepetes goudotii          | Pava maraquera           | 20    | 10.5%      |
| Leptotila verreauxi           | Paloma rabiblanca        | 17    | 8.9%       |
| Didelphis marsupialis         | Zarigüeya común          | 14    | 7.4%       |
| Especies no identificadas     | Not applicable           | 13    | 6.8%       |
| Notosciurus granatensis       | Ardilla de cola roja     | 7     | 3.7%       |
| Eira barbara                  | Hurón mayor              | 7     | 3.7%       |
| Henicorhina leucophrys        | Cucarachero pechigris    | 5     | 2.6%       |
| Cercocyon thous               | Zorro cangrejero         | 1     | 0.5%       |
| Coragyps atratus              | Gallinazo                | 1     | 0.5%       |
| Herpailurus yagouaroundi      | Yaguarundí               | 1     | 0.5%       |
| Mustela frenata               | Comadreja de cola larga  | 1     | 0.5%       |
| Potos flavus                  | Perro de monte           | 1     | 0.5%       |
| Rhynchortyx cinctus           | Perdiz selvática         | 1     | 0.5%       |
| Zonotrichia capensis          | Gorrión americano        | 1     | 0.5%       |
| **Total**                     |                          | 90    |            |

Heliodora 1 (sampling nights = 162, May 9 to October 27, 2018)

| Species                        | Common Name              | Count | Percentage |
|-------------------------------|--------------------------|-------|------------|
| Didelphis marsupialis         | Zarigüeya común          | 14    | 8.6%       |
| Notosciurus granatensis       | Ardilla de cola roja     | 16    | 9.9%       |
| Momotus aequatorialis         | Barranquero              | 1     | 0.6%       |
| **Total**                     |                          | 31    |            |

Heliodora 2 (sampling nights = 162, May 9 to October 27, 2018)

| Species                        | Common Name              | Count | Percentage |
|-------------------------------|--------------------------|-------|------------|
| Didelphis marsupialis         | Zarigüeya común          | 28    | 17.3%      |
| Notosciurus granatensis       | Ardilla de cola roja     | 11    | 6.8%       |
| Cercocyon thous               | Zorro cangrejero         | 2     | 1.2%       |
| Rupornis magnirostris         | Gavilán pollero          | 1     | 0.6%       |
| **Total**                     |                          | 42    |            |

Opossum records = number of nights when the species was observed (not the number of opossum records per night, see data analyses section).

Discussion
In this study we found that ammonia and creolin, but not citronella, had a significant effect to repel opossums even when bait was still available, and when data from all sites was pooled together (regardless of the site). However, in some of the sites (i.e., Morena 2, 3 and 4, table 2), no opossums, or too few, visited the site tested, making impossible to test the chemicals at those specific sites with no opossums. Real situations, where human-opossum conflict, are the scenarios where these chemicals should be tested next without having to bait the area to attract the opossums. Ammonia and human urine have been used successfully to deter and drive away black bears when humans encountered them in Montana (Hunt 1977), and red pepper (capsaicin) sprays in Alaska (Smith et al., 1998) as well. Furthermore, it should be considered that the effectiveness of any chemical tested may be affected by several factors, including weather conditions such as rain, relative humidity, wind temperature, the variability of the opossum population density throughout the year (Mason, 1998; this study), and the bait used (this study).

Chemical repellents act in different ways, they may produce sensory irritation, semiochemical mimicry (e.g., pheromones or allomones), or digestive malaise (Brown et al., 1970; Borden, 1989; Mason, 1998). Ammonia gasses can be very harmful to humans if lethal amounts are inhaled, they may cause larynx blocking and lungs distension and congestion (ATSDR, 2004). Creolin case is like ammonia in that exposure to phenol, its main constituent, may be rapidly absorbed through the skin, respiratory and digestive systems conducing to a systemic toxicity (Vearrier et al., 2015). Thus, like the effect of capsaicin (the active component of chili peppers) in some mammals (Norman et al., 1992; Smith et al., 1998), the repellent efficiency of ammonia and creolin in opossums was likely sensorial, and its efficiency may lie in that they produce irritation and short-term pain, its avoidance is immediate, no learning is required, and adaptation to learn its avoidance is minimal (Mason, 1998; Osborn and Parker, 2002). Further toxicity effects on animals are unknown.

On the other hand, although citronella is mainly used as mosquito repellent (Muller et al., 2009), finding that it does not repel opossums supports the thesis that irritants are effective within some taxa (insects), but rarely among others (mammals or birds) (Mason, 1998). In
addition, citronella is used as a fragrance ingredient in cosmetics, and has antibacterial,
antifungal and antiparasitic properties (Sharma et al., 2019; Kamal et al., 2020), properties
that seem desirable rather than unpleasant.

An important question is whether opossums could get habituated to chemical repellents.
Previous studies have shown that mammals can get habituated to pungent chemicals, such as
wolverines (Gulo gulo) to lambs with a mixture of olfactory aversive oils in a dispenser
attached to the neck and ear-tags. This result however was observed when wolverines did not
have untreated lambs as an alternative to eat (Landa et al., 1998; Landa and Tømmerås 2015;
Smith et al., 2000). Whether opossums can get used to ammonia or creolin would need to be
properly tested. Meanwhile, if chemical repellents are to be used, it would be advisable to
use them only when really needed and not as a preventive measure for long periods of time.

Finally, the wildlife diversity recorded in our study was known already in Envigado and the
Área Metropolitana (Alcaldía de Envigado, 2018). The urban park held a lower species
richness, but opossums were relatively more common than at the natural forest. This is
expected given that opossums are highly unselective in its food habits and may take
advantage from any resources (McManus 1970), including trash cans in urban parks
(personal communication with park rangers). They also have been reported in diverse
environments associated to humans such as crops and roads (Orjuela and Jiménez 2004).
This finding is rather important because opossums may have been underestimated in its
ecological role in urban environments as evidenced by the current human-opossum conflict
going on in Antioquia (FUNDZAR personal communication). It is common species, not
species richness, the ones expected to shape the environment by having more interactions
with other species and the habitat itself (Gaston, 2010; Winfree et al., 2015). Populations of
common species may decline because they are the first to suffer from any pressure on
biodiversity (Gaston, 2010), and even more serious is the case of species in direct conflict
with humans. Thus, future studies to monitor opossums’ abundance are desirable.
In conclusion, ammonia and creolin were chemicals that have the potential to repel opossums. Citronella on the other hand had no effect on reducing the number of opossums. These chemicals were tested in natural habitats, thus next they should be tested on real human-opossums conflict scenarios to probe their repellent potential; however, caution is warranted given its irritant, flammable, and corrosive properties. Nonetheless, we suggest that any management action to improve the welfare of mistreated opossums should be accompanied by education, so we humans learn to value and cohabit peacefully with synanthropic wildlife.

Declarations

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Conflicts of interest

The authors declare they have no conflicts of interest with regard to the work presented in this report.

Authors contributions
KN Rodríguez and DR. Aguirre conceived the study, collected field data, and wrote the final report. CP Ceballos conceived the experimental design, administered the project, performed the statistical analyses, and wrote the manuscript.

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