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WILDLIFE RESEARCH

Evaluation of 8 years of fertility control (nicarbazin) to manage urban pigeon populations

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ABSTRACT

Context. The common pigeon (*Columba livia var. domestica*) is a synurbic species widely distributed around the world. High local densities of pigeons have negative impacts on animal and public health. Urban pigeon fouling also damages buildings and infrastructures, resulting in increased maintenance costs. Although the reduction of food and shelter would be the most effective control method, it does not apply in most cases where the amount of shelter and food can be unlimited and control very difficult achieve. However, a reduction and control of the population by fertility control using nicarbazin (NCZ, Ovistop®) could be achieved without the need to capture and remove any specimens. **Aim and methods.** The aims of this study were (1) to describe the experience of up to 8 years of use of fertility control by NCZ on pigeon numbers in 24 towns and cities in Catalonia (Spain), (2) to assess the potential for non-target species to be affected by NCZ, and (3) to quantify the costs of implementing local population control of urban pigeons via NCZ. Local number of pigeons was estimated via population censuses. **Key results.** From the beginning of the treatment, a significant steady decreasing trend (average of −12% per year) in the pigeon abundance was registered. In very few instances, non-target birds species were observed to feed on NCZ. **Conclusions and implications.** NZC was an effective and selective method of animal welfare to reduce the total number of pigeons in the municipalities included in this study, while not affecting other non-target species. The estimated cost of the annual treatment was €33.6 per pigeon; in 68% of the municipalities, the total annual cost was halved after 3 years of treatment. The findings of this study are in agreement with previous experiences controlling pigeon colonies by using NCZ in other countries.

Keywords: breeding biology, *Columba livia var. domestica*, contraception, population control, population management, urban ecology, urban wildlife, wildlife conflict.

Introduction

The common pigeon (*Columba livia* var. *domestica*) is a synurbic species widely distributed around the world (Luniak 2004). Its high breeding rate, the existence of a large number of resources and the lack of predators often causes relatively high local pigeon densities, with the species being often referred to as 'overabundant'. Pigeon overpopulation can negatively affect the health of the pigeons themselves, lead to conflicts between pigeons and humans, and, in some cases, pose a public health risk because pigeons act as vectors of several pathogens including *Chlamydophila psittaci, Cryptococcus neoformans and Salmonella* (Haag-Wackernagel and Moch 2004). Urban pigeon fouling also damages buildings, monuments and infrastructures, resulting in increased maintenance costs (Giunchi *et al*. 2012).

For these reasons, overabundant populations of urban pigeons must be managed to reduce the negative impacts of this species. Apart from the physical measures to prevent pigeons from resting on buildings and monuments (spikes, networks), several methods have been applied to reduce bird numbers. Although the reduction of food and shelter would be the most effective in theory, it does not apply in most cities where pigeons' access to widespread shelter and food often cannot be prevented. Culling, traditionally

Collection: Fertility Control for Wildlife in the 21st Century used to control urban pigeons, has been show to be ineffective (Senar *et al.* 2009) and there is also a growing public concern regarding lethal methods of population control (Fagerstone *et al.* 2008, 2010; Massei and Cowan 2014).

An alternative that has been used successfully in Italy, Spain, Belgium, Portugal, USA and Hungary has been the reduction of the birth rate by using a contraceptive based on nicarbazin (NCZ) as the active ingredient of baits (Lavín *et al.* 2006; Avery *et al.* 2008; Ferri *et al.* 2009; Albonetti *et al.* 2015; González-Crespo and Lavín 2022). A reduction in birth rate leads to a progressive reduction in the number of individuals. Therefore, a reduction of the local number of pigeons can be achieved without the need to capture and eliminate any animals. For this reason, this method is supported by the public.

When using oral contraceptives, potential consumption by non-target species must be minimised (González-Crespo and Lavín 2022). Although the NCZ treatment has been shown to be safe for some non-target species, concerns about potential negative effects on other wildlife and ecosystems have persisted. Hence, the monitoring of contraceptive uptake by non-target species is an important aspect of pigeon population management. In addition, very few studies have reported the costs of implementing fertility control for wildlife, although this aspect is a key element when public authorities assess cost and benefits of different methods for reducing human–wildlife conflicts.

The aims of this study were (1) to describe the results of up to 8 years of use of fertility control by NCZ in 24 towns and cities in Catalonia (Spain), (2) to assess the potential for non-target species to be affected by NCZ, and (3) to quantify the costs of implementing local population control of urban pigeons by using NCZ.

Materials and methods

The product

The oral contraceptive used was Ovistop® (produced by ACME Srl, Italy), a veterinary drug with NCZ as an active ingredient in a concentration of 800 mg/kg of bait. The bait was composed of corn kernels, dimethycone, stearic acid and butylated hydroxytoluene.

NCZ belongs to the carbanylide group. It is an equimolar complex of 4.4′dinitrocarbanilide (DNC) and 2-hydroxy-4,6-dimethylpirimidine (HDP). DNC is the active component, whereas HDP prevents DNC aggregation and allows its absorption in the gut (Rogers *et al.* 1983). Pigeons treated with 400 ppm NCZ concentration ceased egg-laying and recovered usual egg-laying rates after NCZ treatment was suspended (Jones *et al.* 1990; Hughes *et al.* 1991; Bursi *et al.* 2001; Johnston *et al.* 2002; Yoder *et al.* 2005). The effects are confined to the fertilisation and maturation processes of the egg, without interference with physiological processes, including those related to the reproductive system (Bursi *et al.* 2001).

Method of administration

The treatment was applied from 15 March to 15 December annually. The NCZ-treated bait was administered via automatic hopper feeders (AHF, Fig. 1*a*, *b*). Each AHF spread the corresponding dose (8 g/pigeon) daily at 07:30 hours by a motor dispersing the bait ~5 m. To adjust the dose, a pre-baiting for 15 days was conducted by attracting pigeon to the AHF by using plain corn kernels. The number of pigeons attracted to the site was measured once per week. Once the number was stable, treatment began with Ovistop®, adjusting the dose to the number of pigeons. During January, February and the first 2 weeks of March, plain corn kernels were supplied in a dose of 4 g/pigeon.day to attract pigeons to the AHF.

AHFs were located above the ground level, generally on terraces. In some cases, this was not possible owing to the absence of suitable places or because pigeons were fed on public places such as squares. In these instances, the AHFs were located in these places. The number of points of administration of the treatment varied according to the size and the

Fig. 1. (*a*) Automatic hopper feeders model for terraces. (*b*) Automatic hopper feeders model for squares.

number of pigeons in each municipality. Table 1 describes the year treatment started, the number of points, location (square or terraces), number of year of treatment and associated costs for each of the municipalities.

Table 1. Number of treatment points, location, duration, and associated cost.

Municipality	Start year (number of years)	Number of treatment points	Location	Estimated cost[A] (€)
Arenys de Mar	2016 (6)	2	Terrace	39 144
Badia del Vallès	2016 (6)	4	Two squares/two terraces	18 177.6
Calaf	2018 (3)	3	Two squares/one terrace	34 305.6
Capellades	2017 (7)	3	Terrace	55 440
Cardedeu	2017 (4)	7	Terrace	145 622.4
Cardona	2014 (8)	1	Terrace	83 932.8
Castellar del Vallès	2018 (4)	2	Terrace	25 468.8
Constantí	2017 (5)	3	Terrace	31 046.4
Cornellà de Llobregat	2021 (1)	2	Square	9576
Figueres	2021 (1)	6	Three squares/ three terraces	22 713.6
Igualada	2018 (4)	7	Square	107 604
La Bisbal del Penedès	2020 (2)	1	Terrace	3662.4
La Pobla de Claramunt	2017 (5)	1	Terrace	15 859.2
La Seu d'Urgell	2014 (8)	3	Terrace	58 665.6
Molins de Rei	2014 (8)	3	One square/two terraces	229 656
Olesa de Montserrat	2015 (7)	3	Two squares/one terrace	199 281.6
Puig-Reig	2016 (6)	2	Square	55 624.8
Ripoll	2015 (7)	3	Square	102 211.2
Sant Fruitós de Bages	2019 (3)	3	Terrace	59 623.2
Sant Vicenç de Castellet	2017 (4)	2	One square/one terrace	23 049.6
Solsona	2015 (8)	2	Terrace	96 919.2
Vidreres	2021 (2)	1	Terrace	5040
Viladecavalls	2018 (4)	1	Terrace	15 052.8
Vilafranca del Penedès	2016 (5)	6	Four squares/two terraces	66 292.8
Vilanova del Camí	2017 (5)	2	Terrace	30 542.4

[A]The associated costs of annual treatment were calculated on the basis of an estimation of €33.6 per pigeon.

Evaluation of results

Census of pigeon variation

During March, before starting the treatment, a census of pigeons was conducted (pre-treatment census). This method involved dividing the urban area of the municipality into grids of 200 m × 200 m. Each of the grids was travelled in a line as straight as possible by one observer who recorded the number of pigeons. Pigeons in flight were not counted if they flew in the same direction as the observer was walking, but were counted if they did so in the opposite direction. This avoided the risk of birds being counted twice by the observer.

In municipalities with a larger urban area (Igualada, Vilafranca del Penedès, Cornellà de Llobregat and Olesa de Montserrat), the area was divided into two halves and both halves were travelled in parallel by observers each following the methodology described above.

In the case of the municipality of Cornellà de Llobregat, the census was conducted only in the southern part (Barrio de la Riera) because the treatment was located in this area of the municipality.

In each municipality, the census was repeated a second time at least 1 week after the first one. Results were considered valid when the difference in the number of pigeons was below 10% of consecutive counts. If the difference was greater, a third census was conducted. In all instances, the maximum number of pigeons observed was used to estimate the local population.

In December, a new census (post-treatment census) was conducted in each of the municipalities, following the same methodology as described above. Censuses were conducted during peak activity of pigeons, i.e. March from 09:30 hours to 13:30 hours and in December from 10:00 hours to 14:00 hours. Censuses were not conducted on days with rain, wind or abnormal temperatures, to prevent climate factors from altering the results.

To test for statistical differences in the number of pigeons in each municipality among years, the results of the census were analysed by linear mixed models (LMMs). The response variable, maximum number of pigeons observed in each census, was tested for normality and log-transformed to meet the normality assumption. The year of the census was included as a fixed component and the municipality was included as a random component. Statistical analyses on population trends were performed using RStudio-2022.07.1-554 (RStudio, Inc.). LMMs were run using the lme4 package developed by Bates *et al.* (2015), and *post hoc* tests for the LMM were performed using the multcomp package (Package 'multcomp' 2021).

Nest activity

The activity of pigeon nests near the treatment administration points was monitored as another indicator of the efficacy of NCZ in suppressing reproduction. Nest monitoring could not be performed in all the municipalities included in the study, because only few of the pigeon breeding colonies were available to observers. Nests were monitored in the following populations:

- Cardona: three nests at the church
- La Seu d'Urgell: three nests at the cathedral
- Calaf: seven nests at the Plaça Bertran i Morros building
- La Bisbal del Penedès: one nest at Hotel d'Entitats
- Constantí: eight nests at ancient wall near the library
- Vidreres: four nests at the church

Evaluation of intake by non-target species

In parallel with the evaluation of the effectiveness of the NCZ in reducing the number of pigeons, the potential intake by non-target species was also evaluated. This was undertaken through trail cameras in all those administration points located above the ground level (Victure HC100). Cameras were scheduled to start recordings at least 1 h before the daily dose of bait was administered and up to 1 h later. The treated bait was uniformly spread among the pigeons by the AHFs, and observations were confirmed, fully ingested within 2 min. Therefore, we considered 2 min sufficient for the cameras to record any potential non-target species feeding on NCZ treated bait. The cameras recorded videos each time movement was detected. The videos were recorded every day at least for a month, the average time recorded for each point was 3 months and the recorded videos were analysed individually. For the AHF located in squares, direct observations at NCZ spreading time were made.

Estimate of the associated costs

On the basis of the costs incurred when using NCZ-treated bait, the annual cost of the treatment was calculated to be €33.6 per pigeon. These costs included the treated bait, staff time and the rent of the AHF. The calculations were based on the initial number of pigeons reported each year and were therefore considered to be an overestimation of the total expenses. However, these calculations provided a rough estimate of the potential cost for each municipality to implement the NCZ treatment for pigeon population management. It is important to note that the actual costs for each municipality may differ as a result of various factors such as the size of the population, number of devices required or number of years. Nonetheless, having an estimate of the potential costs is a valuable tool for decision-makers and stakeholders to evaluate the financial feasibility of implementing this type of treatment for pigeon population management.

Results

Nicarbazin effectiveness

Pigeon census variation

The LMM results showed differences ($F = 26.893$, $P < 2.2 \times 10^{16}$) in the maximum number of pigeons observed in each census, across the municipalities included in the study among the monitoring years (Table 2, Fig. 2). From the beginning of the treatment and across the treatment years, a significant steady decreasing trend (Fig. 2) in the pigeon abundance was registered.

The population trend (Fig. 2) and *post hoc* tests results (Table 3) showed a significant decrease in the number of pigeons during the first 2 years of treatment. After the second year of treatment, the rate of reduction in the local number of pigeons slowed down but continued throughout the years.

Nest activity

Cardona: three nests at the church. All the nests ceased egg-laying activity after 1 month of treatment. No other egg-laying during the treatment was observed. After the winter break without treatment, egg-laying was observed in April. This occurrence, namely the alternation of one egg-laying after the winter break and the lack of additional egg-laying after a month of treatment was repeated throughout the 8-year period.

La Seu d'Urgell: three nests at the cathedral. In the first treatment, Year 2 nests ceased egg-laying activity after 1 month of treatment. In the third nest, egg-laying occurred during the second month of treatment but the eggs did not hatch. Once examined, it was observed that the yolk and albumen were mixed. In the remaining treatment years after the winter break without treatment, egg-laying was observed in April in all the three nests and chicks developed normally. After a month of treatment, no additional egg-laying was observed.

Calaf: seven nests at the Plaça Bertran i Morros building. After two treatment months, egg-laying did not occur in all the seven nests. No egg-laying was observed in the following years.

La Bisbal del Penedès: one nest at Hotel d'Entitats. During the second treatment month, egg-laying was observed but the eggs did not hatch. Once examined, it was observed that the yolk and albumen were mixed. No further egg-laying was observed in the following years.

Constantí: eight nests at ancient wall near the library. After two treatment months, egg-laying disappeared in all the seven nests. No egg-laying was observed in the following years.

Vidreres: four nests at church. In the first month of treatment, egg-laying was observed in all four nests. The eggs hatched and chicks developed normally into adults. In the second treatment month, egg-laying was observed in three nests and the fourth ceased the egg-laying activity. The eggs did not hatch in all the three nests. After these, no further egg-laying was observed in the four nests.

Intake by non-target species

Only 16 of 23 194 (0.07%) observations in three municipalities registered non-target species other than pigeons, Eurasian collared doves (*Streptopelia decaocto*) and magpie (*Pica pica*) in the proximity of the feeders (Table 4), rarely

Table 2. Census variation during the treatment years.

Municipality	Year 0	Year 1		Year 2			Year 3			Year 4		
	N	*N*	PROP	*N*	PROP	P_ACU	*N*	PROP	P_ACU	*N*	PROP	P_ACU
Arenys de Mar	**331**	137	**−58.61**	140	2.19	**−57.70**	140	0.00	**−57.70**	133	−5.00	**−59.82**
Badia del Vallès	**148**	83	**−43.92**	72	−13.25	**−51.35**	62	−13.89	**−58.11**	56	−9.68	**−62.16**
Calaf	**335**	248	**−25.97**	233	−6.05	**−30.45**	205	−12.02	**−38.81**			
Capellades	**343**	284	**−17.35**	203	−28.40	**−40.82**	172	−15.52	**−50.00**	202	17.78	**−41.11**
Cardedeu	**1500**	931	**−37.93**	697	−25.19	**−53.57**	620	−11.06	**−58.70**	587	−5.25	**−60.87**
Cardona	**1100**	308	**−72.00**	250	−18.83	**−77.27**	210	−16.00	**−80.91**	216	2.86	**−80.36**
Castellar del Vallès	**231**	197	**−14.72**	140	−28.93	**−39.39**	104	−25.71	**−54.98**	86	−17.31	**−62.77**
Constantí	**287**	273	**−4.88**	108	−60.44	**−62.37**	94	−12.96	**−67.25**	76	−19.15	**−73.52**
Cornella de Llobregat	**191**	94	**−50.79**									
Figueres	**397**	279	**−50.79**									
Igualada	**984**	725	**−29.72**	648	−10.63	**−34.16**	420	−35.14	**−57.30**	427	1.67	**−56.58**
La Bisbal del Penedès	**52**	35	**−26.33**	22	−37.14	**−57.69**						
La Pobla de Claramunt	**168**	105	**−32.69**	88	−16.19	**−47.62**	63	−28.41	**−62.50**	24	−61.90	**−85.71**
La Seu d'Urgell[A]	**217**	168	**−37.50**	153	−8.93	**−29.49**	175	14.38	**−19.35**	131	−25.14	**−39.63**
Molins de Rei	**1467**	1155	**−22.58**	973	−15.76	**−33.67**	766	−21.27	**−47.78**	777	1.44	**−47.03**
Olesa de Montserrat	**1183**	1005	**−21.27**	770	−23.34	**−34.91**	830	7.73	**−29.88**	630	−24.05	**−46.75**
Puig-Reig	**476**	378	**−15.09**	186	−50.93	**−61.03**	168	−9.43	**−64.71**	151	−10.42	**−68.38**
Ripoll	**637**	483	**−20.59**	385	−20.29	**−39.56**	511	32.73	**−19.78**	404	−20.94	**−36.58**
Sant Fruitós de Bages	**655**	431	**−24.18**	392	−8.94	**−40.11**	298	−24.11	**−54.55**			
Sant Vicenç de Castellet	**245**	143	**−34.22**	129	−9.79	**−47.35**	90	−30.23	**−63.27**	79	−12.22	**−67.76**
Solsona	**784**	532	**−41.63**	343	−35.53	**−56.25**	308	−10.20	**−60.71**	273	−11.36	**−65.18**
Vidreres	**81**	69	**−32.14**									
Viladecavalls	**120**	87	**−14.81**	80	−8.05	**−33.33**	80	0.00	**−33.33**	81	1.25	**−32.50**
Vilafranca del Penedès	**697**	537	**−27.50**	189	−64.80	**−72.88**	177	−6.35	**−74.61**	198	11.86	**−71.59**
Vilanova del Camí	**224**	182	**−22.96**	151	−17.03	**−32.59**	125	−17.22	**−44.20**	112	−10.40	**−50.00**

Municipality	Year 5			Year 6			Year 7			Year 8		
	N	PROP	P_ACU	*N*	PROP	P_ACU	*N*	PROP	P_ACU	*N*	PROP	P_ACU
Arenys de Mar	182	36.84	**−45.02**	102	−43.96	**−69.18**						
Badia del Vallès	58	3.57	**−60.81**	62	6.90	**−58.11**						
Calaf												
Capellades	139	−31.19	**−59.48**	169	21.58	**−50.73**	139	−17.75	**−59.48**			
Cardedeu												
Cardona	190	−12.04	**−82.73**	126	−33.68	**−88.55**	98	−22.22	**−91.09**	84	−14.29	**−92.36**
Castellar del Vallès												
Constantí	86	13.16	**−70.03**									
Cornella de Llobregat												
Figueres												
Igualada												
La Bisbal del Penedès												
La Pobla de Claramunt	24	0.00	**−85.71**									
La Seu d'urgell[A]	118	−9.92	**−45.62**	466	294.49	**114.52**	319	−31.58	**46.77**	198	−37.83	**−8.76**
Molins de Rei	648	−16.67	**−55.86**	536	−17.30	**−63.50**	514	−4.01	**−64.96**	511	−0.58	**−65.17**
Olesa de Montserrat	532	−15.56	**−55.03**	508	−4.51	**−57.06**	474	−6.69	**−59.93**			

(*Continued on next page*)

Table 2. (*Continued*).

Municipality	Year 5			Year 6			Year 7			Year 8		
	N	PROP	P_ACU	*N*	PROP	P_ACU	*N*	PROP	P_ACU	*N*	PROP	P_ACU
Puig-Reig	144	−4.65	**−69.85**	154	7.32	**−67.65**						
Ripoll	353	−12.62	**−44.58**	171	−51.56	**−73.16**	98	−42.69	**−84.62**			
Sant Fruitós de Bages												
Sant Vicenç de Castellet												
Solsona	235	−13.92	**−70.03**	210	−10.64	**−73.21**	200	−5.00	**−74.55**	197	−1.25	**−74.87**
Vidreres												
Viladecavalls												
Vilafranca del Penedès	175	−11.62	**−74.89**									
Vilanova del Camí	115	2.68	**−48.66**									

N, total number of pigeons; PROP, proportional difference from previous year; P_ACU, accumulative proportional difference from year 0. Bold data shows initial number of pigeons and proportional change through the study period.
[A]From Year 6, the treatment at the Cathedral in La Seu D'Urgell has been withdrawn because of works; 80% of the city pigeon population was present at this point.

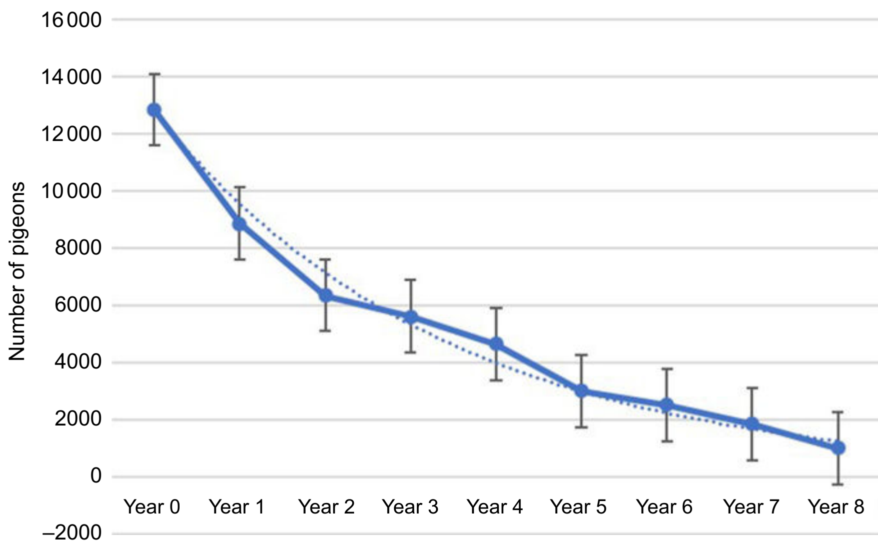

Fig. 2. Population trend of the total number of pigeons during the study years.

feeding on treated kernels and, when feeding, only ingesting ~3 g of product.

Estimated costs

Over the course of the study period, the estimated average annual cost of the treatment for each municipality was €7672.56. During the first year of treatment, the average cost was €17273.09 because of a higher initial number of pigeons. However, after 3 years of treatment, the total annual cost was reduced by 50% in 68% of the municipalities.

Discussion

Overall, the results of the present study that quantified the effects of delivering an oral contraceptive to urban pigeons in 24 cities for up to 8 years showed that this method significantly reduced the local numbers of pigeons, with little impact on non-target species. The findings of this study are in agreement with previous experiences, where similar trends were described in experiences controlling pigeon colonies using NCZ in Italy (Ferri *et al.* 2009; Albonetti *et al.* 2015), Spain (Lavín *et al.* 2006; González-Crespo and Lavín 2022), and USA (Fagerstone *et al.* 2008) and in Canada geese in USA (Bynum *et al.* 2007).

The population trend during the study years can be divided into two periods (Fig. 2, Table 3). The first period comprises the first and second year of treatment, with a significant decrease in the number of pigeons represented by a steeper slope. In the second period (Years 3–8 of treatment), the number of pigeons continued to decrease, albeit at a lower

Table 3. Results of the *post hoc* tests (Tukey test) of the registered population trend among treatment years. Bold data indicates statistically significant differences.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Year 0	0.3842 ± 0.0812 s.e., t = 4.729, ***P* = 0.0002**	0.6714 ± 0.0852 s.e., t = 7.877, ***P* < 0.0001**	0.7949 ± 0.0866 s.e., t = 9.178, ***P* < 0.0001**	0.9329 ± 0.0895 s.e., t = 10.419, ***P* < 0.0001**	1.0098 ± 0.0994 s.e., t = 10.163, ***P* < 0.0001**	0.9874 ± 0.1123 s.e., t = 8.79, ***P* < 0.0001**	1.2079 ± 0.129 s.e., t = 9.361, ***P* < 0.0001**	1.2313 ± 0.163 s.e., t = 7.552, ***P* < 0.0001**
Year 1		0.2872 ± 0.0852 s.e., t = 3.369, ***P* = 0.0275**	0.4107 ± 0.0866 s.e., t = 4.742, ***P* = 0.0002**	0.5486 ± 0.0895 s.e., t = 6.128, ***P* < 0.0001**	0.6256 ± 0.0994 s.e., t = 6.296, ***P* < 0.0001**	0.6032 ± 0.1123 s.e., t = 5.37, ***P* < 0.0001**	0.8237 ± 0.129 s.e., t = 6.383, ***P* < 0.0001**	0.8471 ± 0.163 s.e., t = 5.195, ***P* < 0.0001**
Year 2			0.1235 ± 0.088 s.e., t = 1.404, P = 0.894	0.2615 ± 0.0908 s.e., t = 2.878, P = 0.105	0.3384 ± 0.1005 s.e., t = 3.366, ***P* = 0.0278**	0.316 ± 0.1134 s.e., t = 2.787, P = 0.1307	0.5365 ± 0.1299 s.e., t = 4.129, ***P* = 0.0022**	0.5599 ± 0.1638 s.e., t = 3.419, ***P* = 0.0237**
Year 3				0.1379 ± 0.0915 s.e., t = 1.507, P = 0.8499	0.2149 ± 0.1011 s.e., t = 2.125, P = 0.4618	0.1924 ± 0.1139 s.e., t = 1.69, P = 0.7516	0.413 ± 0.1304 s.e., t = 3.167, ***P* = 0.0493**	0.4364 ± 0.1641 s.e., t = 2.659, P = 0.1748
Year 4					0.077 ± 0.1027 s.e., t = 0.75, P = 0.9979	0.0545 ± 0.1153 s.e., t = 0.473, P = 0.9999	0.2751 ± 0.1316 s.e., t = 2.09, P = 0.4851	0.2985 ± 0.1651 s.e., t = 1.808, P = 0.6769
Year 5						−0.0225 ± 0.1205 s.e., t = −0.186, P = 1	0.1981 ± 0.1363 s.e., t = 1.454, P = 0.8739	0.2215 ± 0.1688 s.e., t = 1.312, P = 0.9258
Year 6							0.2206 ± 0.1433 s.e., t = 1.539, P = 0.8345	0.2439 ± 0.1745 s.e., t = 1.398, P = 0.8966
Year 7								0.0234 ± 0.183 s.e., t = 0.128, P = 1

rate. These differences between periods are normal and are the result of the effect of the treatment. As reproduction, and therefore juvenile recruitment, stopped, the treated population is mainly composed by adult individuals after the second year of treatment.

The disappearance of egg-laying in nests demonstrates that NCZ suppresses reproduction after 1 month of treatment. Egg-laying reappeared in some places where treatment was suspended during the winter and disappeared again once the treatment was restarted. Eggs laid after 2 months of treatment did not hatch and their content showed a mixing of albumen and yolk (Yoder *et al.* 2005), reflecting the action of the NCZ, making the yolk wall permeable.

The safety of the NCZ treatment for non-target species has been well established, being consistent with previous experiences (González-Crespo and Lavín 2022). This study confirmed that only a negligible proportion of observations (Table 4) recorded Eurasian collared doves and magpies consuming the bait, and also that the amount ingested by these birds was unlikely to cause any impact on reproduction. This suggests that the attraction of the bait to other species is low, possibly owing to the drug formulation being based on whole corn kernels, which also makes it too large to be ingested by species smaller than a pigeon. Previous studies (González-Crespo and Lavín 2022) have shown that NCZ-treated baits have a very low risk of ingestion by non-target species. Furthermore, if ingested, the drug is rapidly metabolised and does not accumulate in the tissues of the animals (Hughes *et al.* 1991; Johnston *et al.* 2002; Yoder *et al.* 2005). In addition, the NCZ treatment has been shown to have no impact on the reproductive biology or behaviour of non-target species, ensuring that its use is both effective and humane (González-Crespo and Lavín 2022).

In terms of costs, the first year of treatment was more expensive because of the higher initial number of pigeons. The significant reduction in the annual cost of the treatment, halved after 3 years, highlighted the long-term cost savings associated with the NCZ treatment. The reduction in costs is due to the sustained effectiveness of the treatment in reducing the size of the pigeon populations over time. The

Table 4. Observations of non-target species consuming nicarbazin.

	No. of observations	No. of observations other species	Other species observed	% Observations with other species with respect to total observations
Arenys de Mar	1800	3	Eurasian collared doves	0.17
Badia del Vallès	1830	None		
Calaf	720	None		
Capellades	1440	None		
Cardedeu	1700	6	Magpie	0.35
Cardona	900	None		
Castellar del Vallès	1800	None		
Constantí	1440	None		
Cornellà de Llobregat	6	None		
Figueres	274	None		
Igualada	72	None		
La Bisbal del Penedès	360	None		
La Pobla de Claramunt	900	None		
La Seu d'Urgell	900	None		
Molins de Rei	1500	None		
Olesa de Montserrat	1085	None		
Puig-Reig	15	None		
Ripoll	21	None		
Sant Fruitós de Bages	720	None		
Sant Vicenç de Castellet	900	None		
Solsona	1800	None		
Vidreres	186	None		
Viladecavalls	125	None		
Vilafranca del Penedès	1800	None		
Vilanova del Camí	900	7	Eurasian collared doves/magpie	0.78
Total	23 194	16		0.07

NCZ treatment effectively controls pigeon fertility and reduces their ability to reproduce, leading to a decrease in the population size and management costs. Unlike traditional methods such as culling, which provide only short-term solutions (Senar *et al.* 2009), the NCZ treatment is regarded as a more humane and long-term solution. This means that the treatment can be implemented continuously over time without negatively affecting the local ecosystem.

Combination of fertility control with other management techniques, such as food reduction and nest elimination, can be an effective integrated strategy for managing urban pigeon populations (González-Crespo and Lavín 2022). Such a strategy can also be a more sustainable approach to managing pigeon populations. The benefits of incorporating an integrated management strategy are two-fold. First, by reducing the amount of food and nesting material available, it reduces the number of pigeons in a given area. Second, by eliminating food and nests, it discourages pigeons from returning to the area to breed. This can be an effective way to prevent pigeon populations from rebounding in areas where fertility control alone may not be sufficient to control the population. Overall, the combination of these methods shows promise as a viable integrated management strategy for controlling pigeon populations in urban areas.

In conclusion, our study provides evidence that the NCZ could represent a sustainable solution for managing urban pigeon populations. The long-term cost savings associated with the treatment highlighted its potential as a viable option for municipalities seeking to control pigeon populations and to mitigate the negative impacts of overpopulation on public health, infrastructure maintenance costs, without having an impact on the environment and other non-target species.

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