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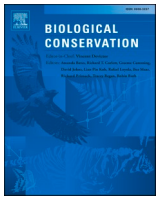

Short communication

Water canals may promote large-scale defaunation of the Gran Chaco

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ABSTRACT

In the Gran Chaco, one of the most biodiverse, yet imperiled, arid biomes in the world, open-to-air concrete water canals may threaten wildlife via drowning and habitat fragmentation, although these effects are usually overlooked. We performed field surveys and local people interviews along 250 km of canals in the Gran Chaco ecoregion of Argentina during austral spring and summer (six months). We documented 207 drowned individuals of 35 wildlife species, but more realistic estimations could increase this number to the thousands. Six species of conservation concern drowned in the canal, and eight of the drowned species have decreasing population trends. Drownings in some mammal species decreased with time without any mitigation measures implemented at the canal yet, suggesting an ongoing, large-scale population reduction due to this high mortality rate. Since mitigation measures applied in other regions were not effective to stop drowning and population isolation, these infrastructures should be avoided in arid environments worldwide.

1. Introduction

The Great Chaco, or the Gran Chaco, ecoregion is the second largest forest biome in South America after the Amazonia, as well as the largest continuous tropical and subtropical dry forest globally, and hosts one of the most diverse hotspots in the world (Redford et al., 1990). Within it, the Dry Chaco (hereafter Chaco), is currently one of the most threatened ecosystems in the world (de la Sancha et al., 2021), with impressively high forest cover loss in the last decades (de la Sancha et al., 2021), and a high rate of wildlife extinction due to habitat loss, fragmentation and hunting (Semper-Pascual et al., 2018; Romero-Muñoz et al., 2020a). Additionally, there is a lack of knowledge on the ecology and conservation threats for many of the species of this dry ecosystem (Nori et al., 2016), all of which calls for urgent action in this unique biodiversity hotspot (Kuemmerle et al., 2017).

As in other arid and semiarid environments worldwide, annual precipitation in the Chaco is low (Cabrera, 1976), and there is a general lack of natural water bodies for human consumption or development of production activities (e.g., cattle ranching, agriculture) (Jobbágy et al., 2008). This has forced human beings to develop water canals, which transfer this scarce resource from areas of surplus supply to those in deficit. Nowadays, water canals are a priority infrastructure for society, in a way that many human populations rely solely on this imported water source (Borsato et al., 2020).

However, open-to-air water canals are linear infrastructures that strongly alter the landscape, and which could pose serious threats to wildlife in multiple ways. First, they create physical barriers in their ranging areas, promoting habitat fragmentation (Azedo et al., 2022), they disrupt animals' movements, affecting their behaviors (Baechli et al., 2021), and thus they may isolate populations, hindering regular gene flow, potentially having adverse effects in species conservation. Second, these canals are a significant cause of wildlife death; when they are lined with concrete or PVC, they become slippery and unclimbable for animals that fall down on them when attempting to cross or drink water (Gačić et al., 2013), which eventually die drowned. Numbers are dramatic in some cases (Peris and Morales, 2004; Godinho and Onofre, 2013), with even thousands of drowned animals per year (Davies et al., 1992). Although these human infrastructures are widely used worldwide, and their effects on wildlife are relatively well-known, the attention received to studying the possible solutions to reduce their ecological impact has been scarce compared to other linear infrastructures (e.g., roads) (Baechli et al., 2021).

In a context of aridity and drought in the Chaco, animals may be attracted to drinking water and/or foraging in the canal or nearby areas,

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thus increasing their exposure to this mortality source (Krausman and Bucci, 2010). The combined effect of deforestation and the construction of the water canals may have severe effects on animal movements and ranging areas. This could potentially force them to either move into suboptimal habitats where they may be more exposed to other threats such as poaching (Romero-Muñoz et al., 2020b), and/or attempt to cross these linear infrastructures, even if they entail a high risk of mortality. In this sense, it is key to understand the impact of water canals to wildlife in arid ecosystems such as the Gran Chaco, considered one of the most vulnerable terrestrial biomes on the world (de la Sancha et al., 2021).

2. Methods

The "Canal de la Patria" (northern Argentina, Fig. 1) is a 250-km long, 1.5-m high, and 4-m wide, open-to-air concrete water canal, with walls between 60 and 70 degrees of steepness (Fig. 1), that started operating in September 2023 to bring water for human consumption and for irrigation to fields. We performed six surveys in austral spring and summer. Four of them were separated by a month (October 24, November 16, December 15, February 19, hereafter "monthly surveys" -January could not be done-), one of them was done a week after the one of February (February 27, hereafter "weekly survey"), and an additional one a day after this last one (February 28, hereafter "daily survey"). This was done to assess the accuracy of our estimations across different lapses of time, given that drowned animals may be removed or washed up from the study area with time. We traversed the whole length of the canal, recording and removing every animal that had fallen into the canal, as well as the location where we found each of them. Additionally, we carried out in-person interviews with 21 inhabitants of the area, who reported additional wildlife drownings, as well as their date and location.

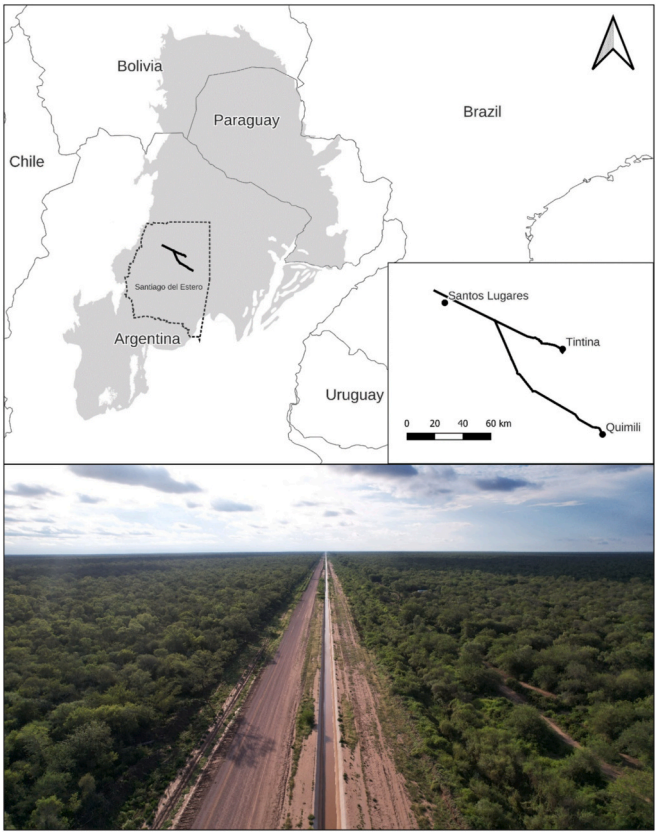

Fig. 1. Above, the Great Chaco (or Gran Chaco) ecoregion (shaded in gray), including large areas of Argentina, Paraguay, Bolivia and Brazil. The dotted line encompasses Santiago del Estero province (northern Argentina), and the "Canal de la Patria" open-to-air concrete water canal is represented by the black, thick lines inside this province, and zoomed it at the right part of the figure. Below, a picture taken with a drone of the section of the canal (from above), and the Gran Chaco ecosystem surrounding it.

3. Results

We recorded 207 drowned individuals of 35 terrestrial vertebrate species at the canal (Table 1). The wildlife species which most often drowned in the canal were the Giant anteater (*Myrmecophaga tridactyla*, $n = 38$, Vulnerable), the Chaco tortoise (*Chelonoidis chilensis*, $n = 21$, Vulnerable), the Gray brocket (*Mazama gouazoubira*, $n = 12$, Least Concern) and the Collared peccary (*Pecari tajacu*, $n = 10$, Vulnerable for Argentina) (SAyDS, 2019; IUCN, 2024). Other wildlife species of conservation concern that drowned in the canal were the Southern long-nosed armadillo (*Dasypus hybridus*, $n = 6$, Near Threatened), the Southern tamandua (*Tamandua tetradactyla*, n = 1, Near Threatened for Argentina), and the Three-banded armadillo (*Tolypeutes matacus*, n = 1, Near Threatened), and eight of the drowned species have decreasing population trends at a global scale (SAyDS, 2019; IUCN, 2024) (Table 1).

Additionally, only taking into account drowned individuals recorded in our surveys (and not the ones reported by interviewed people), the average number of individuals found during the four monthly surveys ($\bar{x} = 26.75$) was similar to the number of individuals found during the survey made one week after the fourth monthly survey ($n = 25$), but higher than that of the daily survey ($n = 16$). Lastly, the temporal occurrence of drowned wildlife differed with the time elapsed since the canal started operating (Fig. 2). In the cases of the Giant anteater ($r = -0.838$, $P < 0.001$), and they Gray brocket ($r = -0.804$, $P < 0.005$), the two mammals most frequently found drowned during surveys (Table 1), fewer individuals drowned as the weeks went by; the Chaco tortoise ($r = -0.222$, $P = 0.488$) and the Argentine boa ($r = 0.303$, $P = 0.338$) showed a non-significant trend (Fig. 2).

4. Discussion

The great amount, and diversity, of animals found dead in this open-to-air water canal suggests that this linear infrastructure is a mortality source that significantly contributes to the population decrease of Chacoan wildlife, adding to habitat loss, fragmentation and hunting (Semper-Pascual et al., 2018; Romero-Muñoz et al., 2020a, 2020b). Additionally, we found six species of conservation concern that drowned in the canal, totaling more than one-third of the individuals found (Table 1), which reflects the damage that this human infrastructure can cause to threatened animals. The example of the Giant anteater is critical: the 38 drownings documented in just six months possibly imply a comparatively high proportion of individuals from the regional population of this species (< 5000 individuals; IUCN, 2024). In this and other slow-life species with long generation times (IUCN, 2024), this mortality source could jeopardize the long-term viability of their global populations.

Moreover, the adverse effects of this infrastructure may reach other species that we did not record. For instance, the area is inhabited by other globally threatened terrestrial species, such as the Chacoan (*Catagonus wagneri*) and the White-lipped (*Tayassu pecari*) peccary, and the Giant armadillo (*Priodontes maximus*) (IUCN, 2024). Also, since we documented four bird species (one of them being a raptor) drowned in the canal, other birds such as the endangered Chaco eagle (*Buteogallus coronatus*), which inhabits the region and for which drowning is an important mortality source (Sarasola et al., 2022), could eventually fall into it, compromising its long-term survival as with other threatened species (Albanesi et al., 2016).

Besides, given the similarity in the numbers of drowned individuals found between the monthly and the weekly surveys, and the relatively high number of individuals found during the daily one, we believe that every survey performed only accounted for the reality occurred during

Table 1
Drowned individuals found in the "Canal de la Patria", northern Argentina, during six months of surveys and interviews with local people, sorted by class and alphabetically by species scientific name. The conservation status of each species is given globally, together with its population trend (IUCN, 2024) and in Argentina (SAyDS, 2019). LC = Least Concern; NT = Near Threatened; VU = Vulnerable; NA = Not Available; INV = Invasive species.

Class	Scientific name	Common Name	Number	Conservation status		Population trend
				Global	Argentina	
Amphibians						
	Physalaemus biligonigerus	Weeping frog	1	LC	LC	Stable
	Rhinella arenarum	Argentine toad	5	LC	LC	Stable
	Rhinella schneideri	Cope's toad	1	LC	LC	Stable
Birds						
	Caracara plancus	Crested caracara	2	LC	LC	Stable
	Columbina picui	Picui ground dove	1	LC	LC	Stable
	Passeriformes	Not identified	1	NA	NA	NA
	Phalacrocorax brasilianus	Neotropic comorant	2	LC	LC	Increasing
	Zenaida auriculata	Eared dove	8	LC	LC	Increasing
Mammals						
	Conepatus chinga	Molina's hog-nosed skunk	2	LC	LC	Decreasing
	Ctenomys sp.	Tuco tuco	1	NA	NA	NA
	Dasypus hybridus	Southern long-nosed armadillo	2	NT	NT	Decreasing
	Herpailurus yagouaroundi	Jaguarundi	1	LC	LC	Decreasing
	Lagostomus maximus	Plains viscacha	3	LC	LC	Unknown
	Leopardus geoffroyi	Geoffroy's cat	3	LC	LC	Stable
	Lycalopex griseus	South American gray fox	9	LC	[a]	Stable
	Lycalopex gymnocercus	Pampas fox	2	LC	LC	Stable
	Mazama gouazoubira	Gray brocket	12	LC	LC	Decreasing
	Myrmecophaga tridactyla	Giant anteater	38	VU	VU	Decreasing
	Pecari tajacu	Collared peccary	10	LC	VU	Stable
	Puma concolor	Cougar	1	LC	LC	Decreasing
	Rattus norvegicus	Brown rat	9	LC	INV	Stable
	Sus scrofa	Wild Boar	3	LC	INV	Unknown
	Tamandua tetradactyla	Southern tamandua	1	LC	NT	Unknown
	Tolypeutes matacus	Three banded armadillo	1	NT	NT	Decreasing
Reptiles						
	Amphisbaena bolivica	Worm lizard	20	LC	LC	Stable
	Boa constrictor occidentalis	Argentine boa	8	LC	EN	Decreasing
	Bothrops diporus	Painted Lancehead	12	LC	LC	Unknown
	Chelonoidis chilensis	Chaco tortoise	21	VU	VU	Unknown
	Crotalus durissus terrificus	South American rattlesnake	2	LC	LC	Unknown
	Micrurus pyrrhocryptus	Argentinian coral snake	3	LC	LC	Unknown
	Ophiodes intermedius	Legless lizard	1	LC	LC	Stable
	Oxyrhopus rhombifer	Amazon false coral snake	2	LC	LC	Stable
	Philodryas psammophidea	Günther's green racer	5	LC	LC	Unknown
	Salvator rufescens	Red Tegu	4	LC	LC	Unknown
	Sibynomorphus turgidus	Bolivian Tree Snake	3	LC	LC	Stable
	Xenodon merremi	Wagler's snake	1	LC	LC	Unknown
		Non-identified snake	6	NA	NA	NA
Total			207			

[a] The conservation status in Argentina of *Lycalopex griseus* is not given, since according to SAyDS (2019), *L. griseus* and L. *gymnocercus* are the same species.

the previous hours (likely 24 to 48 h.). This affirmation is supported by most locals' testimonies, who removed (and sometimes burnt) carcasses from the canal every time they found them, to avoid water fouling; this probably led to an underestimation of the real number of drowned animals. Thus, we could estimate the number of drowned individuals during six months to potentially reach thousands of individuals, an unprecedented case regarding wildlife mortality in the region. Additionally, the negative trends over time in the number of some terrestrial mammals found drowned probably does not reflect an habituation of wildlife to the canal, but rather a severe decline in their field abundance in areas surrounding it as a result of the high and sudden mortality experienced. This is reinforced by the fact that no intervention has been conducted on this infrastructure to avoid or reduce wildlife drowning yet. However, this negative trend was not observed in poikilotherm vertebrates such as the Argentine boa (*Boa constrictor occidentalis*), which is more active in autumn (Leynaud et al., 2008), so we could expect this and other reptiles to be in the peak of their mortality rate after austral summer (i.e., after our surveys).

Although open-to-air water canals are a relatively old and well-known wildlife conservation issue (Comrie-Greig, 1986), none of the possible proposed solutions to reduce their impacts have completely removed them. For instance, the addition of stairs inside and/or on the sides of the canal has proved to be ineffective for panicked and small-to-medium sized animals (Davies et al., 1992). Protective fences along the canal may avoid some larger animals from crossing the canal (Gačić et al., 2013), but smaller species or birds could still reach this infrastructure, apart from the possibility that certain animals could break the fence (Peris and Morales, 2004; Godinho and Onofre, 2013). Additionally, fences would promote population isolation if enough passages were not built, with the resultant negative barrier effects on gene flow (Baechli et al., 2021). Concerning wildlife passages and culverts, some species may be less likely to cross them (Krausman and Bucci, 2010; Baechli et al., 2021), and its use might be determined by the surrounding landscape context (Azedo et al., 2022). Moreover, previous studies in Spain have encountered great mortality rates, even in the presence of several passages per canal stretch km (Peris and Morales, 2004). Thus, building hundreds of passages in long canals, apart from being expensive, would not be a certainty of avoiding wildlife mortality. Further research on other alternatives is needed to ascertain the real impact of these mitigation measures.

Considering water canals' long-lasting operative lifespan, the effects of this linear infrastructure could result in a severe decline, or a large-scale disappearance, of wildlife across hundreds of thousands of hectares, in addition to changing animals' ranging behavior and eventually

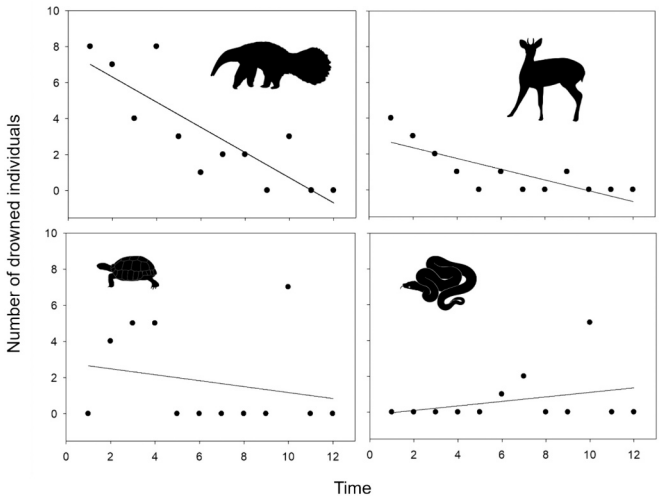

Fig. 2. Number of drowned individuals in the "Canal de la Patria" open-to-air concrete water canal in the Great Chaco, or Gran Chaco, ecoregion (Santiago del Estero province, northern Argentina), during every fortnight (15 days) of the survey, starting on October 1, 2023 and ending on March 30, 2024. Data belongs, from top to bottom and from left to right, to the Giant anteater (*Myrmecophaga tridactyla*), the Gray brocket (*Mazama gouazoubira*), the Chaco tortoise (*Chelonoidis chilensis*), and the Argentine boa (*Boa constrictor occidentalis*), and it corresponds to both field surveys and in-person interviews.

isolating their populations, thus worsening the ongoing negative effects of habitat loss and poaching in this ecoregion (Romero-Muñoz et al., 2020a, 2020b). Lastly, being the only available water source in the area, the attractiveness of this human infrastructure to animals may potentially work as a wildlife sink whose action would extend beyond the geographic scope of the canal itself. In fact, at least 6000 km of open-to-air concrete water canals are currently operative through arid and semiarid ecoregions of Argentina (D. Gallego, unpubl. data), with scarce information on wildlife drownings or mortality monitoring in them. Bearing in mind that the Gran Chaco encompasses four different countries (Fig. 1), the effects of regional high mortality rates by water canals, particularly on endangered species with reduced populations, are likely to compromise species conservation at global and transboundary scales.

5. Conclusions

Given the multiplicity and seriousness of the conservation threats posed by open-to-air concrete irrigation or water canals and the inefficiency of mitigation measures implemented worldwide to minimize them, we suggest that this open-to-air design should be completely forbidden in arid and semiarid landscapes where their harmful effects and impacts on wildlife are worst. Furthermore, and for those canals already built, we urge authorities to implement the only effective mitigation measure to avoid both mortality by drowning and habitat fragmentation: the intubation or enclosure of the canals. This would still allow locals to access water via pumping or openings in the canal, but would remove all negative effects on wildlife. Additionally, this action should *a priori* be implemented in future water transport constructions to avoid similar ecocides, especially in the Gran Chaco ecoregion, an arid realm identified as being in need of urgent conservation actions. We strongly encourage collaboration among researchers, lawmakers and environmental agents to prevent water canals from causing massive defaunations in arid ecosystems worldwide.

CRediT authorship contribution statement

Diego Gallego-García: Writing – review & editing, Writing – original draft, Visualization, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **José Hernán Sarasola:** Writing – review & editing, Visualization, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data is already available in Table 1

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