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Attraction is not diversion: testing rainwater troughs as a measure to reduce wildlife visits to apiaries in Calakmul, Mexico

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Abstract

In water-limited landscapes the water that people keep for their own purposes becomes disproportionately attractive to wildlife, and the places where they keep it are where the two demands meet. Apiaries in Calakmul, southern Mexico, hold open water through the dry season, and providing water for wildlife away from the hives has been recommended there but never tested. We interviewed 48 beekeepers about their water supply and its constraints, installed rainwater collection systems feeding drinking troughs beside apiaries, and compared wildlife use of apiaries next to a trough with apiaries at least 1 km away over 10,863 camera-trap days at 24 stations. The beekeepers named water scarcity and the labour of fetching it, not wildlife, as their main constraints. The troughs worked as an alternative, drawing two to three times the visitation of apiaries. Even so, apiaries beside a trough did not differ from apiaries far from one in visitation frequency, in the proportion of days or weeks with records, or in the interval between visits, though all four measures pointed in the predicted direction. The observed differences were smaller than the design could resolve, and analyses of individual species gave the same result. Apiary use was instead predicted by the water provisioned for the colonies. Where it was left within reach of wildlife, apiaries received nearly three times the visits. Attraction to a provisioned alternative need not produce diversion, and these systems may serve coexistence by providing water that colonies and wildlife share, not by keeping the two apart.

1. Introduction

Competition for limited resources is a principal source of conflict between people and wildlife (Nyhus 2016; König et al. 2020). Where a resource that people maintain also meets a physiological requirement of wild animals, both uses converge on the same points in the landscape. Measures intended to reduce the resulting conflict can be divided into those that lower the frequency or severity of encounters and those that raise tolerance for them (Treves et al. 2009). Diversionary provisioning belongs to the first group: an attractive resource is supplied away from the site of conflict so that animals redistribute towards it (Kubasiewicz et al. 2016). Diversion in this sense implies a mechanism: animals relocate because the provisioned resource substitutes for the contested one. Yet not every provisioned resource that attracts animals meets this condition.

The evidence base for diversionary provisioning has been built almost entirely with food, and its effectiveness has been inconsistent (Kubasiewicz et al. 2016). Where the approach is used, it is deployed against a resource that fluctuates, and provisioning is timed to the period in which the contested resource is scarce and the conflict most acute (Arnold et al. 2018). Recent experimental work has been designed so that the provisioned food acts as an alternative to the contested resource, not an addition to it (Bamber et al. 2024). Whether the same logic extends to water, a resource with different properties, remains open.

A further limitation is that attraction and diversion are observed in different places and are rarely distinguished. Attraction is measured at the provisioned resource; diversion can only be measured at the

site of conflict. A provisioned resource can therefore be heavily used while nothing changes at the conflict site nearby, because the animals it attracts need not be the ones that would otherwise have gone there. Artificial water has been examined chiefly as a way to support populations through drought or to manage their distribution (Smit et al. 2007; Epaphras et al. 2008). Where troughs were installed partly to keep a wild ungulate inside a protected area and away from surrounding crops, that function was stated but not evaluated (Eliades et al. 2022). In Namibia, elephants kept damaging village pumps, pipes and storage tanks even after water was provided for them away from settlements (Ramey et al. 2013). That evidence came from incident reports and incidental observation, with no comparison against unprovisioned sites, and the authors attributed the damage to the quality of the water, not to its availability. Where provisioned water was kept reliably full, damage was reported to fall (Wenborn et al. 2025). Camera-trap studies in the Neotropics have repeatedly recorded wildlife at artificial water points (Contreras-Moreno et al. 2024, 2025). Records of this kind establish attraction; testing diversion requires monitoring the conflict sites themselves against comparable sites left unprovisioned.

Seasonally dry tropical forests offer an appropriate setting in which to test this question. These forests support diverse assemblages of terrestrial birds and mammals while being strongly water-limited for part of the year, so that the few remaining water bodies become hotspots of animal activity (Delgado-Martínez et al. 2023). In the Calakmul region of Campeche, in the Selva Maya of southern Mexico, karst geology promotes rapid infiltration, so surface drainage is poorly integrated and almost entirely intermittent (García Gil et al. 2002). Water availability governs where large vertebrates occur and how far they travel (Reyna-Hurtado et al. 2009; Pérez-Cortez et al. 2012). Where natural sources are so scarce, water stored by people becomes unusually attractive to wildlife, and the places where it is kept become the points where human and animal needs meet.

Beekeeping is one such place, and among the principal rural livelihoods of the region (Martínez-Puc et al. 2018). It also depends on the forest remaining standing, since the yield of an apiary follows the native melliferous flora around it (Zúñiga-Díaz et al. 2024). Colonies must be watered, and water at the hive also deters ants, so beekeepers carry it in and keep open containers filled through the dry season. Each apiary is in effect a small, dependable water source in a landscape with almost none, and birds and mammals come to drink from it. The overlap costs beekeepers labour and containers, and placing water containers on the periphery of apiaries has been recommended in the region on that basis, though never tested (Pérez-Flores et al. 2021). It is unknown how much wildlife actually uses apiary water, or whether beekeepers themselves count it among the constraints on their work. This matters because conflict follows perceived as much as realised impact (Bennett 2016; IUCN SSC HWCTF 2020).

In this study, we evaluate a pilot intervention in which rainwater collection systems coupled with wildlife drinking troughs were installed and maintained by beekeepers on communally managed lands in Calakmul. Semi-structured surveys were conducted with beekeepers across the region, and camera traps were deployed at the troughs, at the apiary nearest each trough and at apiaries distant from any trough. Our objectives were to (i) characterise how beekeepers provision water at their apiaries, which wildlife they observe at it and whether they regard it as a constraint on their activity; (ii) test whether

apiaries near a trough receive lower or less regular wildlife use than apiaries without one; and (iii) test whether wildlife use of apiaries tracks water availability in the landscape, since offering water can only divert use that scarcity drives. We characterise apiary use with several complementary measures instead of a single one. We predicted that wildlife use of apiaries would be lower where a trough had been installed nearby. Evaluating whether a recommended but untested measure achieves what is claimed for it, and identifying what governs wildlife use of apiary water if it does not, can inform the design of coexistence interventions in water-limited landscapes.

2. Materials and methods

2.1. Study area

The study was conducted in the communal lands of Nuevo Conhuás and Unión 20 de Junio, municipality of Calakmul, Campeche, southern Mexico. Nuevo Conhuás lies within the Balam Kú Biosphere Reserve (18.538799, -89.921436), a federal protected area of 463,442 ha decreed in 2023 (DOF 2023), while Unión 20 de Junio (18.809979, -89.291596) lies on the periphery of the Calakmul Biosphere Reserve (Fig. 1). The vegetation is medium and low semi-evergreen tropical forest interspersed with secondary growth and small-scale agriculture and some cattle ranching lands. The climate is tropical wet and dry (Aw; Beck et al. 2018), with a mean annual precipitation of 1,076 mm (Martínez and Galindo-Leal 2002); the rainy season runs from June to November and the dry season from December to May (García Gil et al. 2002).

2.2. Apiary water provisioning

Apiaries are established along unpaved forest roads, typically about 500 m apart and holding up to 20 hives. Ants are excluded from the hives either by cement trays of water supporting the legs of the hive stands, a practice now declining, or by inverted cut bottles fitted to those legs, which is increasingly common. Beekeepers supply drinking water for their colonies in open, steep-sided 200-L drums, refilled throughout rainless periods and, in the dry season, approximately every week. These drums occasionally trap and drown coatis (*Nasua narica*) and birds. To prevent this, and to reduce evaporation and use by wildlife, beekeepers increasingly cover them with wooden grates, which exclude most vertebrates. Whether the water remains within reach of wildlife therefore varies among apiaries (Fig. S1).

2.3. Beekeeper interviews

We interviewed 48 beekeepers from 12 communities. Interviews were conducted in Spanish. Before each interview the respondent was read a statement of the purpose of the study and of the use that would be made of their answers, and was asked whether they agreed to take part; those who agreed signed a consent form. Participation was voluntary, responses were anonymised and no identifying information was retained. Interviews covered the respondent's apiaries and hives, how water is supplied, the constraints perceived in supplying it, and the wildlife observed at the apiaries. Verbatim answers were coded into controlled categories, and all 48 respondents answered every question.

2.4. Rainwater collection systems and troughs

The systems were installed in response to the needs the interviews identified and to a preliminary camera deployment. Wildlife is known to visit apiaries in the region (Pérez-Flores et al. 2021), but not whether it came to them for water; cameras placed at three apiaries in 2022 recorded animals drinking from the containers provisioned for the colonies. Those records were not systematised, and the three apiaries are not among the stations analysed here.

Each system consists of a catchment of corrugated metal sheets measuring 6.4 m by 3 m, giving 19.2 m², mounted on wooden posts with the catchment at a minimum height of 2 m and connected by pipes to a 5,000-L plastic tank; runoff enters the tank directly, without a first-flush diverter. The tank supplies a 120-L drinking trough placed less than 20 m away (1.27 × 0.66 × 0.33 m, high-density polyethylene), and the stored water is also used by the beekeepers for their work with the hives. A thick log and several branches were placed in each trough so that small animals entering the water could climb out (Fig. S2). Systems were sited in existing canopy gaps, so that no trees were felled. We provided the materials; the beekeepers installed and maintained the systems and kept the troughs supplied.

2.5. Study design

We compared three site types: the troughs (Trough), the apiary nearest each system located less than 100 m away (Near), and apiaries at least 1 km from any trough (Far). The analysis comprised 24 camera stations, eight of each type.

2.6. Camera trapping, sampling effort and events

One camera trap was installed at each station at a height of approximately 40 cm, facing the water: the trough at Trough stations, and at apiaries the drums or the water-filled bases of the hive stands. At apiaries the field of view always included the hives as well as the water, so that wildlife activity at the apiary was also recorded. Two models were used: Browning BTC-8E-HP5, set to record 20-s videos with a 5-s recovery period, and Browning BTC-5FHDR, set to take three photographs per trigger with a 5-s recovery period. Monitoring ran from 14 January 2023 to 12 May 2026 and produced 39,493 records; part of the imagery was processed in Wildlife Insights (Ahumada et al. 2020), and all identifications were verified. All measures analysed depend on the timing of independent events, not on how long an animal remained in view, so the difference between the two models does not affect them.

Periods in which a camera was not operating were discarded, and effort was computed with camtrapR (Niedballa et al. 2016). Consecutive files more than 30 min apart opened a new independent event, and within that interval a record was also treated as independent when its species had not appeared in the preceding file.

2.7. Statistical analyses

All analyses were performed in R 4.4.2 (R Core Team 2024). Species recorded at fewer than five of the 24 stations were excluded throughout (20 of 50 species, 141 events, 1.7% of the total and 33 of the 2,878

events at apiaries). The threshold was applied once across all stations, not within site types, so that every analysis uses the same species. Contrasts were obtained from estimated marginal means with *emmeans* (Lenth and Piaskowski 2026), adjusted by Tukey's method and corrected across species with the Benjamini–Hochberg procedure where the same contrast was tested for several species (Benjamini and Hochberg 1995). Capture frequency is reported as independent events per 100 camera-trap days. Residuals were examined with *DHARMa* (Hartig 2024) using 500 simulations and aggregated to the station, the level at which the contrasts are estimated; no model deviated there. Interview data were summarised descriptively; because no variable links a respondent to a camera station, the correspondence between species named and recorded is regional.

The contrast central to the intervention, between Near and Far apiaries, was examined with four measures, since a detection rate alone confounds how many animals are present with how they move (Broadley et al. 2019; Hofmeester et al. 2019). Capture frequency was events per station-month, modelled with a negative binomial mixed model (nbinom2, *glmmTMB*; Brooks et al. 2017) with the logarithm of operating days as an offset. Active days was whether each operating station-day recorded an event and weeks with records whether each station-week with at least four operating days did so, both binomial, so their contrasts are odds ratios. The interval between visits was the number of camera-operating days between consecutive days with a detection, so that a period with the camera off is not read as an absence, modelled as Gamma with log link. All four models included station as a random intercept, and each measure was also analysed separately for the 14 species with at least 40 events at apiaries, recorded at four or more apiaries and present in both groups.

For every Far–Near contrast we report the minimum detectable ratio, exp(1.96 × SE), where SE is the standard error of the contrast on the log scale (Lakens 2022). Because a non-significant contrast does not show that there is no effect, we also tested capture frequency for equivalence with two one-sided tests (Schuirmann 1987), against margins of a two-fold and a 1.5-fold difference. Because not all sites were monitored in every month, we repeated the capture-frequency contrast as a sensitivity check, first with calendar month as an additional random intercept and then restricted to the 22 months in which both groups operated.

Whether water provisioned for the colonies was accessible to wildlife (Section 2.2) was unbalanced between groups, with accessible water at six of eight Near and three of eight Far apiaries. Because it is expected to influence apiary use independently of the troughs, each measure was refitted with it as an additive fixed effect and both versions reported. Accessibility was not considered when the systems were allocated, so this is a sensitivity analysis rather than the pre-specified contrast. Marginal means were computed with equal weights across the covariate's levels, since proportional weights would reconstruct the imbalance the adjustment is meant to remove. No interaction was fitted, because one of the four cells contains two stations. P values were corrected across the four measures within each specification, and the model with accessible water was also repeated with calendar month as an additional random intercept.

To confirm that the troughs functioned as intended, we compared capture frequency among the three site types and tested whether use tracked water availability. Capture frequency was modelled from the total events at each station with a negative binomial model, with the logarithm of camera-trap days as an offset. Rainfall was recorded in Nuevo Conhuás with a tipping-bucket rain gauge (0.254 mm per tip), and air temperature with a logger reading every 30 min. The three stations in Unión 20 de Junio lie far from the gauge and were excluded from the analyses involving rainfall. For the rainfall response, monthly events per station were modelled with site type, standardised rainfall accumulated over the preceding 60 days, the window with the lowest AIC among ten candidate climate variables (rainfall accumulated over 7 to 120 days, dry-spell length, days since the last rain and temperature), and their interaction, effort as an offset and station as a random intercept. Because consecutive months at a station are correlated and rainfall is itself a smooth function of time, the model-based p value is anticonservative; an autoregressive structure did not converge, so significance was assessed by permuting site type among stations, the units to which it was assigned (Anderson and ter Braak 2003), with a generalised additive model including a smooth of calendar time as a further check (Wood 2017).

3. Results

3.1. Water provisioning and perceived constraints

The 48 beekeepers interviewed managed 3,245 hives across a median of two apiaries each. All reported wildlife at their apiaries and 47 (98%) carried water to them, repeating the trip every six days on average; 77% named water scarcity as a constraint and 71% the labour of hauling water. Only three (6%) harvested rainwater, and the water they provided was held mostly in open basins and drums. Fewer than half, 22 of 48 (46%), named wildlife at the water as a constraint, against the 100% who reported its presence (Fig. 2).

Every respondent named at least one wild species visiting their apiaries, the median being three, and recognition concentrated on two (Table S1). Twelve of the thirteen species named were also recorded by the cameras, six of which are shown in Fig. S3; the exception was the spider monkey, an arboreal species ground-level cameras would not detect.

3.2. Wildlife use of apiaries near and far from troughs

The 24 stations operated for 10,863 camera-trap days, 4,371 at troughs, 4,003 at Near and 2,489 at Far apiaries, and yielded 8,144 independent events of 50 bird and mammal species (Tables S2–S4). Troughs accounted for 65% of all events on 40% of the effort.

None of the four measures distinguished Far from Near apiaries, and all four pointed in the predicted direction; in every case the observed ratio was smaller than the minimum detectable ratio (Table 1). Equivalence could not be claimed either, a two-fold margin returning p = 0.079 and a 1.5-fold margin p = 0.27. In the sensitivity checks, adding calendar month as a random intercept moved the ratio to 1.47, and

restricting the data to the 22 months in which both groups operated returned 1.28. The contrast remained non-significant in both.

Table 1
Far versus Near apiaries on the four measures of use, as estimated marginal means and Far/Near ratios (rate ratio for capture frequency, odds ratios for active days and weeks with records, ratio of means for days between visits). Ratios above 1, or below 1 for days between visits, support the prediction. MDR, minimum detectable ratio (α = 0.05, two-sided). The adjusted columns include accessible water as an additive covariate. p values are corrected across the four measures in each column (Benjamini–Hochberg)

Measure	Far	Near	Ratio	95% CI	p	MDR	Adjusted ratio (95% CI)	Adjusted p
Capture frequency	38.5	32.2	1.20	0.59–2.44	0.65	2.04	1.78 (0.98–3.24)	0.10
Active days	29.9%	25.9%	1.22	0.51–2.95	0.65	2.41	1.90 (0.88–4.09)	0.10
Weeks with records	86.6%	78.8%	1.73	0.44–6.77	0.65	3.91	3.86 (1.10–13.54)	0.10
Days between visits	3.51	4.11	0.85	0.49–1.50	0.65	1.76	0.65 (0.40–1.08)	0.10

Of the 14 species modelled separately (Table S5; Fig. S4), two contrasts survived correction, in opposite directions. *Sciurus deppei* returned sooner to Far apiaries (ratio of intervals 0.38, adjusted p = 0.019), as predicted, whereas *Panthera onca* returned more often to Near apiaries, its intervals between visits being 2.83 times longer at Far apiaries (adjusted p = 0.0027). *Urocyon cinereoargenteus* occurred three to four times more often at Far apiaries across independent measures, but the difference did not survive correction (adjusted p = 0.39). Across species, only a slight majority of contrasts pointed in the predicted direction: 33 of 55 (60%). This held for 8 of the 14 species in each of capture frequency, active days and weeks with records, and for 9 of 13 in the interval between visits.

3.3. Water accessibility at the apiary

Whether the water carried in for the colonies was left within reach of wildlife predicted apiary use far better than proximity to a trough. Accessible water raised capture frequency 2.71-fold (95% CI 1.48–4.99, p = 0.0013), the odds of an active day 3.16-fold (1.46–6.85, p = 0.0036) and of a week with records 5.85-fold (1.65–20.74, p = 0.0062), and roughly halved the interval between visits (0.49, 0.30–0.81, p = 0.0059); all four survived correction, and adding calendar month as a random intercept did not weaken the effect (capture frequency 2.92, 1.58–5.39; adjusted p ≤ 0.003 for all four measures). Observed capture frequency was higher at Far than Near apiaries within each level of the covariate (Fig. 3): 30.0 against 19.9 events per 100 camera-trap days where water was excluded, and 97.0 against 35.6 where accessible. Pooling the levels therefore obscured the contrast. Entering accessible water as an additive covariate roughly doubled the Far/Near ratio on the four measures of use (Table 1; Fig. S5), although no adjusted contrast survived correction. With calendar month also in the model, the adjusted contrast did

survive correction (capture frequency 2.22, 1.21–4.08, adjusted p = 0.019; adjusted p ≤ 0.021 for all four measures).

3.4. Use of troughs and response to water availability

Troughs received two to three times the visitation of either apiary type (Fig. 4a; Far/Trough ratio 0.47, p = 0.036; Near/Trough 0.37, p = 0.0037), while the apiary types did not differ (1.26, p = 0.74). Of the 40 species recorded at apiaries, 39 also occurred at troughs, and ten were recorded only at troughs. Among the 30 species retained for analysis, troughs held all 30, Far apiaries 28 and Near apiaries 27. Use responded differently to water availability: the slope against rainfall accumulated over the preceding 60 days was − 0.623 at troughs (95% CI -0.764 to -0.482), -0.316 at Near apiaries (-0.481 to -0.151) and − 0.072 at Far apiaries (-0.287 to 0.144), a negative slope meaning more visits as the landscape dries (Fig. 4b; interaction χ^2 = 19.21, permutation p = 0.027). When a smooth of calendar time was added, the response to rainfall remained clear at troughs (p = 0.0008) but not at Near (p = 0.096) or Far apiaries (p = 0.86). Full results are in the supplementary material (Tables S6, S7; Fig. S6).

4. Discussion

A rainwater-fed trough standing beside an apiary did not reduce the wildlife that came to that apiary. Animals used the troughs readily, two to three times as often as they used apiaries, which is what artificial water sources are known to draw, here and elsewhere (Armenteros et al. 2021; Contreras-Moreno et al. 2024, 2025; Sánchez-Pinzón et al. 2025), and their use rose as the dry season advanced. The alternative was there and it was taken up, yet the apiaries beside it went on receiving much the same visits as apiaries with no trough within a kilometre. The difference we recorded was far smaller than this trial could have told apart from chance. We have therefore not shown that troughs make no difference; we failed to find the reduction they were installed to produce.

The reason may lie in what the troughs were competing with. Reviews of diversionary provisioning report inconsistent outcomes and frequent unintended effects (Milner et al. 2014; Garshelis et al. 2017), and the review that separates uptake from outcome found that animals taking the provisioned resource did not reliably deliver the result managers wanted: of thirteen trials in which conflict reduction could be assessed, five succeeded, and uptake itself is most likely where the population is limited by the resource offered (Kubasiewicz et al. 2016). Ours is another such case, and apiary water is not limiting in that sense. Beekeepers refill the drums roughly every week through the dry season, so that while natural water retreats from the landscape and use of the troughs climbs, the water standing among the hives stays where it is; visits to apiaries well away from a trough showed no sign of rising as the landscape dried. Animals readily take up anthropogenic food subsidies that are predictable in space and time (Oro et al. 2013), and water kept permanently topped up is predictable in the same way, leaving an alternative nearby with nothing to substitute for. The closest published parallel comes from Namibia, where elephants went on damaging pumps, pipes and storage tanks although drinking pools had been provided for them nearby, though there the preference was put down to water quality, not availability (Ramey et al.

2013). In the same region damage occurred where dams had been left empty and fell where water was kept permanently available (Wenborn et al. 2025). We are not aware of this condition having been tested directly, and our result is consistent with it without demonstrating it.

What did separate one apiary from another was not the trough nearby but the water already standing among the hives. Where the drums and the water-filled stands were left open, apiaries received nearly three times the visits of apiaries where that water was covered, and animals returned in half the time. We had not set out to examine this, and it is distributed unevenly enough across our sites that its weight relative to the troughs remains unsettled, but it points somewhere practical: what a beekeeper does with the water they are already carrying in matters more to the wildlife at the apiary than whether a trough stands close to it. Excluding animals from those containers is the more direct of the two options, though we know of no study that has compared exclusion at the conflict site with provision of an alternative beside it.

The interviews place these systems in a different frame from the one that prompted them. Every beekeeper reported wildlife at the apiary, but fewer than half called it a constraint on their work, while 77% named the scarcity of water and 71% the labour of fetching it, a trip made on average every six days; only three of the 48 collected rainwater. The burden they describe is the water, not the animals at it. On that evidence, these systems contribute to coexistence by sharing water, not by separating wildlife from the apiaries. The same captured rainfall waters the colonies, spares the beekeeper a journey and supports a broad assemblage of vertebrates, including ten species that never appeared at the apiaries at all. That lowers the cost of living alongside wildlife without removing the overlap, which fits the view that some residual conflict is intrinsic to coexistence and not a sign of failure (Hill 2021). It also matches work on beekeeper–wildlife conflict elsewhere in the Neotropics that pairs mitigation at the apiary with support for the beekeeper instead of removing the species (Desbiez et al. 2020; Catapani et al. 2021). Whether it raises tolerance is less certain. Where tolerance has been modelled, it was driven by perceived, not tangible, costs and benefits (Kansky et al. 2016), so what may count is how beekeepers regard the labour saved, not the hours it returns. It also argues for reading what people say alongside what the cameras record, since uptake of a measure can follow its acceptability instead of its performance (Volski et al. 2021).

Two limitations qualify this trial. Whether apiary water was left within reach of wildlife was not considered when the systems were sited, and it happened to be more common at apiaries beside a trough, so its influence and that of the troughs cannot be separated cleanly. When both it and the timing of monitoring were taken into account, apiaries beside a trough did receive fewer visits, but that estimate rests on two stations; it is a reason to test troughs where apiary water is covered, not evidence that they work. Concentrating animals at a water point also carries risks we did not measure: parasites accumulate at water sources, increasingly so as conditions dry (Titcomb et al. 2021); waterholes carry elevated predation risk, to which prey respond by avoiding the riskiest sites and hours (Valeix et al. 2009); and drought raises both visitation and the overlap between species at artificial water, which its

authors argue elevates the risk of disease spillover (Ndachena et al. 2025). Where these systems are installed more widely, those risks would need to be monitored alongside the benefits.

4.1. Recommendations

Exclude wildlife from apiary water, and provide water separately. Accessible water was the strongest predictor of visitation we measured, so covering the drums is the most effective measure available and is already spreading among beekeepers. In Cantabrian apiaries damaged by brown bears, attack probability fell with the number of preventive measures in place, and protecting before a first attack was far more effective than afterwards (Naves et al. 2018). In Neotropical apiaries, hive stands at least 1.3 m high are the most effective protection against giant armadillos, while fencing is credited with preventing tayra damage (Desbiez et al. 2020). Because surface water is scarce in this landscape, exclusion should be paired with a water point nearby, not applied alone.

Fit escape structures to every water container. The open drums in which beekeepers store water occasionally trap and drown coatis and birds. A thick log and several branches, as placed in each of our troughs, cost nothing and allowed animals entering the water to climb out. The same provision should be standard in the drums themselves wherever they are left open.

Build adoption on the labour saved, not on conflict reduction. Only 6% of beekeepers harvest rainwater although 71% describe hauling water as a burden, and that gap is the strongest argument for uptake. Because the beekeepers installed and maintained the systems themselves, community-led expansion appears feasible. Wildlife-friendly certification of honey has precedent: in South Africa, beekeepers protecting their own hives cut honey badger damage from 21.8% to 6% (Begg 2001), and the Badger–Beekeeper Extension Programme established in 2002, which included a Badger Friendly label, is credited with all but ending the killing of badgers by participating beekeepers (Begg et al. 2016). Consumer prioritisation remained low, however, so certification can complement the labour benefit but not replace it.

Declarations

Ethics approval

This study did not require approval by an ethics committee. Under Mexican regulations such review applies to health-related research; this study consisted of interviews with adult beekeepers about their own practices, conducted with written informed consent and reported anonymously. Camera trapping was carried out on communal lands, within or on the periphery of the Balam Kú and Calakmul biosphere reserves, with the authorisation of the landholders of each parcel. No animal was captured, handled or sampled. Mexican wildlife law (Ley General de Vida Silvestre) requires a SEMARNAT permit for the scientific collection of specimens, which this study did not involve, and makes no provision for review by an animal ethics committee. The research was conducted in accordance with the 1964 Declaration of Helsinki and its later amendments.

Consent to participate

Written informed consent was obtained from every respondent before the interview. A statement of the purpose of the study and of the use that would be made of the answers was read aloud to each respondent, who then signed a consent form. Participation was voluntary.

Consent to publish

Not applicable. No identifying information is reported and no individual respondent can be recognised from the data presented.

Competing interests

The authors declare no competing interests.

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Author Contribution

CMDM: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition. MWF: Conceptualization, Methodology, Resources, Writing – review & editing, Supervision, Funding acquisition. VECQ, ASH and GHA: Validation, Data curation, Writing – review & editing. All authors read and approved the final manuscript.

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Data Availability

The data and R code that support the findings of this study will be deposited in a public repository upon acceptance of the article.

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Figures

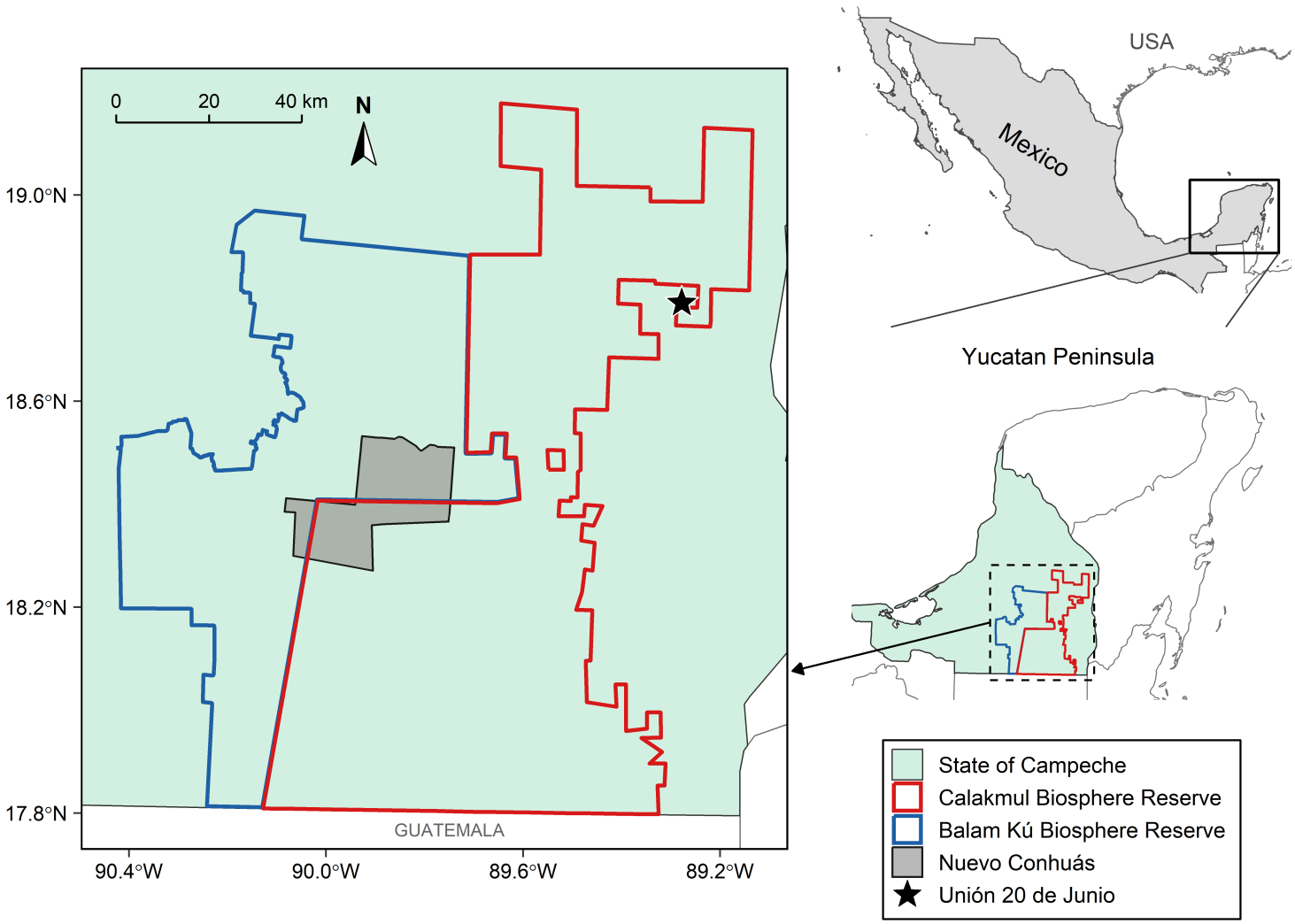

Figure 1

Study area in the municipality of Calakmul, Campeche, Mexico: the Calakmul and Balam Kú Biosphere Reserves, the communal lands of Nuevo Conhuás and the location of the communal lands of Unión 20 de Junio (star). The insets locate the Yucatan Peninsula in Mexico and the main panel in the peninsula (dashed box)

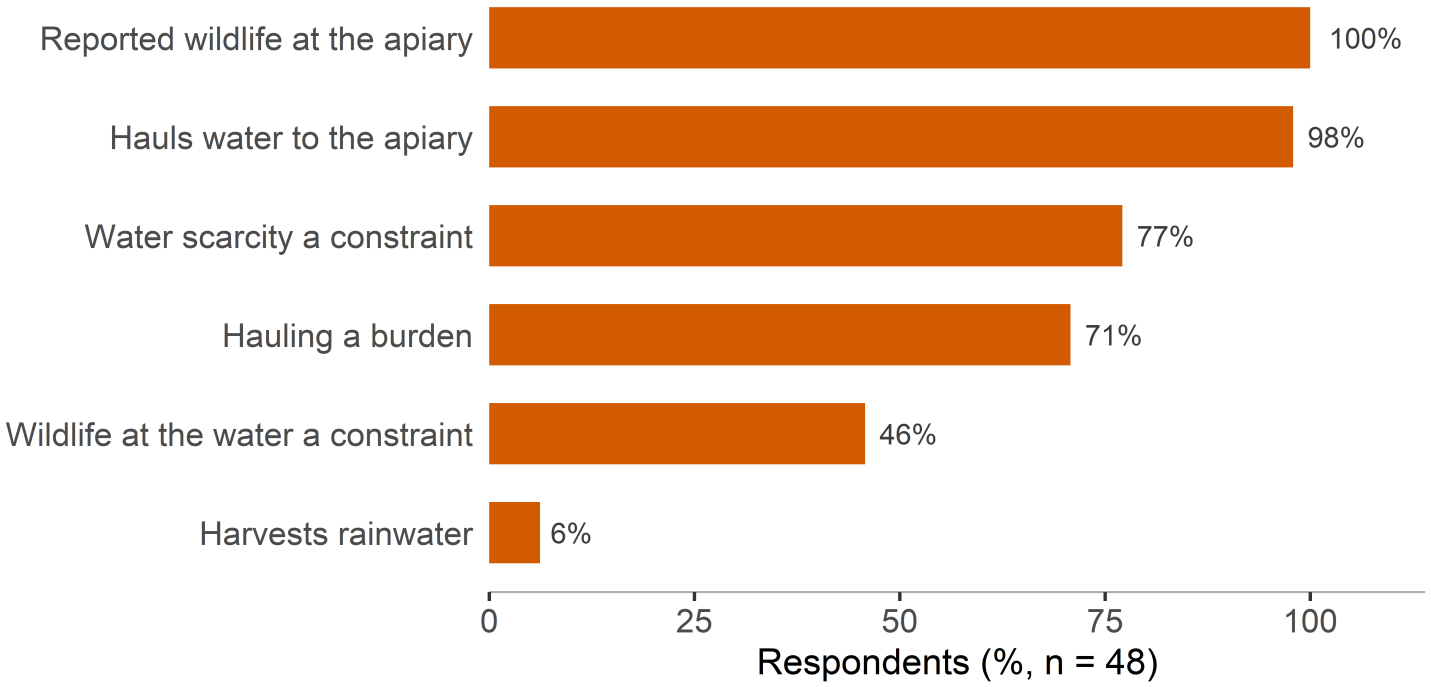

Figure 2

Water provisioning at apiaries and the constraints perceived by the 48 beekeepers interviewed. Bars give the percentage of respondents reporting each item

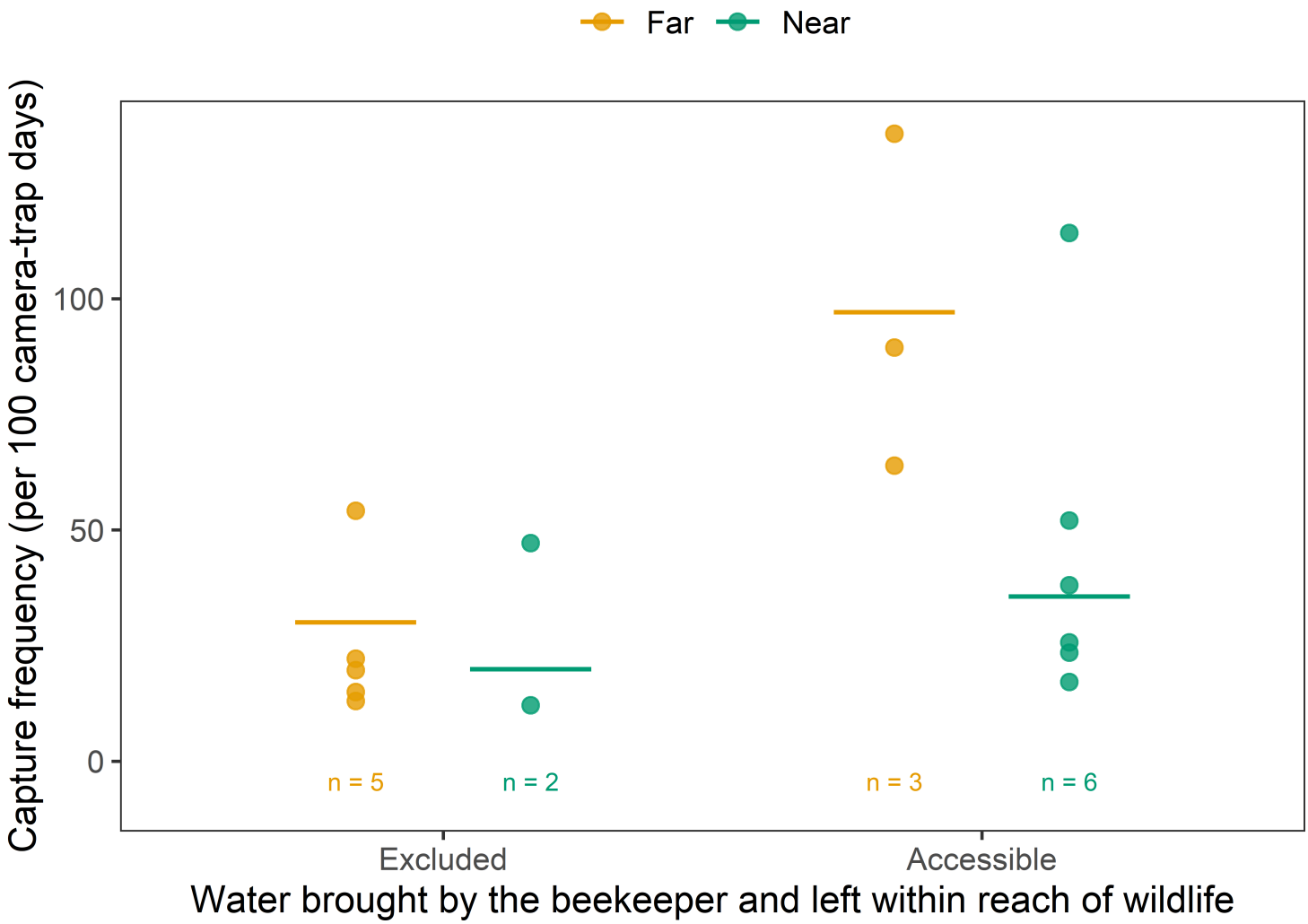

Figure 3

Capture frequency at Far (orange) and Near (green) apiaries according to whether the water provisioned for the colonies was left within reach of wildlife. Points are individual apiaries and horizontal bars the pooled capture frequency of each cell, in independent events per 100 camera-trap days; n is the number of apiaries in the cell

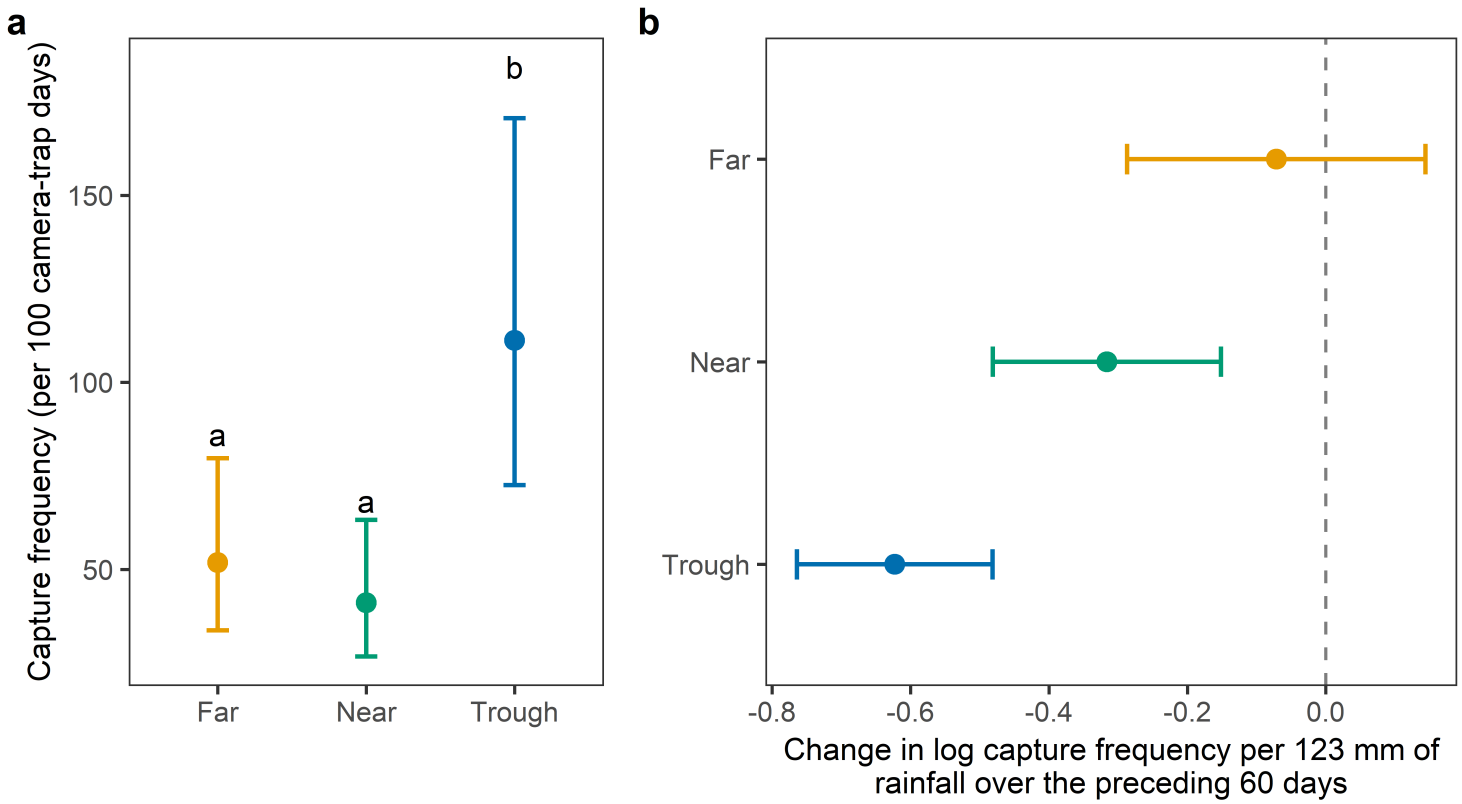

Figure 4

Wildlife use of rainwater troughs compared with apiaries near (Near) and far (Far) from a trough. (a) Capture frequency, in independent events per 100 camera-trap days, estimated with a negative binomial model, with 95% confidence intervals; site types sharing a letter do not differ (Tukey-adjusted $p > 0.05$). (b) Slope of monthly capture frequency against rainfall accumulated over the preceding 60 days, on the log scale per standard deviation of rainfall (123 mm), with 95% confidence intervals; a negative slope means more visits as the landscape dries

Supplementary Files

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