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Reproductive seasonality and partial semelparity in a population of Gracilinanus agilis in the Brazilian Caatinga

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Abstract

The agile gracile opossum *Gracilinanus agilis* (Didelphidae) is partially semelparous in some South American biomes; whether this strategy is expressed in the Caatinga, its most extreme habitat, remained unknown. Using multistate multievent capture–mark–recapture models, we analysed 415 captures of 131 individuals across 41 sessions (23,575 trap-nights, 2014–2018) and estimated apparent monthly survival (φ), the transition of non-breeders into the breeding population (ψ), and recapture. Survival and breeding transitions were driven by reproductive seasonality rather than rainfall. Non-breeder survival was higher during the non-reproductive period (φ = 0.94, 95% CI 0.64–0.99) than during the reproductive period (φ = 0.66, 95% CI 0.37–0.86); breeder survival was constant (φ = 0.73, 95% CI 0.67–0.78). The transition peaked before, rather than within, the reproductive season (ψ = 0.57, 95% CI 0.35–0.77 vs 0.12, 95% CI 0.02–0.53): individuals attained breeding condition in advance of the resource peak, consistent with the anticipatory, photoperiod-cued maturation typical of semelparous marsupials. Sex and rainfall had no detectable effects. Monthly breeder survival (0.73) yields a cumulative annual probability of only ~ 0.02, and only two individuals (one per sex) were recorded breeding in a second season, confirming near-complete post-reproductive turnover. Our results provide the first evidence of partial semelparity for *G. agilis* in the Caatinga, and show that reproductive seasonality – rather than rainfall – governs its survival and breeding transitions.

Introduction

Understanding how vital rates such as survival, reproduction, and recruitment vary in space and time is central to population ecology and to the conservation of species facing environmental change (Lebreton et al. 1992; Lopes and Leiner 2015; Ferreira et al. 2020). For Neotropical small mammals, this understanding remains fragmentary: long-term, individual-based demographic studies are concentrated in a few species and regions, and small terrestrial marsupials in semi-arid environments are particularly underrepresented (Albuquerque et al. 2012; Vieira et al. 2017; Ferreira et al. 2020). Filling this gap is important because vital rates are the demographic expression of life-history strategies. These strategies are shaped by the interplay between endogenous factors (e.g. density, reproductive effort, competition) and exogenous factors such as seasonality, resource availability, and climatic harshness (Meserve et al. 2003; Krebs 2013; Vieira et al. 2017) – interactions that can push species towards extreme positions on the iteroparity–semelparity continuum (Stott et al. 2024).

Among the most important axes of life-history variation is the continuum between iteroparity, in which individuals reproduce in several seasons, and semelparity, in which reproduction is concentrated in a single, intense event followed by death (Wolfe et al. 2004; Fisher et al. 2013; Stott et al. 2024). Between these extremes lies partial semelparity, in which most individuals die after their first reproduction, but a small fraction survives to breed again (Martins et al. 2006a,b; Leiner et al. 2008). Among mammals, semelparity is rare and is restricted to small insectivorous marsupials of the Dasyuridae (Australia and New Guinea) and Didelphidae (South America) (Fisher et al. 2013). Fisher and Salguero-Gómez (2022) framed the evolution of “reproductive death” under two non-exclusive scenarios: a demographic model,

in which semelparity is favoured where post-reproductive survival is intrinsically low and future reproduction is therefore unlikely; and a reproductive-effort model, in which channelling all reproductive investment into a single event yields disproportionate fitness gains. Comparative work indicates that sperm competition is a major driver of suicidal reproduction in mammals, and that reproductive timing in semelparous species is often cued by a species-specific rate of change of photoperiod rather than by resource peaks alone (Fisher et al. 2013).

The cost of reproduction that underlies semelparity is frequently sex-biased. In strongly semelparous marsupials, males invest heavily in pre- and post-copulatory competition, sustaining high physiological stress, sleep loss, and rapid somatic deterioration, and typically die shortly after mating (Bradley 2003; Boonstra 2005; Gaschk et al. 2023; Zaid et al. 2024). Females, in contrast, more often survive until their young are weaned, but pay the energetic cost of gestation and prolonged lactation, which can also depress their survival (Harder 1992; Fisher et al. 2006; Fisher and Blomberg 2011; Zangrandi and Vieira 2023). The relative magnitude of these costs differs among species and populations, producing a spectrum from male-only (partial) semelparity to reproductive death in both sexes (Martins et al. 2006b; Fisher et al. 2013; Albanese et al. 2021).

In Brazil, semelparity in small didelphids has been documented in the Cerrado, Atlantic Forest, and Pantanal (Leiner et al. 2008; Andreazzi et al. 2011; Lopes and Leiner 2015; Puida and Paglia 2015; Zangrandi et al. 2023). The Caatinga, however, remains almost unstudied in this respect, despite being the most water-limited and seasonally extreme of the biomes inhabited by these species. The Caatinga is a seasonally dry tropical forest covering about 10% of Brazil's territory (IBGE 2019), characterised by consistently high temperatures (mean ~ 25–30°C year-round), low and concentrated rainfall (300–1000 mm/year, falling mainly between January and May), and prolonged droughts (Nimer 1972; Ab'Saber 1974; Carvalho et al. 2011; de Queiroz et al. 2017), factors known to structure the demography of small mammals in xeric habitats (Sobral and Oliveira 2014). Its vegetation is dominated by drought-adapted thorny trees, shrubs, succulents, cacti, and seasonal herbaceous plants, creating a highly seasonal environment in which resource availability is concentrated within relatively short favourable periods. Such environmental constraints make the Caatinga an ideal system for investigating the demographic and reproductive consequences of extreme seasonality in small mammals. Because reproductive death is expected to be favoured precisely where adult survival is low and resources are pulsed (Fisher and Salguero-Gómez 2022), the Caatinga offers a strong test of whether *G. agilis* expresses semelparity, and of how extreme seasonality shapes its survival and recruitment.

The agile gracile opossum *Gracilinanus agilis* (Burmeister 1854) is a small (13–45 g), nocturnal, solitary, arboreal didelphid with an insectivorous–omnivorous diet (Rossi and Bianconi 2011; Paglia et al. 2012; Camargo et al. 2014). This dietary flexibility may allow the species to exploit seasonal pulses of arthropods, fruits, and other food resources, potentially facilitating reproductive synchronisation with periods of increased productivity. It is widely distributed in South America and, in Brazil, occupies the highly seasonal Caatinga, Cerrado, and Pantanal biomes (Gardner 2008; Paglia et al. 2012). In the Cerrado and Pantanal, it synchronises breeding with the rainy season and the associated peak in primary

productivity (Andreazzi et al. 2011; Puida and Paglia 2015; Zangrandi and Vieira 2023), and it has been described as partially semelparous, with strong post-reproductive senescence and little overlap between generations (Martins et al. 2006a; Lopes and Leiner 2015; Puida and Paglia 2015; Zangrandi and Vieira 2023).

Whether *G. agilis* expresses this strategy in the Caatinga, what environmental factors govern it, and whether it is sex-biased remain open questions. Seasonal increases in resource availability associated with rainfall may favour reproductive synchronisation and elevated reproductive investment during short favourable periods. Consequently, demographic rates may be influenced either directly by rainfall or indirectly through biologically defined reproductive seasons. We addressed these questions using a multistate multievent capture–mark–recapture framework, classifying individuals as non-breeders or breeders based on external characters (see Methods) and estimating apparent monthly survival (φ), the transition from non-breeder to breeder (ψ), and recapture probability (p). We tested the predictions of three hypotheses: (i) *H1 (degree of semelparity)* – If Caatinga conditions favour reproductive death (Fisher and Salguero-Gómez 2022), survival should decline markedly after the reproductive period and very few individuals should reach a second reproductive event; (ii) *H2 (reproductive seasonality vs rainfall)* – If reproductive timing is more closely associated with seasonal reproductive schedules than with short-term variation in rainfall, survival and breeding recruitment should track the reproductive period rather than accumulated rainfall between intervals; (iii) *H3 (sex differences)* – If reproductive costs are male-biased, males should show lower or more steeply declining survival around the reproductive period than females.

Materials and Methods

Study area

The study was conducted in an 8.25-ha fragment of native Caatinga in the state of Rio Grande do Norte, north-eastern Brazil (05°03'43" S, 37°23'54" W). The fragment is a well-preserved stand of dense hyperxerophilous shrub–tree vegetation with a high density of *Copernicia prunifera* (Maia-Silva et al. 2012; Torquato 2015). The climate is hot semi-arid (BSh in the Köppen classification; Alvares et al. 2013), with two well-defined seasons. The mean annual temperature is 27.6°C, and the long-term (1964–2019) mean annual precipitation is 689.8 mm (Silva 2014; EMA-UFERSA 2019). Rainfall is strongly concentrated: based on data from the Mossoró meteorological station of the Agricultural Research Corporation of Rio Grande do Norte (EMPARN), the rainy period (January–July) and the dry period (August–December) received, respectively, mean seasonal totals of 548.3 mm and 3.4 mm over the study period.

Reproductive periods

Because reproduction of *G. agilis* in the study area was confined to the rainy season, we defined two periods for analysis: a reproductive period (January–July) and a non-reproductive period (August–December). This biologically defined seasonality was used as a categorical covariate in the models (see below). For capture–recapture modelling, reproductive months were coded as 1 and non-reproductive months as 0 according to the interval between consecutive trapping sessions.

Field sampling and data collection

Agile gracile opossums were captured monthly or bimonthly from June 2014 to November 2018, in 41 sampling sessions of five consecutive nights each. We used 115 live traps (59 Sherman traps, 30 × 8 × 9 cm; 56 Tomahawk traps, 45 × 16 × 16 cm) arranged in a grid of 13 parallel transects spaced 25 m apart. Traps remained permanently in the field, were activated in the late afternoon, baited with a mixture of banana, maise flakes, peanut, and sardine, and checked each morning.

All captured individuals were marked with numbered ear tags. Sex was determined by the presence of scrotal testes (males) or their absence (females). Reproductive status was assessed in the field from external characters: breeding females had a naked (hairless) belly with enlarged, lactating nipples, whereas non-breeding females had a fur-covered belly; males were classified as reproductive when the scrotal width exceeded 13 mm (following Hernandez et al. 2018). We note that this threshold was derived from a different population and has not been validated experimentally; we therefore treat it as a field proxy for reproductive condition and discuss its limitations below. Dental eruption (Macedo et al. 2006) was used to corroborate the finding that small, young individuals were non-breeders. After handling, all animals were released at the capture site.

Mean percentages of breeders and non-breeders were calculated from raw capture data as the proportion of individuals assigned to each reproductive category during each trapping session and averaged across reproductive and non-reproductive seasons throughout the study period.

All procedures were approved by the Ethics Committee of the Federal Rural University of the Semi-Arid Region (UFERSA; opinion No. 11/2014, process No. 23091.00413/2014-21) and licensed by SISBIO (No. 41686-6), and followed the guidelines of the American Society of Mammalogists for the use of wild mammals in research (Sikes et al. 2016).

Capture–recapture modelling

We built multistate multievent CMR models (Lebreton et al. 1992; Pradel 2005) in E-SURGE 2.1.2 (Choquet and Nogue 2011). We considered three biological states – dead (*d*), non-breeder (*nb*), and breeder (*b*) – and three events: 0 = not detected, 1 = detected as non-breeder, 2 = detected as breeder. Sex (female, male) was coded as an individual covariate in the “headed format” data file (Choquet and Nogue 2011). The multievent structure accommodates uncertainty in state assignment and requires, in addition to the parameters of a classical multistate model, an initial-state probability (the probability of

being in a given state at first capture; Pradel 2005). Our models therefore comprised four parameters: initial state; apparent survival (φ, the probability of surviving and remaining in the study area between consecutive sessions); the transition from non-breeder to breeder (ψ, i.e. recruitment into the breeding population); and recapture (p). Because an individual that has bred cannot revert to the non-breeding state, the transition from breeder to non-breeder was fixed to zero. Sampling intervals were unequal (monthly to bimonthly); we accounted for this using the unequal-time-interval facility of E-SURGE, supplying the elapsed time between consecutive sessions scaled to months, so that φ is expressed on a common monthly time step.

We assessed the goodness of fit (GOF) of the single-state Cormack–Jolly–Seber (CJS) model with U-CARE 2.3.4 (Choquet et al. 2009), separately for females and males. We tested for transience (component 3.SR), which arises when apparent survival in the first interval after marking is lower than in subsequent intervals (Duriez et al. 2009), and for trap-dependence (component 2.CT). We found no evidence of transience ($Z = -0.01$, $P = 0.99$) or trap-dependence ($Z = -0.24$, $P = 0.81$), and the global test was non-significant ($\chi^2 = 13.61$, df = 62, $P = 1$). Because there was no evidence of overdispersion ($\hat{c} \approx 1$), we performed model selection with the Akaike Information Criterion corrected for small sample size (AICc; Burnham and Anderson 2002).

We followed a step-down model-selection procedure (Lebreton et al. 1992; Santoro et al. 2016). Starting from a fully parameterised model that included additive temporal variation in all parameters except recapture, the interaction between sex and reproductive status (non-breeder vs breeder) on apparent survival and recapture, and a sex effect on the transition, we sequentially selected the best structure for each parameter in the order recapture → initial state → transition → apparent survival, retaining at each step the structure with the lowest AICc. Recapture was modelled as time-independent to ensure parameter identifiability and because a preliminary analysis, consistent with the constant field effort, showed no temporal variation in this parameter. Because apparent survival and the transition were our primary interest, we first ran all candidate structures for apparent survival while holding the transition at its most parameterised structure (Online Resource 1), and vice versa (Online Resource 2); we then combined the supported structures (within 2 AICc units of the best model) for both parameters (Online Resource 3). Finally, using the resulting consensual model, we tested the additive effects of two targeted biological covariates – “rain” (rainfall accumulated during the interval t to $t + 1$) and “reproductive period” – on apparent survival and on the transition (Table 1). Throughout, we use φ for apparent survival, ψ for the transition, p for recapture, “·” for a constant (intercept-only) structure, “t” for full time-dependence, “sex” for a sex effect, and “br” for a reproductive-status (breeder vs non-breeder) effect.

Table 1
Model selection for the effects of rainfall ("rain") and reproductive period ("reprod") on apparent survival (φ) and on the transition to breeder (ψ). Each parameter was tested while holding the other at the consensual structure [φ(br) ψ(·); Online Resource 3]. The null model is the most supported model, with no environmental effects (model 1 in Online Resource 3). np, number of parameters; AICc, Akaike Information Criterion corrected for small sample size; ΔAICc, difference from the best model; NB, non-breeders; BR, breeders; br, reproductive-status effect; *t*, time; ·, constant.

Model	Structure	np	Deviance	AICc	ΔAICc
Apparent survival (φ)					
1.7	**φ(NB×reprod + BR) ψ(·)**	**8**	**715.80**	**732.33**	**0.00**
1.5	φ(br×reprod) ψ(·)	9	715.68	734.35	2.02
Null	φ(br) ψ(·)	7	720.91	735.32	2.99
1.2	φ(br + rain) ψ(·)	8	719.83	736.36	4.04
1.4	φ(NB + BR×rain) ψ(·)	8	719.93	736.46	4.13
1.6	φ(br + reprod) ψ(·)	8	719.94	736.47	4.15
1.3	φ(NB×rain + BR) ψ(·)	8	720.71	737.24	4.92
1.8	φ(NB + BR×reprod) ψ(·)	8	720.71	737.24	4.92
1.1	φ(br×rain) ψ(·)	9	719.77	738.43	6.11
Transition to breeder (ψ)					
1.10	**φ(br) ψ(reprod)**	**8**	**713.54**	**730.07**	**0.00**
Null	φ(br) ψ(·)	7	720.91	735.32	5.25
1.9	φ(br) ψ(rain)	8	720.70	737.23	7.16

Results

Across the 41 sampling sessions (23,575 trap-nights), *G. agilis* was captured in 37 sessions, yielding 415 captures of 131 individuals (55 females, 76 males). Reproductive composition shifted seasonally as expected: during the reproductive seasons, breeders and non-breeders represented on average 72% and 28% of captures, respectively, whereas during the non-reproductive seasons these proportions were reversed (24.5% breeders, 75.5% non-breeders).

The most supported model for apparent survival included the reproductive period as a predictor for non-breeders but not for breeders (model 1.7; Table 1). Non-breeder survival was higher during the non-reproductive period (φ = 0.94, 95% CI 0.64–0.99) than during the reproductive period (φ = 0.66, 95% CI 0.37–0.86), whereas breeder survival was constant across periods (φ = 0.73, 95% CI 0.67–0.78; Fig. 1).

Models including accumulated rainfall performed substantially worse (ΔAICc > 4; Table 1), supporting H2.

The breeding transition also varied with the reproductive period (model 1.10; Table 1): it was higher before than within the reproductive season (ψ = 0.57, 95% CI 0.35–0.77 vs ψ = 0.12, 95% CI 0.02–0.53), indicating that non-breeders predominantly acquired breeding status ahead of, rather than during, the reproductive season. Rainfall models for the transition were also poorly supported (ΔAICc > 7; Table 1), consistent with H2. Sex had no detectable effect on apparent survival or on the breeding transition, contrary to H3 (Online Resour).

Monthly breeder survival of 0.73 translates into a cumulative annual survival of only ~ 0.023. Only two of the 131 individuals – one female and one male (1.8% of females, 1.3% of males) – were recaptured breeding in a second reproductive season, supporting H1.

Discussion

Our findings support the hypothesis that *G. agilis* in the Caatinga expresses a high degree of semelparity (H1). Monthly apparent survival of breeders was low (0.73), translating into a cumulative annual survival of only about 0.023, and only two individuals – one of each sex – were recorded reproducing in a second season (1.8% of females, 1.3% of males). Survival therefore declined steeply after the first reproduction but did not reach zero, placing this population firmly within the partial-semelparity portion of the semelparity–iteroparity continuum (Leiner et al. 2008; Fisher et al. 2013; Stott et al. 2024) rather than at the extreme of complete reproductive death. This is, to our knowledge, the first demographic evidence of semelparity in *G. agilis* in the Caatinga, extending a strategy previously described in the Cerrado and Pantanal (Andreazzi et al. 2011; Lopes and Leiner 2015; Puida and Paglia 2015) to the most water-limited and seasonally extreme biome of its range. That a comparable degree of semelparity is expressed under markedly harsher conditions is consistent with the demographic model of reproductive death, in which low and seasonally constrained adult survival makes future reproduction unlikely and favours concentrating reproductive effort into a single event (Fisher and Salguero-Gómez 2022).

Reproduction was strongly seasonal and synchronised with the rainy period (January–July), when food resources peak in the Caatinga (Pinheiro et al. 2002; Batalha and Martins 2004; Vasconcellos et al. 2010; Silva et al. 2020). This seasonal increase in productivity likely enhances the availability of fruits, flowers, seeds, and arthropods, providing favourable energetic conditions for gestation, lactation, and juvenile development. Similar reproductive patterns have been reported in other populations of *G. agilis*, although the timing and duration of reproduction vary geographically. In the Pantanal, reproductive activity is concentrated mainly between December and February (Andreazzi et al. 2011), whereas in Cerrado populations it may extend from June to February depending on local environmental conditions (Lopes and Leiner 2015). In some riparian Cerrado populations, reproductive activity appears even more restricted, with gestation concentrated in September and lactation occurring primarily in November (Puida and Paglia 2015). Comparative analyses across seasonal environments further suggest that

populations of *G. agilis* exhibit considerable variation in reproductive schedules and life-history traits, reflecting local environmental conditions and resource dynamics (Zangrandi and Vieira 2023). These differences suggest that reproductive timing in *G. agilis* is not a fixed species-level trait but responds to local variation in environmental seasonality and resource predictability.

A central prediction of our second hypothesis (H2) was that demographic parameters would be more closely associated with reproductive seasonality than with accumulated rainfall. Our results support this prediction: both survival and transitions into the breeding population were better explained by the reproductive period than by rainfall variation between sampling intervals, and we detected no direct effect of rainfall on any demographic parameter. Two non-exclusive mechanisms may explain this pattern. First, during the rainy season, rainfall accumulated between consecutive intervals may be insufficient to generate a detectable signal, even though cumulative precipitation ultimately governs food availability and can extend the breeding season (Bergallo and Magnusson 1999; Leiner et al. 2008; Camargo et al. 2019). The dietary flexibility of *G. agilis* may further facilitate this ecological adjustment by allowing individuals to exploit a broad range of food resources as they become seasonally available (Camargo et al. 2014), thereby promoting the close alignment between reproductive activity and periods of maximum resource abundance. Second, the onset of reproduction in semelparous marsupials may be influenced by species-specific photoperiodic cues rather than by resource peaks alone, resulting in highly synchronised reproductive activity among years (Fisher et al. 2013). Under this scenario, photoperiod would act as a proximate cue for reproductive activation, whereas rainfall would primarily influence the energetic conditions that determine reproductive success and offspring survival. These mechanisms are not mutually exclusive. Rainfall likely determines the seasonal pulse of resources that makes reproduction energetically viable, whereas photoperiod may synchronise reproductive activity within populations. Under either explanation, the calendar of reproduction – captured by our “reproductive period” covariate – is a more proximate predictor of demography than rainfall, as our model selection indicates. This result aligns with the broader observation that, in semelparous marsupials, the timing of reproduction is strongly decoupled from short-term resource variation (Fisher et al. 2013), and it reinforces the importance of treating reproductive seasonality as a primary demographic driver in highly seasonal habitats.

Beyond identifying the seasonal period as the main driver, our models revealed distinct survival and transition patterns by reproductive status. The clearest seasonal signal was the higher apparent survival of non-breeders during the non-reproductive period than during the reproductive period, while breeders survived at an intermediate, constant rate throughout the year. We interpret this in terms of the population’s cohort structure rather than as a reproductive survival advantage of breeders. In a short-lived, partially semelparous species with little generational overlap, the non-reproductive period is dominated by the new cohort of juveniles and subadults that must survive the dry season before entering the breeding population in the following rainy season. Recruitment therefore appears to be filtered through survival across the dry season and successful transition into reproductive condition before the next breeding period. Rather than occurring through continuous generational replacement, population renewal appears structured by discrete cohorts with limited overlap, a demographic pattern

commonly associated with semelparous life histories. This interpretation is accords with the low degree of generational overlap observed in other populations of *G. agilis* and helps explain the pronounced seasonal turnover documented in our study population. We emphasise, however, that survival estimates for breeders and non-breeders during the reproductive period exhibited broad overlap in their confidence intervals, and therefore our results should not be interpreted as evidence of a biologically meaningful survival difference between reproductive states during this phase of the annual cycle. Agrees with this cohort-based interpretation, the transition into the breeding population was likewise higher during the non-reproductive period (ψ = 0.57) than during the reproductive period (ψ = 0.12). This indicates that non-breeders predominantly attain breeding status before the reproductive season begins, consistent with the synchronised, anticipatory onset of reproduction characteristic of semelparous marsupials: individuals reach reproductive condition in advance of, rather than in response to, the resource peak (Fisher et al. 2013). For a short-lived species in which most individuals breed only once, this anticipatory maturation is the demographic mechanism that aligns first reproduction with the favourable season; whether finer-scale variation in body condition or competition modulates the timing of individual transitions (Kajin et al. 2008; Lopes and Leiner 2015) remains to be tested directly.

Turning to sex differences (H3), we found no effect of sex on apparent survival or on the breeding transition, and only two individuals – one of each sex – reached a second reproduction. This contrasts with the male-biased reproductive death documented in several dasyurids and in some *Gracilinanus microtarsus* populations, where males disappear after mating while females survive longer (Bradley 2003; Boonstra 2005; Martins et al. 2006b; Gaschk et al. 2023; Zaid et al. 2024), but it is agrees with reports of post-reproductive mortality in both sexes in small Neotropical didelphids (Leiner et al. 2008; Baladrón et al. 2012; Albanese et al. 2021). Under the extreme seasonality of the Caatinga, the reproductive period may impose comparable survival costs on both sexes – males through the energetic and physiological toll of mating competition, and females through gestation and prolonged, pouchless parental care (Russell 1982; Harder 1992; Speakman 2008; Fisher and Blomberg 2011). Field observations also revealed signs of physical deterioration in some males near the end of the reproductive season, including fur loss on the rump and chest. Similar evidence of post-reproductive physical deterioration has been reported in other populations of *G. agilis* and is consistent with the physiological costs associated with intense reproductive effort (Lopes and Leiner 2015). The absence of a true marsupium may further increase maternal energetic expenditure because offspring require prolonged direct care and physical support during development (Harder 1992; Fisher and Blomberg 2011). We caution, however, that apparent survival confounds mortality with permanent emigration, and that the relatively small sample and wide confidence intervals limit our power to detect moderate sex differences; the absence of a detectable sex effect should therefore be read as a lack of strong, consistent divergence rather than as proof of identical demography.

Taken together, our estimates describe a Type II survivorship pattern (Lee et al. 1982), with progressive mortality and few individuals persisting to a second reproductive event. The estimated monthly breeder survival of 0.73 corresponds to an annual survival probability of approximately 2.3%, representing one of the lowest long-term survival estimates reported for the genus. Such rapid population turnover, driven by

high post-reproductive mortality, is a hallmark of reproductive death in didelphid marsupials and has broad ecological consequences, including for predator–prey dynamics (Cockburn 1997; Fisher et al. 2001; Boonstra 2005; Fisher et al. 2013). The pattern we describe is most parsimoniously explained by the joint operation of the two evolutionary scenarios proposed by Fisher and Salguero-Gómez (2022): the seasonally low adult survival of the Caatinga satisfies the demographic model, while the synchronised concentration of reproduction into a single, intense season is consistent with the reproductive-effort model. Distinguishing the relative contribution of these mechanisms – and clarifying whether the absence of a sex effect reflects genuinely shared costs or limited statistical power – will require physiological data on stress and senescence (e.g. corticosteroid profiles; Edwards et al. 2016; Hernandez et al. 2018; Delehanty and Boonstra 2023) alongside longer or larger CMR datasets. While the demographic patterns observed provide strong support for these interpretations, several limitations should be considered when evaluating the strength of our inferences.Apparent survival cannot be separated from permanent emigration without auxiliary data; the field criterion for male reproductive condition (scrotal width > 13 mm) was adopted from another population and has not been experimentally validated; and the precision of period-specific estimates is limited by sample size, as reflected in the wide confidence intervals. Despite these limitations, the convergence of low cumulative survival, steep post-reproductive decline, negligible second reproduction in both sexes, and seasonally structured survival and transitions provides consistent support for partial semelparity in this population and reinforces the importance of reproductive seasonality as a key driver of demographic dynamics in the Caatinga.

This study provides the first demographic evidence that *Gracilinanus agilis* exhibits a high degree of partial semelparity in the Caatinga, extending a life-history strategy previously documented in the Cerrado and Pantanal to the most seasonally restrictive biome within the species' distribution. The extremely low annual survival of breeders, the negligible proportion of individuals reproducing in a second season, and the pronounced seasonal turnover observed in the population indicate that reproduction is concentrated within a narrow temporal window and followed by substantial post-reproductive mortality.

Our results further demonstrate that reproductive seasonality, rather than accumulated rainfall per se, is the primary driver of survival and recruitment dynamics in this population. Together, these findings support the view that semelparity in *G. agilis* is a flexible life-history strategy shaped by strong seasonal constraints on survival and reproduction. Future studies integrating physiological indicators of stress and senescence with long-term demographic monitoring across different biomes will be important for understanding the mechanisms underlying post-reproductive mortality and geographic variation in the degree of semelparity.

Declarations

Statement of Animal Ethics:

All procedures involving animals were approved by the Ethics Committee of the Federal Rural University of the Semi-Arid Region (UFERSA; Opinion No. 11/2014, Process No. 23091.00413/2014-21) and were conducted under SISBIO license No. 41686-6. All animal handling and research procedures followed the guidelines of the American Society of Mammalogists for the use of wild mammals in research (Sikes et al., 2016).

Conflict of Interest Statement

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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Figures

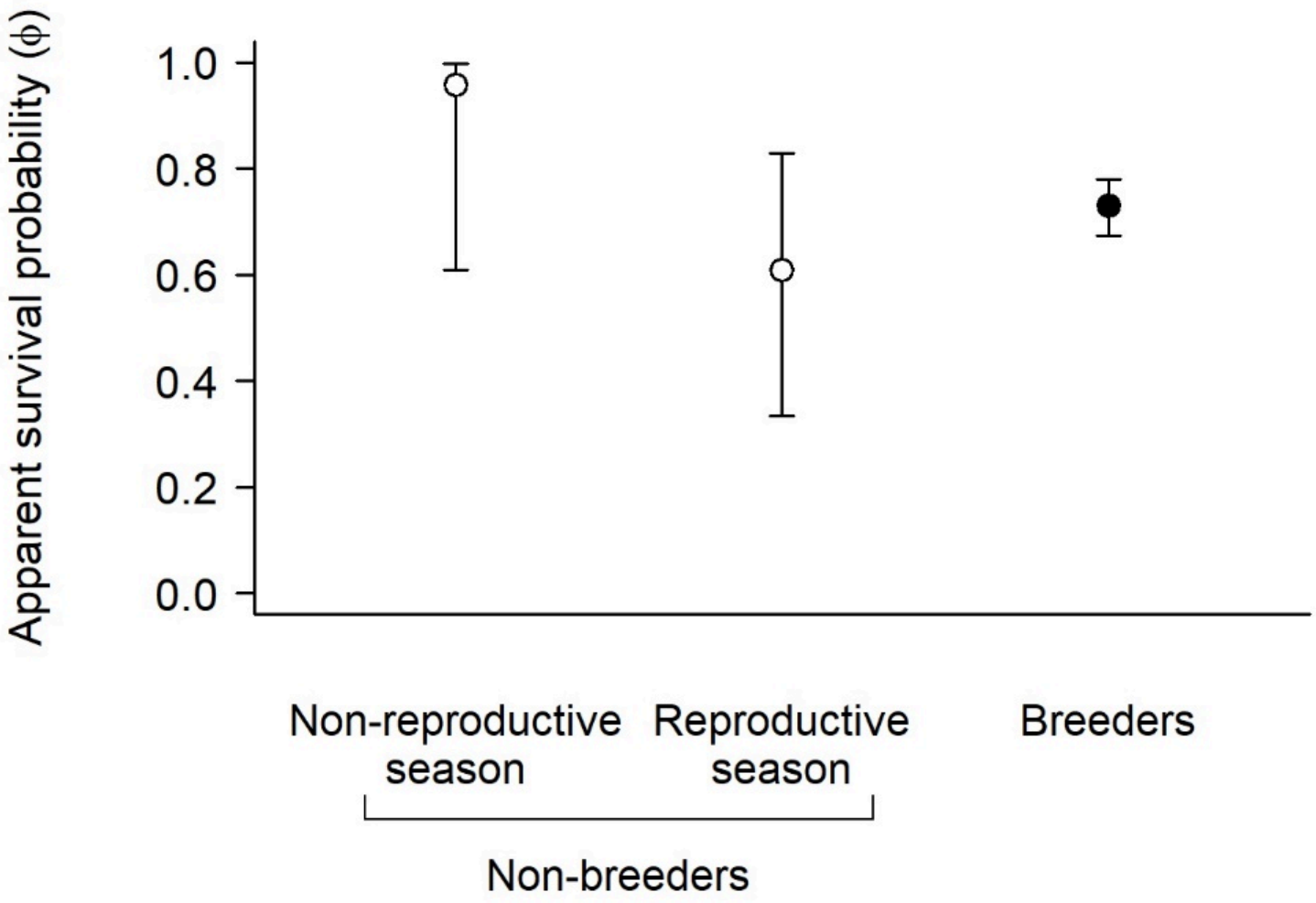


Figure 1

Apparent monthly survival (*φ*) and 95% confidence intervals for breeding and non-breeding *Gracilinanus agilis* during the reproductive and non-reproductive periods in the semi-arid Caatinga

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