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Biodiversity assessments vary with time-to-independence filter in camera trap studies

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ABSTRACT

Context. Camera traps are an essential tool for biodiversity monitoring, yet variations in the definition of time-to-independence (defined as the minimum time between consecutive records of the same species at a camera station considered to represent independent records) can influence species records and data comparability across studies. **Aims.** Our study examines how different time-to-independence filters (30 min, 60 min, 12 h, and 24 h) affect the detection, and estimated richness, abundance, and composition of medium- and large-bodied mammals in the Tapajós National Forest, Brazilian Amazon. We expected that (1) estimated species richness would be similar among filters and (2) apparent species composition would vary more for rarely captured species than for commonly captured species ones across time-to-independence filters. **Methods.** Using standardized camera-trap data from 38 plots, we applied the four thresholds to generate species accumulation curves, rank-abundance curves, and apparent species composition matrices to assess how filtering alters species records and inferred community structure. **Key results.** Our findings indicated that estimated species richness remained consistent across filters, suggesting that studies based on species richness can integrate datasets with varying time-to-independence filters without introducing significant biases. Conversely, species abundance ranks and apparent composition varied notably across filters, particularly for rarely captured species, which exhibited greater sensitivity to temporal aggregation. Although commonly captured species were consistently detected across all filters, certain species that were infrequently recorded using short time-to-independence filters (i.e. 30 and 60 min) became frequently detected with longer filters (i.e. 24 h), altering their classification from 'rare' to 'common'. **Conclusions.** The stability of species richness across filters supports the use of datasets with different time frames in macroecological studies, enabling large-scale biodiversity assessments. However, the temporal sensitivity of apparent species composition, especially for rarely captured species, underscores the necessity of caution in community-level analyses. **Implications.** Studies investigating species interactions or community structure should account for the effects of time-to-independence filters when comparing datasets. Standardizing camera-trap protocols or implementing methodological adjustments for different time-to-independence filters will be crucial for enhancing data comparability in ecological studies and ensuring robust conservation assessments.

Keywords: Amazon rainforest, biodiversity monitoring, camera traps, community ecology, detection frequency, independent records, species composition, species richness.

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Introduction

In recent decades, global environmental changes, which are primarily driven by climate change, have significantly affected biodiversity (Malhi *et al*. 2014; Rodrigues-Filho *et al*. 2024). The intensification of hydrological cycles, coupled with habitat loss, fragmentation, and ecosystem degradation, directly affects species distributions and ecological interactions (Blowes *et al*. 2019; Marta *et al*. 2021). In response to these challenges, wildlife monitoring plays a crucial role in understanding ecological patterns and informing conservation strategies.

Technological advancements have greatly facilitated wildlife monitoring, particularly through environmental sensors, remote monitoring systems, and automatic cameras. Among these, camera traps have become widely used non-invasive tools for recording wildlife, enabling the collection of data on species occurrence, behavior, activity patterns, and interspecific interactions (Rowcliffe and Carbone 2008; Leuchtenberger *et al.* 2014; Chen *et al.* 2022). This information is fundamental for developing effective conservation strategies (Tobler *et al.* 2008) and is especially valuable for ecological studies in remote areas (Castro-Pastene and Cross 2021).

Building on these advances, camera-trap data are employed in studies with diverse objectives, and a critical methodological aspect is the definition of time-to-independence filter (i.e. the minimum time between consecutive records of the same species at a camera trap, which are deemed to constitute independent 'events'), which can influence both results and comparability among studies. For instance, Andrade-Ponce *et al.* (2022) used a 30-min filter to examine mammalian prey–predator co-occurrence, whereas Jeong *et al.* (2024) applied a 60-min filter to assess spatiotemporal segregation in passerines. In contrast, studies focused on single-species behavior, such as territoriality in giant otters (Leuchtenberger *et al.* 2015), or plant–animal interactions often rely on continuous recording (Galetti *et al.* 2015; Da Silva Batista *et al.* 2025), because time-to-independence filters may be less critical when aiming to capture all behaviors and interactions. Furthermore, defining time-to-independence filters is essential for community inventories and long-term monitoring efforts to maximize species independent records over time. Given the challenges of individually identifying mammals in photographic records, several studies use the number of independent records as a proxy for activity, abundance, or apparent species composition (e.g. Tanwar *et al.* 2021; Dueser *et al.* 2025). However, the criteria for determining independence vary considerably, with time-to-independence filters ranging from 30 min (Kelly and Holub 2008) to 60 min (Pires and Galetti 2023) or even 24 h (Brocardo *et al.* 2023). Although it is well recognized that detection rates from camera traps are not directly comparable across species, locations, or time periods (Hayward and Marlow 2014), the use of independent records as a proxy for relative abundance remains in biodiversity studies (Tanwar *et al.* 2021; Dueser *et al.* 2025). This is especially true for large-scale or long-term monitoring programs, where logistical constraints often limit the standardization of methods. Moreover, independent records are still widely applied in activity pattern analyses (Peral *et al.* 2022). In this context, understanding how different time-to-independence filters influence biodiversity metrics is crucial, not to enable direct comparisons among studies, but to evaluate how methodological choices affect ecological inferences within a given study framework (Kelly and Holub 2008; Brocardo *et al.* 2023; Pires and Galetti 2023).

Camera traps can capture a broad range of taxa, including reptiles, birds, and mammals (Torralvo *et al.* 2017; Antunes *et al.* 2022; Schneider *et al.* 2024). However, their primary application has been in surveying medium to large mammals (Agha *et al.* 2018), because these species have a large biomass among the vertebrates, performing several ecological functions that are of interest to researchers and policymakers. In tropical regions, many of these mammals are naturally rare (Yu and Dobson 2000), leading to sporadic detections that complicate the establishment of standardized recording filters. Rarely captured species, owing to their low detectability, may appear only in specific time frames, whereas commonly captured species are recorded more consistently. This discrepancy can introduce biases of an abundance of species estimates and community composition analyses, as the choice of the time-to-independence filter may either amplify or reduce the apparent presence of rarely captured species. Therefore, defining an appropriate filter is crucial to ensuring a balanced representation of biodiversity and minimizing methodological inconsistencies across studies.

The growing emphasis on data sharing in ecology has encouraged the deposition of datasets in publicly accessible repositories, enabling broader ecological inquiries (Vanderbilt *et al.* 2015; Acevedo *et al.* 2022). Consequently, the increasing reliance on literature reviews, databases, and data papers containing camera-trap records (e.g. Antunes *et al.* 2022) underscores the need for standardization or, at the very least, an understanding of the impact of different time-to-independence filters when comparing data from various recording protocols.

Given this context, our study aims to address the following questions: (1) do different time-to-independence filters affect the number of independent records and the estimated species richness (on the basis of species accumulation curves) of medium and large mammals? We expected that estimated species richness would be similar between filters. (2) Does the choice of time-to-independence filter affect the composition patterns of commonly and rarely captured rare species differently? We expected that the apparent species composition of commonly captured species would remain unchanged regardless of the chosen time to filter, whereas, for the entire assemblage and for rarely captured species, in particular, apparent species composition, would differ when comparing very different filters (e.g. 30 min and 24 h). To answer these questions, we investigated whether independent record counts and local apparent species composition change across different time-to-independence filters and whether these differences are driven by the differential contribution of apparently common and rarely captured species. Our findings may contribute to the standardization of camera-trap monitoring protocols, improving data comparability, particularly in the context of collaborative research initiatives.

Materials and methods

Study area

The study was conducted in the Tapajós National Forest (TNF), a protected area that permits the sustainable use of natural resources by local communities. Covering 572,319 ha, the TNF is dominated by *terra firme* forest (Veloso *et al.* 1991) and ranges in altitude from 8 to 330 m. The area experiences a mean annual temperature of 25.5°C and an average annual precipitation of 1820 mm, with a 4-month dry season from August to November. Approximately 9000 people live in the TNF across 31 communities, including indigenous groups. Deforestation and habitat fragmentation, caused by the construction of the Cuiabá–Santarém Highway (BR-163) in 1970 and the expansion of soybean cultivation in the 1990s (Fearnside 2007; Garrett *et al.* 2013), make the TNF critical for mammal conservation in the region (Sampaio *et al.* 2010). We selected TNF as our study area because it hosts both abundant and rarely captured species (see Rosa *et al.* 2021; Brocardo *et al.* 2023), enabling an evaluation of the effects of time-to-independence filter on both groups.

Mammal sampling

To monitor biodiversity in the TNF, we established four rapid ecological assessments and long-term ecological research (RAPELD) modules as part of the Brazilian Biodiversity Research Program (PPBio) (Magnusson *et al.* 2005). Each module covers 5 km^2 (1 km wide × 5 km long) and consists of 10 regularly spaced plots (250 m in length, with variable width following the terrain contour), separated by a minimum distance of 1 km (Magnusson 2013) (Fig. 1).

We installed one camera trap in each plot to sample mammals between July and December 2019 (dry season). The camera models used were Bushnell 12Mp Natureview Cam Essential HD Low Glow® (n = 12), Primos Proof Cam 3 Review® (n = 5), and Moultrie A5 Low Glow Game Camera® (n = 3). Subtle differences among camera trap models mainly in trigger sensitivity and detection range could affect detection probabilities (e.g. Rovero *et al.* 2013; Driessen *et al.* 2017). Because we could not use the same camera model at all stations, we selected only models with comparable specifications (low-glow infrared, <1 s trigger speed), and therefore we assume that the bias caused by camera model differences was minimal. We installed camera traps in robust trees along the plots (1 per plot), at a height of 30–40 cm above the ground, positioned near animal trails, and programmed to capture either three consecutive photographs per trigger or 10-s videos, with a 1-s delay between triggers. Cameras operated continuously for 24 h a day over 34 days. We recorded the location of each camera by using a GPS device (Garmin 62S, Garmin International Inc., Kansas, USA). Owing to the limited number of available camera traps and logistical constraints, sampling was conducted sequentially across modules, with each module being fully sampled before moving to the next, to ensure that rotation did not affect the detection of rarely captured species within each module. We collected data from 38 plots, because two camera traps malfunctioned during the study period.

Data analysis

Do different times-to-independence filters affect the number of independent records and estimated species richness of medium and large mammals?

To assess the influence of different time-to-independence filters on species independent records and comparability, we analyzed data using four filters, namely, 30 min, 60 min, 12 h, and 24 h. We defined time-to-independence as the minimum elapsed time required between two consecutive records of a species at the same camera to consider them as independent records. For each filter, we calculated the number of independent records at the species level. On the basis of these data, we constructed a rank-abundance curve (RAC) to track the species' abundance change across time-to-independence filters. Additionally, we generated species accumulation curves for each filter to compare estimated species richness. To determine whether filters with fewer independent records exhibited estimated species richness comparable to those with a greater number of records, we performed a rarefaction analysis (Chao *et al.* 2014; Hsieh *et al.* 2016).

Does the choice of time-to-independence filters affect the composition patterns of commonly and rarely captured species differently?

We built a species-by-site matrix on the basis of the number of independent records of each species. As the definition of time-to-independence filter influences how many records are counted as independent, the total records per species varied across the four filters (30 min, 60 min, 12 h, and 24 h). These variations affect the relative abundance and, consequently, the patterns in apparent species composition explored in multivariate analyses We applied non-metric multidimensional scaling (NMDS) to visualize compositional differences, reducing the multidimensional data to a single dimension. Stress value remained below 0.2, indicating that the ordination preserved similarity patterns without significant distortion. Using NMDS Axis 1 and the number of independent records, we tested whether apparent species composition and abundance (measured as the number of independent records based on a given filter) differed from time-to-independence filters. We conducted an analysis of covariance (ANCOVA) to determine whether apparent species composition and record numbers were comparable across time-to-independence filters, considering the entire assemblage, commonly captured species, and rarely captured species separately. Species rarity was defined on the basis of independent frequency in camera traps, as represented in the rank-abundance curve (RAC). We classified as 'common' the species accounting for more

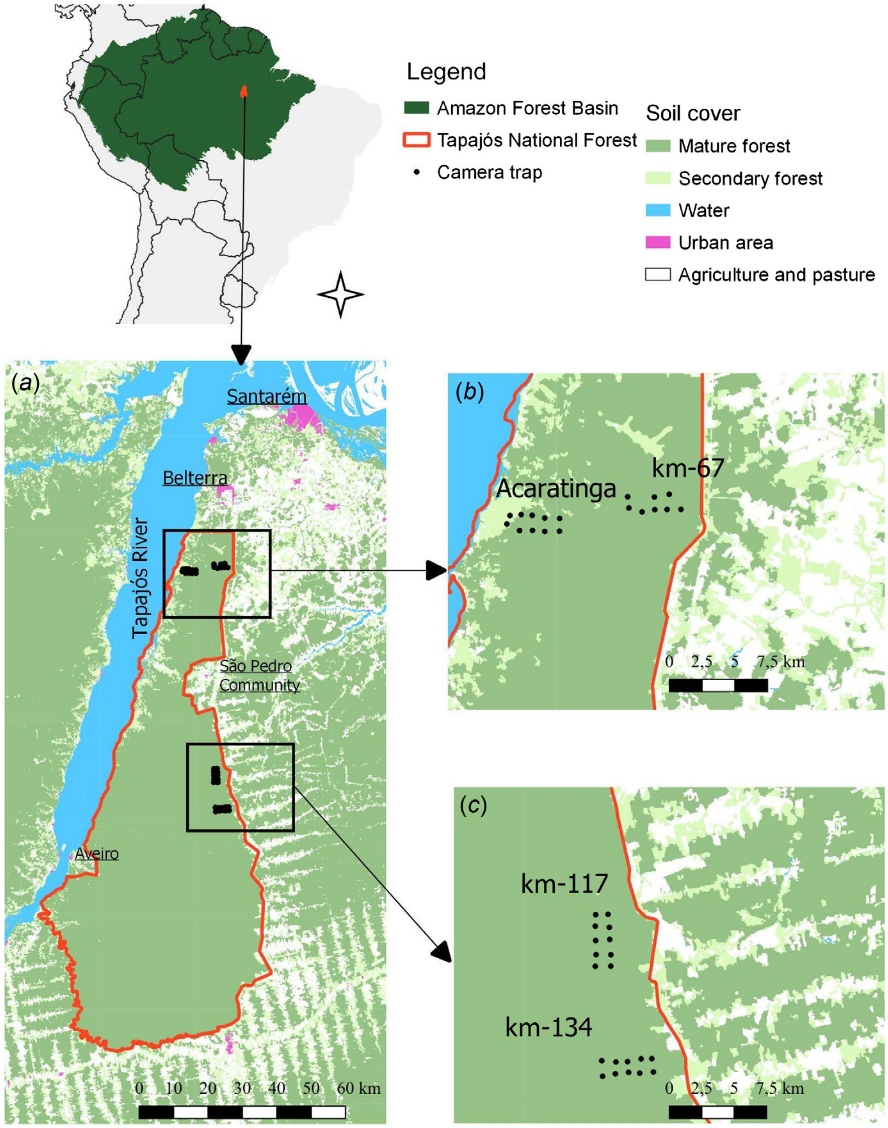

Fig. 1. (*a*) Map of location of the Tapajós National Forest and (*b*, *c*) images of areas around RAPELD-modules. Black dots represent the location of the camera installation.

than 5% of the total photographic records, and as 'rare' those contributing less than 5%. This classification reflects relative detectability rather than true ecological abundance (Magurran and Henderson 2011). For example, a significant ($P < 0.05$) relationship between estimates derived from the 30-min and 60-min time-to-independence filters indicates that estimated species richness and apparent species composition increase in a similar manner across filters, suggesting that responses derived from different time-to-independence filters tend to be comparable. However, the strength of this relationship might vary across comparisons. To facilitate interpretation, we incorporated a 1:1 reference line in the dispersal plots to highlight comparisons with higher similarity in apparent species composition and abundance. Conversely, significant differences between categories (entire assemblage, commonly captured species, and rarely captured species) would suggest that responses vary depending on species group classification.

Results

We recorded a total of 26 mammal species (Table 1). The number of records per camera trap station ranged from 3 to 98 at the 30-min filter (mean ± s.d.: 26 ± 24.09), from 3 to 80 at the 60-min filter (mean ± s.d.: 26 ± 22.40), from 3 to 65 at the 12-h filter (mean ± s.d.: 23 ± 16.34), and from 3 to 50 at the 24-h filter (mean ± s.d.: 21 ± 12.92). The relatively most frequently recorded species were orange agouti (*Dasyprocta croconota*) and spotted paca (*Cuniculus paca*), which were classified as commonly captured across all time-to-independence

Table 1. Total number of records of ground-dwelling mammals across time-to-independence filters in Tapajós National Forest (TNF). Species are ordered according to their abundance rank.

Species	30 min	60 min	12 h	24 h	Category
Dasyprocta croconota	807	763	561	465	Common
Cuniculus paca	170	164	146	123	Common
Didelphis marsupialis	76	75	74	66	Common
Passalites nemorivagus	63	63	59	54	Common/rare[A]
Dasypus kappleri	49	49	49	45	Rare
Dasypus novemcinctus	42	42	41	41	Rare
Pecari tajacu	28	27	26	26	Rare
Mazama americana	14	14	14	13	Rare
Leopardus pardalis	11	11	11	11	Rare
Mazama sp.	10	10	10	10	Rare
Nasua nasua	8	8	7	7	Rare
Tamandua tetradactyla	8	8	8	8	Rare
Myrmecophaga tridactyla	7	7	7	7	Rare
Proechimys sp.	6	5	4	3	Rare
Dasypus sp.	5	5	4	4	Rare
Leopardus wiedii	4	4	4	4	Rare
Eira barbara	3	3	3	3	Rare
Panthera onca	3	3	3	3	Rare
Priodontes maximus	3	3	3	3	Rare
Cabassous unicinctus	2	2	2	2	Rare
Puma concolor	2	2	2	2	Rare
Tapirus terrestres	2	2	2	2	Rare
Atelocynus microtis	1	1	1	1	Rare
Cerdocyon thous	1	1	1	1	Rare
Euphractuss excinctus	1	1	1	1	Rare
Potos flavus	1	1	1	1	Rare
Total	1327	1274	1044	906	

[A]Species classified as rare in the 30- and 60-min time-to-independence filters, but classified as common in the 12- and 24-h filters.

filters. In contrast, the least recorded species six-banded armadillo (*Euphractus sexcinctus*), kinkajou (*Potos flavus*), short-eared dog (*Atelocynus microtis*), jaguar (*Panthera onca*), panther (*Puma concolor*), and margay (*Leopardus wiedii*) were categorized as rare.

Do different times-to-independence filters affect the number of independent records and estimated species richness of medium and large mammals?

We did not observe substantial differences in the estimated species richness across time-to-independence filters, as indicated by consistent species rankings in the rank-abundance curve (RAC) plots, with minimal deviation being reflected in the overlapping red lines (Fig. 2*a*). Across all filters, *Dasyprocta croconota*, *Cuniculus paca*, and black-eared opossum (*Didelphis marsupialis*) consistently ranked among the most abundant species. Furthermore, when species richness was standardized on the basis of the total number of individuals, no significant differences were detected among time-to-independence filters, as indicated by the overlapping confidence intervals (Fig. 2*b*).

Does the choice of time-to-independence filters affect the composition patterns of commonly and rarely captured species differently?

Mammal apparent species composition was similar between the 30-min and 60-min filters, as indicated by the strong correlation between NMDS scores ($P < 0.001$; Table 2, Fig. 3). This similarity was consistent for both common and rarely captured species ($P = 0.14$). We observed a comparable pattern when comparing the 12- and 24-h filters (Fig. 3). However, in other comparisons, apparent species composition differed when considering both rare and commonly captured species (Fig. 3). Among all time-to-independence filter comparisons, the composition of commonly captured species closely followed the expected 1:1 relationship (dashed line in Fig. 3). In contrast, the overall assemblage and rarely captured species differed from the 1:1 expected relationship.

We observed a strong correlation between the mammal abundance (number of records) across the different time-to-independence filters analyzed ($P < 0.05$; Table 2, Fig. 4). The strongest relationships occurred between the closest filters (30 vs 60 min and 12 vs 24 h), as indicated by their proximity to the 1:1 line (Fig. 4). In most cases, the relative abundance of rarely captured species remained consistent across filters. However, the 12-h filter showed significant differences from the 30-min and 24-h filters (orange line in Fig. 4).

Discussion

In this study, we investigated whether diversity (i.e. species rank and estimated richness), abundance, and composition of mammal species are more similar between closer time-to-independence filters. Perhaps the most striking finding was that these metrics exhibit significant differences across filters, particularly when comparing longer time-to-independence filters. However, estimated species richness remained consistent across filters, but only when accounting for differences in sampling effort through rarefaction techniques. Notably, rarely captured species contributed significantly to the observed variations in apparent species composition, emphasizing the need for careful selection of time-to-independence filters in camera-trap studies, especially in community ecology research. This consideration is particularly relevant in tropical regions, which are biodiversity hotspots and harbor a high proportion of rarely captured species (Magurran 2021).

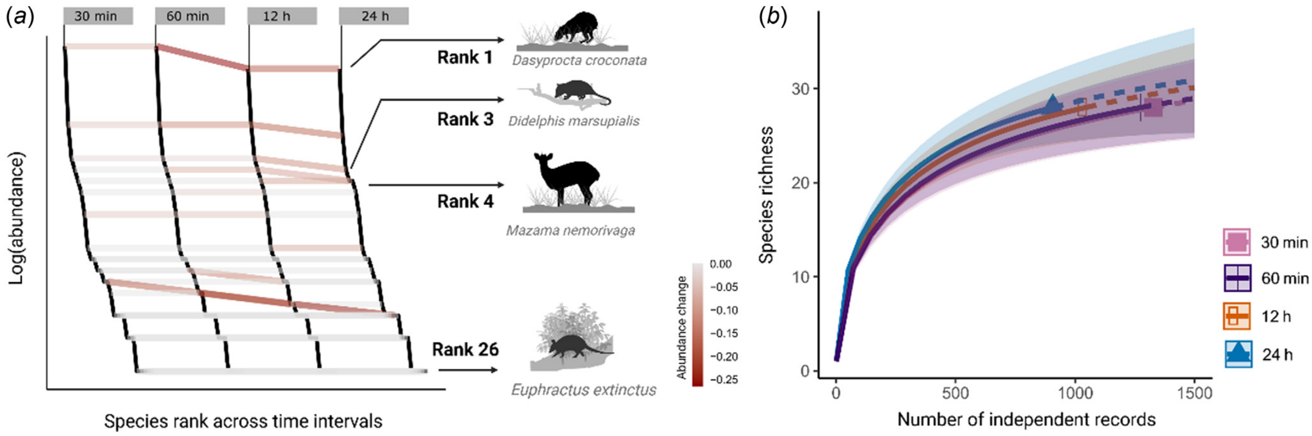

Fig. 2. (*a*) Rank species rank plot (RAC) for the four-time-to-independence filters. The red lines connect the same species across time-to-independence filters, whereas the color indicates changes in abundance. For example, *Dasyprocta croconota*, although remaining at Rank 1 in all filters, showed a considerable decrease in abundance (~15%) between the 60-min and 12-h filters. (*b*) Estimated mammal richness (solid curve) and extrapolation (dotted curve), based on the number of records. Shaded areas indicate the 95% confidence interval. Figure part *a* is built under the R script available on https://doi.org/10.6084/m9.figshare.25021103.v2.

Table 2. Summary of results from ANCOVA analyses, testing the individual effects of composition (NMDS scores) and abundance across time-to-independence filters, as well as their interaction with species category (assemblage, common, and rare).

Item	t60			t12			t24		
	t	slope	*P*	T	Slope	*P*	t	slope	*P*
Composition									
t30	**31.10**	**0.93**	**<0.001**	**9.87**	**0.87**	**<0.001**	**9.64**	**0.82**	**<0.001**
t30 × group	1.16	0.05	0.140	**−2.64**	**−0.74**	**0.023**	**−2.84**	**−0.70**	**0.018**
t60	–	–	–	**8.03**	**0.78**	**<0.001**	**7.91**	**0.74**	**<0.001**
t60 × group	–	–	–	**−3.16**	**−0.84**	**<0.001**	**−3.8**	**−0.60**	**<0.001**
t12	–	–	–	–	–	–	**65.7**	**0.94**	**<0.001**
t12 × group	–	–	–	–	–	–	**−8.33**	**−3.6**	**0.006**
Abundance									
t30	**31.10**	**0.93**	**<0.001**	**9.87**	**0.87**	**<0.001**	**8.07**	**0.68**	**<0.001**
t30 × group	1.16	0.28	0.140	**−2.64**	**−0.75**	**0.023**	−2.48	−0.49	0.135
t60	–	–	–	**6.57**	**0.56**	**<0.001**	**6.06**	**0.59**	**<0.001**
t60 × group	–	–	–	−1.68	−0.36	0.756	−2.00	−0.38	0.615
t12	–	–	–	–	–	–	**65.49**	**1.03**	**<0.001**
t12 × group	–	–	–	–	–	–	**3.41**	**0.70**	**0.012**

Bold values indicate statistically significant results. t30, composition or abundance at 30 min; t60, composition or abundance at 60 min; t12, composition or abundance at 12 h; t24, composition or abundance at 24 h. Interactions between time-to-independence filters and species category are indicated by ×.

Species rank varies across time-to-independence filters, but estimated species richness remains stable

The variation in species ranking across time-to-independence filters suggests that a species classified as rare in one filter may appear as common in another. Whereas some dominant species, such as *Dasyprocta croconota*, *Cuniculus paca*, and *Didelphis marsupialis*, consistently ranked among the most abundant across all filters, other species exhibited fluctuations in their relative abundance. For example, Amazonian brown brocket deer (*Passalites nemorivagus*), which was among the least detected species in shorter time-to-independence filters (30 and 60 min), appeared more frequently in longer filters (12 and 24 h). This finding highlighted that the choice of time-to-independence filter can influence species classification, potentially affecting ecological interpretations.

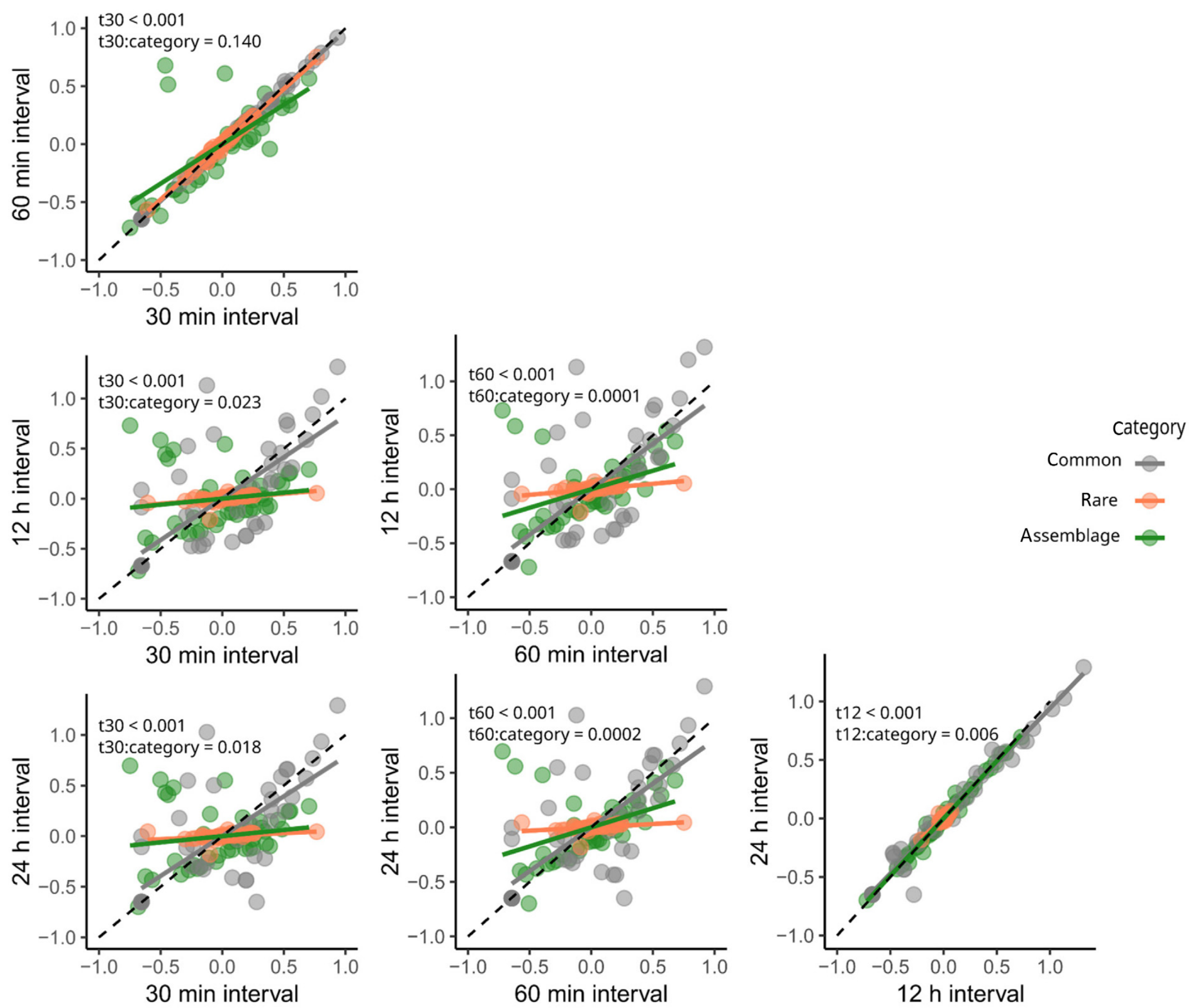

Fig. 3. Relationships between NMDS Axis 1 scores, used as indicators of apparent species composition, across time-to-independence filters. Each point represents a camera-trap sampling unit (n = 38), with scores derived from separate NMDS analyses for each of the three species categories (entire assemblage, commonly captured species, and rarely captured species), resulting in 120 points per time-to-independence filters. The dashed line represents the 1:1 relationship between x- and y-axis values. Colors indicate the species category: common (gray), rare (orange), and entire assemblage (green).

The classification of species as rare or common is a widely used criterion in conservation planning (Arponen 2012); however, our results showed that, where relative numbers of photographic captures are used as proxies for relative abundance, this status can shift depending on the time-to-independence filter applied. This finding highlighted a critical methodological sensitivity; depending on whether conservation priorities emphasize rare (Mouillot *et al*. 2013; Leitão *et al*. 2016) or commonly captured species (Gaston and Fuller 2008), such rank changes could directly affect strategic decisions. For instance, *Leopardus wiedii*, identified as the rarest species in our dataset under shorter filter, may not retain this status under longer filter, potentially altering its perceived conservation urgency. These results reinforce the need for methodological transparency and standardization when defining species detection criteria for biodiversity assessments and conservation planning. Indeed, our findings call into question the use of detection rates as informative metrics for conservation planning, echoing extensive literature on this issue (e.g. Jennelle *et al*. 2002). Estimated species richness remained stable even when comparing widely different time-to-independence filters (e.g. 30 min vs 24 h). This indicates that studies focusing on species richness can confidently adopt any time-to-independence filter with minimal impact on their findings. This flexibility in study design has important implications for biodiversity monitoring, because it facilitates the integration of datasets collected under different protocols, enhancing comparability across regions, and enabling collaborative research efforts. More broadly, these findings support large-scale ecological

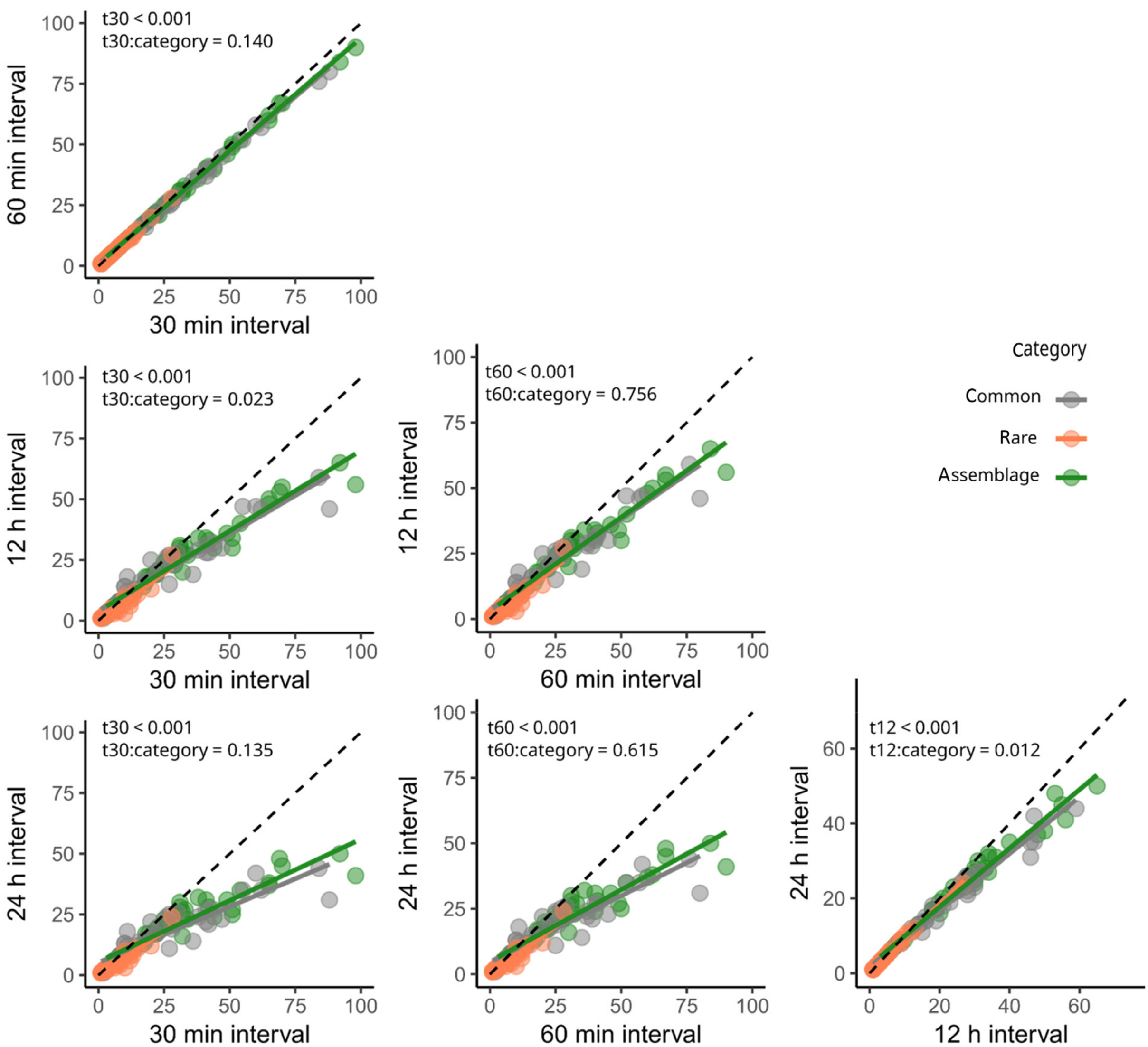

Fig. 4. Relationships among species abundance (i.e. number of independent records) across time-to-independence filters. Each point represents a camera-trap sampling unit (n = 38), with abundance values being calculated separately for each species category (entire assemblage, commonly captured species, and rarely captured rare species), resulting in 120 data points per comparison. The dashed line indicates the expected 1:1 relationship between x- and y-axis values. Colors represent the species category: common (gray), rare (orange), and entire assemblage (green).

research aiming to compare estimated species richness patterns across regions (e.g. Antunes *et al.* 2022). By demonstrating that species richness remains consistent across time-to-independence filters, our study has reinforced the reliability of data aggregation from multiple sources, contributing to more comprehensive and standardized ecological assessments.

Rarely captured species pose challenges for assemblage-based studies using camera traps

Our findings showed that apparent species composition remains consistent within shorter time-to-independence filters (30 and 60 min) and within longer time-to-independence filters (12 and 24 h), but significant differences emerge when comparing short versus long filters. These differences are primarily driven by changes in the relative frequency of detection of rarely photographed species. For instance, *Passalites nemorivagus* was classified as commonly captured under short time-to-independence filters but shifted to a rarely-captured category when longer filters were applied. Such rank shifts alter the relative contribution of species to the photographic assemblage and can generate pronounced differences in apparent community composition. Importantly, even species that are consistently detected across filters may change their relative position within the assemblage, whereas transitions from commonly to rarely captured have a particularly strong influence on compositional patterns. In contrast, species that remain consistently dominant tend to show stable contributions across filters (Fig. 3). This result has important implications for community ecology studies. First, the divergence observed among filters when considering the entire community and rarely captured species highlights the need for well-defined criteria when comparing studies that employ different sampling configurations. Second, studies focusing on commonly captured species, such as those investigating ecosystem services (Arévalo-Sandi *et al*. 2018), may rely on data collected under varying time-to-independence filters without significant bias. Consequently, studies in degraded areas, where species diversity is lower and commonly captured species dominate, can utilize any time-to-independence filter for species independent records. However, in relatively well-preserved ecosystems, particularly in tropical regions with high biodiversity, results may vary considerably among filters because of the differences in rarely captured species independent records rates.

Our findings also suggest that inferred species abundance responds differently to time-to-independence filters, depending on whether a species is commonly or rarely captured. Commonly captured species exhibited greater fluctuations in detection rates across filters, particularly when comparing shorter (30 min) and longer (12 and 24 h) time-to-independence filters. This indicates that their detectability is more sensitive to the choice of time-to-independence filter, likely because their frequent occurrences lead to higher variation when records are aggregated over different time-to-independence filters. In contrast, rarely captured species showed more stable relative abundance estimates across filters, primarily owing to their intrinsically lower detection rates. Their relative stability across different filters suggests that low detectability is not merely an artifact of sampling protocols but rather reflects ecological traits, such as restricted habitat use and elusive behavior (Desbiez *et al*. 2021). This highlights the importance of considering both methodological and ecological factors when interpreting species abundance patterns.

These differences have key implications for biodiversity monitoring and conservation planning. Because commonly captured species exhibit more pronounced detection variability, studies focusing on population trends or species interactions should carefully evaluate how time-to-independence filters might influence their results and should consider whether detection frequencies are a useful metric for these purposes. However, for rarely captured species, detectability remains a fundamental challenge, regardless of time-to-independence filters. Therefore, conservation strategies aimed at assessing rarely captured species populations must account for their low detection probabilities and ensure that monitoring protocols are designed to maximize their chances of being recorded. By integrating both the frequency of species records and detection of biases linked to rarity, biodiversity assessments can provide a more accurate and ecologically meaningful representation of community dynamics.

Conclusions

Our findings emphasize the importance of standardizing sampling protocols to enhance the comparability of studies of detection frequencies based on camera trapping in biodiversity monitoring and conservation. The absence of significant differences in estimated species richness across time-to-independence filters suggests that studies can adopt either shorter or longer filters without compromising overall species diversity estimates. However, variations in apparent species composition, particularly driven by differences in the detection of rarely versus commonly captured species, underscore the need for careful consideration in studies focusing on population dynamics and ecological interactions.

Future research should investigate whether these patterns hold across different seasons and habitats and explore how time-to-independence filters influence the detection of species behaviors and interspecific interactions. By refining data collection and interpretation methodologies, such studies can contribute to more effective conservation strategies. Ultimately, the adoption of standardized and comparable approaches will be essential for ensuring the reliability of biodiversity data and maximizing its applicability in ecological and conservation decision-making.

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Data availability. All data used to run analyses is provided in Table 1.

Conflicts of interest. The authors declare that they have no conflicts of interest.

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