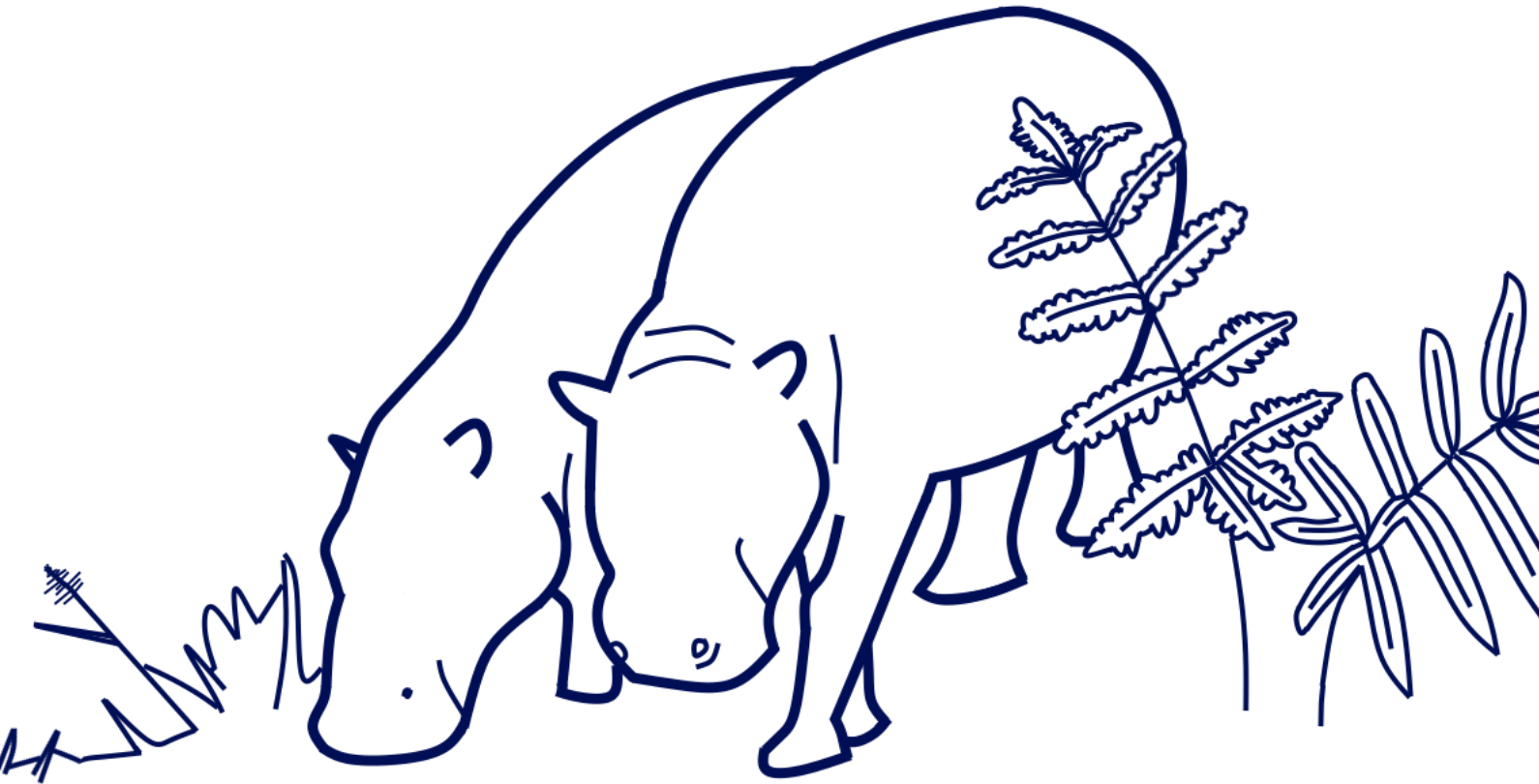


MSc Research Project Report, Biology, Leiden University

Environmental Drivers of Fine-Scale Density Patterns of the Pygmy Hippopotamus *Choeropsis liberiensis* in the Primary Lowland Rainforest of Taï National Park, Côte d'Ivoire



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PYGMY HIPPOPOTAMUS *CHOEROPSIS LIBERIENSIS* IN THE PRIMARY
LOWLAND RAINFOREST OF TAÏ NATIONAL PARK, CÔTE D'IVOIRE**

**Contribution to the IBREAM-CSRS Taï Hippo Project
& the IBREAM 'Bending the Curve' program 2025-2030**

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**Extended Version, English
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Abstract

Against the backdrop of persistent deforestation and habitat loss, there is an urgent need to better understand which factors shape the population densities of wildlife inhabiting the Upper Guinean rainforest in West Africa to help inform conservation policy. Prior studies on the pygmy hippopotamus *Choeropsis liberiensis*, a large mammal endemic to the region, have revealed spatial variation in their population abundance that cannot solely be attributed to anthropogenic factors. Here, we combine pygmy hippo fecal densities obtained via line transects with field-measured and geospatial data on vegetation structure, vegetation composition, and other key habitat features in Taï National Park, Côte d'Ivoire. Our linear mixed model explained 19.0% of fecal density variance through fixed effects alone and 62.7% when accounting for transect-level variation. We found a significant, positive effect for the proximity to minor forest creeks, and significant, negative effects for the proximity to human footpaths and the depth of the litter layer. Marginally significant, positive effects were also found for the proximity to major rivers, the height of the angiosperm undergrowth, and the abundance of ferns, and a marginally significant, negative effect was observed for camp proximity. Through camera trapping we also expand the list of known dietary sources of the pygmy hippo by four plant species and observe a maimed individual, possibly caused by a discarded fishing net. We also provide a phytosociological classification for the most common fern species in the study area. The observed importance of small, rain-fed watercourses to the pygmy hippo comes with implications for conservation planning, as this habitat feature may well be under threat from deforestation-induced aridification in the wider region.

Keywords: West Africa, Upper Guinean Rainforest, Conservation, Habitat Selection, Foraging, Pteridophyta, Phytosociology, Vegetation Physiognomy, Aridification.

1. Introduction

The Upper Guinean rainforest is a geographically distinct patch of tropical lowland rainforest in West Africa centered on several significant refugia and hotspots of speciation, giving rise to a unique and diverse ecosystem with high endemism (Chapman, 1983; Hardy et al., 2013). Over the past century subsistence agriculture, export-oriented cash crop production, mining for minerals and logging have fueled a drastic decline in forest cover (Erazo-Mera et al., 2024). The Upper Guinean rainforest is now perhaps better thought of as a historical grouping of three fragmented rainforest blocks, with the Taï-Grebo-Sapo complex of Liberia and Côte d'Ivoire being the largest but also remaining largely unprotected and vulnerable to further degradation (Sayer et al., 1992) (Fig. 1). The ecological integrity of these forests is often assessed through the status of flagship species, including the pygmy hippopotamus *Choeropsis liberiensis* (Morton, 1849; hereafter pygmy hippo), which has become restricted to the Upper Guinean rainforest following the extinction of the Nigerian subspecies (Robinson, 2013).

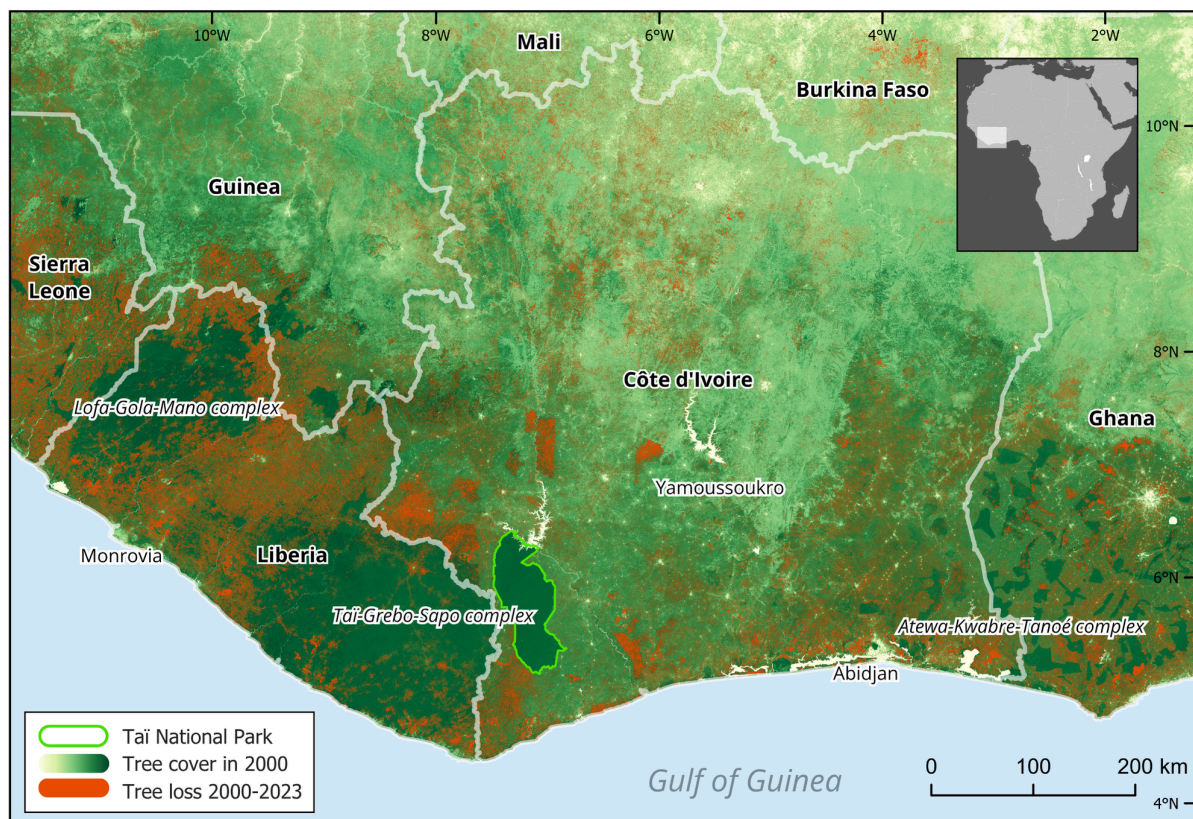


Fig. 1. Location of Taï National Park (inc. N'Zo Partial Faunal Reserve) within the Upper Guinean rainforest of West Africa. Tree cover as of 2000 (greenshade) and deforestation between 2000 and 2023 (red) adapted from updated dataset of Hansen et al. (2013).

The pygmy hippo is commonly seen as one of the most cryptic large mammals of the Upper Guinean Rainforest, as live encounters of wild pygmy hippos are exceedingly rare and almost always fleeting (Robinson et al., 2017). Most knowledge on the physiology, behavior and life history of this species is derived from animals in captivity (Flacke et al., 2015). Compared to their closest living relative, the common hippopotamus, the pygmy hippo enjoys a more terrestrial and solitary lifestyle. Bülow (1987), using VHF transmitters on pygmy hippos translocated from Taï National Park (NP) to Azagny NP, concluded that

females defend small territories of 0.4-0.6 km², while males occupy larger ranges (1.5-1.6 km²) that overlap with those of multiple females. Pygmy hippos have been observed using cavities below tree roots along river banks as resting sites during the daytime (Eltringham, 1993); it is hypothesized that such burrows serve as central nodes within a network of trails that are used to navigate the forest, with peak activity just after sunset and before sunrise (Ouattara et al., 2019).

Recent work has brought to light variation in the population density of the pygmy hippo across its range, also within presumably suitable patches of habitat. Bogui et al. (2016) report substantial spatial variation in the density of droppings and other presence indicators within Taï NP. The authors largely attributed this to the historically stronger anthropogenic disturbance in the eastern half of the park (see also N'Goran et al., 2013; Waltert et al., 2010), though quantification of poaching, mining and logging indices only explained part of the observed variance. Additionally, multiple years of extensive ecological surveys in the transboundary Lofa-Gola-Mano forest complex of Liberia and Sierra Leone yielded relatively few pygmy hippo signs within protected areas compared to the number of signs recorded in community-managed areas and former agricultural sites (Garteh, 2013; Hillers et al., 2017; Klop et al., 2008). The idea that human activity may not be the sole factor affecting pygmy hippo numbers is further supported by high encounter rates in zones of secondary vegetation within Taï NP (Hoppe-Dominik et al., 2011) and reports of pygmy hippos foraging on plantations in Sierra Leone (Conway, 2013).

Environmental heterogeneity and habitat preferences could potentially account for part of this variation. While the pygmy hippo has traditionally been viewed as rather flexible in terms of habitat selection within the rainforest (Roth et al., 2004), recent work has indicated that variation in vegetation structure may influence their density on a local scale (Ouattara et al., 2019; Rijkers, 2024). This could be caused by the effect vegetation structure and composition have on important abiotic habitat characteristics such as temperature and humidity (Jiang et al., 2016; Slik et al., 2009). There could also be a dietary component: while the complete extent of their diet has yet to be grasped, studies so far have shown that the pygmy hippo does have preferences for specific foods (Bülow, 1987; Hendier et al., 2021; Hentschel, 1990), which could influence habitat selection in turn (Bobrowski et al., 2020; Etzenhouser et al., 1998; Regolin et al., 2021).

The difficulties in providing a coherent explanation for pygmy hippo abundance across its range highlight that our understanding of their ecology remains limited. This hinders our ability to identify important population cores, designate viable population corridors and draw up effective management plans (Freeman et al., 2019). Against the backdrop of rampant deforestation (Hansen et al., 2013), a suspected continuous population decline (Ransom et al., 2015) and ongoing talks about establishing additional protected areas (Crawford, 2013; Junker et al., 2015; Ouattara et al., 2018, 2022; Wild Chimpanzee Foundation, 2011, 2023), there is an urgent need for a better understanding of the interaction between pygmy hippos and their natural environment (Adou Yao et al., 2005; Bogui et al., 2016; Chatelain et al., 2001; Hillers et al., 2017).

The present study aims to quantify the relative importance of a multitude of environmental factors that are hypothesized to drive pygmy hippo density patterns on a local scale. We ask:

what are the environmental drivers of pygmy hippo density in Taï NP? To this end we combine pygmy hippo density data, derived from systematic line transect surveys, with a novel protocol to assess selected characteristics of the vegetation. Regarding its physical structure (physiognomy), we include a range of measurements spanning from the litter layer to the tree canopy. In terms of composition, our efforts are centered on the ferns (Pteridophyta), as they seem to be an important food source for the pygmy hippo (Bülow, 1987; Hendier et al., 2021; Hentschel, 1990) and are good indicators for subtle variations in local conditions (De Rouw, 1991). We hypothesize pygmy hippo densities are highest in areas close to rivers and away from sources of anthropogenic disturbance, that feature low canopy closure, high tree basal area, dense undergrowth, high fern abundance, low litter layer cover and low elevation. Our results offer new perspectives on the habitat requirements of this reclusive semi-aquatic mammal, with implications for conservation planning and future research.

2. Materials and Methods

2.1 Study area

The study was performed from January to March 2025 in sector Djouroutou of the UNESCO World Heritage Site of Taï NP, situated in the southwest of Côte d'Ivoire (Fig. 2). Taï NP falls under the jurisdiction of the Office Ivoirien des Parcs et Réserves (OIPR). Most of the gently hilly landscape is between 100-200 meters above sea level, with an inselberg just east of the study zone reaching up to 400 meters in elevation. Average temperatures are between 24-27 °C with a humidity above 85% across the entire year. Taï NP experiences a coastal-inland precipitation gradient, with annual rainfall in the southwest averaging 2200 mm compared to 1700 mm in the northeast. The wet season lasts from March to November (with a small dry period in July and August), with the large dry season spanning December to March (Waitkuwait, 1985). The 21.5 km² study zone falls within the largest of the catchments of Taï NP, that of the Cavally River, with the north of the study zone demarcated by the Hana tributary. The two camps in the research zone (Ecotel Touraco and Camp Chimpanzee) are connected by a large 'layon' (permanently cleared human footpath) that is travelled on a near-daily basis, and is surrounded by a grid of lesser layons. To our knowledge, only the outer edges of our study zone have been covered by prior pygmy hippo studies: Hana-based searches by Digbeu et al. (2024) and Rijkers (2024), one clearcut transect of unknown length in the extreme west by Hoppe-Dominik et al. (2011) and five transects in the northeast surveyed by OIPR and reported on by Bogui et al. (2016). The latter were incorporated into our sampling design (Section 2.2.1).

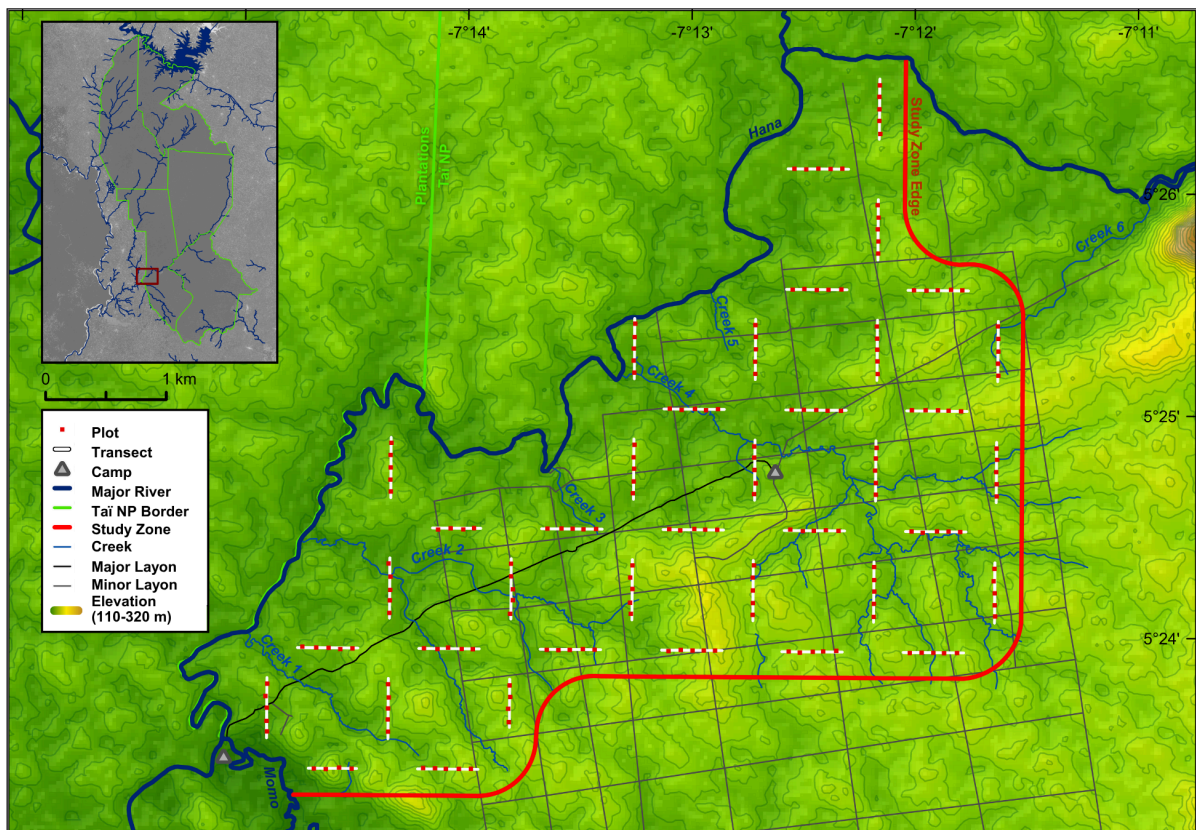


Fig. 2. Study zone and sampling design within Taï NP, with location of camps (Ecotel Touraco in the west and Camp Chimpanzee in the east), 'layons' (permanently cleared human footpaths; courtesy of MPI EVA) and year-round active water courses. Baselayer: NASA SRTM DEM elevation (30 m).

2.2 Pygmy hippo density versus environmental conditions

2.2.1 Pygmy hippo density survey

Relative population densities were estimated by performing fecal standing crop counts along line transects, an established method for difficult to observe ungulates (Barnes, 2001; Hoppe-Dominik et al., 2011), including the pygmy hippo (Roth et al., 2004). Counts were performed by two observers along 39 transects of 500 meters, which were centered on the edges of a systematic grid of 1x1 km squares (Fig. 2). This design has historically been used for biomonitoring both in Taï NP (Bogui et al., 2016; Diarrassouba et al., 2019) and elsewhere in the Upper Guinean rainforest (Furnell et al., 2015). Whenever a transect ran parallel to a layon (permanently cleared human footpath), an effort was made to stay at a minimum distance of approximately ten meters, even if that meant slightly deviating from the planned heading. The transects were walked slowly (<1 km/h), using a Garmin GPSMAP 65s and a compass for navigation and clearing obstacles using a machete. On three occasions, the transect was shortened by 100 m at one end due to difficulties accessing the terrain.

All feces that were encountered over the course of the project were registered, though they were only scored as 'in' when they were found directly on the transect, not if they were found during subsequent explorations that deviated from the transect. For all signs of pygmy hippo presence, the following information was logged:

1. Date and location
2. Finder
3. Collected or uncollected (see Section 2.3.2)
4. Type of sign
 - a. Territorial dung (TER)
 - b. Defecation dung (DEF)
 - c. Footprint (IMP)
 - d. Potential burrow (POT)
5. Level of dung degradation (Hendier, 2019)
 - a. Level 1: Very fresh, smell, 1 or 2 days ago.
 - b. Level 2: Fresh, less smell, 3 to 5 days ago.
 - c. Level 3: A bit old, more than 1 week, no mushrooms, quite dry, lack of odor.
 - d. Level 4: Old, more than 2 weeks, mushrooms present, fecal quantity can stay high.
 - e. Level 5: Very old, black residues and very dry.
 - f. Level 5+: Almost disappeared, black/brown dry tracks, no residues anymore.

2.2.2 Environmental assessment

2.2.2.1 Sampling frequency

Data on the environmental conditions along the transects were gathered at hundred meter intervals (at 50 m, 150 m, 250 m, 350 m & 450 m) (Fig. 3). Firstly, at each environmental assessment location a square plot was established using metal pegs marked with colored tape. The coordinates, elevation and slope angle were noted. After this, the measurements described in Sections 2.2.2.2 through 2.2.2.5 were taken.

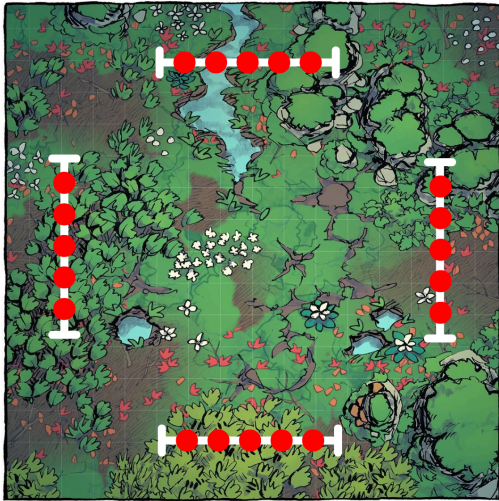
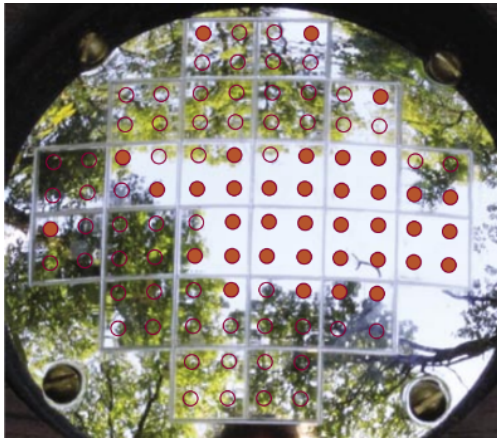


Fig. 3. Rough visualization of the five sampling plots (red) as positioned along four 500 m transects (white).

2.2.2.2 Canopy closure

Forest floor conditions and undergrowth composition are heavily dependent on the density of the canopy above (MacDougall & Kellman, 1992; Pfeifer et al., 2019; Senior et al., 2017). This factor has been included in past studies on pygmy hippo ecology by scoring local conditions as 'open' or 'closed' (Ouattara et al., 2019; Rijkers, 2024). In this study canopy closure was quantified using a spherical convex densiometer (Forestry Suppliers Inc., 2021). This is a small handheld mirror divided into cells, with which the user then determines how much of the image consists of unobstructed sky (Fig. 4). This count was repeated four times at each plot, rotating 90 degrees each time and taking the average. While the spherical densiometer isn't as precise as some of the more modern electronic techniques available, it is easy to implement and also sensitive to relatively minor changes in canopy closure and light penetration (Baudry et al., 2014).

A



B

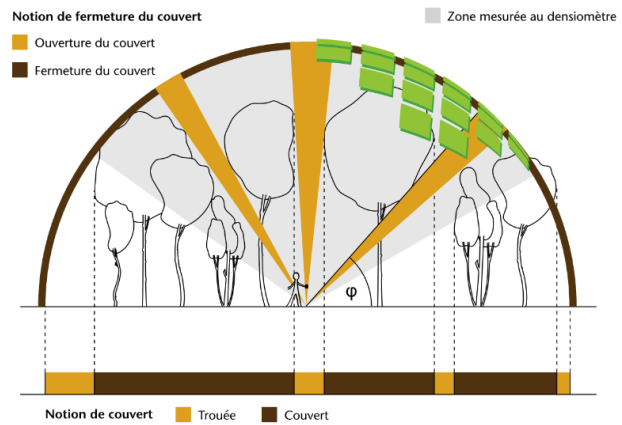


Fig. 4. Application of a spherical densiometer. A: The user imagines four equidistant points inside each cell on the mirror and scores these as ‘open’ (red) or ‘closed’ (clear). B: Range of the canopy taken into consideration when using a spherical densiometer. Adapted from Baudry et al., (2014).

2.2.2.3 Tree properties

Tree size and stem density are important characteristics of the overall forest composition and the point-centered quarter method was chosen to express this in a quantifiable way (Mitchell, 2023). At every plot, four imaginary quarters were designated based on the location of the four plot pegs (see Section 2.2.2.1). The circumference (C) of the nearest tree (defined as a woody stem with a >10cm diameter at breast height (= 130 cm above the ground)) in every quadrant was measured, as well as the distance (d) of the tree to the center of the plot (Fig. 5). For the purposes of further analysis, these measurements were combined into a single value using the following formula:

$$\text{basal area (m}^2/\text{ha)} = \frac{\sum(\frac{c_i^2}{4\pi})}{(\bar{d})^2} \times 10000$$

with c_i the circumference of tree i (in centimeters)

with \bar{d} the average distance to the four trees in the plot (in centimeters)

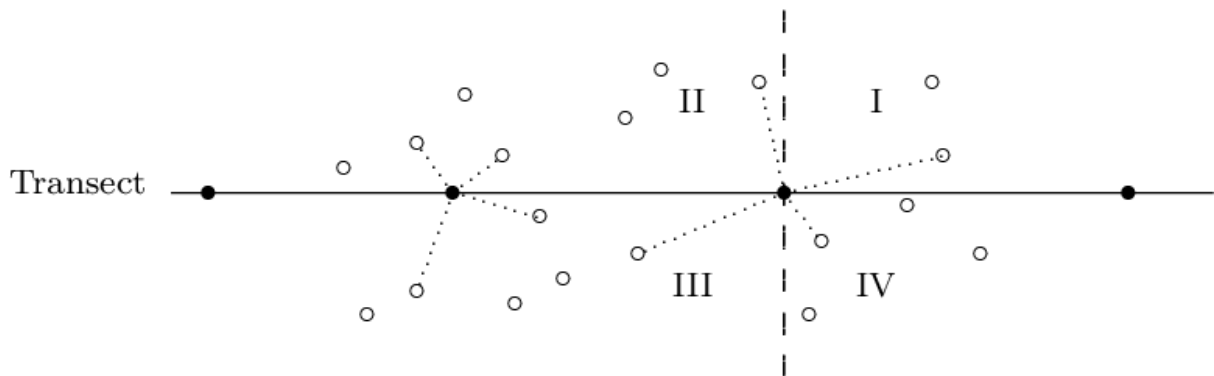


Fig. 5. Application of the point-centered quarter method, whereby the distance to and circumference of trees along the transect is measured at regular intervals in four imaginary quarters (I-IV). Adapted from Mitchell (2023).

2.2.2.4 *Fern diversity and abundance*

With a complete flora survey being overly time-consuming, we focussed our efforts on the ferns (Pteridophyta). Not only is this group particularly responsive to fine-scale environmental heterogeneity (De Rouw, 1991), but ferns are also remarkably well-represented in the scarce literature that exists on the pygmy hippo's diet. The 16 species of fern known to be consumed by the pygmy hippo (Appendix 1) represent a large portion of the total number of species available to them in Taï NP (Chatelain et al., 2001; Roux, 2009), despite ferns classically not being thought of as an important food source for herbivores (Page, 2002; Richardson & Walker, 2010).

Within each environmental assessment plot all ferns were identified and their coverage was noted as a percentage of the total plot surface (excluding ferns occurring at a height greater than 1,30 meters; widely creeping, moss-like species of Selaginellaceae; and near-microscopic, epiphytic species of Hymenophyllaceae, as those were judged to be of little interest to the pygmy hippo). A plot size of 3x3 meters was chosen, as small herbs tend to occur across relatively small surface areas. A larger surface area, while theoretically resulting in a more representative sample, would have necessitated a decrease in our total number of observations, which we deemed less favorable given the overall objectives of the study (De Rouw, 1991; Dengler, 2017). We also scored the four trees from Section 2.2.2.3 for the absence or presence of low-epiphytic and scandent ferns.

The identification of ferns was performed using a self-made key of all ferns known to occur in the lowland forests of Liberia and/or Côte d'Ivoire (Roux, 2009) with special emphasis on vegetative traits, with the key modelled after Crouch et al. (2011) and compiling information from sources including regional keys and overviews (Benl., 1978, 1980, 1982, 1988, 1991; Harley, 1955, 1976), taxonomic monographs and revisions (Holttum, 1986; Jongkind & De Winter, 2015), fernsofafrica.com and pteridoportal.org. The resulting key was refined through a week of manually inspecting herbarium specimens at Naturalis Biodiversity Center, with the final product attached in Supplementary Document 1. In the field, vouchers were collected of all species when they were encountered for the first time, in case of uncertainty about their identity and when particularly well-developed specimens were encountered. Duplicates were deposited at the Centre Suisse de Recherches Scientifiques (CSRS) and at the Institute for Breeding Rare and Endangered African Mammals (IBREAM).

2.2.2.5 *Structure of undergrowth and litter layer*

Not only the coverage of individual fern species were estimated, but also the total coverage of all ferns and the total coverage of all angiosperms (flowering plants). An estimate was made of the average coverage and height of the total undergrowth as a proxy for visibility, as undergrowth height has been shown to correspond strongly with this (Higgins et al., 2012) and direct horizontal coverage measurement techniques are relatively time consuming (Pop, 2020). The coverage and average height of leaf litter were also measured.

2.2.2.6 *Geospatial data*

Lastly, the field-collected environmental dataset was augmented with spatial and remote-sensing properties (Table 1). Most of these were selected because they have been proven important to the pygmy hippo in other modelling studies (Bogui et al., 2016; Freeman

et al., 2019; Hillers et al., 2017), except for ‘distance to camps’, which was included because they represent major sources of noise and human activity in our study area.

Table 1. Geospatial data included in the pygmy hippo density analysis. OIPR: Office Ivoirien des Parcs et Réserves. MPI EVA: Max Planck Institute for Evolutionary Anthropology.

Variable	Source
Distance to major rivers (Hana, Momo)	OIPR (with minor adjustments based on ground-truthing)
Distance to creeks	Recorded on the ground; breakdown of fully ground-truthed sections and partially inferred sections available in Appendix 2
Distance to major layon (travelled near-daily)	Recorded on the ground
Distance to minor layon (travelled extensively)	MPI EVA
Distance to camps	Recorded on the ground
Distance to park boundary	OIPR
Moderate-Resolution Imaging Spectroradiometer Enhanced Vegetation Index (MODIS EVI)	NASA MODIS/Terra Vegetation Indices 16-Day L3 Global 250m SIN Grid V061; layer 2025033, quality level 3/8

2.2.3 Data processing and modelling

2.2.3.1 Fecal density estimation

Data processing took place in RStudio version 2024.12.1 (Posit Team, 2024) and ArcGIS Pro version 3.1.2 (Esri, 2023). ChatGPT (OpenAI, 2025) was used in troubleshooting and enhancing the scripts. Firstly, the built-in kernel density tool in ArcGIS Pro was used to acquire a fecal density value for each environmental assessment plot. As the main variation seemed to be within rather than between transects, the search radius was set to 350 meters, which is the highest value that could have been used without different transects interacting. For the output ‘expected counts’ was chosen, as this generated slightly fewer zeros. Upon extraction from the raster ‘interpolation’ was set to ‘yes’.

2.2.3.2 Fern classification

In order to decrease dimensionality, a phytosociological analysis was performed on the fern occurrence data. The underlying concept of phytosociology is that discrete groups of plant species can be designated that occupy a similar ecological position and tend to co-occur. Conversely, the presence of species that occur at low densities may be inferred by checking for the presence of more common members of the same phytosociological group, reducing sampling error when dealing with limited plot sizes. At any given location one or more phytosociological groups may be present, together forming the overall community (De Rouw et al., 1990; Dengler, 2017). Following earlier botanical work in Taï NP (De Rouw et al., 1990; Denguéadhé Kolongo et al., 2006), the basis for our classification was provided by feeding the coverage data per plot into the divisive clustering algorithm TWINSpan

(Two-Way Indicator Species Analysis; Hill, 1979), ported into RStudio using package *twinspan* (Oksanen, 2019). TWINSPAN automatically assigns an 'iclass' value to each species, which are shared across species that behave similarly. Only fern species that occurred in five or more plots were included. This was followed by a manual refinement step, whereby the automatic classifications were compared with field notes on each species' perceived niche and species were reassigned in case of major discrepancies, as described by De Rouw (1991). After this, the summed coverage of each phytosociological group per plot was calculated and used in further modelling.

2.2.3.3 Modelling

Subsequently the data were prepared for modelling by checking for collinearity among the independent variables using a Pearson correlation matrix, dropping one of each variable pair for which $|r| > 0.7$. We further assessed multicollinearity by calculating Variance Inflation Factors (VIF) from a linear model including all fixed predictors using package *car* (Fox & Weisberg, 2019), omitting those with $VIF > 5$ from further analysis. All remaining independent variables were centered and scaled using a z-transformation and then included in a linear mixed model (LMM) assuming a Gaussian error distribution together with a random intercept per transect using package *lme4* (Bates et al., 2015). Model fitting was performed using maximum likelihood estimation. Simplifications of the model were evaluated by performing dredging with package *MuMIn* (Bartoń, 2025), but this only resulted in minor AIC improvements at the cost of much interpretability, leading us to retain all fixed effects. To obtain robust estimates of uncertainty around the fixed effects, parametric bootstrapping was performed ($n = 2,000$ runs). Lastly, the model residuals were checked for spatial autocorrelation by loading them into ArcGIS Pro and calculating Moran's I for the eight nearest neighbours of each point. Normality of model residuals was evaluated with package *DHARMA* (Hartig, 2024).

2.3 Other research activities

2.3.1 Camera trapping

Camera traps (7x Browning BTC-5HDPX; 6x Browning BTC-8A) were deployed ad-hoc throughout the study zone. Their primary objective was to provide contextualisation of the observed fecal densities. As such, they were primarily located in zones of high fecal density, especially near bodies of water or where well-defined fauna passages were discernible (Fig. 10). Usually one camera was installed per location, but occasionally two or three were placed together. Consecutive deployments lasted around 12 nights on average, but depending on whether or not a location was considered successful and whether or not a 'fresh' camera trap was available, some outgoing cameras were immediately replaced by a new one to continue monitoring, increasing average monitoring time per location to 17 nights (minimum: 8, maximum: 51). Whenever feeding behavior was captured on the footage, an effort was made to identify those plants and a brief description of the surrounding vegetation was made.

2.3.2 Fecal samples

Whenever fresh or geographically isolated droppings were encountered, these were sampled as part of IBREAM's biobanking and conservation detection dog (CDD) programs. For all feces, three different collection methods were employed: (1) applying a thin layer of feces to a Whatmann FTA Card, which were put in store-bought ziplock bags after short air-drying; (2) applying a thin layer of feces to a Whatman 903 Proteinsaver Card, which were put in two store-bought ziplock bags and moved to a freezer as soon as possible; (3) preservation inside 1,5-2,0 mL plastic tubes, which were put in two store-bought ziplock bags and moved to a freezer as soon as possible. For every dung pile a new set of disposable latex gloves and a wooden applicator were used. The FTA Cards were transferred to Wageningen University and Research with analysis slated to begin in September 2025; the Proteinsaver Cards are held by IBREAM's CDD program awaiting the outcome of the genetic analysis; the plastic tubes remain in storage at CSRS.

2.3.3 Pilots on fecal degradation and bioacoustics

Over the course of this project contributions were made to more experimental lines of research at IBREAM. An experiment was performed to evaluate the efficacy of different storage methods for pygmy hippo feces in absence of refrigeration for the purposes of CDD analysis. An experiment was also performed to evaluate how the detectability of pygmy hippo feces by a CDD changes with age. Lastly, a trial was performed both in zoos and in the rainforest on the potential applications of bioacoustic monitoring for future studies. The latter is discussed in more detail in Appendix 3, the contributions to the CDD program will be the subject of a separate report (Snelleman & Kempkes, in prep.).

3. Results

3.1 Pygmy hippo density

Over the course of the project, a total of 406 pygmy hippo droppings were encountered. Overall statistics on fecal age and fecal type can be found in Table 2. Of these droppings, 76 were encountered along transects (N=39). One transect yielded a record 14 pygmy hippo feces, far above the mean value of 1.59 feces for all other transects (SD = 1.50), or the next highest count (6). We attribute this to the presence of a clearly discernable animal passage that ran almost perfectly parallel to the transect for most of its length. This transect was deemed an outlier and was excluded from modelling, leaving 38 transects with 62 feces (including ten transects with zero feces) as the basis for further analysis. The extrapolated fecal densities along the transect are visualised in Fig. 6.

Table 2. Properties of all pygmy hippo feces encountered over the course of the study period (on and off-transect). Fecal age and type categories after Hendier (2019).

	Territorial dung	Defecation dung	Unknown	Total
Cat. 1	16	0	0	16 (3,94%)
Cat. 2	9	5	0	14 (3,45%)
Cat. 3	47	9	0	56 (13,8%)
Cat. 4	1	12	0	13 (3,20%)
Cat. 5	236	14	0	250 (61,6%)
Cat. 5+	41	1	0	42 (10,3%)
Mixed age	8	0	0	8 (1,97%)
Unknown	1	0	6	7 (1,72%)
Total	359 (88,4%)	41 (10,1%)	6 (1,48%)	406 (100%)

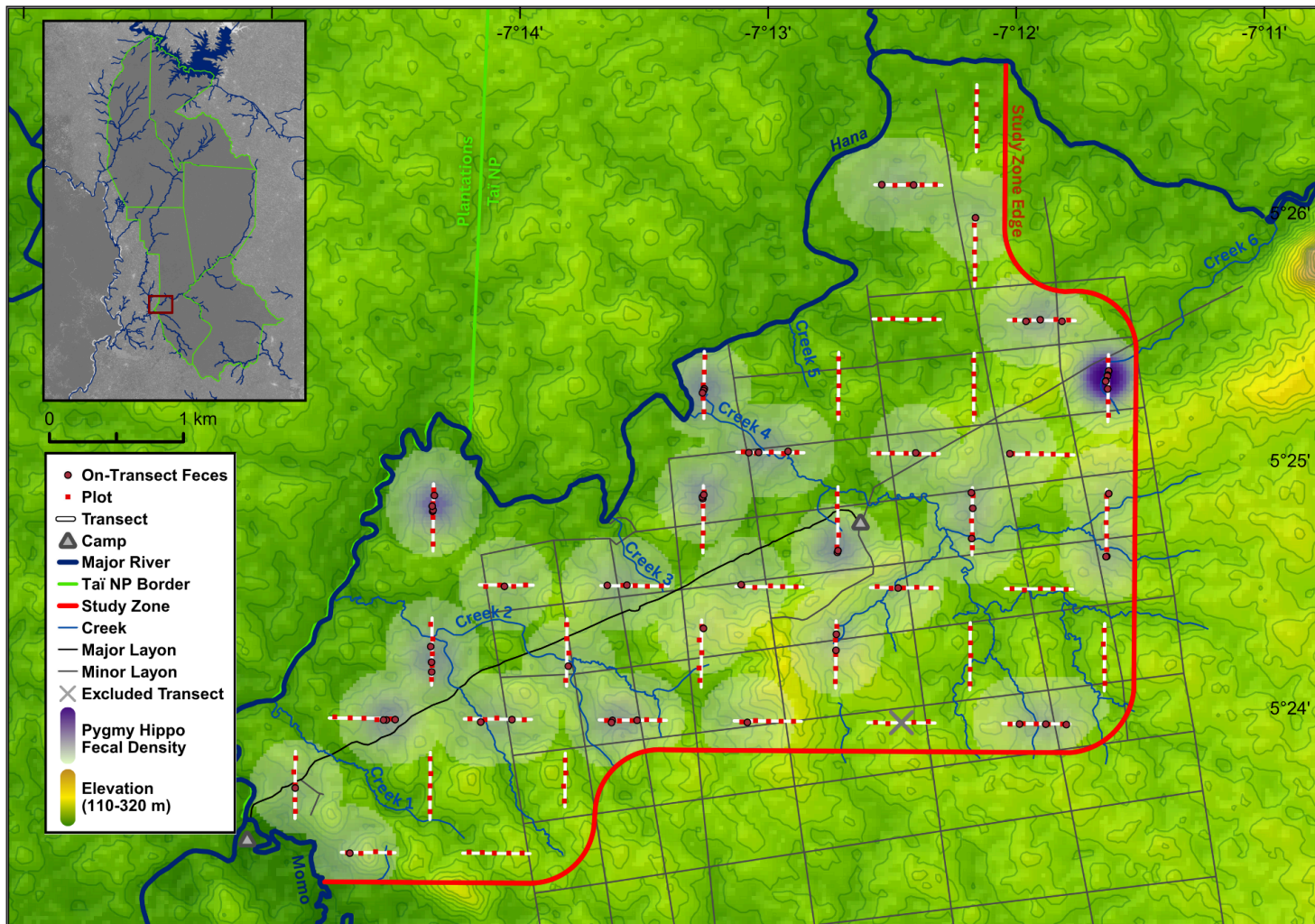


Fig. 6. Distribution of on-transect pygmy hippo feces and associated kernel density values within the study zone. Baselayer: NASA SRTM DEM elevation (30 m), layout of minor layons courtesy of MPI EVA.

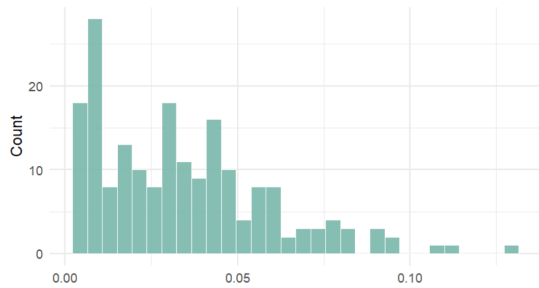
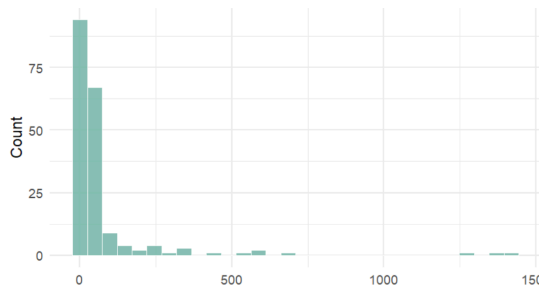
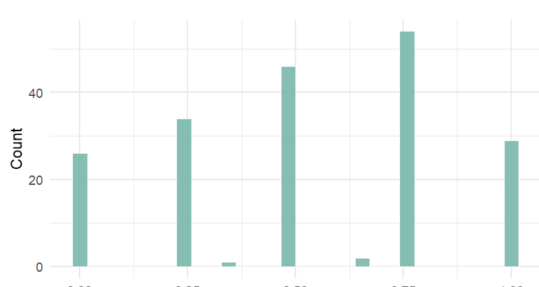
3.2 Vegetation composition and structure

The environmental assessment protocol was performed at hundred meters intervals along all transects, resulting in a total of 187 observations. A total of 42 species of pteridophyte were encountered over the course of the project. Of these, 19 were only ever found outside of environmental assessment plots. Of the remaining 23 species that did occur inside the plots, 11 were encountered in five plots or more and were included in further analyses. TWINSpan separated these into four classes. Upon manual inspection, two species were reassigned from TWINSpan's initial indication: *Pteris burtonii* and *Asplenium variabile*. Originally, *P. burtonii* clustered with Group D. However, based on our personal observations this species seems to occupy a niche more similar to that of Group C. TWINSpan's alternate classification is most likely the result of the inclusion of (a large number of) midslope plots in the dataset, where this species still occurs in relatively high densities (compared to other members of Group C) among the more dominant members of Group D, but it disappears at higher positions whereas the other species of Group D do not. *A. variabile* clustered with Group C but was moved to Group A. Unlike true members of Group C, *A. variabile* is able to occur even at the apexes of hills (especially as a lithophyte), albeit at very low densities, making it susceptible to being undersampled there. The final phytosociological groupings as included in the pygmy hippo niche model are shown in Table 3; a full species list, including notes on ecology, can be found in Appendix 4. The values and spread of the physiognomic variables are summarized in Table 4.

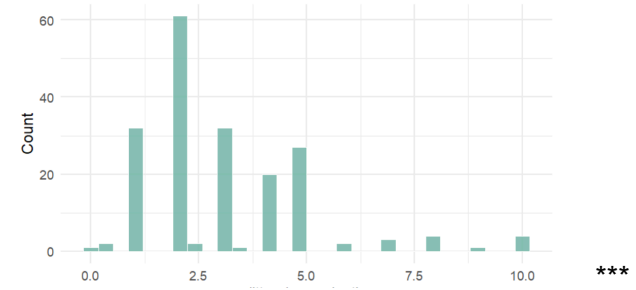
Table 3. Phytosociological classification of all terrestrial, lithophytic and low-epiphytic fern species encountered in ≥ 5 plots (3x3 meters, N=187). Species known to be included in the diet of the pygmy hippo (Hentschel, 1990) are marked with ✓.

Association	Species	% of plots	Rank	PH food
Group A	<i>Lomariopsis guineensis</i>	81,8%	1	✓
	<i>Asplenium variabile</i>	12,5%	5	
Group B	<i>Adiantum vogelii</i>	3,1%	9	✓
	<i>Asplenium africanum</i>	3,1%	9	
Group C	<i>Pteris burtonii</i>	24,0%	4	✓
	<i>Triplophyllum pilosissimum</i>	7,8%	6	✓
	<i>Nephrolepis biserrata</i>	6,8%	7	✓
	<i>Arthropteris palisotii</i>	4,7%	8	
Group D	<i>Triplophyllum protensum</i>	34,9%	2	✓
	<i>Lomariopsis rossii</i>	31,8%	3	
	<i>Triplophyllum fraternum</i>	3,1%	9	

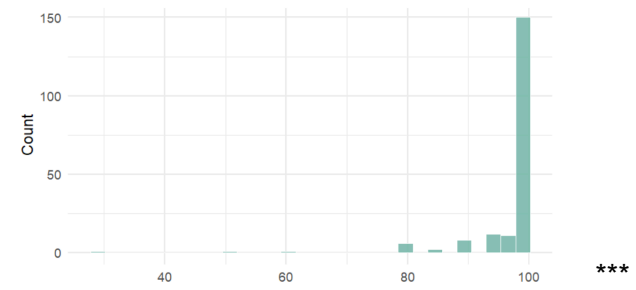
Table 4. Distribution of physiognomic environmental indicator values among plots. Column 'normality' denotes the p-value of Shapiro-Wilk Test, with significant values indicative of non-parametrically distributed data (* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$).

Factor	Minimum	Mean	Maximum	SD	Distribution	Normality
Canopy openness (%)	0.26	3.49	12.76	2.50		***
Basal area (m ² / ha)	2.32	78.26	1421.66	191.03		***
Trees with epiphytic ferns (%)	0	53.47	100	31.62		***

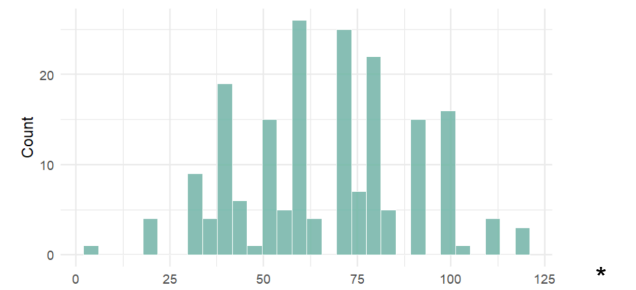
Litter layer depth 0.00 3.07 10.00 1.96



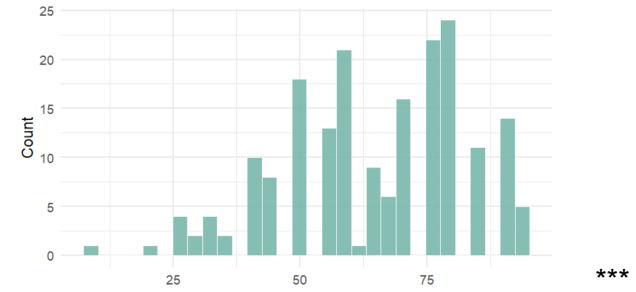
Litter layer coverage (%) 30.00 97.01 100.00 7.75



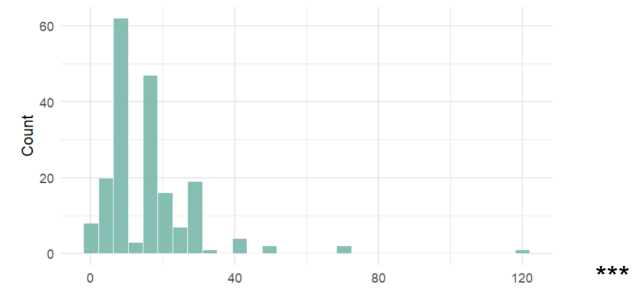
Average angiosperm height (cm) 5.00 66.32 120.00 23.01



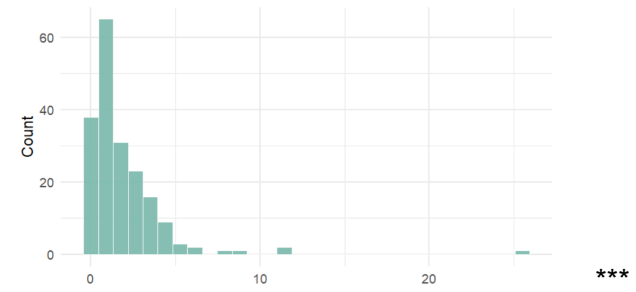
Angiosperm coverage (%)	10.00	64.89	95.00	17.84
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Average fern height (cm)	0.00	15.92	120.00	13.22
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Fern coverage (%)	0.00	1.91	25.5	2.60
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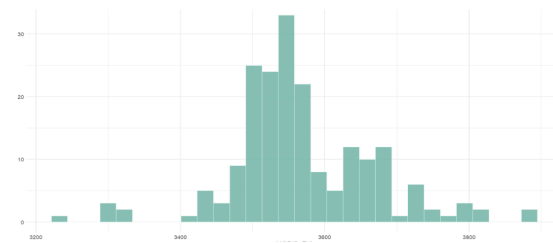
MODIS EVI

0.323

0.357

0.388

0.010



3.3 Effects of environmental conditions on fecal densities

The initial screening for collinearity resulted in the exclusion of two predictors: ‘distance to park boundary’ ($r = 0.707$ with ‘distance to major rivers’; $VIF = 10.49$) and ‘distance to major layon’ ($VIF = 7.96$). Out of the twenty remaining predictors, ‘distance to minor layons’ (positive effect), ‘distance to creek’ (negative effect) and ‘litter layer depth’ (negative effect) showed a significant correlation with fecal density. Notably, while $p > 0.05$ for ‘distance to camp’ and ‘distance to major rivers’, the bootstrapped interval of their estimated effect size remains clear of zero, suggesting a consistent directional effect under repeated sampling. ‘Angiosperm height’ and ‘fern cover’ also show marginally significant p values (Table 5; Fig. 7). The response curves of the three significant and four marginally significant effects are shown in Fig. 8.

Table 5. Estimated effect sizes of the fixed-effect variables on pygmy hippo fecal density, with 95% confidence intervals based on parametric bootstrapping ($N=2,000$). Marginally significant and significant p values marked: • $p \leq 0.15$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

Predictor	Estimate	95% CI lower	95% CI upper	t value	p value
dist. minor layons	0.001367	0.000469	0.001978	2.722	0.00732 **
dist. creeks	-0.001491	-0.002990	-0.001415	-2.237	0.02948 *
litter layer depth	-0.000644	-0.001360	-0.000200	-2.142	0.03371 *
angiosperm height	0.000479	-0.000154	0.000942	1.698	0.09140 •
dist. camp	0.001065	0.000361	0.001707	1.709	0.09469 •
dist major rivers	-0.001114	-0.002053	-0.000571	-1.639	0.10806 •
fern cover	0.000424	-0.000145	0.001010	1.449	0.14935 •
slope angle	-0.000431	-0.001183	0.000012	-1.393	0.16577
canopy closure	-0.000368	-0.001224	0.000216	-0.926	0.35560
litter layer cover	0.000261	-0.000170	0.000888	0.965	0.33620
fern group D	-0.000271	-0.000915	0.000261	-0.844	0.39999
elevation	0.000241	-0.000322	0.000894	0.722	0.47098
fern group B	-0.000169	-0.000661	0.000323	-0.642	0.52166
fern group C	0.000154	-0.000408	0.000564	0.609	0.54376
fern height	0.000131	-0.000422	0.000694	0.462	0.64485
basal area	-0.000121	-0.000655	0.000383	-0.444	0.65733
trees w. epi. ferns	0.000100	-0.000466	0.000679	0.325	0.74546
fern group A	-0.000073	-0.000691	0.000344	0.275	0.78395
angiosperm cover	-0.000066	-0.000661	0.000466	-0.224	0.82336
MODIS EVI	-0.000015	-0.000881	0.000478	-0.038	0.97009

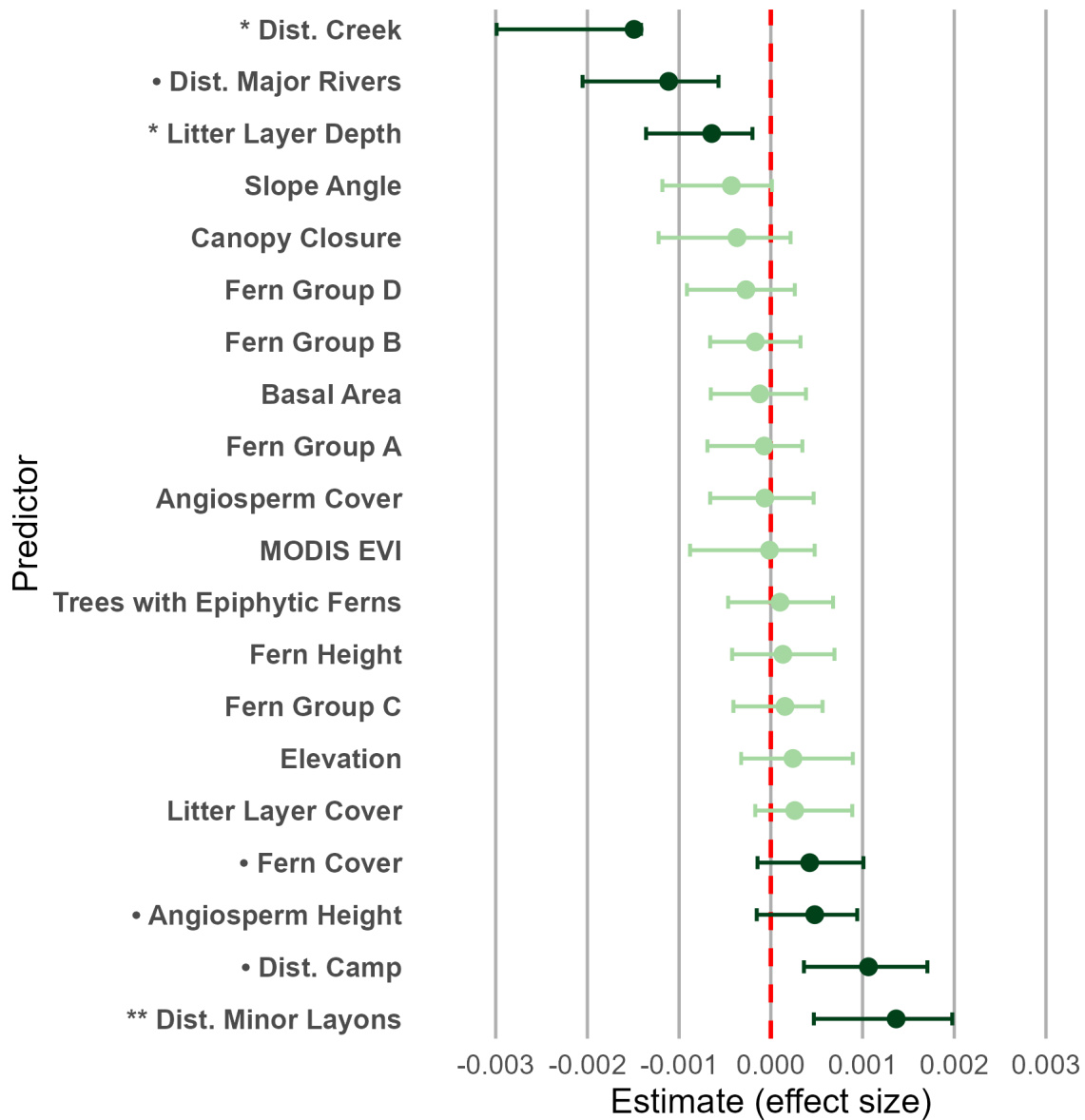


Fig. 7. Estimated effect sizes of the fixed-effect variables on pygmy hippo fecal density, including 95% confidence intervals based on 2,000 parametric bootstrapping replicates. Non-significant effects are shown in light green, significant and marginally significant effects are shown in dark green and marked: • $p \leq 0.15$, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

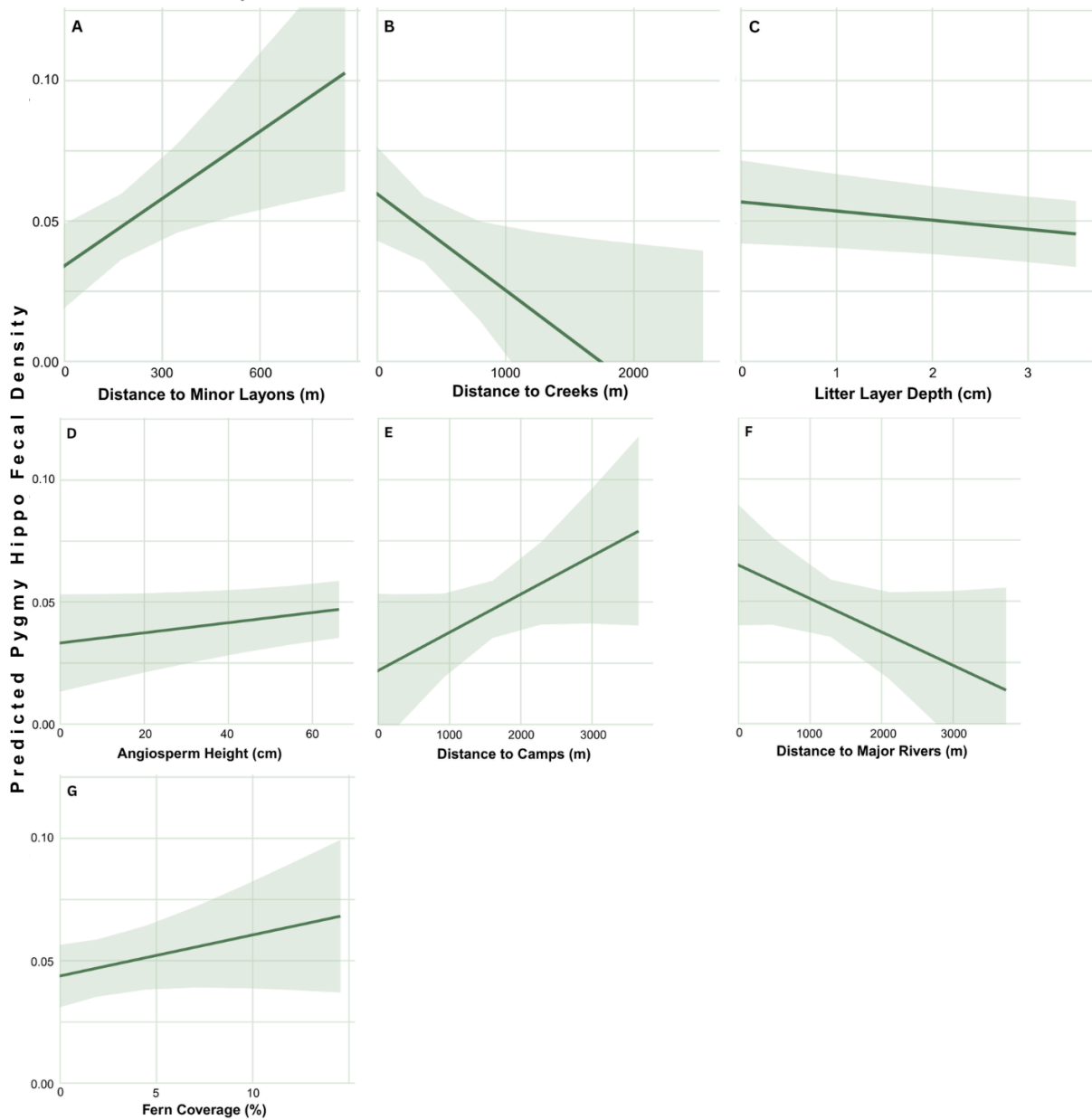


Fig. 8. Response curves of the three significant ($p \leq 0.05$) and four marginally significant ($0.05 \leq p \leq 0.15$) effects on pygmy hippo fecal density. A: Distance to minor layons (**). B: Distance to creek (*). C: litter layer depth (*). D: Angiosperm height. E: Distance to camp. F: Distance to major rivers. G: Fern cover.

The model explained 19.0% of variance through fixed effects alone (marginal $R^2 = 0.190$), and 62.7% when accounting for transect-level variation (conditional $R^2 = 0.627$). Fig. 9 visualises the models predicted versus actual values. Global Moran's I of the model residuals returned a value of 0.267, implying a moderate but acceptable degree of spatial autocorrelation.

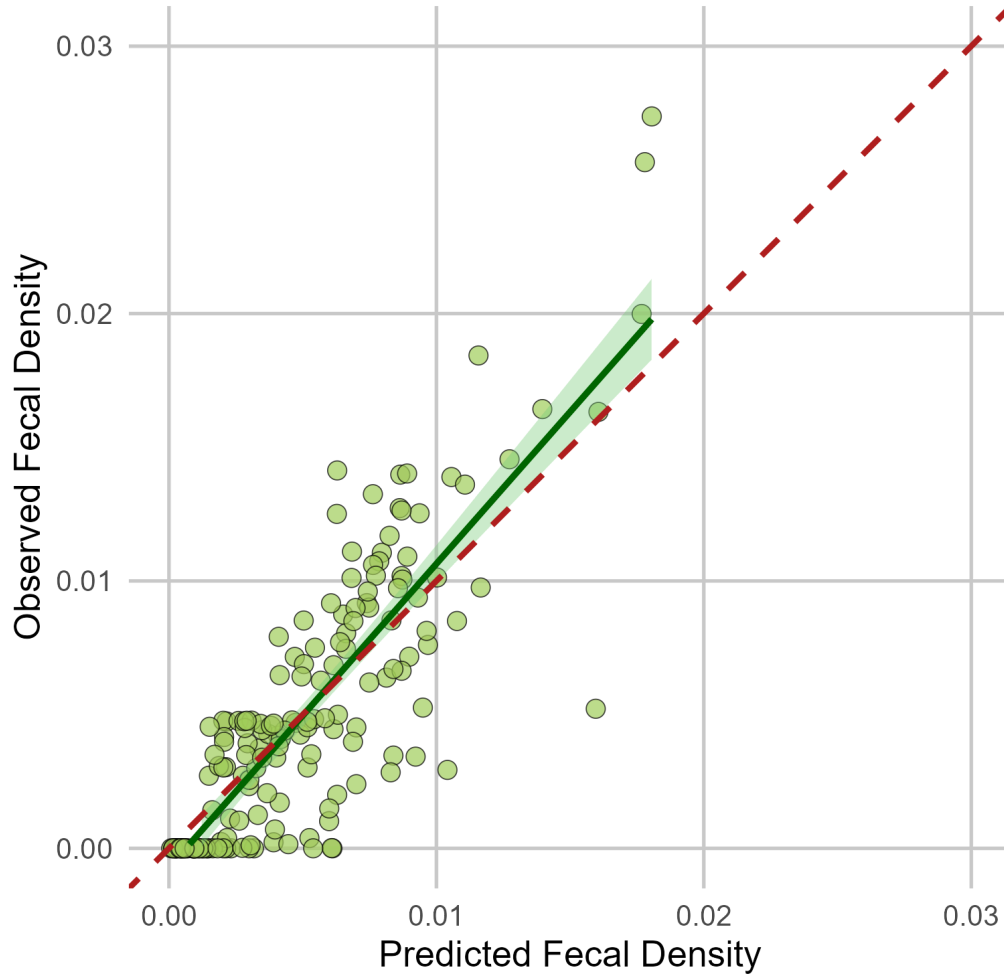


Fig. 9. Observed versus predicted fecal densities based on the model. Dashed red line shows ideal 1:1 regression, continuous green line shows actual linear relationship (standard error shaded).

3.4 Camera trapping

Over a total effort of 365 trapping nights at 21 locations, 12 unique passage events occurred at 7 locations (Fig. 10), resulting in an average of 3.3 captures per 100 trap nights. These revealed a minimum of nine individuals in the study area: two adult males, one adult female without young and three adult females with one young each (one female offspring, the other two of unknown sex).

On five occasions did we find in the recorded footage a pygmy hippo feeding as it passed the camera. Seven plant species could be confirmed as being part of the diet of the pygmy hippo this way. The identification of the Marantaceae is considered tentative, as it lacked inflorescences or fruits and as such it is hard to rule out allied species with certainty. These observations are summarized in Table 6, pictures of their herbarium specimens are available in Appendix 5.

At location 'Grand Pont' in Creek 4 two camera trapping events occurred, neither of which allowed for a sex to be assigned, and the second time the left eye did not show a reflection of the infrared flash, whereas the first time it did. Out of caution we treat this as one animal with a new injury and assume this to be the same female that was recorded not far from here only 40 minutes after the first sighting.

Apart from the aforementioned animal with a damaged eye, one more injured animal was observed. The female occupying the northwestern territory (Fig. 10) was missing her left front hoof, resulting in a noticeable limp. This way we were able to confirm this female had already been observed less than a kilometer from here on the other side of the Hana by an IBREAM camera trap operated by Kevin Tanguy in 2023. The other pygmy hippos were not able to be connected to prior monitoring results.

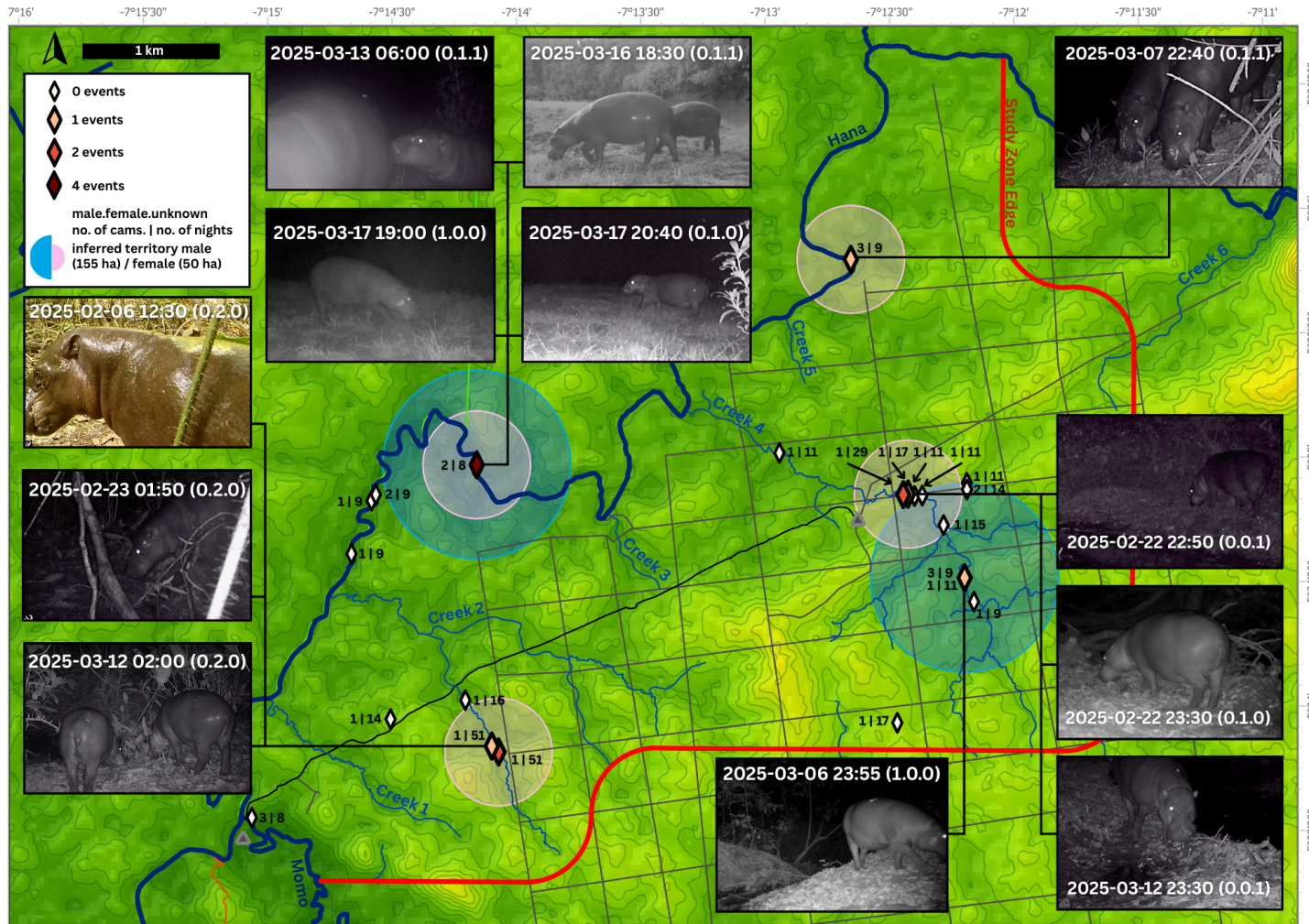


Fig. 10. Deployments of camera traps, color-scaled for the number of pygmy hippo passages. The numbers next to the camera symbols show the number of cameras active at any given moment and number of monitored nights (no. of cams | no. of nights), with the numbers next to the date and time showing the sex of the observed animals (male.female.unknown). Inferred territory sizes after Bülow (1987). Baselayer: NASA SRTM DEM elevation (30 m), layout of minor layons courtesy of MPI EVA.

Table 6. Plant species observed to be eaten by the pygmy hippo through camera trapping. Abbreviations under ‘associated vegetation’ denote habit (T: Trees. H: Herbs. R: Climbing palms).

Species eaten	<i>Landolphia incerta</i>	<i>Hymenocoleus hirsutus</i>	cf. <i>Marantochloa purpurea</i>	<i>Glinus oppositifolius</i>	<i>Steinchisma laxum</i>	<i>Nelsonia smithii</i>	<i>Ruellia primuloides</i>
Family	Apocynaceae	Rubiaceae	Marantaceae	Molluginaceae	Poaceae	Acanthaceae	Acanthaceae
Habit and notable traits	Herbaceous vine; leaves with pronounced apical drip tip, weakly folded along primary nerve, reddish when young.	Creeping herb; leaves cordate, hairy above on primary nerve, below also on secondary nerves; resembles <i>Geophila afzelii</i> .	Large monocot; petioles long; lamina asymmetrical, relatively narrow, apex cuspidate; faint hairs along midrib below.	Herb; leaves small, whorled, glabrous, apex faintly crenulate; pronounced tap root; resembles <i>Mollugo</i> spp.	Grass; racemes at ± right angles to the erect central stem, each featuring many white to purple spikelets.	Creeping herb; leaves above with short stout hairs; hairy bracts forming a small cone-like structure; resembles <i>Phaulopsis</i> spp.	Woody shrub; leaf pairs unequal, base asymmetrical, cystoliths conspicuous, scattered hairs on margins; resembles <i>Lankesteria</i> spp.
Events	2025-02-06 (subadult female)	2025-03-13 (adult female with subadult female)		2025-03-07 (adult female with young)		2025-03-12 (adult, likely female)	2025-03-06 (adult male)
Location of feeding observation	Animal passage in upstream lowland of Creek 2, on firm soil.	Animal passage in upstream lowland of Creek 2, on weakly marshy soil.		Embankment of the Hana, seasonally inundated, partially sun-exposed.		Streambed of Creek 4, subject to periodic inundation.	High embankment of Creek 4.
Notes on associated vegetation	R: <i>Calamus deeratus</i> . H: <i>Arthropteris palisotii</i> , <i>Lomariopsis</i> spp. <i>guineensis</i> & <i>rossii</i> , <i>Pteris burtonii</i> .	Not far from <i>L. incerta</i> feeding observation; also noted the large monocot <i>Palisota hirsuta</i> , with herbivory signs of uncertain origin.		T: <i>Uapaca heudelotii</i> . H: <i>Oldenlandia lancifolia</i> (grazing signs, origin uncertain), <i>Alternanthera sessilis</i> , <i>Ceratopteris cornuta</i> , <i>Pityrogramma calomelanos</i> .		H: <i>Aneilema umbrosum</i> (grazing signs, origin uncertain).	T: <i>Sacoglottis gabonensis</i> , <i>Scytopetalum tieghemii</i> . H: <i>Lomariopsis guineensis</i> , <i>Pteris burtonii</i> , <i>Triplophyllum protensum</i> .

4. Discussion

This study set out to quantify the relative importance of a multitude of environmental factors thought to drive pygmy hippo density patterns on a local scale. We combined data from 187 samples of relevant environmental conditions with pygmy hippo fecal counts from 38 line transects, revealing several important relationships. Three of these were statistically significant: pygmy hippos showed a distinct preference for areas far away from footpaths, near forest creeks and with a shallow litter layer. Additionally, four more variables showed a marginally significant correlation, implying they are also of considerable importance: pygmy hippos showed a preference for areas far away from camps, with a tall angiosperm undergrowth and high fern cover, and near major rivers.

The general dependence of the pygmy hippo on the availability of water courses matches well with what is known from earlier studies (Bogui et al., 2016; Conway, 2013; Hillers et al., 2017), though to our knowledge no prior research has attempted to separate the effects of different river types before. The countless small, rain-fed forest streams in Taï NP haven't been comprehensively mapped and as such tend to be excluded from niche modelling studies. After performing on-ground charting within our small section of forest, we revealed that these creeks provide an even more important habitat than the Hana and Momo rivers do. Considering such major rivers occur relatively scarcely in Taï NP and pygmy hippos are thought to defend small, fixed territories (Bülow, 1987), they are probably simply inaccessible to a large share of the population. Comparatively, the cumulative length of all forest creeks is much larger, allowing for more territories to be centered on them. An additional aspect might be that of the associated vegetation: the large rivers in the study zone are (partly) bordered by floodplains with grasses, tall herbs and shrubs, as well as species-poor *Plagiosiphon* stands further inland (Guillaumet, 1967), instead of the 'regular' high forests and bas-fonds that border the creeks.

The increase in fecal density with an increased distance to the minor layons (extensively trafficked human pathways) and encampments matches well with the general characterization of the pygmy hippo as a timid animal that seeks to avoid humans. However, especially their relationship with human pathways warrants a more nuanced interpretation. The number of feces encountered outside of transects far outweighs the on-transect count, with some of the densest clusters actually observed directly on the layons (Appendix 6). It is our impression that the fecal density as one moves away from a layon is actually somewhat bimodal, with one sharp peak directly along the paths (undetected by our model) and one diffuse peak further into the shrubbery (detected by our model). High densities of pygmy hippo feces along human clearings have been reported before (Hentschel, 1990). Even if their ease of navigation and their relative abundance of small herbs (pers. obs.) do lead to an earnestly high visitation rate of the layons, that still does not explain why there is a relative lack of hippo feces in their direct vicinity. As such, we hypothesize preferential defecation is the driving force of this pattern, whereby these corridors represent an advantageous location for territorial defense and olfactory communication. Such a variation in defecation likelihood has been observed before in other territorial mammal species in the context of human roads (Krofel et al., 2017; Rafiq et al., 2020). Indeed, our findings also hint at the active selection of defecation sites in other ways: a small number of 'mixed age' feces were observed, suggesting re-marking of old sprays does occur occasionally, and out of a total of 41 defecation-type feces, eight occurred within a single cluster of 50 meters that was

devoid of any spray-type dung. With spatial defecation probabilities in this species likely non-random, the inferred ecological preferences from this study should be validated through other forms of biomonitoring, such as systematic camera trapping or GPS collaring.

The negative relationship between pygmy hippo fecal density and litter layer height, albeit a weak one, had not been established nor studied before. Most research on the interaction between large mammals and leaf litter stems from temperate regions (i.e., Dhimi et al., 2023; Neupane et al., 2022). An enclosure experiment, whereby large mammals were barred from entering, has shown leaf litter in temperate forests may build up as a result of no large mammals passing through (Ramirez et al., 2019), which could potentially be the case here. Indeed, we generally noticed thicker litter layers in pockets of forest that were particularly difficult to traverse due to fallen trees and branches, which might have an enclosure-like effect. Another important factor might be that thicker layers of dried leaf litter produce more noise when walking. If true, this might be an effect that's most pronounced during the dry season.

Apart from litter layer depth, few of the vegetation measurements explained much of the variance in fecal densities. Both the total coverage of ferns and the height of the angiosperm undergrowth do warrant inclusion in future studies based on their near-significant effects, which follow the hypothesized patterns. Angiosperm height is closely related to the overall density of the undergrowth, which the pygmy hippo prefers to be closed according to Ouattara et al. (2019). That study also reported observing signs of pygmy hippo activity mostly under 'open' canopy conditions, but our quantified approach to this habitat characteristic does not support such a preference. Furthermore we expected the availability of ferns to be of importance to the pygmy hippo because they are an important element of their diet (Hentschel, 1990). Our data support such a positive relationship.

Further breaking down fern coverage into multiple phytosociological groupings did not reveal any correlations, though it does offer interesting ecological insights into the included species themselves. The fern survey resulted in the recognition of four sociological groups, each corresponding to a relatively distinct niche. Group A occurred in nearly all plots, reflecting its ability to grow through the entirety of the high forest. The only area where it's generally not accompanied by any of the other fern groups is the *Plagiosiphon*-dominated zone just behind the levees of the Hana. Group B develops most often in seasonally inundated areas and seems to thrive under relatively strong disturbance, also developing along some of the layons. Group C is also indicative of wet growing conditions, but seems to prefer soils that remain wet through the dry season. Finally, Group D corresponds to species that occur on well-drained upslope positions. The transitional zone between Group C and Group D covers much of the study zone. While there are no prior phytosociological studies in the Upper Guinean rainforest with a scope as local as ours, making direct comparison difficult, De Rouw et al. (1990) place the most common fern species along a similar gradient of moisture dependency. Notably, despite representing different vegetation types, all fern groups included members known to fall within the diet of the pygmy hippo. This might be an incentive for the pygmy hippo to forage throughout different parts of the landscape.

Camera trapping proved to be a fruitful technique for uncovering new knowledge about the diet of the pygmy hippo, with our capture rate of 3.3 events per 100 nights exceeding that of

the (more systematic) efforts by Conway (2013) and Van Heukelum (2011). This way seven plant species could be identified as eaten, of which four haven't been reported before (the exceptions being *Hymenocoleus hirsutus* and *Steinchisma laxum* under synonyms in Hentschel, 1990, and *Marantochloa purpurea* in Hendier et al., 2021). Out of the four new species, two (*Glinus oppositifolius* and *Nelsonia smithii*) are small forest floor herbs and one (*Landolphia incerta*) is a climbing but still non-woody species. In this sense, they fit in well with the type of greenery thought to be preferred by the pygmy hippo (Robinson et al., 2017). *Ruellia primuloides* is a woody shrub, but our herbarium specimen suggests the pygmy hippo defoliates it without eating the larger woody stems. It is also a relatively abundant species in this part of Taï NP (Van Rompaey et al., 2001), which matches well with the idea that the pygmy hippo adapts its diet to local conditions (Hendier et al., 2021; Mo, 2022).

Especially the aforementioned importance of small, rainfed creeks to the pygmy hippo comes with implications for conservation planning. All creeks included in our model remained active through the 2025 dry season, but did shrink to the point where they could easily be waded through in most places. Exposed sand and gravel beds were a common sight, locations deep enough for a pygmy hippo to wallow only occurred sporadically, and root structures that in the rainy season might serve as burrows sat largely exposed. In time, deforestation-induced aridification in the southwest of Côte d'Ivoire (Brou, 2010; Kühl et al., 2012) may well result in more and more of these important habitat elements fully falling dry. Evidence is mounting that climatic conditions within Taï NP are already shifting. Phenological records suggest that various tree species are showing signs of drought stress (Taï Chimpanzee Project, in prep.). We add to this the observation that the fern *Triplophyllum protensum* is now the dominant element of the upslope herbaceous stratum in our study zone, rather than the more water-associated species *Pteris burtonii* (Table 3). This is in stark contrast to De Rouw et al. (1990), who considered the appearance of *P. burtonii* on crests a distinctive feature of the relatively wetter south of Taï NP (a boundary drawn approximately 30 km north of our study zone). We also point out our mean MODIS EVI (Table 4), which is lower than reported for other semi-deciduous African rainforests (Gond et al., 2013). As ongoing deforestation in the region continues to exacerbate the trend of aridification, there is a risk that the surface area of suitable pygmy hippo habitat will be the next to start contracting due to the disappearance of creeks, even within protected areas. Especially since it is presently not included in their IUCN Red List assessment (Ransom et al., 2015), the threat posed to the pygmy hippopotamus by aridification warrants urgent investigation.

Lastly, camera trapping also revealed a female pygmy hippo missing her front left hoof. With no records of snare traps being used in the forest or adjacent plantations (Couturier, pers. comm.), and leopards not known for targeting hooves (Blanco & Luzardo-Vera, 2021), we deem it most likely that this pygmy hippo was ensnared by a fishing net at a younger age. Over the course of this project, a considerable number of fishing nets were recovered from the Hana river, many of which appeared to have already been abandoned for some time. We caution that fishing nets, especially when abandoned and superficially covered by sediment, could present yet another threat to the pygmy hippo. Especially in areas where legal fishing coincides with important pygmy hippo habitat, such as parts of the Lofa-Gola-Mano landscape (Garteh, 2013), community awareness initiatives could help reduce this additional pressure on a species that's already facing many challenges and will continue to do so in the years ahead.

5. Conclusions

A total of 62 pygmy hippo droppings across 38 transects were combined with 187 datapoints of ground-collected and geospatial data on vegetation composition, vegetation structure and other key habitat features, resulting in a model that explained about 18.2% of fecal density variance through its fixed effects alone. The model revealed that pygmy hippo fecal densities are positively associated with the proximity of creeks and negatively associated with litter layer depth and footpath proximity. Marginally significant effects were observed for the height of the angiosperm undergrowth, fern cover, proximity to major rivers and proximity to camps. The apparent importance of small, rain-fed forest creeks to the pygmy hippo may well represent a risk in a region suffering from aridification, something which deserves urgent investigation and underlines the importance of halting deforestation in West Africa. Lastly, camera trapping has expanded the known list of plants on which the pygmy hippo forages by four species and has provided the first tentative evidence that fishing nets pose a threat to the pygmy hippo.

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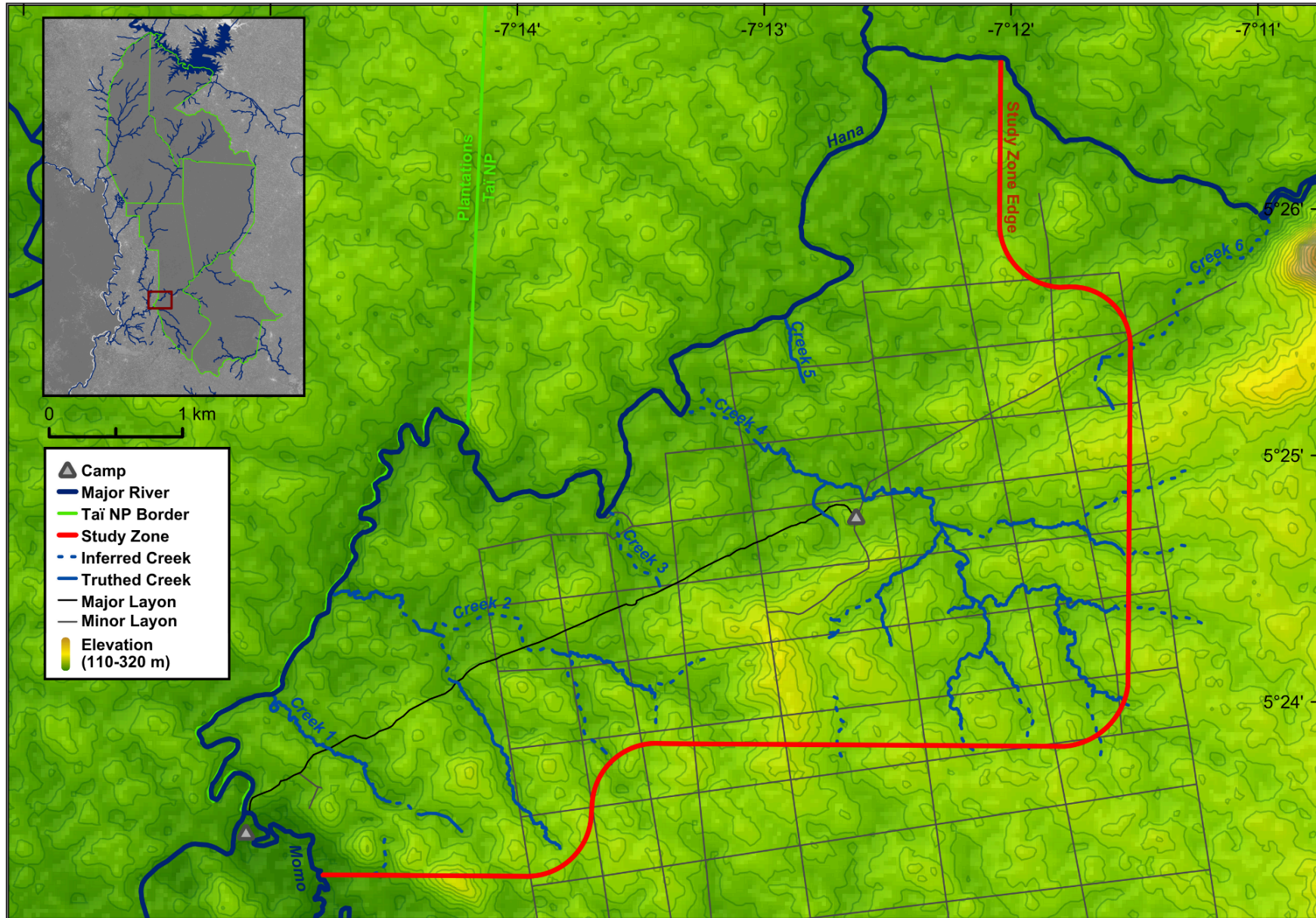
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Appendix 1. Fern species eaten by the pygmy hippo

Table s1-1. Ferns (Pteridophyta) confirmed to be eaten by pygmy hippos. List adapted from Hentschel (1990), as no additional fern species have been reported in the diet of the pygmy hippo since the submission of this dissertation. Taxonomy after Roux (2009). 'Presumed synonyms' refer to plants listed by Hentschel (1990) under names that don't identically match the official spelling of any species or synonym thereof.

Family	Species	Comments
Adiantaceae	<i>Adiantum vogelii</i>	Also listed by Bülow (1987).
Dryopteridaceae	<i>Lastreopsis currorii</i>	Under synonym <i>Ctenitis efulensis</i> .
Gleicheniaceae	<i>Dicranopteris linearis</i>	
Lindsaeaceae	<i>Lomariopsis guineensis</i>	Also listed by Bülow (1987); considered a 'favorite'.
Lygodiaceae	<i>Lygodium smithianum</i>	
	<i>Lygodium spec.?</i>	Listed by Hentschel (1990) as <i>Lygodium cernum</i> : the closest valid name to this would be <i>Lycopodiella cernua</i> , but given the extreme morphological differences between <i>Lygodium</i> and <i>Lycopodiella</i> and the explicit listing within 'Schizeaceae' we don't feel confident in such an interpretation.
Nephrolepidaceae	<i>Nephrolepis biserrata</i>	Also listed by Bülow (1987) and Hendier (2019); considered a 'favorite'.
Polypodiaceae	<i>Microsorium punctatum</i>	Under (presumed) synonym <i>Microsorium punctatum</i> .
Pteridaceae	<i>Pteris burtonii</i>	Also listed by Hendier (2019); considered a 'favorite'.
Selaginellaceae	<i>Selaginella myosurus</i>	Under synonym <i>Selaginella scandens</i> .
	<i>Selaginella vogelii</i>	Under (presumed) synonym <i>Selaginella vogelei</i> .
Tectariaceae	<i>Triplophyllum protensum</i>	Under synonym <i>Ctenitis protensa</i> ; also listed by Bülow (1987); considered a 'favorite'.
	<i>Triplophyllum pilosissimum</i>	Listed under two synonyms: <i>Ctenitis variabilis</i> & (presumed) <i>Ctenitis polissima</i> ; considered a 'favorite'.
Thelypteridaceae	<i>Christella dentata</i>	Under synonym <i>Cyclosorus dentatus</i> .
	<i>Cyclosorus striatus</i>	Considered a 'favorite'.
Woodsiaceae	<i>Diplazium proliferum</i>	Under synonym <i>Athyrium proliferatum</i> ; considered a 'favorite'.

Appendix 2. Ground-truthing of the permanently active creeks in the study zone



Appendix 3. Pilot with acoustic monitoring of the pygmy hippo

s3-1. Introduction

Acoustic perception and vocalisation in the pygmy hippo have received very little attention, with the only known projects being those of the French CeMEB Labex PygmHippoCom (i.e., Pezzino, 2018; Orliac et al., 2023) and the Italy-based REC Association (i.e., Santoro et al., 2024). This, whilst both active vocalisation and passive observation of the local soundscape are almost certainly an important aspect of the behavior of these territorial inhabitants of the dense rainforest undergrowth and murky river systems. The closest living relative of the pygmy hippo, the common hippopotamus (*Hippopotamus amphibius*), is known to inhabit and participate in an intricate 'amphibious' soundscape. When partially submerged, they boast a vast repertoire of sounds that are transmitted to water and air simultaneously and they are also known to produce loud 'clicks', 'croaks' and 'whines' exclusively underwater. These sounds are associated with specific behaviors in conspecifics, implying they are used for communication (Barklow, 1997). Furthermore, in captivity river hippos clicks have also been observed to be more frequently produced during foraging, implying hippos may also exhibit some form of echolocation (Maust-Mohl et al., 2018).

Over the course of this study, we aimed to address the following research questions:

1. Do pygmy hippos vocalize underwater?
2. Are hippo-visited sites acoustically distinct from sites where no pygmy hippos visited, either above water or underwater?
3. To what extent is the difference directly determined by hippo presence as determined through camera trapping?
4. How do isolated pools and continuous streams differ in soundscape?

Unfortunately, many hurdles were encountered in search of answers to these questions. At the time of writing of this report, the recordings have yet to be fully analyzed. As such, the remainder of this appendix is structured somewhat atypically, with the methodology combined with some of the results.

s3-2. Research activities

s3-2.1 Materials

The Institute of Biology Leiden kindly provided four microphones to the project: 2x AudioMoth and 2x HydroMoth. This microphone is hailed for being one of the cheapest options that is still of sufficient quality for scientific research. They are extremely simple devices, with all electronics built into a small metal plate to which the user can attach three AA batteries and a microSD. Configuration takes place by attaching the device with a USB cable to a laptop that has the (very simple) configuration app installed. Once configured, the user puts the microphones into a proprietary waterproof plastic casing and the microphone can be deployed. The files were reviewed in Audacity version 3.0.2.

s3-2.2 Ex situ pilot

ZooParc Overloon and the Rotterdam Zoo kindly lent their facilities for a pilot, with the goal of establishing a basic understanding of both the equipment and pygmy hippo vocalization. Both zoos were encouraged to also place some food inside the water to encourage possible echolocation.

At ZooParc Overloon, the zookeepers indicated the pygmy hippos (a mother and her adult daughter) mostly stayed inside due to the cold weather. As such all microphones were deployed inside, with the two HydroMoths hidden inside the drain of the (small) pool and the AudioMoths attached to a disused pipeline just below the ceiling (Fig. s3-1). All microphones were set to record for 29 minutes and then save for 1 minute, with a 16000 Hz sampling rate. Other than that, different settings were tested across the microphones (Table s3-1).

A



B



Fig. s3-1. The recording setup in the pygmy hippo enclosure of ZooParc Overloon. A: Overview of the enclosure. B: Location of the AudioMoths (installed along a pipe just below the ceiling) and the HydroMoths (installed below the drain in the center of the now-drained pool).

Table s3-1. Microphone settings for the pilot at ZooParc Overloon.

Microphone	Gain	Recording period
Audio1	Low-Medium	00.00-00.00
Audio2	Low	17.00-10.00
Hydro3	Low-Medium	00.00-00.00
Hydro4	Low	17.00-10.00

The microphones were activated on 07/12/2024 at 10.00. On 10/12 at 09.00, Hydro3 ceased recording for unknown reasons. The remaining three microphones continued recording until their removal on 12/12 at 09.00. Hydro3 is the only microphone where some limited screening of the recordings has taken place, with the most interesting noise being heard 07/12 at approximately 17.30 (Fig. s3-2).

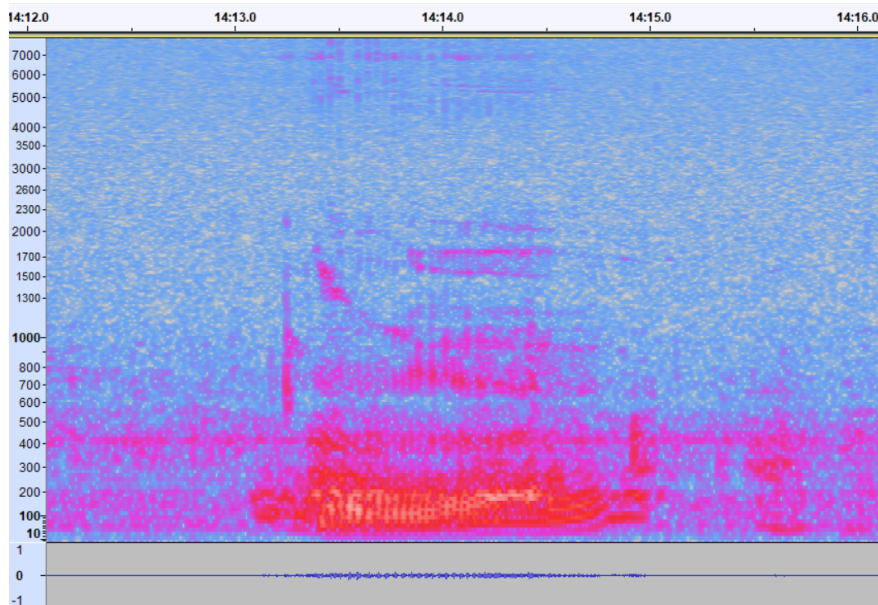


Fig. s3-2. Spectrogram of a sound that was only heard underwater at ZooParc Overloon and was not heard at any other moment, potentially being of pygmy hippo origin. Recorded on 17/12 at approximately 17.30.

At the Rotterdam Zoo, the solitary female was apparently more willing to use both the inside and outside facilities. As such, one HydroMoth and one AudioMoth were installed in both parts of the enclosure (Fig. s3-3). We maintained the same record-sleep cycle and sampling rate as at ZooParc Overloon and we chose a gain level based largely on how much echo we expected (Table s3-2).

Table s3-2. Microphone settings for the pilot at the Rotterdam Zoo.

Location	Microphone	Gain	Recording period
Inside	Audio1	Medium	16.30-10.30
	Hydro4	Medium	16.30-10.30
Outside	Audio2	Medium	16.30-10.30
	Hydro3	Low-Medium	16.30-10.30

The microphones were activated on 15/12/2024 at 16.30 and all continued functioning until their removal on 19/12/2024 at 10.30, except for Hydro3, which had ceased recording three hours earlier. Again, these files await systematic and thorough review. On the indoor HydroMoth, twice did we note five small peaks below 2.5 kHz within half a second, which we deem interesting (Fig. s3-4).

A**B****C****D**

Fig. s3-3. The recording setup in the pygmy hippo enclosure of the Rotterdam Zoo. A: Hydrophone installation in the indoor enclosure. B: AudioMoth installation in the indoor enclosure. C: AudioMoth installation in the outdoor enclosure. D: HydroMoth installation in the outdoor enclosure.

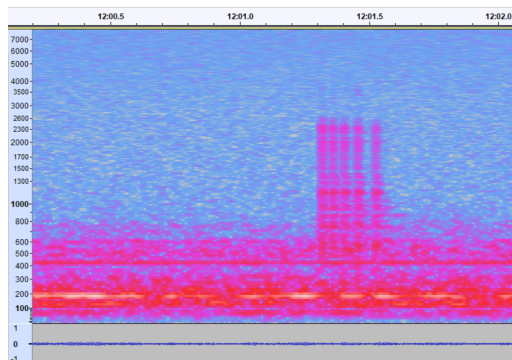
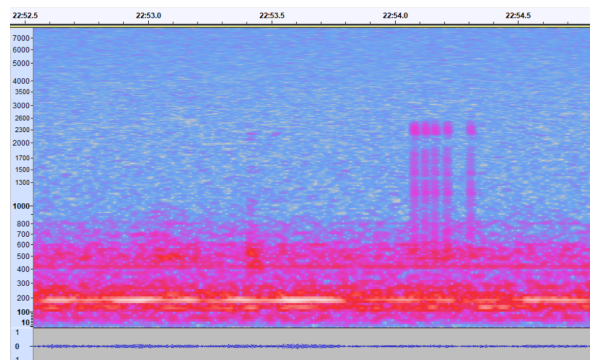
A**B**

Fig. s3-4. Spectrogram of a sound that was only heard underwater at the Rotterdam Zoo and was not heard at any other moment, potentially being of pygmy hippo origin. A: Recorded on 12/17 at approximately 03:00. B: Recorded on 12/17 at approximately 16:30.

s3-2.3 In situ pilot

As already mentioned in the introduction, initially we intended to target two different types of water bodies for the in situ pilot: stationary pools and connected rivers. With this paired sampling design, we would account for night-specific variation in conditions and cultivate a dataset that would be interesting to analyze on a soundscape-level, even if we still struggled to attribute specific species to the noises we captured. However, it soon became apparent that hardly any stationary pools occur in the study area and as such we changed our plans to studying the difference between the Hana and the small forest creeks.

On 27/02/2025 we went to deploy the first round of this recording setup. First, one HydroMoth and one AudioMoth were installed at a suspected pygmy hippo burrow along Creek 4. The HydroMoth was installed on the northern access to this cavity. It was attached to a waterlogged branch with a ziptie, and that branch was in turn connected to a tree root using a rope. The AudioMoth was attached to a small tree growing directly on top of the cavity. Three camera traps were installed in close proximity to each other, covering all probable access routes to this high-banked site (Fig. s3-5).

A



B



Fig. s3-5. Recording setup at Creek 4. A: The southern approach to the recording site, showing the intricate root structure created largely by two *Sacoglottis gabonensis* trees, below which there is a cavity in the river bank that extends all the way to the other side of this meander. One of the three camera traps deployed here can be seen in the left of the picture. B: The HydroMoth connected to a waterlogged branch, which was then lowered into the water at the northern entrance of the cavity.

It was at this point that we noticed a malfunction with the second AudioMoth. Returning to the camp to reconfigure it with the laptop seemed to alleviate the problem, but upon arrival at the Hana recording site, it malfunctioned again. We have since concluded a hardware failure has occurred with this microphone, quite possibly having been damaged somewhere in transit to the forest despite having been carefully packed. This meant the intended side-by-side sampling design was no longer possible. It was at this point we switched our design to entirely maximise the chances of capturing a pygmy hippo passage, meaning we also opted to go for fewer, longer deployment periods instead of many short deployments at

different sites. The remaining HydroMoth was attached to a dead, largely submersed tree using rope and zipties and again surrounded by three camera traps (Fig. s3-6).



Fig. s3-6. Recording setup on the banks of the Hana. The HydroMoth is attached to the dead log in the left of the picture, one of the three camera traps can be seen attached to the stilt roots of an *Uapaca heudelotii*.

Out of caution the sampling rate for both sites was increased to 32000 Hz, maintaining the same record-sleep cycle as with the in situ trials. An overview of settings and performances for this first round of deployments is given in Table s3-3.

Table s3-3. Microphone settings and performances for the first deployment in Tai NP.

Location	Microphone	Gain	Recording period	Recording failure
Creek 4	Audio2	Medium	00.00-00.00	02/03 23.30
	Hydro1	Medium	00.00-00.00	02/03 09.00
Hana	Hydro4	Medium-High	00.00-00.00	05/03 04.00

At Creek 4 a male pygmy hippo approached (and then turned away from) the southern edge of the setup after both microphones had already failed. At the Hana, a female with her calf approached the setup (never actually going into the river), but also only after the microphone had already ceased recording. The recordings have not yet been screened for vocalisations from more distant animals.

Only one more deployment took place, this time in the west of the study zone, navigating upstream on the Hana from Ecotel Touraco using a motorboat. The microphones were again divided across two sites, both along the Hana along grassy shores with signs of pygmy hippo activity, each accompanied by two camera traps (Fig. s3-7). We maintained the same sampling rates, record-sleep cycles and recording periods as for the first deployment, the remaining parameters are summarized in Table s3-4.

A**B**

Fig. s3-7. Recording setup at ‘Hana Downstream’. A: Installation of one of two camera traps. B: The second camera trap, with the HydroMoth and AudioMoth both installed on the large dead tree just behind.

Table s3-4. Microphone settings and performances for the second deployment in Tai NP.

Location	Microphone	Gain	Recording commenced	Recording failure
Downstream	Audio2	Medium-High	09/03 13.00	12/03 11.30
	Hydro3	Medium-High	09/03 13.00	12/03 07.00
Hippo Beach	Hydro4	Medium-High	10/03 15.30	16/03 03.30

The camera traps revealed no passages at the downstream location. While ‘Hippo Beach’ yielded a record four different passage events, only the very first of these (13/03 06.00) happened when the microphone was still operating. Spectrogram and auditory analysis of 2.5 hours of recording surrounding this event revealed no sounds that meaningfully stood out.

s3-3. Discussion and recommendations

No conclusions on pygmy hippo vocalisation either above or below water can be drawn from this pilot. Within the segments of audio that have been reviewed, at most there are some minor squeeks, croaks and snorts that could potentially be of hippo origin, though it must be asked if these actually serve any purpose or are simply byproducts of respiration, digestion and movement.

We think the reason our efforts weren’t fruitful is twofold. Firstly, the AudioMoth is simply not suitable for studying pygmy hippos in the wild. Even under favorable conditions they are not expected to last longer than a week, which clashes with the fact that pygmy hippos tend to avoid areas recently disturbed by humans (Conway, 2013). Depending on what kind of error the AudioMoth experiences, the system can even reactivate the blinking LED indicators and actively scare away any animals that approach. Furthermore, their calibration is reset

whenever its batteries or SD card are changed (or if they shift in transit), necessitating either a return to camp or the transportation of a laptop into the forest, neither of which is desirable.

Secondly, the recordings took place almost completely 'blind': i.e., we don't have any visual information to contextualise the audio with. This leaves the source of even the most significant sounds that are captured entirely up to speculation. Without knowing what kind of forms pygmy hippo vocalisation (and, crucially, also the other (aquatic) animals in Taï NP) can take, how can those subtle sounds be found within hundreds of hours of recordings? The current efforts to adapt acoustics into a form of biomonitoring amount to searching for a needle of unknown description in a haystack. Therefore we suggest a mixed ethological approach in a zoo as a good place to start for future studies: while recording, have an observer track the activities of the animal in detail (crucially also at night). This could then not only be used to filter through the audio in a more targeted and informed manner, but it would also yield 'worthwhile' data by itself should the acoustic element again prove scant.

That's not to say this line of research is a doomed endeavour. Over the course of this study, we did learn others have occasionally heard major vocalisations from the pygmy hippo. Guides of Taï Forest Lodges have heard loud 'roars' from multiple directions on the banks of the Hana during the dry season at night, possibly representing some kind of territorial or sexual display. Furthermore, both the Rotterdam Zoo and ZooParc Overloon have daytime recordings of their females grunting while on land (Fig. s3-8). Both zoos suspected that these coincided with their estrus, and ZooParc Overloon elaborated that the female first started producing this noise when she entered the males enclosure before it had been cleaned, seemingly becoming restless and actively sniffing his odor. The male is said to produce the same call, albeit softer, as the female has continued producing these sounds whenever the animals are in adjacent enclosures. These leads are absolutely worth chasing, but that should be done so with dedicated resources and an understanding that learning the language of the generally soft-spoken pygmy hippo from scratch won't be accomplished overnight.

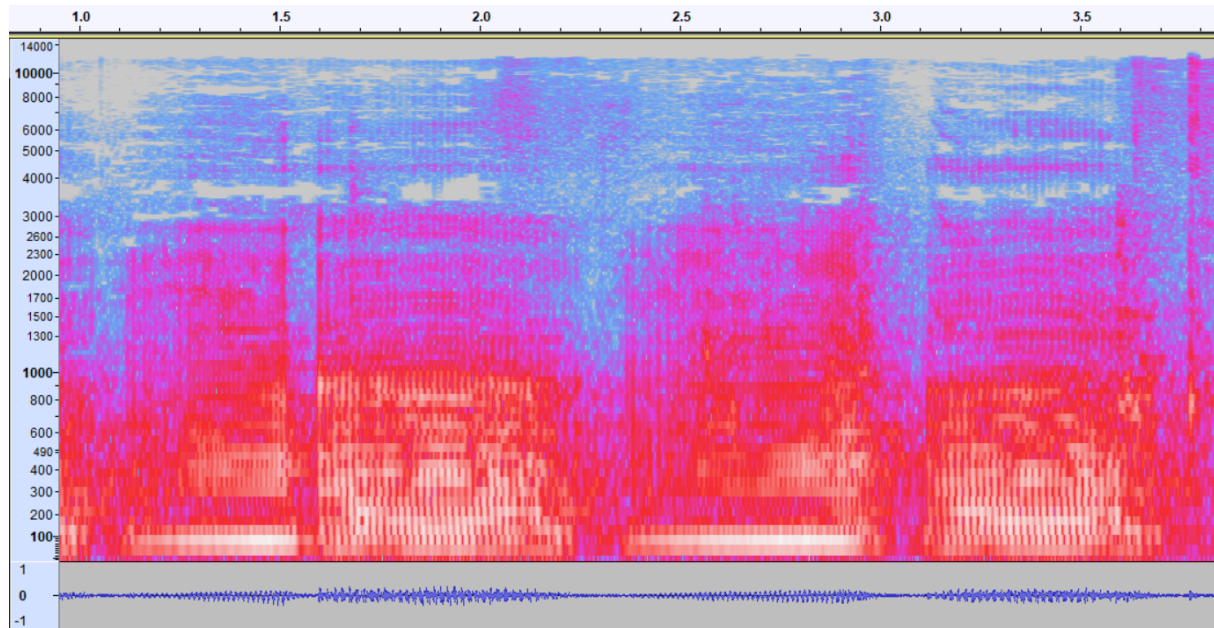


Fig. s3-8. Spectrogram of daytime, terrestrial vocalisations by a female pygmy hippo in ZooParc Overloon, thought to represent a mating call. The vocalisation is an extensive repetition of two tones, the first increasing in pitch and the second, more rumbling, decreasing in pitch. Recording by the staff of ZooParc Overloon.

s3-4. References

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Appendix 4. List of fern species in the Djouroutou research zone of Taï NP

Table s4-1. All pteridophytes encountered over the course of the study period in the Djouroutou research area with notes on ecology. If no occurrence rate within plots (3x3 meters, N=187) is given for a species, that means it was only ever observed outside of them. Groups that were noted as present, but excluded from species-level identification and as such not included below: near-microscopic epiphytic Hymenophyllaceae; Selaginellaceae with a widely creeping, moss-like habit; large high epiphytes such as *Platyserium* and allies. Species known to be included in the diet of the pygmy hippo (Hentschel, 1990) are marked with ✓.

Species	Family	Notes on ecology
<i>Abrodictyum guineense</i> (Afzel. ex Sw.) J.P.Roux	Hymenophyllaceae	Occurred in 1.5% of plots. Overall rare, but can form small dense clusters on steep slopes.
<i>Adiantum vogelii</i> Mett. ex Keyserl. ✓	Adiantaceae	Occurred in 3.1% of plots; Group B (found most commonly in seasonally inundated marshes and other high-disturbance locations, such as footpaths and Ecotel Touraco).
<i>Alsophila cameroonina</i> (Hook.) R.M.Tryon	Cyatheaceae	One known locality: two young specimens growing on a very steep slope bordering a seasonally active creek that drains south towards the Momo.
<i>Arthropteris palisotii</i> (Desv.) Alston,	Tectariaceae	Occurred in 4.7% of plots; Group C (found most commonly in year-round marshy area, though it can also be found at a much decreased density further upslope in some places).
<i>Asplenium aethiopicum</i> (Burm.f.) Bech.	Aspleniaceae	One known locality: some small specimens growing as lithophytes along a rocky footpath along the steep slopes up the mountain south of Camp Chimpanzee.
<i>Asplenium africanum</i> Desv.	Aspleniaceae	Occurred in 3.1% of plots; Group B (while seemingly abundant as a high epiphyte, as a low epiphyte it was only ever recorded in seasonally inundated marsh forests and on lowslope positions).
<i>Asplenium cf. buettneri</i> Hieron. ex Brause	Aspleniaceae	One known locality: as a small lithophyte on the footpath on the north slope of Mont Niénokoué as one approaches the border between the <i>Plagiosiphon</i> forest and the savanna-like vegetation.
<i>Asplenium variabile</i> Hook.	Aspleniaceae	Occurred in 12.5% of plots; Group A (generalists; notable for occurring largely as a terrestrial species in lowland marshes, primarily as an epiphyte on the midslope and primarily as a lithophyte further upslope). At a very small stadium, this species can easily be confused with <i>Lomariopsis guineensis</i> .
<i>Blotiella currorii</i> (Hook.) R.M.Tryon	Dennstaedtiaceae	Occurred in 0.5% of plots. Exclusive to well-developed marsh forest.
<i>Bolbitis acrostichoides</i> (Afzel. ex Sw.) Ching	Dryopteridaceae	Exclusive to rocky streambeds, just above the water line (in association with <i>Lomariopsis palustris</i> and <i>Triplophyllum securidiforme</i>).
<i>Bolbitis auriculata</i> (Lam.) Alston	Dryopteridaceae	Occurred in 1.0% of plots. Borders rocky creeks and occasionally seen in well-developed marsh forest.
<i>Christella dentata</i> (Forssk.) Brownsey & Jermy ✓	Thelypteridaceae	Only noted growing in a concrete crack at the edge of an anthropogenic clearing in full sun (Ecotel Touraco). It is possible it shares a niche with the more abundant <i>Cyclosorus</i>

		<i>striatus</i> , with which it bears a striking resemblance at a distance.
<i>Cyclosorus striatus</i> (Schumach.) Ching ✓	Thelypteridaceae	Forms large, dense stands in sunny, disturbed locations such as marsh clearings, the floodplains of the Momo and treefalls, otherwise does not occur within true high forest.
<i>Dicranopteris linearis</i> (Burm.f.) Underw. ✓	Gleicheniaceae	Occurred in 0.5% of plots (as a juvenile). Only observed one well-developed specimen in the high forest, growing over the base of an uprooted tree along a footpath. By contrast, it is by far the most abundant fern growing along the dirt road that connects the villages west of Taï NP, creating massive stands where it is occasionally joined by <i>Pteridium aquilinum</i> .
<i>Diplazium sammatii</i> (Kuhn) C.Chr.	Woodsiaceae	Restricted to well-developed marsh forests where it occurs in low densities.
<i>Lastreopsis curroii</i> (Mett. ex Kuhn) Tindale ✓	Dryopteridaceae	Occurred in 0.5% of plots. Exclusive to well-developed marsh forest. One time a small specimen was seen growing on a decaying log.
<i>Lomariopsis guineensis</i> (Underw.) Alston ✓	Lomariopsidaceae	Occurred in 81.8% of plots; Group A (generalist, by far the most common fern species in the high forest)
<i>Lomariopsis palustris</i> (Hook.) Mett. ex Kuhn	Lomariopsidaceae	Exclusive to rocky streambeds, just above the water line (in association with <i>Bolbitis acrostichoides</i> and <i>Triplophyllum securidiforme</i>). In absence of fertile fronds, it is hard to distinguish between this species and <i>L. guineensis</i> with certainty.
<i>Lomariopsis rossii</i> Holttum	Lomariopsidaceae	Occurred in 31.8% of plots; Group D (most associated with dry upslope positions, though it is the least 'faithful' member of its group and the only fertile specimen was actually seen directly along Creek 2).
<i>Lygodium microphyllum</i> (Cav.) R.Br.	Lygodiaceae	Restricted to strongly disturbed areas, rare inside the rainforest: noted growing on the metal frame of a solar panel array in a grassy clearing at Ecotel Touraco.
<i>Lygodium smithianum</i> C.Presl ex Kuhn ✓	Lygodiaceae	Restricted to strongly disturbed areas, rare inside the rainforest: noted in direct sunlight on the exposed soil of a high-slope treefall alongside <i>Pityrogramma calomelanos</i> .
<i>Marattia fraxinea</i> Sm.	Marattiaceae	Occurred in 0.5% of plots. Restricted to steep slopes bordering creeks and bas-fonds.
<i>Microgramma mauritiana</i> (Willd.) Tardieu	Polypodiaceae	Occurred in 0.5% of plots. This species stands out most on savanna-like hilltops (such as Mont Niénokoué and Crête Robert), where it can creep widely on tree roots. Otherwise it was noted twice in the high forest on dead logs, possibly originally having grown in the canopy.
<i>Microlepia speluncae</i> (L.) T.Moore	Dennstaedtiaceae	Rare, only noted on three occasions, always in well-developed marsh forest, possibly preferentially near dead logs.
<i>Microsorium punctatum</i> (L.) Copel. ✓	Polypodiaceae	Occurred in 0.5% of plots (on a fallen-over tree). High epiphyte that seems quite common.
<i>Microsorium scolopendria</i> (Burm.f.) Copel.	Polypodiaceae	High epiphyte that seems relatively common. Also found as a low epiphyte outside of the high forest and terrestrially on Mont Niénokoué.

<i>Nephrolepis biserrata</i> (Sw.) Schott ✓	Nephrolepidaceae	Occurred in 6.8% of plots; Group C (marsh forest). Though it is very common outside of the rainforest, inside it is mainly seen growing on dead wood in marshy areas, as a low epiphyte on the base of <i>Raphia</i> palms or as a high epiphyte. In that latter context it can also occur outside of the bas-fonds.
<i>Nephrolepis undulata</i> (Afzel. ex Sw.) J.Sm.	Nephrolepidaceae	Occurred in 0.5% of plots. An uncommon species that seems to be restricted to dead logs.
<i>Pellaea doniana</i> J.Sm. ex Hook.	Sinopteridaceae	Restricted to savanna-like hilltops (such as Mont Niénokoué and Crête Robert).
<i>Pityrogramma calomelanos</i> (L.) Link	Pteridaceae	This non-native species occurs prolifically in disturbed areas, such as the banks of the Hana, the clearings at Ecotel Touraco and Camp Chimpanzee and at treefalls, in association with <i>Cyclosorus striatus</i> .
<i>Pneumatopteris afra</i> (H.Christ) Holttum	Thelypteridaceae	Uncommon, restricted to well-developed marsh forest.
<i>Pteris burtonii</i> Baker ✓	Pteridaceae	Occurred in 24.0% of plots; Group C (most commonly in marsh forest, but also not uncommon on lowslopes and sometimes at reduced density if conditions are extremely marshy).
<i>Pteris hamulosa</i> (H.Christ) H.Christ	Pteridaceae	Occurred in 1.0% of plots. Uncommon, seemingly prefers growing along footpaths, not recorded in marshy areas.
<i>Pteris mildbraedii</i> Hieron.	Pteridaceae	Two known localities, both in well-developed marsh forest with open undergrowth.
<i>Selaginella versicolor</i> Spring	Selaginellaceae	Occurred in 1.5% of plots. Restricted to well-developed marsh forests, where it can occasionally form dense stands.
<i>Selaginella vogelii</i> Spring ✓	Selaginellaceae	Occurred in 0.5% of plots. Compared to <i>S. versicolor</i> seemingly slightly more drought-resistant. Generally at low densities.
<i>Tectaria fernandensis</i> (Baker) C.Chr.	Tectariaceae	Rare: the only well-developed specimens were growing directly along Creek 6, upstream, with smaller specimens seen a handful of times along footpaths in marshy areas.
<i>Triplophyllum fraternum</i> (Mett. ex Kuhn) Holttum	Tectariaceae	Occurred in 3,1% of plots; Group D (never in large numbers, densest on midslope positions but also seen upslope. Note: the species concepts of this species and <i>T. jenseniae</i> are not clearly delineated, but we deem our assemblage generally homogeneous. One small but fertile specimen (Kempkes 46) tentatively attributed to this species was collected in the well-developed upstream marsh of Creek 5).
<i>Triplophyllum pilosissimum</i> (J.Sm. ex T.Moore) Holttum ✓	Tectariaceae	Occurred in 7,8% of plots; Group C (marsh forests). Seems to span the same range of conditions as <i>Pteris burtonii</i> , but with peak density skewed slightly towards wetter conditions.
<i>Triplophyllum protensum</i> (Afzel. ex Sw.) Holttum ✓	Tectariaceae	Occurred in 34,9% of plots; Group D (generally restricted to midslope and higher). Note: the species concepts of this species and <i>T. vogelii</i> are not clearly delineated, but we deem our assemblage homogeneous.
<i>Triplophyllum securidiforme</i> (Hook.) Holttum	Tectariaceae	Restricted to rocky streambeds, just above the waterline (in association with <i>Lomariopsis palustris</i> and <i>Bolbitis acrostichoides</i>).

Triplophyllum cf. *troupinii* Tectariaceae
(Pic.Serm.) Holttum

Only noted once along a footpath through a well-developed marsh forest. The shortly acuminate apices of the pinnules of this specimen (Kempkes 38) are the main reason for attributing it to this species.

Appendix 5. Plants observed to be eaten by the pygmy hippo



Fig. s5-1. *Landolphia incerta* (K.Schum.) J.G.M.Pers. Specimen: Kempkes 209. Verified by S. B. G. Dougouné.



Fig. s5-2. *Hymenocoleus hirsutus* (Benth.) Robbr. Specimen: Kempkes 200. Verified by C. C. H. Jongkind.



Fig. s5-3. cf. *Marantochloa purpurea* (Ridl.) Milne-Redh. Specimen: Kempkes 207.



Fig. s5-4. *Glinus oppositifolius* (L.) Aug. DC. Specimen: Kempkes 201. Verified by S. van Zon.



Fig. s5-5. *Steinchisma laxum* (Sw.) Zuloaga. Specimen: Kempkes 204. Verified by T. van der Zon.



Fig. s5-6. *Nelsonia smithii* Oerst. Specimen: Kempkes 202. Verified by S. van Zon.



Fig. s5-7. *Ruellia primuloides* (T.Anderson ex Benth.) Heine. Kempkes 208. Verified by S. van Zon.

Appendix 6. Complete map of all observed pygmy hippopotamus feces

