Grass diversity and pasture quality baseline assessement in central Madagascar

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Abstract
Poaceae family contributes to Madagascar's biodiversity hotspot with 217 of 541 grass species endemic to the island, although their forage value is unknown, at least in the scientific literature. Our research aims 1) to describe the diversity of native and endemic grasses thereby recognising the role of grass species diversity in forage and ecosystem management and 2) to provide new knowledge about pasture management based on the relationship between grazing capacity and productivity within experimental pastureland plots under different fire and grazing treatments. Our study seeks to provide information to inform improvements in livestock nutrition via grazing management of natural pastures in central Madagascar, specifically around the Ankafobe, Ibity and Itremo Protected Areas. Sampling in different grassy habitats was undertaken to develop a grass checklist and overview of grass diversity across the project sites. Further, in the communal and experimental pastures standardised grass surveys were carried out to compare grazing capacity and biomass productivity in the experimental pastures. Our regional survey recorded 123 Poaceae species during the first year: including 90% native species (of which 34% were endemic) and 10% introduced species. Thirty species, all C4 and belonging to PACMAD clade, are found within established pasture grasslands. Across communal pastures the most frequently recorded species and thus most frequently grazed are *Loudetia simplex, Aristida rufescens, Panicum luridum, Schizachyrium sanguineum, Hyparrhenia rufa* and *Aristida tenuissima* – these species are predominantly associated with fire. The grazing capacity baseline, at about 0.7 to 0.8 ha/zebu/year, is similar across all experimental sites that are also characterised by having a similar climate, acidic soils with low nitrogen and phosphorus, and., Annual biomass production appears to be driven by fire frequency: at both Itremo and Ankafobe, where fire is an annual occurrence, biomass yield is 2.4-2.9t/ha whereas at Ibity, where fire frequency is fire every 3-4 years, biomass productivity is 6.9t/ha. However, it is unclear how these productivity estimates relate to forage quality; the relationship will be the subject of future work.

Introduction
Currently grassland and savannah cover > 65% of Madagascar's land area (Moat and Smith 2007), and across the island 591 grass species are recorded with 217 classified as endemic. Across the island, livestock numbers are diminishing (Rasambainarivo and Ranaivoarivelo 2003). Most of Malagasy farmers own use cattle (*Bos indicus*) as working animals, transport, for cultivating land, to provide fertilizer and number of livestock have relationship to poverty (Ralison 2003). Despite the centrality of livestock to the livelihoods of Malagasy smallholders, livestock tend to be undernourished particularly during the dry season as the main livestock food source are senesced grasslands. Livestock malnutrition is largely caused by the low quality of pasture resources in landscapes with low soil fertility and seasonally dry climates. Poor pasture management also contributes to malnutrition due to a lack of accessible knowledge about grazing capacity, forage quality, and productivity. Grazing capacity refers to the optimum animal population density that a particular area can sustain over a long-time span (Holechek et al. 2004). Grazing capacity reflects estimated pasture area sufficient for feeding an average head of cattle per year. Biomass productivity is expressed as the available fodder that an area can provide. Livestock malnutrition drives numerous negative impacts such as low livestock reproduction rate, low milk and meat production, in addition to the low fertilizer availability causing further poverty. This research aims 1) to inventory the diversity of native and endemic grasses for building knowledge and recognising the forage value of these species 2) to provide Malagasy practitioners with basic pasture management knowledge of grazing capacity and biomass productivity for exploitation and sustainable management of the natural pasture. This study is working towards improving livestock nutrition through improved pasture land management in the Central Highland of Madagascar including Ankafobe, Ibity and Itremo Protected Areas (PA) and their surrounded villages.

Methods

Study sites

Ankafobe, Ibity and Itremo PA are located between E042°15'00" and E47°12'04" longitude and S18°06'00'' and S24° 13'00'' latitude. They are elevated between 1000 to 1620m with a subhumid bioclimate, characterized by about six months of dry season (May-October) and six months of wet season (November-April), an annual average temperature between 21 to 25°C and an annual average rainfall between 1416 to 1583mm, with December, January and February recorded as the wettest months, although these means conceal large annual variations. They cover a total land area of 31057.87ha with 60% grassland. Itremo and Ibity represent a similar geology dominated by schistes, micaschistes, quartzites, migmatites and marbles and Ankafobe has the same geology as Ankazobe Tampoketsa, included in the Precambrian system with granitoid migmatite formations which give a uniformly crystalline aspect. Ankafobe and Itremo are subjected to fire annually and Ibity every 3-4 years or more. The three sites have an acidic soil with low nitrogen (N) and phosphorus (P) content; and high iron (Fe) content is observed in Ankafobe.

Grass diversity

Regional exploratory grass collecting in different habitat types was carried out for a grass diversity overview across the project sites. A baseline of species known from previous collections at the three sites (KMCC database January 2022) was compiled together with the present research. A standardised sampling method to quantify herbaceous richness and the rank frequency of constituent species over 16.5 m^2 per site following the method of the Global Grassy Group (Lehmann et al. 2022) was applied across 30 communal pastures across the three regions (i.e., 10 plots for each site). Sampling was undertaken from March to May 2022, during and at the later part of the wet season. This method consists of floristic inventories and collecting information on the site, geology, herbivory, fire, and soil. Fertile herbarium vouchers were made for taxonomic verification.

Pasture quality baseline assessement

Biomass sample collection was carried out in the late wet season across the three experimental project sites; 1ha grazed only by the cow project every day about two hours and 1ha burnt annually and grazed after fire by the project cow every day about two hours (Lehmann et al., 2022). Sampling consisted of clipping, drying and weighing herbaceous material in ten 0.5 x 0.5m quadrats randomly distributed within a 1 ha site. An estimation of biomass productivity is then calculated as tonne/ha. Grazing capacity survey was conducted using the herbaceous survey step-point method introduced by University of Pretoria (Truter and Venter 2017). A line transect is laid out in a homogeneous site. Point observations are made every 1m on each side of the transect line. At least 200 grass species observations points were recorded for one site.

Analyses

Species identification was carried out via spikelet dissection, observation under the microscope, and reference to the existing grass floras (Bosser 1969; Vorontsova et al. 2013 and 2018) and digital herbarium specimens available via the Museum National d'Histoire Naturelle (MNHN) website. Species distribution data are from the Madagascar Grass Atlas (Rabarivola et al. 2019). Data on the photosynthetic system is from Osborne et al. (2014). Species frequency figures are from presence/absence in each plot. Ecological status is from Solofondranohatra et al. (2020). Grazing capacity is calculated from total species strike/non-strike observations survey adjusted to the local annual rainfall average (Truter and Venter 2017). Biomass is obtained by weighing air dried herbaceous material from 2.5m^2 converted to t/ha for each experimental site.

Results and Discussion

Grass diversity

The regional baseline before project implementation showed that 112 Poaceae species had been recorded from the three sites. This number increased to 123 (one quarter of Madagascar's Poaceae) during the first year of the project. These species are found in different habitat types including grassland, gallery forest, Tapia woodland, rocky outcrops, stream sides, marshes, swamps, fields and roadsides. 56% of the grass species encountered were native but not endemic, endemic species make up 34 %, and introduced species 10%.

Among this regional list, 30 species, all using the C4 synthetic pathway, are recorded from grassland used as communal pasture. Representative species are represented in Table 1 where 73% are non-endemic natives, 17% are endemic and 10 % introduced. These species all belong to the tropical PACMAD clade (Panicoideae, 33%; Andropogoneae 27%; Chloridoideae 33% and Aristidoideae 7%; Soreng et al., 2022). More detailed research is needed to help understand the ecological determinants influencing this diversity and endemicity, including analysis of fire, soil, grazing, climate, and geology.

Figure 1: Endemic species to the Central Highland of Madagascar scanned by Nanjarisoa, 2022 (**a)** *Aristida tenuissima* (**b)** *Andropogon ibityensis* **(c)** *Eragrostis lateritica* **(d)** *Panicum luridum*

Figure 2: Grassland during wet season (a) and dry season (b) in Ankafobe experimental site grazed only

Communal pasture in highland Madagascar is dominated mostly by *Loudetia simplex*, *Aristida rufescens*, *Panicum luridum*, *Schizachyrium sanguineum*, *Hyparrhenia rufa* and *Aristida*. Grazing evidence are mostly observed in these species in all site.

Species	**Subfamily**	**Photosynthetic system**	**Distribution**	**Frequency in the 30 plots**	**Grazing**	**Ecological status (Solofondranohatra 2020)**
Aristida rufescens	Aristidoideae	C4	E	22	G	F
Aristida tenuissima	Aristidoideae	C4	E	15	NG	F
Ctenium concinnum	Chloridoideae	C4	N	7	NG	F
Eragrostis lateritica	Chloridoideae	C4	E	11	NG	Gr
Heteropogon contortus	Andropogoneae	C4	N	7	G	F
Hyparrhenia rufa	Andropogoneae	C4	N	19	G	F
Loudetia simplex	Panicoideae	C4	N	24	G	F
Melinis repens	Panicoideae	C4	N	7	G	F
Panicum luridum	Panicoideae	C4	E	20	G	Gr
Paspalum scrobiculatum	Panicoideae	C4	I	8	NG	Gr
Schizachyrium brevifolium	Andropogoneae	C4	N	9	NG	Int
Schizachyrium sanguineum	Andropogoneae	C4	N	20	G	F
Sporobolus centrifugus	Chloridoideae	C4	N	8	G	F
Trachypogon spicatus	Andropogoneae	C4	N	7	NG	F

Table 1: Representative pasture species within the 30 plots with frequency between 5-22; N=native, E=endemic, I=likely introduced; NG=non-grazed, G=grazed; F=associated to fire, Gr=associated to grazing, Int: intermediate

Baseline pasture quality assessment

Biomass productivity

The baseline pasture biomass shown in the table 3 shows that Ankafobe and Itremo pastures associated with annual fires produce lower biomass (1.6-2.9t/ha), while pasture burned every 3-4 years such as Ibity produce greater biomass (3.9-6.1t/ha). These values are quite similar to those reported from the Fianarantsoa Region with 2.53-3.30t/ha (Rakotoarimanana et al. 2007). Biomass productivity will be recorded periodically to understand the dynamic impact of fire and its frequency on biomass produced. Pasture productivity in Central highland of Madagascar is generally moderate, sufficient to feed livestock, however the forage value of constitutive species is still unknown and need to be quantified in the future.

Site	Grazed and burnt	Grazed only	Fire history
Ankafobe	2.4t/ ha	1.6t/ha	Annual fire, last fire 2021
Ibity	6.1t/ha	3.9t/ha	Fire frequency burnt: every 3-4 years Fire frequency unburnt: every 10 years
Itremo	2.67t/ha	2.9t/ha	Annual fire, last fire October 2021

Table 2: Baseline pasture biomass for the 3 sites related to their fire history

Grazing capacity baseline in the experimental site

In general, grazing capacity seems similar across the three sites, with one zebu of about 250kg needing 0.7 to 0.8 ha of pasture to meet its annual nutritional needs. These sites are also experiencing quite similar rainfall, as well as acidic soil with low nitrogen and phosphorus.

Conclusions

About a quarter of the Malagasy Poaceae species are found in the three projects sites: Ankafobe, Ibity and Itremo. Most species found in grassland pasture and appreciated by cattle livestock are associated with fire. Fire frequency plays a role in biomass productivity, with both annual fires and prolonged period with no fire leading to low biomass productivity, whereas fires every 3-4 years were associated with more biomass. Grazing capacity about 0.7-0.8ha/zebu/year is moderate for cattle livestock in Central Madagascar. Acidic soil and low levels of nitrogen and phosphorus are related to an overall poor quality of pastoral resources. Increasing the abundance of species suitable for grazing by reducing fires from annual to every 3-4 years could improve pasture condition. Manure remaining on the pasture during cattle grazing may not be enough to maintain a proactive soil pH. The overall area of grassland available in Madagascar is large, but accessible quality pasture associated with both water resource and good security is nevertheless difficult to find. Good management of accessible pasture using a rotational grazing method could help manage these pastures sustainably and increase productivity.

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