# Interrelatedness of Grazing Livestock with Vegetation Parameters and Farmers' Livelihoods in the Mahafaly Region, Southwestern Madagascar

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Ökologische Agrarwissenschaften
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**Interrelatedness of grazing livestock with vegetation parameters and farmers' livelihoods in the Mahafaly region, southwestern Madagascar**

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To my dogs –

to those that survived human cruelty on Madagascar and the many that did not. As they have often been the only creatures far and wide that seemed to listen AND to understand me.

And to Mahita –

who proved in a fatal way that *malasos* are more than just rumors.

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**Summary**

Despite its biological and cultural richness, Madagascar is among the world's poorest countries. A still rapidly growing population in conjunction with increasing poverty, lack of education, and an almost chronic misgovernment and corruption implicate an ongoing exploitation of the island's natural resources and land cover change. Agriculture, mostly subsistence-oriented, is still the mainstay of the national economy. Livestock, and in particular cattle, thereby plays a significant economic, cultural, and social role for local communities – especially in the dry South and Southwest where until today agropastoral groups keep large herds of extensively farmed zebu cattle and small ruminants.

The region is one of the island's economically and climatically most disadvantaged, suffering from low rainfall with high interannual variability. Livestock farmers therefore have to face several constraints such as seasonal water and forage shortage, but also epizootic diseases and an enhancing number of violent conflicts related to livestock raiding, reflecting the country's ongoing political and economic crisis. At the same time, the importance of animals as symbol of wealth and prestige still leads to the widespread belief that livestock keeping contributes little to food security or other livelihoods of the rural population while posing a serious threat to the region's environment. Against this background, the present study aims to get deeper insight into the highly extensive system of animal husbandry in the Mahafaly region of southwestern Madagascar. It tries to understand the major drivers for pastoral dynamics, land and resource use along a gradient in altitude and vegetation to consider the area's high spatial and temporal heterogeneity. The study also analyzes the reproductive performance of local livestock as well as the owners' culling strategies to determine herd dynamics, opportunities for economic growth, and future potential for rural development.

To investigate seasonal variations in movement and land use patterns of local livestock herds, individual cattle and goats from four villages, equally distributed within the region's coastal zone and inland plateau, were fitted with GPS tracking collars and their behavior during pasturing was observed. Across seasons, plateau herds from both livestock species covered longer distances (cattle 13.6±3.02 km, goats 12.3±3.48 km) and were found further away from the settlements (cattle 3.1±0.96 km, goats 2.8±0.98 km) than those from the coastal plain (*walking_dist*:

cattle 9.5±3.25 km, goats 9.2±2.57 km; *max_dist*: cattle 2.6±1.28 km, goats 1.8±0.61 km). Transhumant cattle were detected more vulnerable through limited access to pasture land and water resources compared to local herds. Significant differences in land use reflected the spatial occurrence of specific land cover classes around the villages. Seasonal water shortage has been confirmed as a key constraint on the plateau while livestock keeping along the coast is more limited by dry season forage availability. However, recent security issues and land use conflicts with local crop farmers are gaining importance and force livestock owners to adapt their traditional grazing management, resulting in spatio-temporal variation of livestock numbers and in the impending risk of local overgrazing and degradation of rangelands.

In order to determine the preference of livestock for specific plant species as well as the nutritional quality of natural rangeland vegetation, the feeding behavior of local cattle and small ruminants was observed and important forage plants as well as fecal samples were analyzed for nutrient concentration and diet digestibility. Among the 133 plant species consumed by livestock, 13 were determined of major importance for the animals' nutrition. While cattle largely relied on grasses as the principal component of their diet, small ruminants had a stronger preference for ligneous vegetation. The nutritive value and digestibility of the natural forage, as well as its abundance in the coastal zone, substantially decreased over the course of the dry season and emphasized the importance of supplementary forage plants, in particular *Euphorbia stenoclada*. At the same time, an unsustainable utilization and overexploitation of its wild stocks may raise the pressure on the vegetation and pasture resources within the nearby Tsimanampetsotsa National Park.

Finally, progeny history interviews with livestock breeders from six villages were conducted to analyze the productivity of local cattle and goat herds. Age at first parturition was 40.5±0.59 months for cattle and 21.3±0.63 months for goats. Both species showed long parturition intervals (cattle 24.1±0.48 months, goats 12.4±0.30 months), mostly due to the maintenance of poorly performing breeding females within the herds. Reported offspring mortality, however, was low with 2.5% of cattle and 18.8% of goats dying before reaching maturity. At the same time, economic information was used to estimate annual revenues from livestock keeping. It revealed higher than expected market dynamics, especially for zebus, resulting in annual contribution margins of 33 € per cattle unit and 11 € per goat unit. The application of the PRY Herd Life model to simulate herd development for present management and two alternate scenarios confirmed the economic profitability of the current livestock system and showed potential for further productive and economic development. However, this might be clearly limited by the region’s restricted carrying capacity.

Summarizing, this study illustrates the highly extensive and resources-driven character of the livestock system in the Mahafaly region, with herd mobility being a central element to cope with seasonal shortages in forage and water. But additional key drivers and external factors are gaining importance and increasingly affect migration decisions and grazing management. This leads to an increased risk of local overgrazing and overexploitation of natural pasture resources and intensifies the tension between pastoral and conservation interests. At the same time, it hampers the region’s agronomic development, which has not yet been fully exploited. The situation therefore demonstrates the need for practical improvement suggestions and implication measures, such as the systematic forestation of supplemental forage plant species in the coastal zone or a stronger integration of animal husbandry and crop production, to sustain the traditional livestock system without compromising peoples’ livelihoods while at the same time minimizing the pastoral impact on the area’s unique nature and environment.

## Zusammenfassung

Trotz seiner Vielfalt an natürlichen und kulturellen Ressourcen gehört Madagaskar bis heute zu den ärmsten Ländern der Welt. Eine stetig wachsende Bevölkerung in Verbindung mit steigender Armut, einem unzureichenden Bildungssystem sowie politischer Misswirtschaft und Korruption führen zu einer anhaltenden Ausbeutung von Naturschätzen sowie großflächigen Landnutzungsänderungen. Noch immer stellt die subsistenz-orientierte Landwirtschaft einen der wichtigsten Wirtschaftszweige des Landes dar. Der Besitz von Nutzieren und vor allem Rindern ist dabei von besonders großer wirtschaftlicher aber auch sozio-kultureller Bedeutung für die lokale Bevölkerung. Dies trifft vor allem auf den trockenen Süden und Südwesten der Insel zu, wo agropastorale Gruppen bis heute große Viehherden auf traditionell-extensive Weise halten.

Infolge geringer Niederschlagsmengen mit starken jährlichen Schwankungen gehört diese Region zu den klimatischen aber auch wirtschaftlichen Problemzonen des Landes. Nutztierhalter sehen sich dabei ebenfalls diversen Erschwernissen wie saisonaler Wasser- und Futterknappheit, Tierseuchen aber auch einer zunehmenden Zahl gewaltsamer Übergriffe in Zusammenhang mit organisiertem Viehdiebstahl ausgesetzt, welche die politische und wirtschaftliche Krise Madagaskars widerspiegeln. Gleichzeitig führt die Bedeutung der Nutztiere als Statussymbol in der Außenbetrachtung bis heute zu der weitverbreiteten Annahme, dass die Viehhaltung nur einen geringen Beitrag zur Ernährungssicherheit sowie zum weiteren Lebensunterhalt der Landbevölkerung beiträgt, sie dafür aber eine umso größere Bedrohung für die Natur darstellt. Vor diesem Hintergrund ist es das Ziel der vorliegenden Arbeit, einen tieferen Einblick in das extensive Tierhaltungssystem in der Mahafaly-Region im Südwesten Madagaskars zu gewähren. Unter Berücksichtigung der großen räumlichen und zeitlichen Heterogenität der Gegend werden dabei die treibenden Faktoren identifiziert, welche einen wesentlichen Einfluss auf die pastoralen Dynamiken sowie Ressourcen- und Landnutzungsentscheidungen ausüben. Darüber hinaus werden die Reproduktionsleistungen der beiden bedeutendsten Nutztierarten sowie Zuchtstrategien untersucht, um das wirtschaftliche Nutzungs- und zukünftige Entwicklungspotential der Tierhaltung in der Region zu ermitteln.

Für die Analyse saisonaler Fluktuationen in den Bewegungs- und Landnutzungsmustern örtlicher Rinder- und Ziegenherden wurden Tiere aus vier gleichmäßig zwischen

dem Küstenstreifen sowie dem Inlandplateau der Untersuchungsregion verteilten Dörfern mit GPS-Halsbändern ausgestattet und ihre Aktivitätsmuster beobachtet. Im Jahresdurchschnitt legten Plateauherden beider Nutztierarten längere Tagesdistanzen (Rinder 13,6±3.02 km, Ziegen 12,3±3.48 km) und Maximalentfernungen zu den heimischen Siedlungen zurück (Rinder 3,1±0,96 km, Ziegen 2,8±0,98 km) als Herden von der Küste (*Tagesdistanz*: Rinder 9,5±3,25 km, Ziegen 9,2±2,57 km; *Maximaldistanz*: Rinder 2,6±1,28 km, Ziegen 1,8±0,61 km). Rinderherden auf Transhumanz nahmen eine Sonderstellung ein. Ihr Zugang zu Weide- und Wasserreserven erschien gegenüber lokalen Herden eingeschränkt zu sein, was sich im direkten Vergleich in längeren täglichen Weiderouten äußerte. Der Einfluss saisonaler Wasserknappheit konnte als wesentliches Hemmnis für die Tierhaltung auf dem Plateau bestätigt werden, während das System in der Küstenregion eher durch die dortige Futterverfügbarkeit während der Trockenzeit limitiert ist. Allerdings gewinnen Sicherheitsaspekte sowie Landnutzungskonflikte mit örtlichen Ackerbauern zunehmend an Bedeutung und zwingen die Nutztierhalter zu einer Anpassung ihres traditionellen Weidemanagements. Dies wiederum hat eine räumliche und zeitliche Verschiebung der Besatzdichten zur Folge und könnte mit der Zeit verstärkt zu örtlichen Überweidungseffekten führen.

Des Weiteren wurde die Präferenz für bestimmte Futterpflanzen sowie der Nährwert der natürlichen Weidevegetation untersucht. Das Fressverhalten der Tiere wurde beobachtet und der Nährstoffgehalt sowie die Verdaulichkeit der Diät durch Analyse der wichtigsten Futterpflanzen und anhand von Kotproben bestimmt. 13 der insgesamt 133 Pflanzenarten, welchen von den Tieren gefressen wurden, waren für deren Ernährung von besonderer Bedeutung. Während Rinder vorranging Gräser konsumierten, fraßen kleine Wiederkäuer verstärkt an Gehölzen. Der Nährwert sowie die Verdaulichkeit der Futterpflanzen nahmen im Laufe der Trockenzeit erheblich ab; an der Küste traf dies auch auf die Abundanz der als Futtergrundlage zur Verfügung stehenden natürlichen Vegetation zu. In dieser Zeit des Jahres kommt der Nutzung bestimmter sukkulenter Futterpflanzen wie *Euphorbia stenoclada* eine wichtige Bedeutung zu. Allerdings weisen deren Bestände in der Region zunehmend Zeichen der Übernutzung auf. Hält die bisherige, wenig nahhaltige Verwendung an, könnte der Druck auf die natürlichen Vegetations- und Weideressourcen im nahegelegenen Tsimanampetsotsa Nationalpark weiter zunehmen.

Abschließend wurden in sechs Dörfern Interviews mit Tierhaltern zur Quantifizierung reproduktiver Leistungsparameter einheimischer Rinder und Ziegen durchgeführt. Das ermittelte Erstwurfalter betrug für Rinder 40,5±0,59 und für Ziegen 21,3±0,63 Monate. Beide Arten wiesen hohe Zwischenwurfzeiten auf (24,1±0,48 Monate bei Rindern und 12,4±0,30 Monate bei Ziegen), was als Folge des weitgehenden Verbleibs von Muttertieren mit schwacher Reproduktionsleistung in den Herden zu sehen ist. Die von den Herdenbesitzern angegebenen Sterblichkeitsraten der Nachkommen vor Erreichen der Geschlechtsreife waren dagegen gering; sie betrug bei Rindern 2,5 % und bei Ziegen 18,8 %. Zusätzlich zu den Reproduktionsleistungen wurden ökonomische Daten zur Berechnung jährlicher Einnahmen durch die Nutztierhaltung erhoben. Hierbei zeigten sich insbesondere bei den Zebus höhere Marktdynamiken als erwartet. Der jährlich Deckungsbeitrag pro Nutztiereinheit lag für Rinder bei 33 € und für Ziegen bei 11 €. Mit Hilfe des PRY-Herdenmodells wurde die durchschnittliche Herdenproduktivität unter aktuellem Management quantifiziert sowie für zwei verbesserte Haltungsszenarien simuliert. Die wirtschaftliche Rentabilität des derzeitigen Viehhaltungssystems wurde dabei bestätigt. Es weist zudem noch erhebliches Entwicklungspotential auf, welches jedoch durch die begrenzte natürliche Tragfähigkeit der Region beschränkt sein dürfte.

Die vorliegende Studie veranschaulicht zusammenfassend den extensiven und ressourcengesteuerten Charakter der Nutztierhaltung in der Mahafaly-Region und stellt die besondere Bedeutung der Herdenmobilität als Bewältigungsstrategie im Umgang mit saisonaler Futter- und Wasserknappheit heraus. Gleichzeitig verdeutlichen die Ergebnisse den zunehmenden Einfluss externer Faktoren auf pastorale Entscheidungsprozesse. Diese erhöhen örtlich das Risiko von Überweidung und Übernutzung natürlicher Ressourcen und verstärken die Spannungen zwischen Tierhaltungs- und Naturschutzinteressen. Gleichzeitig belasten sie das vorhandene landwirtschaftliche Entwicklungspotential, welches für die Region bislang bei weitem noch nicht ausgeschöpft ist. Konkrete Handlungsempfehlungen und Maßnahmen wie die systematische Anpflanzung von Futterpflanzen in der Küstenregion oder eine stärkere Vernetzung von Tierhaltung und Ackerbau erscheinen daher erforderlich, um die traditionelle Viehwirtschaft als Lebensgrundlage der lokalen Bevölkerung zu bewahren und gleichzeitig negative Auswirkungen auf die einzigartige Natur und Umwelt in der Region zu begrenzen.

**Résumé**

En dépit de sa richesse biologique et culturelle, Madagascar figure parmi les pays les plus pauvres du monde. L'accroissement rapide de la population, couplée avec l'augmentation de la pauvreté, le manque d'éducation, et l'ingérence presque chronique et la corruption ont conduit à la surexploitation actuelle des ressources naturelles de l'île et aux changements des couvertures du sol. L'agriculture, principalement orientée à la subsistance, demeure encore le pilier de l'économie nationale. Le bétail, notamment les bovins, joue ainsi un rôle économique, culturel et social important pour les communautés locales, plus particulièrement dans la région aride du sud et sud-ouest de Madagascar où, jusqu'à maintenant des populations agropastorales exercent encore des élevages extensives de grands troupeaux de zébus et des petits ruminants.

Economiquement et climatiquement, la région est l'une des plus démunies de l'île, souffrant de manque de pluie avec une forte variabilité interannuelle. Les éleveurs doivent donc faire face à plusieurs contraintes telles que la pénurie d'eau et de fourrage saisonnière, mais aussi les maladies épizootiques et à l'accroissement de violence liée au vol de bétail, reflétant la crise politique et économique actuelle du pays. En même temps, l'importance des animaux comme symbole de richesse et de prestige mène à croire que l'élevage contribue faiblement à la sécurité alimentaire ou aux moyens de subsistance de la population rurale, tout en étant une menace sérieuse pour l'environnement de la région. Dans ce contexte, la présente étude vise à obtenir un aperçu plus approfondi du système d'élevage extensif utilisé dans la région Mahafaly, dans le sud-ouest de Madagascar. Ce travail essaye de comprendre les principaux facteurs conduisant à la dynamique, l'utilisation des terres et des ressources pastorales suivant un gradient altitudinal et de la végétation afin d'identifier les régions à forte hétérogénéité spatiale et temporelle. Ensuite, nous analysons également les performances de reproduction de bétail local, ainsi que les stratégies d'abattage des propriétaires afin de déterminer la dynamique des troupeaux, des opportunités de croissance économique, et un potentiel futur pour le développement rural.

Pour étudier la variation saisonnière du mouvement et du schéma de l'utilisation des terres par les troupeaux locaux, des zébus et de chèvres individuels issus de quatre villages, répartis à part égale entre le littoral et le plateau, ont été équipés de colliers de repérage par GPS, et leur comportement sur pâturage a été observée. À travers les saisons, les troupeaux des deux espèces de bétail du plateau ont parcouru de plus longues distances (bovins 13,6±3,02 km, chèvres 12,3±3,48 km) et ont été trouvés plus loin des colonies (bovins 3,1±0,96 km, chèvres 2,8±0,98 km) que ceux du littoral (*distance de marche* : bovins 9,5±3,25 km, chèvres 9,2±2,57 km; *dist_max*: bovins 2,6±1,28 km, chèvres 1,8±0,61 km). Les troupeaux transhumants ont été détectés plus vulnérables par rapport aux troupeaux locaux, à cause de leur accès limité en ressources, telles que les zones de pâturage et l'eau. Les différences significatives notées sur le système d'utilisation des terres reflétaient l'occurrence spatiale de la présence des classes spécifiques de couverture du sol autour des villages et la variation saisonnière en disponibilité des plantes fourragères. La pénurie d'eau saisonnière a été confirmée comme une contrainte majeure sur le plateau, tandis que l'élevage du bétail dans le littoral est surtout limité par la disponibilité des fourrages pendant la saison sèche. Toutefois, les questions de sécurité récentes et les conflits sur l'utilisation des terres avec les agriculteurs locaux ont pris de l'importance, et forçant ainsi les propriétaires de bétail à adapter leur gestion de pâturage traditionnelle, résultant à une variation spatio-temporelle du nombre de cheptel et du risque imminent de surpâturage local et de la dégradation des pâturages.

Afin de déterminer la préférence du bétail pour les espèces végétales spécifiques, ainsi que la valeur fourragère de la végétation des pâturages, le comportement alimentaire des bovins et des petits ruminants a été observé. Les échantillons de plantes fourragères importantes, et ceux des matières fécales ont été prélevés et analysés, afin de déterminer respectivement la concentration en éléments nutritifs et la digestibilité. Parmi les 133 espèces végétales consommées par les troupeaux observés, 13 ont été déterminés comme d'une importance majeure pour la nutrition des animaux. Tandis que les bovins préféraient largement les herbes comme composante principale de leur alimentation, les petits ruminants ont eu une forte préférence pour les plantes ligneuses. La valeur nutritive et la digestibilité de fourrage, ainsi que leur abondance dans le littoral ont sensiblement diminué au cours de la saison sèche, soulignant ainsi l'importance des plantes fourragères supplémentaires, en particulier l'*Euphorbia stenoclada*. En même temps, l'utilisation non durable et la surexploitation des stocks sauvages peuvent augmenter la pression sur la végétation et les ressources fourragères situées à proximité du Parc National de Tsimanampetsotsa.

Enfin, des entrevues sur l'histoire de la descendance de bétail avec les éleveurs, venant de six villages, ont été conduites pour analyser la productivité des bovins et celle de chèvres locales. L'âge au premier vêlage était de 40,5±0,59 mois pour les bovins et de 21,3±0,63 mois pour les chèvres. Les deux espèces de bétail ont montré un long intervalle de vêlage (bovins 24,1±0,48 mois, chèvres 12,4±0,30 mois), principalement à cause du maintien des femelles à fertilité faible au sein des troupeaux. Cependant, le taux de mortalité des progénitures était faible ; seulement 2,5% des bovins et 18,8% des chèvres meurent avant d'atteindre la maturité. En même temps, les informations financières ont été utilisées pour estimer les revenus annuels de l'élevage. Ces revenus s'avèrent être plus élevés que la dynamique du marché prévue, en particulier pour les zébus, résultant ainsi à des marges de cotisation annuelle de 33€ par unité de bovin et 11€ par unité de chèvre. L'application du modèle de survie des troupeaux 'PRY' pour simuler la croissance des troupeaux représentant la gestion actuelle et celle des deux scénarios alternatives, a confirmé la rentabilité économique du système d'élevage actuel et a également montré un potentiel pour un développement ultérieur en termes de production et d'économie. Toutefois, ceci pourrait être nettement limité par la capacité de charge restreinte de la région.

En résumé, cette étude illustre le caractère très extensif et axé sur des ressources naturelles du système d'élevage dans la région Mahafaly. La mobilité des troupeaux constitue l'élément central de stratégie pour faire face à des pénuries d'eau et de fourrage saisonnières, mais les facteurs-clefs supplémentaires et les facteurs externes gagnent de l'importance et influencent de plus en plus les décisions sur la migration et la gestion des pâturages. Cela conduit à un risque accru de surpâturage, à une surexploitation des ressources fourragères locales, et à l'intensification des tensions entre les intérêts pastoraux et de la conservation naturelle. A la même occasion, cela entrave le développement agronomique de la région, qui n'a pas encore été entièrement exploité.

**Famintinana**

Na dia manan-karena biolojika sy ara-kolontsaina maro aza i Madagasikara, dia anisan'ireo firenena izay mahantra indrindra eran-tany. Ny fitomboan'ny mponina haingana ampian’ny fahantrana sy ny tsy fahampian’ny fampianarana, sy ny tsy fahaiza-mitantana ary ny kolikoly no nampirongatra ny fitrandrahana mihopampana ireo harena voajanahary sy ny fiovan’ny firafitry ny ala. Ny fambolena, izay miompana indrindra amin’ny fivelomana, no mbola fototry ny toe-karem-pirenena. Ny biby fiompy, fa indrindra ny omby, dia manan-danja tokoa ara-toekarena, ara-kolontsaina, sy ara-tsosialy ho an'ny mponina ambanivohitra, fa indrindra any amin'ny faritra maina any atsimo sy atsimo-andrefan’ny nosy, izay mbola ahitana mandrak’androany ireo vondrom-piompy izay mbola mampihatra ny fiompiana nentim-paharazana.

Ny faritra atsimo dia iray amin'ireo faritra sahirana indrindra ao Madagasikara, na ara-toe-karena izany na ara-toetr’andro, vokatrin’ny tsy fampiany rotsakorana izay be fiovaovana isan-taona. Vokatra ireo dia voatery tsy maintsy miatrika fijaliana maro ireo mpiompy, toy ny vanim-potoana tsy fisian’ny rano, ny tsy fahampian’ny sakafom-biby, fa koa ireo valan’aretina maro sy ny fitomboan’ny herisetra izay mifandray amin’ny halatr’omby, izay fitaratrin’ny krizy ara-politika sy ara-toekarena hiainan’ny firenena amin’izao fotoana izao.

Marihina fa ny fiompiana omby dia manana ny ajarany lehibe ao amin’ny famaritana ny toerana ara-piaraha monina (marika ny fananan-karena sy voninahitra), mifanohitra amin’izany anefa ny olana ateraky ny fiompiana omby amin’ny fiarovana ny ala.

Mifandraika amin’izany foto-kevitra izany, ity fikarohana ity izay mifantoka indrindra amin’ny fandalinana misimisy kokoa ny fomba fiompiana any amin’ny faritra Mahafaly any atsimo-andrefan'i Madagasikara. Ity asa ity dia miezaka ny hahatakatra ny fifandraisana eo amin’ny fampiarasana ny hareana voajanahary sy ny fitatanana maharitra ny fampiasan-tany amin’ny resaka fiompiana ny biby fiompy.Ity fikarohana ity dia manadihady ihany koa ny anjara-toeran’ny fiompian’omby eo amin’ny fivoharan’ny toe-karena, ary fahafahana mampandroso ny faritra ambanivohitra.

Mba hafantarana ny fiovaovan’ny vanim-potoana fivezivezen’ireo biby fiompy, ary ny fomba fampiasaina ny tany, ny omby sy osy tsirairay avy amin’ny tanàna efatra,

izay nozaraina mitovy amin'ny faritra amoron-tsiraka sy ivo tany , dia nopetahana rojo hahafahana manara-maso ny diany sy ny fomba fihetsiny mandritra ny fotoana hisakafoanany ireo biby notsongaina. Nandritry ny taona, ny biby fiompy avy eny amin'ny tany avo dia hita fa nandeha nisinisy kokoa (omby 13,6±3,02 km, osy 12.3±3,48 km) ary niala ny toerana fiaviany lavidavitra kokoa (omby 3.1±0,96 km, osy 2.8±0,98 km), raha oharina amin'ireo avy any amin'ny lemaka amoron-tsiraka (*refy_fandehanana*: omby 9.5±3,25 km, osy 9.2±2,57 km, *refy_lavitra indrindra*: omby 2.6±1,28 km, osy 1,8±0,61 km). Ireo biby fiompy mpifindra toerana dia hita fa marefo kokoa noho ireo avy eo an-toerana, vokatry ny tsy fahampian'ny rano sy tany fisakafoanan'omby. Ireo fisamihafana tsapa tamin'ny ireo fomba fampiasana ny tany dia mampiseho ny fisian'ny karazana rakotry ny tany manokana manodidina ireo tanàna. Ny vanim-potoana tsy fahampian-drano dia voamarika ho toy ny sakany lehibe indrindra ho an'ny fiompiana eny amin'ny tany avo, raha toa ka ny tsy fahampian'ny sakafom-biby fiompy no mibahan-toerana eny amoron-tsiraka mandritra ny maintany. Na dia izany aza, ny resaka tsy fandriam-pahalemana tatoato sy ny ady mikasika ny fampiasana ny tany misy amin'ireo mpiompy sy mpamboly dia nahay nahazo vahana. Araka izany dia voatery tsy maintsy nanova ny fomba fitantanana nentin-paharazana ireo faritra fisakafoanany omby ireo tompon'omby. Taty afara, ity farany dia niteraka ny fiovaovan'ny isam-biby fiompy isam-paritra sy isam-potoana, ary koa nitera-doza mitatao amin'ny mety hisiany fampiasana mihoa-pefy sy fahasimbany ireo faritra fisakafoanan'omby eny an-toerana.

Mba hahafantarana ireo karazan-javamaniry tena ankafiziny ireo biby fiompy ary ny kalitaony otri-kainan'ireo zava-maniry, dia narahina maso ny fomba fisakafoanan'ireo omby sy ireo biby kely fiompy mandinika hafa. Ny santionan-javamaniry tena manan-danja sy ny taim-biby dia nohadihadiana, mba hamantarana ny habeny otrikaina sy ny fandevonany ireo biby ireo zavamaniry ireo. Tamin'ireo 133 karazan-javamaniry izay hoanin'ireo biby fiompy, ny 13 dia voamarina fa manan-danja tokoa amin'ny sakafon'ireo biby. Raha toa ka hita ny omby fa mihinana ahitra maitso amin'ny ankapobeny, ireo biby fiompy kely mandinika kosa dia mankafy ireo zavamaniry mandady. Ny lanjany otri-kaina sy ny fandevonana, ary koa ny habetsahan'ireo sakafom-biby eny amin'ny faritra amoron-tsiraka, dia hita fa nisy fihenany nandritra ny maintany, izay nanamafy ny maha zava-dehibe ireo sakafon'omby fanampiny, fa indrindra ny *Euphorbia stenoclada*. Mandritra izany fotoana izany, ny fampiasana tsy maharitra ary mihoa-pefy ireo tahirin-tsakafo eny ifotony dia mety hampiakatra ny tsindry eo amin'ny zavamaniry sy ny sakafon-biby manodidina ny ala fadin'ny Tsimanampetsotsa.

Farany, ny resaka nifanaovana tamin'ny mpiompy avy amin'ny tanàna enina mikasika ny tantarany fiterahan'ireo biby fiompy, dia natao mba hahafantarana ny vokam-piterahan'ireo omby sy osy any an-toerana. Ny fiterahana voalohany dia 40,5±0,59 volana ho an'ny omby, ary 21,3±0,63 volana kosa ho an'ny osy. Misy elanelana be mampisaraka ny fotoam-piterahan'ireo biby fiompy roa ireo (omby 24,1±0,48 volana, osy 12,4±0.30 volana), vokatry ny tsy fikarakarana ireo omby sy osy vavy tsy matanjaka ao anatin'ny andian'omby. Fa na dia izany, ny lanjam-pahafatesan'ireo zanak'omby sy osy dia hita fa ambany. Eo amin'ny 2,5% ny omby sy 18.8% ny osy ihany no maty alohany fahalebeazan'izy ireo. Nandritra izany foto-ana izany, ireo tahirin-kevitra ara-bola dia nampiasaina mba haminavinana ny fidi-ram-bola avy amin'ny ny fiompiana isan-taona. Ity farany dia hita fa nihoatra lavitra ny fidiram-bola nieritreretina araka ny fiovaovany vidin'omby eny an-tsena, fa in-drindra ho an'ny omby, izay niteraka tahirim-bola manodidina ny 33 € isaky ny omby sy 11 € isaky ny osy isan-taona. Ny fampiharana ny modelin'ny fianana 'PRY', mba haminavinaina ny fitombony omby avy amin'ny fomba fitantanana ankehitriny, sy ny tranga fanampiny roa hafa, dia nanamarina ny tombotsoa ara-toekarena ateraky ny fomba fiompiana ankehitriny sy koa nampiseho ny maha zavadehibe azy amin'ny fampandrosoana amin'ny ho avy amin'ny resaka famokarana sy toe-karena. Na izany aza, ity dia mety ho voasakan'izay zavatra zakanny faritra.

Raha fintinina, ity fikarohana ity dia mampiseho ny fomba fiompy tena malalaka, sady miankina amin'ny zava-maniry any amin'ny faritra Mahafaly. Ny fampiovaovana ny toeranam-piraofan'ny biby fiompy dia azo lazaina ho teti-kevitra hiadiana amin'ny fiovaovan'ny vanim-potoana tsy fisiany orana sy sakafom-biby, fa ireo antony fan-ampiny sy ireo avy ireo antony maro hafa dia mahay mahazo vahana ary manery ankolaka ny fanapahan-kevitra amin'ny famindrana biby sy ny fitantanana ireo tany firaofan'omby. Izany dia nitarika ny fahamaroan'ireo omby tafaohoatra mitrandraka ny teora-mpihinanan'omby, sy ny fampiasana miompampana ny harena voajanaha-rin'ireo toera-mpihinanan'omby ao an-toerana, ny fitomboan'ny ady anivon'ireo mpi-ompy sy ny mpiaro ny harena voajanahary. Izany dia mampihena sy manakana ny fivelaran'ny teo-karen'ny faritra, izay mbola tsy tena voatrandraka tanteraka. Noho izany ny toe-javatra miseho izany dia ilaina ny manolotra soso-kevitra arahin'asa, toy ny fanatsarana ny tany firaofan'omby sy osay amin'ny alalan'ny fambolena ireo karazan-kazo hafa fihinan'omby amin'ny faritra amon-tsiraka, na koa ny fanatsarana ny fampiarahana ny fiompiana sy fambolena mba hanohanana ny fimpioana nentimpaharazana, fa kosa tsy manenlingelina ny fiveloman'ireo mponina ao an-toerana, ary manena ny fiantraikan'ireo fiompiam-biby eo amin'ny tontolo tokan'ny faritra.

# Chapter 1

## General Introduction and Research Objectives

## 1.1 General background

### 1.1.1 Rangeland dynamics and the role of pastoral mobility

Rangelands, including grasslands, shrublands, savannas, and tundra, sustain large numbers of livestock and are home to more wild grazers and browsers than are other environmental regions in the world (Allen-Diaz, 1996). Serving as natural pastures, they represent 24% of the global land area and are an irreplaceable source of livelihoods for the rural poor, directly supporting 200 million households and 50% of the world's livestock population (Batello et al., 2011). In arid and semi-arid regions, where pastoral and agropastoral farming practices are considered the most suitable way of adaption to the challenging environmental conditions (Neely et al., 2010), pastoral lifestyles are by now valued more compatible in preserving rangeland integrity compared to other types of land use (Suttie et al., 2005). However, the risk of losing key grazing areas due to degradation or the increasing competition for land resources among different actors has become a major pressure point for the survival of traditional pastoral herding practices and livelihoods (Kideghesho et al., 2013; Oba, 2013).

Today, about 73% of rangelands worldwide are estimated to be affected by soil degradation and desertification (UNCCD, 2009), with unsustainable grazing management, fire, and land-conversion specified as important drivers (Dodd, 1994; Suttie et al., 2005). Pastoralists have for a long time been considered largely responsible for this development. They were accused of destabilizing otherwise stable (or equilibrium) ecosystems by overstocking and overgrazing as a consequence of poor herd management and the keeping of more livestock than actually needed for the purpose of prestige (Lamprey, 1983; Sinclaire and Fryxell, 1985). In the sequel, this perspective on biotic feedbacks has been overtaken by concepts supporting a non-equilibrium approach lesser focusing on carrying capacities (Ellis and Swift, 1988; Westoby et al., 1989). Instead it stressed the influence of abiotic factors, notably the spatial and temporal variability in rainfall, on rangeland dynamics in arid and semi-arid environments and assumed them to have a greater impact on the system's productivity than grazing alone (Behnke et al., 1993; Ellis and Galvin, 1994). Nevertheless, disagreements between these two hypotheses persist (Vetter, 2005). Nowadays, many researchers indicate that most rangeland ecosystems in dry regions feature elements of both, the equilibrium and non-equilibrium concept, and therefore support management recommendations taking into account spatial and temporal heterogeneity (Briske et al., 2003; Illius and O'Connor, 1999) but also promote alternative investment strategies and sustainable economic diversification (Desta and Coppock, 2002).

Regardless of this scientific controversy, pastoral livestock keepers have developed their own strategies to cope with spatio-temporal variability. In particular herd mobility and seasonal migration in terms of nomadic movements or transhumance are crucial elements for the efficient management of fluctuating forage and water availability as a result of highly seasonal precipitation (Behnke et al., 2011; Fernández-Gimenez and Le Febre, 2006). It is thought to increase the number of livestock that can sustainably graze an area without putting continuous pressure on the natural resources throughout the year. At the same time, it allows grazed vegetation to recover and reduces erosion from trampling and overgrazing (Hiernaux and Turner, 1996). Herd mobility therefore is seen as a key element for pastoral livelihoods (Niamir-Fuller, 1999; Turner et al., 2014) and as a critical factor affecting the ecological and economic resilience of livestock production systems (Turner, 1999b). In recent decades, however, external stresses such as land grabbing (Galaty, 2013), restraints in cross-border migrations (International Crisis Group, 2014), national sedentarization policies (Liao et al., 2014), insecurity and banditry (Schilling et al., 2012), but also the increasing conversion of productive grazing areas to cropland (Desta and Coppock, 2002; Fernández-Gimenez and Le Febre, 2006) as well as to protected reserves and parks (Butt, 2012; McCabe, 2003; Turner, 1999a) have caused constraints to pastoral mobility in many parts of the world and formed a source of various conflicts. At the same time, restricted mobility and the confined access or consequent absence of key resource areas has increased the risk of rangeland degradation through concentrating greater numbers of livestock on limited land, leading to an enhanced pressure on the remaining natural forage resources (Fernández-Gimenez and Le Febre, 2006; Illius and O'Connor, 1999). These developments are estimated to become even more serious threats for the livelihoods of pastoral people in the future in the light of rising demographic pressure and the projected effects of climate change resulting in higher climatic variability and lower predictability (Ericksen et al., 2013; Thornton et al., 2009).

### 1.1.2 The contribution of livestock to smallholder farmers' livelihoods

Throughout the world, the keeping of livestock makes a substantial contribution to smallholder livelihoods and poverty reduction (Roland-Holst and Otte, 2006). Being one of the fastest growing agricultural sub-sectors, it accounts for about 30% of the agricultural gross domestic product (GDP) in the developing world and for about 40% of the global GDP (Swanepoel et al., 2010). In sub-Saharan Africa, about 60% of the poor are dependent on livestock (Thornton et al., 2002). At the same time, however, many countries in that region do not take full advantage of the poverty reduction opportunities as livestock production largely remains behind the demand for food and other products of animal origin (Pica-Ciamarra et al., 2007).

Domestic animals thereby provide a variety of livelihood services to rural households, both monetary and non-monetary ones (Upton, 2004; Weiler et al., 2014). Following Sandford and Ashley (2010), nine major motivations to keep livestock can be distinguished: (1) livestock may contribute significantly to household cash income, partially depending on wealth and market orientation (Otte et al., 2012) as well as on the level of diversification and presence of alternative income sources (Little et al., 2008). (2) Livestock generate a regular supply of animal source food and provide an important supplement and alternation to staple plant-based diets (Randolph et al., 2007). However, it makes only a minor contribution to overall food intake for poor farmers who rather tend to sell their animals to buy cheaper sources of calories (Pica-Ciamarra et al., 2011). In pastoral societies, livestock is often accumulated for (3) savings and (4) insurance purposes. The animals therefore serve as capital reserve and buffer stock for times of need (Kosgey et al., 2008; McPeak, 2005), although these accumulation strategies are not always considered effective to ensure farmers' livelihoods (Fafchamps et al., 1998). (5) In many smallholder farming systems, the application of composted livestock dung as natural fertilizer for growing crops remains an important component of soil fertility strategies (Harris, 2002; Liu et al., 2010). (6) Larger livestock species provide draught and hauling power. By helping to plough or weed arable land and to transport goods and people, they reduce human workload and increase land and labor productivity (Barrett, 1992; Powell et al., 2004). (7) While grazing livestock in open access or collectively held rangelands, pastoralists and agropastoralists gain access to scarce rangeland resources by moving their herds in response to changes in pasture availability. Therefore, livestock keeping enables the productive use of large areas of communal land, which for instance in sub-Saharan Africa constitutes nearly half of the land surface (Pica-Ciamarra et al., 2011). Finally, livestock serves as source of (8) prestige and wealth as well as (9) socio-cultural capital. Animals are thereby needed, amongst other things, as payment of dowry or to settle funeral expenses (Schilling et al., 2012); they play a vital role in conflict management (Turner et al., 2012) and are important components of social networks and ties for rural households (Niamir-Fuller and Turner, 1999).

Considering these strong connections between livestock keepers and their animals, their integrity is crucial for the well-being of a substantial share of the world's pastoral and agropastoral societies. However, nowadays many of them face an increasing number of problems and challenges (Pica-Ciamarra et al., 2011; Swallow, 1994). They not only see themselves confronted with temporal variations in rainfall and recurrent livestock diseases, but also with unclear property and restricted access rights to pasture resources, violent conflicts in term of livestock raids, and poor access to markets in combination with high price fluctuations. Livestock keeping households therefore have to adopt production and risk management strategies including mobility and migration, asset accumulation, herd and income diversification, as well as migrant wage income to secure their livings (McPeak, 2005; Swallow, 1994). In addition, this development illustrates the need for policy and institutional reforms and measures as well as knowledge transfer for new technologies not only focusing exclusively on increased livestock production and productivity as well as improved market access, but also taking into account other than pure economic livelihood services provided by livestock (Pica-Ciamarra et al., 2007; Thornton et al., 2009). At the same time, such measures should respect pastoral traditions and habits and involve indigenous knowledge (Homann et al., 2008).

The pictured situation applies for many pastoral and agropastoral societies all over the world. But Africa, which is home to estimated 268 million pastoralists and agropastoralists, living on about 43% of the continent's total land mass and most of them south of the Sahara (African Union, 2010; Swallow, 1994), has always been in a particular focus of scientific investigation regarding the connections between livestock and smallholder livelihoods as well as the interdependencies between livestock and environment. Most research has been conducted on the African continent itself, whereas comparatively few studies were so far dealing with the practice and impact of pastoralism on the island of Madagascar (Kaufmann, 1998; Klein et al., 2008; Wüstefeld, 2004), disregarding the important role of livestock within the Malagasy society and the manifold conflicts between pastoral farmers and other interest groups.

## 1.2 Madagascar

### 1.2.1 Political and environmental degradation

Madagascar, the world's fourth-largest island, is still considered a desired destination for travelers and nature enthusiasts due to its high endemic biodiversity in both, animals and plants (Goodman and Benstead, 2003), but also its human population being a unique product of historical migrations from Africa, the Arab region, southeast Asia, and Polynesia (Cox et al., 2012). However, despite its biological and cultural richness the country is amongst the world's poorest nations with more than 80% of its population living below the poverty line on less than 1.25 $ a day (World Bank, 2015a). The situation even aggravated in recent years as a result of ongoing political and economic instability – especially since the political crisis in 2009 when many international donors redrew their support, leading to a decline in foreign aid of 40% (Ploch and Cook, 2012; WFP and UNICEF, 2011). A new leadership, installed in early 2014, briefly brought new hope but so far failed to measure up to expectations (FAO and WFP, 2014).

This development is paralleled by an ongoing exploitation of the country's natural resources and land cover changes, especially in terms of deforestation, which generates additional environmental problems and is seen as a key contributor to species extinction and climate change (Harper et al., 2007). Over the last decades since gaining independence from French colonial rule in 1960, the rate of total forest loss and fragmentation on Madagascar has been tremendous (Harper et al., 2007; Pollini, 2007; Zinner et al., 2014), mainly caused by slash-and-burn agriculture, logging, the production of fuelwood and charcoal for cooking, but also the expansion of pastureland (Casse et al., 2004; Elmqvist et al., 2007; Sussmann et al., 1994). Nature is therefore paying tribute to a still rapidly growing population which has increased by about 360% within the last 50 years (World Bank, 2015b) and to the country's almost chronic misgovernment and corruption (Randriamalala and Liu, 2010; Zinner et al., 2014). As a consequence, Madagascar has been identified in recent times a threatened biodiversity hotspot and focal point for global conservation action (Myers et al., 2000). In answer to the continuing degradation of the environment, a multi-stage National Environmental Action Plan (NEAP) was launched in 1991, lasting until 2008, with the objective to extensively expand the total area of national parks and nature reserves while at the same time transferring management authority to local communities. It was supposed, in this way, to balance the increasing tension between environmental protection and development targets in terms of poverty alleviation and preservation of rural livelihoods (Quesne and Razafindralambo, 2012; Razafindralambo and Gaylord, 2006). From a present point of view, however, these intentions seem to have largely failed (Kaufmann, 2006; Pollini, 2011). And in some places the recent conservation paradigm has even more intensified existing objections after further instituting exclusionary land from which local people are removed or where their access is restricted.

### 1.2.2 Agricultural system and livestock sector

The daily struggle to cover basic needs is still the main task in life for a considerable share of the Malagasy people. About 80% of the population lives in rural areas, where approximately 78% is engaged in agricultural activities (WFP and UNICEF, 2011). Thus agriculture, although primarily subsistence-oriented with most smallholder farmers owning less than 1.5 ha of land, is to date the main employment sector of the Malagasy economy, accounting for 26% of the national GDP in 2013 (World Bank, 2015b). At the same time, the country's agricultural performance since independence proved insufficient to cope with demographic pressure and contribute to a significant reduction of poverty, despite that natural farming conditions on Madagascar are considered relatively favorable compared to other African countries (Maret, 2007). Recurring periods of civil unrest and political uncertainties have furthermore disrupted the national economy and discouraged investment into agricultural development, and still the vast majority of rural households is economically undiversified and therefore particularly exposed to climatic variations and other external factors (Harvey et al., 2014; WFP and UNICEF, 2011).

Within the agricultural GDP of Madagascar, the livestock sector constitutes about 35% – with cattle, together with poultry, being the dominant species by contributing about 80% to total livestock units[1] (FAO and AGAL, 2005). Its population is estimated at 10 million heads whereby small ruminants play only a minor role at national level, with 2.3 million goats and sheep being mainly concentrated in the island's South and Southwest (FAOSTAT, 2014; Rasambainarivo and Ranaivoarivelo, 2006). Corresponding to total livestock numbers, beef is the most common meat product on Madagascar. Following a phase of stagnation since the 1990s and a strong decline in exports due to poor governmental marketing practices, insufficient slaughtering facilities, and inadequate veterinary services resulting in export embargos for example into the European Union (Maret, 2007), production numbers have increased again, and after loosening some of the export bans, reached about 170,000 tons in 2013 (FAOSTAT, 2014). Until today, intensive animal husbandry accounts only for a negligible share of Madagascar's livestock production. Instead, approximately 90% of cattle, goats, and sheep are still farmed in a largely extensive way by grazing on vast rangelands and permanent meadows that cover more than 64% of the country's land mass (FAOSTAT, 2014). About 72% of households in rural areas own livestock which is estimated the principal source of income for more than one quarter of the rural population (Ralison, 2003). But at the same time, animal production in Madagascar is partially limited because of traditional patterns of livestock ownership and customs that hamper commercialization (Maret, 2007). In particular cattle, besides its economic importance, plays a significant cultural and social role for local communities – especially in the dry South and Southwest where pastoral groups still keep large herds of zebu cattle and small ruminants. Being defined as a livelihood zone with a high percentage of the population reliant on livestock, this region is the country's most disadvantaged from an economic but also climatic point of view (WFP and UNICEF, 2011). Here, severe food insecurity is particularly widespread and further enhanced by unpredictable events such as droughts, cyclones, and crop destruction by locust infestations (FAO and WFP, 2013, 2014), already following a long regional history of subsequent famines and times of need (Wüstefeld, 2004). The region

[1] conversion factor: cattle (0.50), sheep and goats (0.10), pigs (0.20), and poultry (0.01) (FAO and AGAL, 2005)

therefore appears to require particular attention in development policy but also from a scientific perspective.

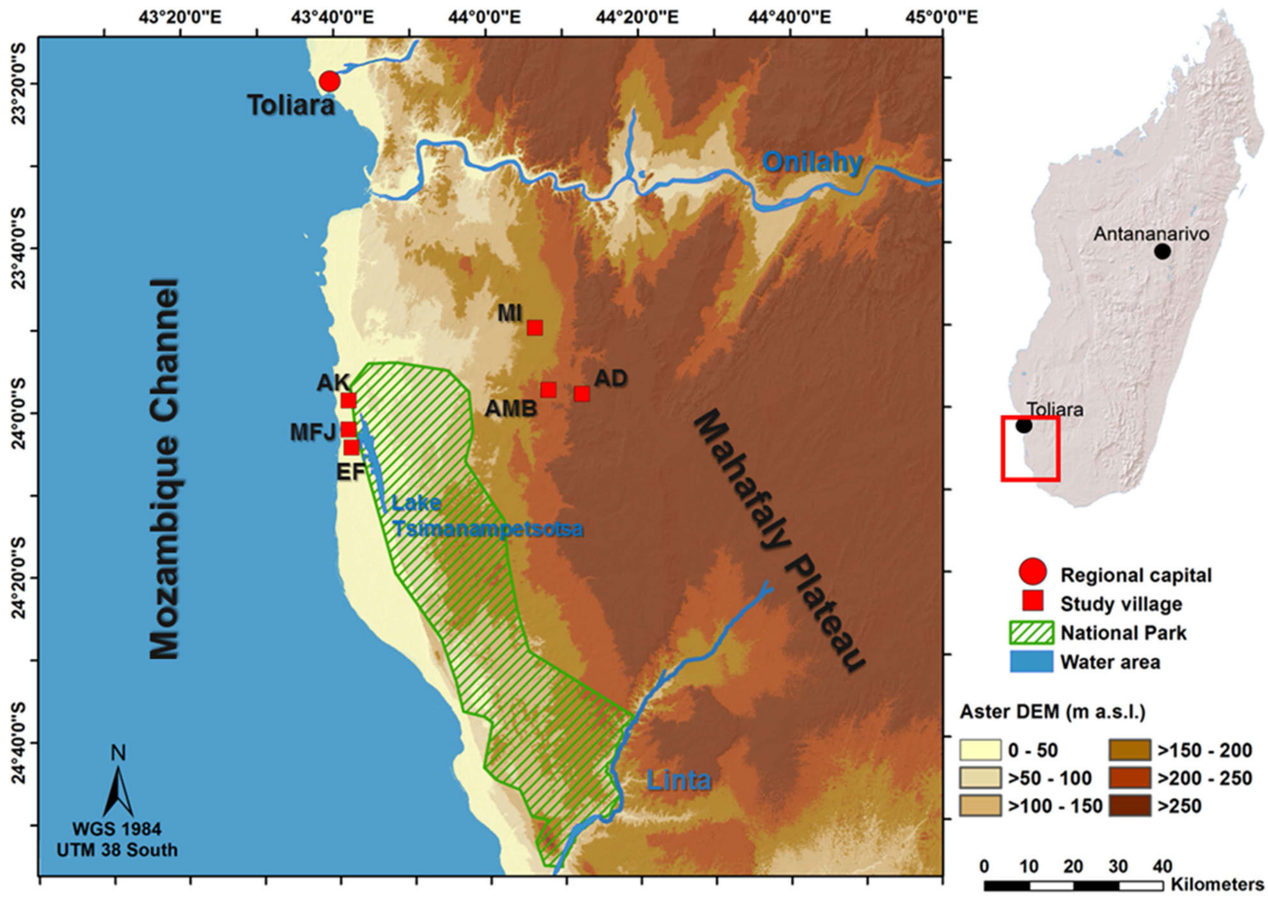


**Figure 1.1.** Elevation map of the study area with location of study villages: Ambory (AMB), Andremba (AD), Ankilibory (AK), Efoetse (EF), Marofijery (MFJ), Miarintsoa (MI). DEM = Digital Elevation Model, m a.s.l = meters above sea level.

## 1.3 The Mahafaly region

### 1.3.1 Climate

The present study was carried out in the northern range of the calcareous Mahafaly Plateau and its adjacent coastal plain in southwestern Madagascar (Figure 1.1). The area is located about 60 km south of the regional capital of Toliara, between the Onilahy and Linta River, and gently rises in altitude from the ocean up to about 350 meters above sea level (m a.s.l.) further inland. According to the Köppen-Geiger climate classification, it lies within a typical hot semi-arid zone (BSh; Peel et al., 2007), while the coastal strip already shows characteristics of arid hot desert climate (BWh). The area belongs to one of the driest regions in Madagascar (WFP and UNICEF, 2011), with an average annual temperature of 24°C and irregular precipitation of less than 500 mm per year (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protegées, 1999). Rainfall mainly occurs during the hot and wet season from December to March, commonly in the form of local convective storms, which also lead to high spatial variability (Rollin and Razafintsalama, 2001) and cause distinct contrasts between coastal zone and inland plateau (Figure 1.2).

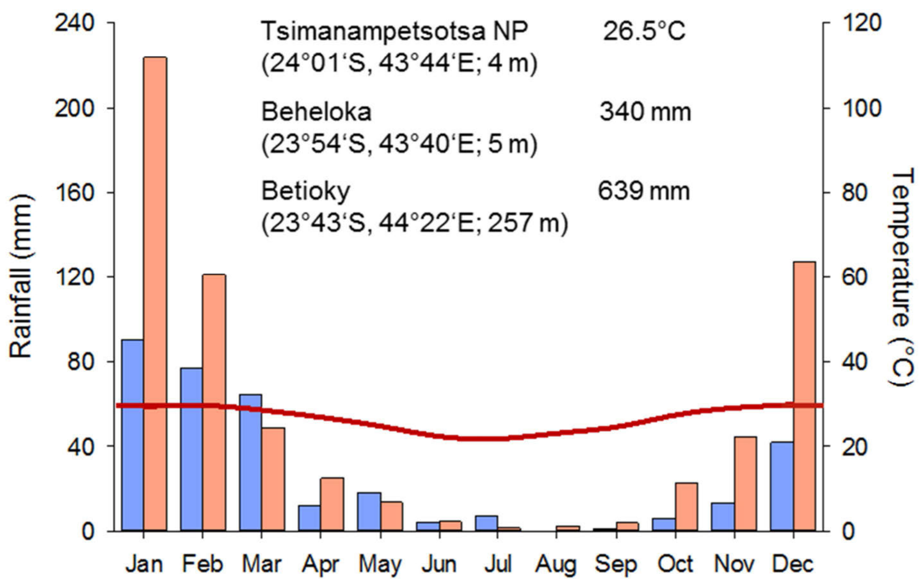


**Figure 1.2.** Aggregated climate diagram for the Mahafaly region, southwestern Madagascar. Monthly rainfall (mm) is shown for Beheloka (coastal plain; blue bars) and Betioky (plateau; red bars) during 20 year average (1995 – 2014; Centre National Antiacridien, Madagascar). Displayed values for both locations indicate total annual rainfall. Mean monthly temperatures (°C) are given for the Tsimanampetsotsa National Park (NP) research camp (red line) as determined during 2006 – 2014 (University of Hamburg, Germany). The displayed value shows the annual average. Elevation for all stations in meters above sea level (m a.s.l.).

### 1.3.2 Hydrogeology

The high seasonality and inter-annual variability of precipitation also reflects in the regular availability of drinking water. As the region lacks a permanent source of surface fresh water, apart from the two distant perennial streams in the North and South, its availability strongly depends on rainfall (Guyot, 2002). Substantial differences are thereby revealed between the coastal plain and the inland area, based on the particular geological and hydrological composition and structure of these two zones. Limited by the Mahafaly Plateau to the East and the Mozambique Channel to the West, the coastal strip forms a continuous band of 1.5 to 15 km width between the Onilahy and Linta River. It is made up by quaternary dunes of different generations with calcareous and sandstone sediments of sandy texture, resulting in a quick percolation of rain water (Guyot, 2002). However, due to a shallow groundwater table and the connection to subterranean aquifers originating further inland, potable water is easily accessible year-round through artificial wells or dug waterholes which are found frequently within and around the settlement areas (Dworak, 2014; Rasoloariniaina et al., 2015; Figure 1.3). Its disposability further improves during the wet season when temporary ponds may form after strong rainfalls within patches of clayey texture (Guyot, 2002). However, the overall water quality in this area is poor, featuring a high salinity because of the close location to the salt-freshwater interface as well as an enhanced nitrogen content and infestation with bacteria, indicating organic pollution (Rasoloariniaina et al., 2015).

Further inland, on the ascent of the Mahafaly Plateau, hundreds of caves and sinkholes can be found. Many of them contain water throughout the years and some of the bigger grottos are of spiritual importance for the local population (Dobrilla, 2014; Guyot, 2002). On the plateau itself, however, water supply is most critical within the study area. It is made up by tertiary limestone (Du Puy and Moat, 1998) and its karstic geology leads to a quick infiltration of rainwater into the ground (Guyot, 2002). During the wet season, water accumulates in man-made rain water catchments (called *sihanaka* by the local population) and is equally used by the people and their livestock for drinking, cleaning, but also as toilet, and therefore again is of very poor quality (Rasoloariniaina et al., 2015). The catchments may contain huge amounts of water but usually fall dry again after just a few weeks or months (Dworak, 2014; Haut de Sigy, 1967). Permanent access to water only exists in very few places where impervious layers keep it closer to the surface and allowed the installation of simple water holes (*vovo*) by the local population or wells by external organizations (Figure 1.3). The main aquifer, however, is located more than 50 m below the surface and therefore not accessible without major technical effort (Dworak, 2014; Haut de Sigy, 1967). As a consequence, people living aside these permanent supply sources had to adapt to secure their all-season water demands, and that of their animals, either by using baobabs or other water-storing plants as natural reservoirs (Pforte, 2010) or by regularly covering long distances for fetching water.

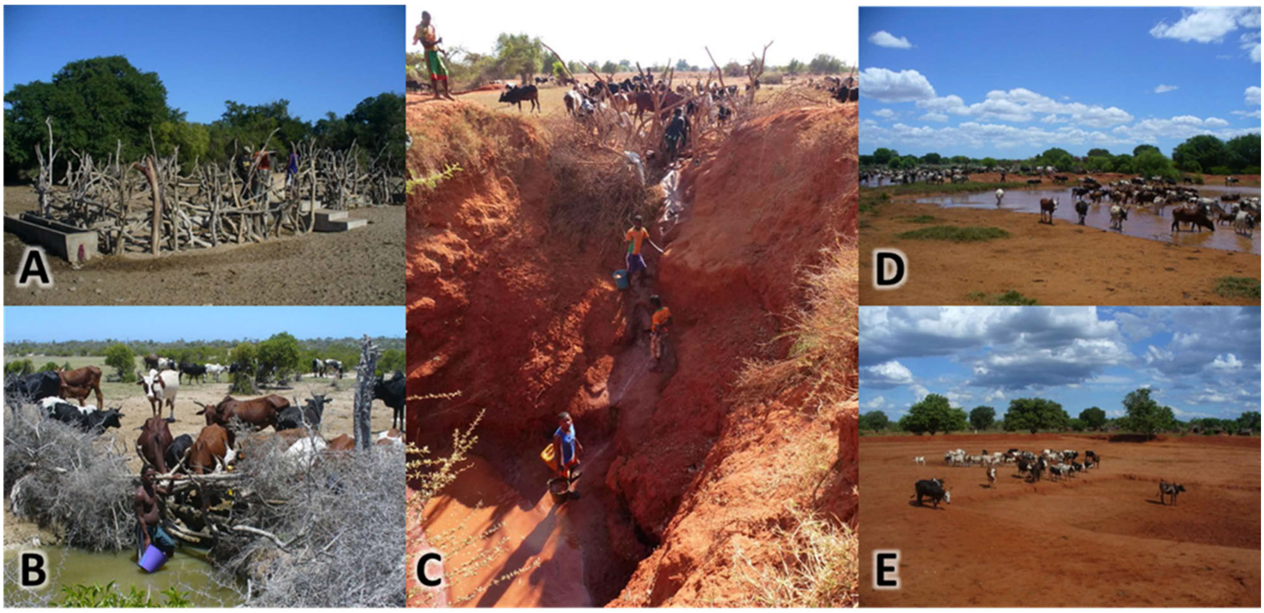


**Figure 1.3.** Spatial and seasonal variability in the availability of water for livestock: (a) constructed well at Marofijery and (b) saline water hole (*vovo*) near Ankilibory, both in the coastal zone; (c) deep water hole (*vovo*) near Maroarivo – one of the few permanent water sources on the limestone plateau at the end of the dry season; (d) temporary water hole (*sihanaka*) near Behalitany (plateau) during the rainy season and (e) water retention basin (*sihanaka*) at Ampotaka (plateau) during the early dry season.

### 1.3.3 Biodiversity and vegetation

Southwestern Madagascar has been defined as part of the Spiny Forest Ecoregion (Fenn, 2003) and is characterized, even for Malagasy standards, by a high biodiversity of animals but in particular plants (Goodman and Benstead, 2003). Between 75% and 90% of its species were found endemic on national or even local level (MNP, 2012; Phillipson, 1996), making this ecoregion a target objective for global nature conservation (Olson and Dinerstein, 2002). Today, large parts of the region’s remaining natural biodiversity are conserved within the Tsimanampetsotsa National Park which covers a total surface area of 43 200 ha after a spacious expansion in 2007 as part of NEAP (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protegées, 1999; MNP, 2012).

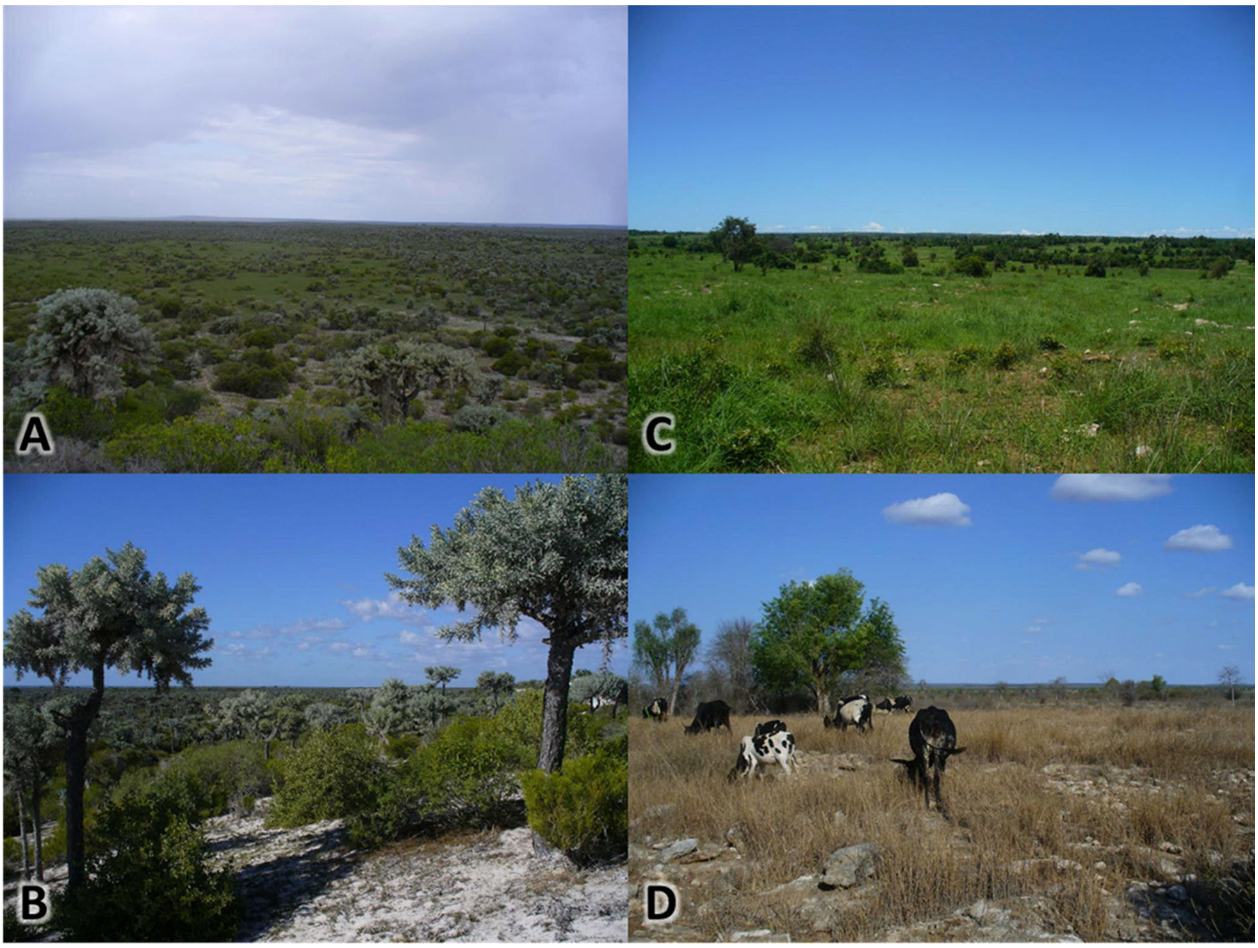


**Figure 1.4.** Spatio-temporal vegetation dynamics: *Euphorbia steonclada* coastal scrubland during (a) the rainy and (b) early dry season; savanna on the limestone plateau during (c) the rainy and (d) late dry season.

Beyond its borders, however, high population growth in combination with inappropriate agricultural practices steadily increases the pressure on land and nature. This is illustrated by a high deforestation rate of 45% over the past 40 years, leading to progressive forest fragmentation and the extension of savannas (Brinkmann et al., 2014). Thus, large parts of the area's landscape today apparently reflect human impact which is further increased by the peoples' ongoing dependency on environmental resources (Projet SuLaMa, 2011). For local livestock herds, for instance, the natural vegetation serves as mainstay of feed supply as they graze almost exclusively on commonly owned pastures and rangelands. These, however, are characterized by high heterogeneity and strong spatio-temporal fluctuations in the abundance and quality of forage as a result of the region's climatic conditions (Figure 1.4). Feed, therefore, together with water, proves to be the second big constraint of livestock keeping in the Mahafaly region.

### 1.3.4 The role of livestock

As in most of rural Madagascar and especially in the island's South, livestock keeping is closely linked to the socio-economic life and cultural traditions of local people in the Mahafaly region (Kaufmann, 1998; Klein et al., 2008). For the area's two most dominant ethnic communities, the eponymous Mahafaly and one of its sub-groups, the Tanalana, the sacrifice and donation of zebu cattle, but also of goats and sheep, are mandatory components of all important rituals and socio-cultural events such as weddings and funerals, and furthermore function to settle disputes and social conflicts (Battistini, 1966; Fauroux, 1989). Beyond that, domestic animals may contribute exceedingly to the livelihood and food security of the rural population in southern Madagascar (Wüstefeld, 2004), and the selling of livestock is an important risk management and coping strategy, for example to compensate crop failures. Finally, people rely on the power of bullocks to pull ox-carts which are still the most common form of transport within this economically underdeveloped region.

As in other parts of the world, local pastoralists have developed specific strategies to adapt to the area's difficult conditions. By performing annual transhumance movements of principally cattle herds to explore more productive pasture grounds for their animals at the beginning of the rainy season (Barraud, 2006) and using supplemental forage plants to overcome regular periods of feed scarcity in the course of the dry season (Kaufmann, 2004; Rabesandratana, 1999), livestock keepers proved relative effective to cope within this harsh environment. However, seasonal forage and water scarcity are only two of manifold challenges livestock farmers face. In recent years, conflicts related to livestock raiding apparently led to declining numbers of cattle as people try to avoid the risk of loss by precautionary selling their animals (Projet SuLaMa, 2011; Thibaud, 2010). At the same time, the extension of the Tsimanampetsotsa National Park further affected the traditional herd and grazing management by restricting the access to traditional grazing grounds (Tsirahamba and Kaufmann, 2008). It therefore appears likely that this multitude of interacting factors may by and by unbalance the area's pastoral system.

So far, previous research on animal husbandry in the Mahafaly region has rather focused on individual aspects, such as the animals' role in culture and tradition (Battistini, 1966), the importance of specific dry season forage plants (Kaufmann, 2011; Radobarimanajaka et al., 2013), or the impact of grazing on the vegetation within the Tsimanampetsotsa National Park (Ratovonamana et al., 2013). However, to understand the overall complexity of the local livestock system and its interdependencies with the environment as well as with peoples' livelihoods, a more holistic approach seems necessary – in particular in view of new challenges and drivers of change.

## 1.4 Study outline and research objectives

Against this background and existing knowledge gaps, the present study wants to gain deeper insight into the highly extensive system of animal husbandry in the Mahafaly region of southwestern Madagascar. It aims to illustrate traditional local livestock practices and to detect major key factors that drive pastoral management decisions, all in view of the area's spatial and temporal heterogeneity and fluctuations in resource availability. Regarding the manifold livelihood services the animals provide to their owners, this work furthermore tends to determine herd dynamics, opportunities for economic development, as well as potential for future improvement within the capacities of the region's natural resources.

The study therefore follows the subsequent research objectives:

- to understand movement and grazing patterns of domestic livestock herds along a regional gradient by illustrating the spatial distribution and seasonal utilization of rangelands and water sources (Chapter 2),
- to identify the animals' major feed resources and most important forage species in seasonal disposability as well as the nutritive value of natural pasture vegetation to depict seasonal variations and potential shortcomings in livestock nutrition (Chapter 3),
- to assess the reproductive performance of local livestock species as well as the system's economic state and potential against the background of available resources (Chapter 4).

Finally, the results and insights gained in the previous chapters are discussed comprehensively to offer a better understanding of still existing constraints and unanswered questions but also of opportunities for development (Chapter 5). This will provide the basis for the preparation and implication of management recommendations and measures that may help to sustain the local livestock system while at the same time minimizing its impact on the region's unique nature and environment.

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# Chapter 2

## Analysis of GPS Trajectories to Assess Spatio-temporal Differences in Grazing Patterns and Land Use Preferences of Domestic Livestock in Southwestern Madagascar

# Analysis of GPS trajectories to assess spatio-temporal differences in grazing patterns and land use preferences of domestic livestock in southwestern Madagascar


## Abstract

In order to investigate spatial and temporal characteristics of the purely grazing-based livestock husbandry system in southwestern Madagascar, individual animals from 12 cattle and 12 goat herds that were equally distributed across four villages were fitted with GPS tracking collars and their behavior during pasturing was directly observed to identify seasonal variations in land use and movement patterns along the regional altitude and vegetation gradient. Monitoring occurred at regular intervals of two months over a 2-year period to capture interannual variability.

Herds of both species from the inland limestone plateau covered longer distances and were found further away from their home corrals than those from the coastal plain. While on transhumance, cattle herds were more vulnerable than local populations to disadvantages such as limited access to pastureland and water sources nearby their temporary homesteads. Most patterns of land use types visited and feeding behavior reflected the spatial occurrence of specific land cover classes around the villages and differed significantly between seasons and sites.

Seasonal water shortage was one of the key factors affecting dry season livestock movements on the plateau but it only played a minor role in the coastal plain where livestock keeping proved to be more limited by feed availability. Recent security issues such as armed cattle raids and land use conflicts are additionally gaining importance. By forcing livestock owners to adapt their grazing management, these developments threaten to destabilize the region’s entire system of animal husbandry.


**Keywords:** Animal husbandry, Cattle raiding, GPS tracking, Grazing itineraries, Seasonality, Transhumance

## 2.1 Introduction

In many pastoral dryland systems, mobility is regarded as a key risk-management approach to cope with seasonal environmental variation (Adriansen, 2008; Niamir-Fuller, 1999a; Turner et al., 2014). Depending on the spatial and temporal variability of important resources such as water and high quality pastures, livestock farmers have to adjust herding strategies to ensure their livelihood (Little and McPeak, 2014; Vetter, 2005). Social networks and herders' knowledge are considered especially important in this regard (Turner, 1999; Turner and Hiernaux, 2002). Today it is largely recognized that existing traditions of mobility and seasonal migration within pastoral societies have to be maintained and re-legitimized to preserve the efficiency of these extensive livestock systems (Niamir-Fuller, 1999a) which play an important role for the food security and well-being of the rural poor in many developing countries (Randolph et al., 2007). However, other constraints of anthropogenic origin such as an increase in insecurity, banditry and farmer-herder conflicts further limit livestock activities (Bassett, 1986; Niamir-Fuller, 1999b; Swallow, 1994; Turner et al., 2014).

In Madagascar, livestock and in particular cattle husbandry plays a significant role for the national economy, with more than half of the island's land surface consisting of natural pastures or artificial meadows (FAOSTAT, 2014). The country's population of cattle, primarily composed of Small East African Zebus (*Bos indicus*) and to a lesser extent *Bos taurus* breeds and crossbreeds, was estimated at 10 million in 2013 (FAOSTAT, 2014) and is mostly found in the western and southern parts of the island where the animals are of particular social importance for their owners (Rasambainarivo and Ranaivoarivelo, 2006). Goats and sheep are less common across the country because of local taboos on respective meat consumption, and are mainly concentrated in the dry south and southwest (FAO and AGAL, 2005). Hence, this region is still renowned for its big herds of extensively farmed zebu cattle and small ruminants even though the numbers have been declining recently due to general increases in violent crime and acts of cattle raids in the countryside (Rasambainarivo and Ranaivoarivelo, 2006). At the same time, the region is one of the country's economically and climatically most disadvantaged. It hardly offers any alternative sources of income apart from agricultural production which again suffers from low rainfall with high interannual variability (Jury, 2003; Wüstefeld, 2004). For this reason, local pastoralists had to develop appropriate measures to deal with these ecological uncertainties. Their traditional herding practices are nevertheless threatened to an increasing degree by access restrictions to potential pasture resources due to private land ownership and the designation of protected areas, which are turning traditional grazing land and migration corridors into no-go areas for livestock (Toutain et al., 2004).

The region's system of livestock and especially cattle husbandry has already been profoundly described by authors such as Battistini (1966), Kaufmann (1998) and Kaufmann and Tsirahamba (2006), yet these studies mainly focused on the area's coastal zone or on a rather general analysis of transhumance movements. Most of them were based on qualitative data while quantitative methods to capture livestock husbandry practices have hardly been applied in this remote area. In addition, the regional conjunction between the availability of pastureland and seasonal migration, that is between areas of departure on and destination of transhumance movements, has not been investigated in detail. Finally, existing literature does so far rarely address the influence of rising insecurity in terms of organized cattle raids on a large scale, affecting the region's pastoral life more recently and excessing the old local tradition and male ritual of stealing just single animals.

The objectives of this study were therefore to (i) understand the animals' movement and grazing patterns within and across their regions by analyzing the spatial distribution and seasonal utilization of pasture areas and water resources over an extended period and to (ii) capture the impact of these varying parameters as well as of the tense security situation on the herding management of local livestock.

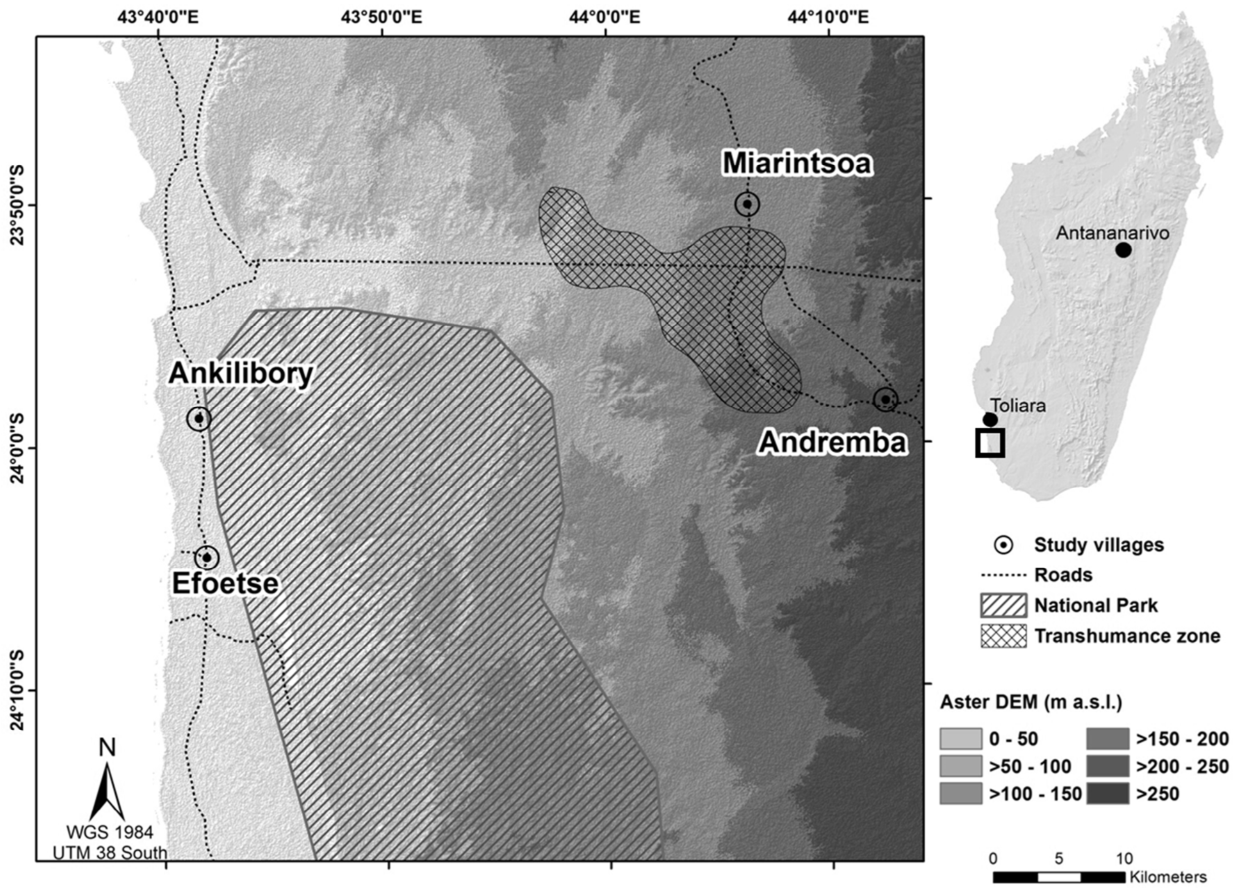


**Figure 2.1.** Location of the study area and villages, Mahafaly region, southwestern Madagascar. Transhumance zone only represents the temporary residence of cattle herds from Ankilibory and Efoetse. Small right-hand inset: location of the study area (encircled in black) within Madagascar. DEM = Digital Elevation Model, m a.s.l = meters above sea level.

## 2.2 Materials and methods

### 2.2.1 Study area

The study region stretches south from Toliara, the administrative center of south-western Madagascar, between the Onilahy and Linta Rivers. It is characterized by arid to semi-arid climatic conditions with an annual mean temperature of 24°C and irregular rainfall between <350 and 500 mm per year (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protégées, 1999), with high small-scale variation, especially during the wet season (Hanisch, 2015). The dry season usually lasts from April to November but is regularly extended until mid to late De-cember by absent rainfall events leading to an increased risk of famine (Wüstefeld, 2004). Furthermore the region is characterized by a high level of endemism in plants (Du Puy and Moat, 1998; Phillipson, 1996) and, to a lesser extent, animals (Garbutt, 2007; Glaw and Vences, 2007; Sinclair and Langrand, 2013). Most of this biodiversity is conserved within the Tsimanampetsotsa National Park (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protégées, 1999) and remaining small patches of sacred forests (Tengö et al., 2007). In other parts of the region a rapidly growing human population, with an annual increase by 3% within the last 20 years and 3.5% within the last 5 years (INSTAT, 2014), and a rising tendency for “clandestine pioneer-agriculture” enhances the pressure on natural resources (Brinkmann et al., 2014).

The area is part of the Mahafaly Plateau and can roughly be divided into two general landscapes – a coastal plain at sea level on sandy soil dominated by loose patches of *Euphorbia stenoclada* Baill. between xerophytic shrub thickets (Razanaka, 1996) and, after a gentle rise in altitude further inland, a limestone plateau of 330 m a.s.l. at maximum, covered with open landscapes on rocky calcareous substrates and *Heteropogon contortus* (L) P.Beauv. ex Roem. & Schult. dominated savanna-like grasslands (Morat, 1973), occasionally interspersed by dense bush- and woodland. The sparsely populated area is mainly inhabited by Mahafaly and Tanalana people. Both can be described as agropastoral societies with a traditional focus on animal husbandry and small-scale agriculture (Battistini, 1966; Kaufmann, 2004; Thielsen, 2014). The animal husbandry system in the whole region is constrained by seasonal water and forage shortage. While the former mainly affects livestock owners from the plateau area in the course of the dry season, the latter is a bigger problem in the coastal plain. To cope with these problems, Tanalana herders from the coastal zone temporarily move their zebu cattle and, in exceptional cases small ruminants, to the plateau, to take advantage of the earlier onset of rains in the upland area and the consequent sprouting of grasses. This traditional form of transhumance as described by Jones (2005) conventionally lasts for several months before the herds return to their home ranges in the coastal plain.

### 2.2.2 Data collection

The present study was carried out with livestock herds from four villages – Ankilibory (23°54'S, 43°41'E; 18 m a.s.l.) and Efoetse (24°04'S, 43°42'E; 17 m a.s.l.) located on the coastal plain as well as Andremba (23°58'S, 44°12'; 273 m a.s.l.) and Miarintsoa (23°50'S, 44°06'E; 183 m a.s.l.) on the limestone plateau (Figure 2.1). The localities were selected based on the results of a foregoing baseline survey (Projet SuLaMa, 2011) willingness of livestock keepers to participate in the study and feasibility of access. According to Neudert et al. (in press), all villages show a community structure typical for this region with Ankilibory, Efoetse and Miarintsoa being exclusively inhabited by Tanalana people, while the population of Andremba consists of Tanalana and Mahafaly in equal shares (Table 2.1).

**Table 2.1.** Major characteristics of the four study villages – Ankilibory, Efoetsy, Andremba, and Miarintsoa.

| | Coast | | Plateau | |
|---|---|---|---|---|
| **Village** | **Ankilibory** | **Efoetse** | **Andremba** | **Miarintsoa** |
| Altitude (m a.s.l.) | 18 | 16 | 273 | 183 |
| Mean annual precipitation (mm)[1] | n/a | 220.5[a] | 451.2[a] | 635.2[b] |
| Population, total (2012)[2] | 748 | 1,294 | 1,048 | 633 |
| Households, total (2012)[2] | 125 | 216 | 175 | 106 |
| TLU*[, 2] | 743 | 1,713 | 1,032 | 641 |
| Study herd sizes, cattle (*n* = 12)[c] | 36±2.6 | 33±3.9 | 32±2.4 | 40±3.0 |
| Study herd sizes, goats (*n* = 11)[c] | 21±3.3 | 41±4.5 | 31±4.7 | 43±3.2 |
| Village pasture area (km$^2$) | 102.8 | 79.8 | 144.8 | 109.9 |
| Available water sources for livestock (thereof permanent) | 7 (7) | 6 (5) | 6 (1) | 2 (0) |

m a.s.l. = meters above sea level, n/a = not available.

* TLU = Tropical Livestock Units (cattle: 0.7 TLU, goats: 0.1 TLU).

[1] Hanisch, unpubl. data, [2] Neudert, unpubl. data.

[a] mean value 2012 + 2013, [b] 2013 only, [c] mean values for study herds 2011 – 2013 ± standard errors.

Between November 2011 and November 2013, one adult female individual each from three representative zebu cattle and goat herds per village was fitted with a GPS tracking collar (GPS PLUS Store On Board, Vectronic Aerospace GmbH, Berlin, Germany). It recorded the diurnal grazing movements and spatial distribution patterns of the animal by logging the geographical position every 30 seconds over three consecutive days at bi-monthly intervals. In the meantime, the collars were removed and utilized in the other villages. Sheep, although also present, were not selected as this species was of minor importance to the local animal husbandry system compared to goats. Experimental animals were chosen from middle social rank to ensure the representability of their mobility and feeding patterns for the whole herd (Moritz et al., 2012; Reinhardt, 1982). Additionally, each collared animal was followed on one of the three observation days and its activities were monitored by direct observation every 5 minutes. Monitoring started in the early morning (usually between 5:30 and 6:30 a.m.) when the animals left their corral (*kialo*) until they came back in the evening (usually between 6:00 and 7:00 p.m.). Geographic positions of all visited temporal and perennial water points were recorded at the same occasion using a handheld GPS unit (Garmin eTrex, Garmin Ltd., Olathe, KS, USA). The survey was occasionally interrupted when some of the herds returned to their village enclosure during lunch break.

### 2.2.3 Data analysis

**General aspects**

A total raw dataset of 787 daily GPS trajectories ($n_{cattle}$ = 418, $n_{goat}$ = 369) and 293 direct observations ($n_{cattle}$ = 145, $n_{goat}$ = 148) entered into analysis. These numbers were slightly lower than expected from the experimental setup as especially goat collars occasionally ran out of battery during use and, in rare cases, the herd owner or his animals were not present when the collars were to be placed, so the herd movements could not be recorded. One goat herd from Ankilibory differed considerably from all others as the tracked animal turned out to be the only adult member of its flock, exclusively ranging within the limited village area accompanied by its recent offspring and mostly feeding on crop residues, which was not the case for the other study herds. Thus, these data were not included in the analysis.

Each study year was divided into three seasons corresponding to the calendar of the local population (Projet SuLaMa, 2011; Ranaivoarivelo and Milleville, 2001). During the hot and wet rainy season *asara* (RS), lasting from December to mid-April, the region receives most of its annual rainfall. Water and food supply for humans and livestock is best at this time of the year. Late single rainfall events may still occur in the course of the cooler early dry season *asotry* (EDS) which lasts until July, when temporary water holes start to vanish, while there is hardly any precipitation during the hot late dry season *afaosa* (LDS). Especially on the limestone plateau, access to water is then limited to a few permanent sources (Table 2.1) and living conditions for people and livestock are the most difficult.

**Processing of GPS and GIS data**

GPS recordings of individual daily tracks were corrected for outliers and missing data and then converted from the original geographic coordinate system to a UTM grid projection (WGS1984, zone 38S) using ArcGIS 10.0 (ESRI, Redlands, CA, USA). Line shapes were created from primary point files to measure the total distance of every daily trajectory (*walking_dist*) while the maximum furthest distance of a herd from its night enclosure (*max_dist*) and the linear distance between the corral and the nearest visited water hole during that specific grazing day (*dist_water*) were calculated using the Near Analysis Tool to depict seasonal variation in water availability. Total daily time on pasture, defined as time outside the enclosure and later referred to as *duration*, resulted either from direct observation or by subtracting track points which, according to the GIS, were located within the herd's corrals.

To analyze the animals' visit frequency of certain land cover classes (LCC), we used an up-to-date digital land cover classification map (Brinkmann et al., 2014). For the purpose of this study, similar land use categories, such as *dry spiny forest thicket* and *open spiny forest* were merged into one category, such as *spiny forest and thicket*, and one additional class, *settlement area*, was defined. This resulted in a total of six LCC (Table 2.2).

The total number of track points per species and observation period was calculated for each LCC. Next, all tracks belonging to herds from the same village that had been measured over the study period were merged and the maximum furthest distance from the settlement center was taken as the radius which defined the total available pasture area of each individual village. A further buffer of 50 m width was finally created on either side of every daily grazing route to delimit the grazing utilization zone for each herd (Samuels et al., 2007; Schlecht et al., 2009).

Direct observation data were classified into three major activity categories consisting of resting (including immobile times of rumination and social interactions such as nursing), feeding (including grazing, browsing, and drinking), and walking (without feeding). Other social activities, such as fighting, were also recorded but their share was negligible. Based on the timing of each activity, the observation data was linked to the corresponding geographic information in the GPS-derived data set (coordinates) and transferred to the digital land cover map. This allowed relating the daily duration of each activity to the total time passed in each LCC.

**Table 2.2**. Land cover classes (LCC) and their absolute ($km^2$) and proportional (%, values in brackets) area distribution within the grazing utilization zones of Andremba, Ankilibory, Efoetse, Miarintsoa, and the transhumance zone of coastal cattle herds (C-T).

| LCC | Class name | Coast | | Plateau | | |
|---|---|---|---|---|---|---|
| | | Ankilibory | Efoetse | Andremba | Miarintsoa | C-T |
| I | Open area and loose shrubland | 80.6 (78.4) | 61.5 (77.1) | 61.9 (42.7) | 7.6 (6.9) | 36.7 (14.4) |
| II | Savanna and productive grassland | 0.4 (0.4) | 0.1 (0.2) | 6.1 (4.2) | 32.2 (29.3) | 30.9 (12.1) |
| III | Wooded savanna | 0.1 (0.1) | <0.1 (<0.1) | 51.3 (35.5) | 41.0 (37.3) | 85.7 (33.5) |
| IV | Spiny forest and thicket | 14.9 (14.5) | 2.6 (3.2) | 15.6 (10.7) | 11.6 (10.5) | 91.1 (35.6) |
| V | Cultivated and abandoned cropland | 6.4 (6.2) | 15.1 (18.9) | 9.7 (6.7) | 16.9 (15.4) | 10.9 (4.1) |
| VI | Settlement area[a] | 0.4 (0.4) | 0.5 (0.6) | 0.2 (0.2) | 0.6 (0.6) | 0.7 (0.3) |
| **Total area mapped ($km^2$)** | | **102.8** | **79.8** | **144.8** | **109.9** | **256.0** |

[a] including livestock enclosures.

Reference: adapted from Brinkmann et al. (2014) → LCC I = Brinkmann-Class 1 + 2 + 3 + 6, LCC II = Cl. 4 + 10, LCC III = Cl. 5, LCC IV = Cl. 7 + 8 + 9, LCC V = Cl. 10, LCC VI = additional class.

### Statistical analysis

Statistical data analyses were performed using SPSS Statistics 20.0.0 (IBM Corp., Armok, NY, USA) adopting a significance level of $p \leq 0.05$. To avoid pseudo-replication, individual tracks and recordings were pooled per herd for every three day survey cycle. This resulted in a total number of 146 cattle and 143 goat datasets which were grouped by season. Data residuals were first checked for normal distribution, investigating the skewness and kurtosis *z*-values as well as the Shapiro-Wilk test *p*-value, before testing for homogeneity of variance. Pair-wise comparisons of means were then carried out using the independent t-test and one-way ANOVA with Tukey post-hoc test for normally distributed as well as the Mann-Whitney *U* and Kruskal-Wallis test for non-normally distributed data sets in case of two and more than two independent variables, respectively. Welch's t-test was used for cases of unequal group variances or sample sizes. All results were specified as mean ± standard error. Statistical analyses were computed to determine the effect of site ($n$ = 2), season ($n$ = 3) and species ($n$ = 2) on the three itinerary characteristics (*walking_dist*, *max_dist*, *dist_water*), daily time on pasture (*duration*) and activity patterns, respectively. As the number of animals per herd did not remain stable over the investigation period, Pearson's coefficients ($r_p$) were calculated to illustrate potential correlations of herd size against characteristics of grazing trajectories (*walking_dist*, *max_dist*, *dist_water*), and *duration*, respectively. Correlations were also computed between *walking_dist* and *dist_water* to verify if the availability of water sources had an effect on the length of daily itineraries.

## 2.3 Results

### 2.3.1 Site specific differences in herd management

Within the research area, cattle and goats were kept and herded separately even if a person owned both species. Thus, joint grazing on pastures only occurred on occasion. The animals were exclusively herded by boys and young men, approximately up to the age of 18, with the youngest herders (5 – 10 years) normally taking care of the goats. Although it was initially planned to work with flocks of similar size, the number of animals within a herd varied a lot between two consecutive surveys, doubling or halving in some cases[1]. During the study period, the average size (± standard errors) of monitored cattle herds varied between 32 (±2.4) in Andremba and 40 (±3.0) in Miarintsoa, and between 21 (±3.3) in Ankilibory and 43 (±3.2) in Miarintsoa for goats.

Most herds were corralled in the village area overnight but some could also be found in small, temporarily inhabited hamlets or separated enclosures up to 5 km away. While on the limestone plateau this small-scale herd displacement mostly occurred during the rainy season, single herds of both species were almost permanently kept outside the residential area in the coastal zone. Especially during the late dry season, some cattle owners from Ankilibory and Efoetse left their animals on their own over longer periods of time without herding and night corralling. Some of these

[1] Reasons for this high variation may be: temporary pooling and splitting of herds of closely related family members, aggregation of prior male cattle for ceremonial purpose before upcoming funeral and wedding ceremonies.

herds entered the Tsimanampetsotsa National Park where grazing is officially prohibited, ranging freely and only occasionally being visited by a herder who would roughly know about the animals' habitual itineraries. This herding strategy was not observed on the plateau side of the study area due to a precarious security situation and the risk of cattle raids. Nonetheless, some plateau herds of mostly cattle sporadically spent the night outside the settlement area, but then stayed in the vicinity (up to 800 m) of their enclosure.

In both observation years, transhumance from the coastal plain to the limestone plateau started between late December and early January, with herders leading their cattle from Ankilibory and Efoetse to neighboring destination areas on the plateau at about 45 km from the home village. This transhumance movement took one or two days. In the destination area the animals were kept in corrals which remained unused for the rest of the year. The timing of departure, the migration routes and the target villages or hamlets were clearly determined by family relations and kinships. From the six study herds practicing transhumance, five already returned to their home territories after spending only a few weeks on the plateau, due to the increasing risk of cattle raids towards the end of the rainy season when long-distance pathways across the plateau get again passable and thus better accessible for thieves. This menace was generally regarded to be much lower in the coastal plain. One inland cattle owner from Miarintsoa sent his herd to an area in the coastal region in the course of the dry season in both observation years. Even though this was the only incident of an 'inverse' transhumance in all of the studied herds, this apparently new management strategy was regularly reported from Tanalana livestock keepers on the limestone plateau who took advantage of family bonds with coastal residents to avoid the rising security risk in their home area. Sporadically this inverse transhumance also involved herds of small ruminants. Apart from these yearly east-west herd movements between the two survey regions, individual herds of both cattle and goats also temporarily moved in a north-south direction towards areas about 10 to 30 km away from their home location to gain access to better feeding resources. However, most of these movement patterns, but also individual herd management characteristics, were too irregular and variable to justify the grouping of the affected herds into subcategories for analysis.

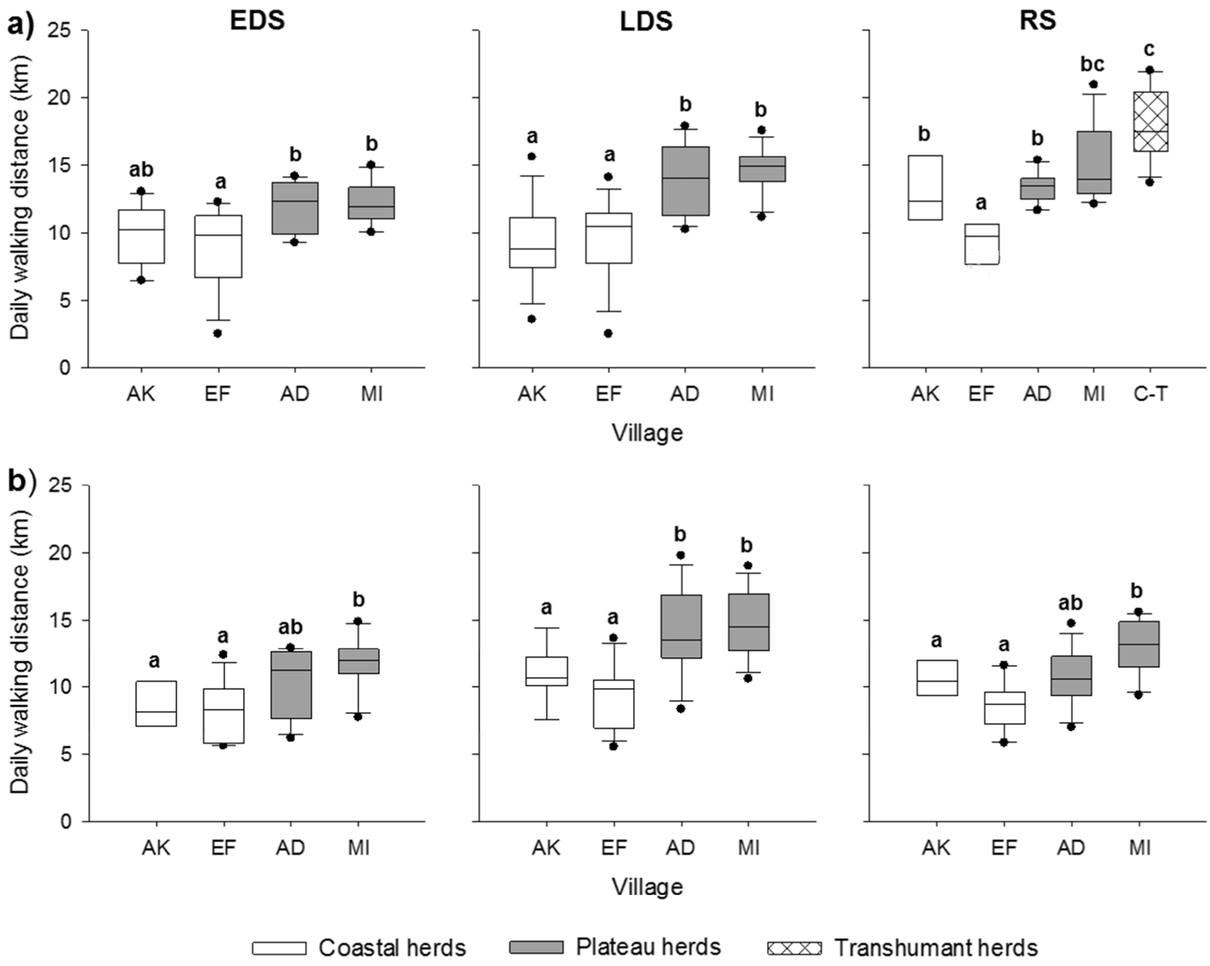


**Figure 2.2.** Seasonal variation in the daily walking distance (km) of (a) cattle and (b) goat herds from Ankilibory (AK), Efoetse (EF), Andremba (AD), Miarintsoa (MI), and the transhumance cattle herds (C-T). Data are given for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS). Medians (black lines inside the boxes), interquartile ranges (width of the boxes representing the middle 50% of data), total data ranges (whiskers), and outliers (black dots) are shown. Different letters above the box plots indicate village differences at $p \leq 0.05$ according to Tukey post-hoc tests.

### 2.3.2 Characteristics of grazing itineraries

On average, cattle herds spent 11.0 – 12.9 h $d^{-1}$ on the pasture with significant differences between seasons ($p < 0.001$) but not villages (Table 2.3). The longest grazing days occurred during the LDS and the shortest in the EDS across all villages (Appendix Figure 2.A.1). As shown in Figure 2.2, herds travelled longest ways (13.8±2.8 km) during the RS, with transhumant cattle covering the furthest distances. A maximum value of 23.2 km on one single day was recorded for a herd from Ankilibory in the course of its stay on the plateau, which was the longest daily track during the whole observation period. Also transhumant cattle were found furthest away from their corral (*max_dist* = 4.4±1.2 km) and thus very clearly differed from resident herds (Appendix Figure 2.A.2). The total mean *walking_dist* was 11.8±2.5 km in the LDS and 10.7±1.4 km in the EDS across sites. Plateau herds differed significantly from coastal ones with regard to *max_dist* ($p < 0.01$) and *dist_water* ($p < 0.001$; Appendix Figure 2.A.3), the latter parameter also showing distinct seasonal fluctuation ($p < 0.01$). Herd size did not significantly correlate with *walking_dist*, *max_*dist, and *dist_water* across regions. But a correlation existed with *dist_water* during the EDS ($r_p = 0.72$, $n = 20$, $p < 0.001$) and RS ($r_p = 0.72$, $n = 10$, $p < 0.05$) when analyzing the data from the coastal plain separately.

In the case of goat herds, *duration* ranged between 9.1 – 10.4 h $d^{-1}$, revealing significant differences between seasons ($p < 0.001$) but not between sites (Appendix Figure 2.A.1). Average *walking_dist* again differed significantly between seasons ($p < 0.001$) and between the two sites of the study area ($p < 0.001$) (Table 2.4). In contrast to cattle herds, itineraries of goats were longer in the LDS (12.3±2.2 km) than in the RS (10.7±1.5 km) and EDS (9.7±1.5 km) across all four villages (Figure 2.2). The longest daily track recorded from plateau goat herds was 24.7 km, thus exceeding the maximum grazing distance measured for cattle. In comparison, goats from the coastal plain never walked more than 14.5 km $d^{-1}$. Throughout the year, *max_dist* was higher for goat herds from Andremba and Miarintsoa compared to those from Ankilibory and Efoetse ($p < 0.001$; Appendix Figure 2.A.2). This parameter also differed seasonally ($p < 0.05$). Finally, clear spatial ($p < 0.001$) and temporal ($p < 0.01$) differences occurred with regard to *dist_water* (Appendix Figure 2.A.3). Unlike in cattle herds, movement patterns of goats varied strongly in relation to herd size, that was negatively correlated with *walking_dist* ($r_p = -0.37$, $n = 59$, $p < 0.01$) and positively with *duration* ($r_p = 0.28$, $n = 59$, $p < 0.05$) for coastal herds. In contrast, herd size on the plateau was significantly correlated to *max_dist* ($r_p = 0.30$, $n = 59$, $p < 0.05$) and *duration* ($r_p = 0.40$, $n = 61$, $p = 0.001$).

**Table 2.3.** Characteristics of the daily grazing itineraries of cattle and their activities on pasture. The number of tracks results from pooling individual herd data per three-day-survey period. Italic values indicate standard errors of the mean.

| Season | Village | Tracks (n) | Itinerary characteristics: walking_dist (km/d) | max_dist (km/d) | dist_water (km/d) | Duration ($h\ d^{-1}$) | Daily activity time (%): Resting | Feeding | Walking |
|---|---|---|---|---|---|---|---|---|---|
| EDS | AK | 10 | 9.8 $^{ab}$ | 2.7 $^{ab}$ | 1.5 $^{ab}$ | 11.3 $^{a}$ | 8.5 $^{a}$ | 69.3 $^{a}$ | 22.2 $^{a}$ |
| | EF | 12 | 9.0 $^{a}$ | 1.9 $^{a}$ | 0.4 $^{ab}$ | 11.0 $^{a}$ | 9.5 $^{a}$ | 66.4 $^{a}$ | 24.1 $^{a}$ |
| | AD | 10 | 11.9 $^{b}$ | 3.1 $^{b}$ | 2.0 $^{ab}$ | 10.6 $^{a}$ | 7.9 $^{a}$ | 66.9 $^{a}$ | 25.2 $^{a}$ |
| | MI | 10 | 12.2 $^{b}$ | 3.2 $^{b}$ | 3.1 $^{b}$ | 11.2 $^{a}$ | 15.8 $^{a}$ | 62.5 $^{a}$ | 21.7 $^{a}$ |
| | | | *0.39* | *0.14* | *0.27* | *0.17* | *1.44* | *1.70* | *1.31* |
| LDS | AK | 14 | 9.2 $^{a}$ | 3.2 $^{ab}$ | 1.8 $^{ab}$ | 13.6 $^{a}$ | 23.6 $^{a}$ | 59.3 $^{a}$ | 17.1 $^{a}$ |
| | EF | 15 | 9.5 $^{a}$ | 2.2 $^{a}$ | 0.7 $^{a}$ | 12.4 $^{a}$ | 13.5 $^{a}$ | 67.1 $^{a}$ | 19.4 $^{a}$ |
| | AD | 15 | 13.9 $^{b}$ | 3.5 $^{ab}$ | 3.2 $^{bc}$ | 12.7 $^{a}$ | 15.5 $^{a}$ | 68.3 $^{a}$ | 16.2 $^{a}$ |
| | MI | 13 | 14.6 $^{b}$ | 3.7 $^{b}$ | 4.5 $^{c}$ | 12.9 $^{a}$ | 18.0 $^{a}$ | 55.9 $^{a}$ | 26.1 $^{a}$ |
| | | | *0.47* | *0.18* | *0.31* | *0.19* | *2.15* | *2.40* | *1.48* |
| RS | AK | 5 | 13.1 $^{b}$ | 3.7 $^{ab}$ | 1.2 $^{a}$ | 12.3 $^{a}$ | 10.7 $^{a}$ | 66.1 $^{a}$ | 23.2 $^{a}$ |
| | EF | 6 | 9.4 $^{a}$ | 1.9 $^{a}$ | 0.7 $^{a}$ | 11.6 $^{a}$ | 18.0 $^{a}$ | 58.8 $^{a}$ | 23.2 $^{a}$ |
| | AD | 11 | 13.4 $^{b}$ | 2.6 $^{ab}$ | 1.0 $^{a}$ | 12.1 $^{a}$ | 24.3 $^{a}$ | 56.1 $^{a}$ | 19.6 $^{a}$ |
| | MI | 12 | 15.0 $^{bc}$ | 2.4 $^{a}$ | 2.0 $^{a}$ | 12.0 $^{a}$ | 12.5 $^{a}$ | 64.9 $^{a}$ | 22.6 $^{a}$ |
| | C-T | 13 | 17.9 $^{c}$ | 4.4 $^{b}$ | 1.9 $^{a}$ | 12.8 $^{a}$ | 6.8 $^{a}$ | 66.9 $^{a}$ | 26.3 $^{a}$ |
| | | | *0.51* | *0.21* | *0.18* | *0.16* | *1.81* | *1.90* | *1.26* |
| **Independent variable** | | ***df*** | | | | | | | |
| Site | | 1 | *** | *** | *** | n.s. | n.s. | n.s. | n.s. |
| Season | | 2 | *** | n.s. | ** | *** | * | n.s. | n.s. |

walk_dist = total distance of daily trajectories, max_dist = furthest distance of a herd from its night enclosure, dist_water = linear distance between night enclosure and the nearest visited water hole.

EDS = early dry season, LDS = late dry season, RS = rainy season.

AD = Andremba, AK = Ankilibory, EF = Efoetse, MI = Miarintsoa, C-T = transhumant cattle herds from AK and EF on plateau.

$^{a, b, c}$ significant differences between means in the same column within one season according to post-hoc tests.

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, n.s. = non-significant.

**Table 2.4.** Characteristics of the daily grazing itineraries of goats and their activities on pasture. The number of tracks results from pooling individual herd data per three-day-survey period. Italic values indicate standard errors of the mean.

| Season | Village | Tracks (n) | Itinerary characteristics | | | | Daily activity time (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | walking_dist (km/d) | max_dist (km/d) | dist_water (km/d) | Duration ($h\ d^{-1}$) | Resting | Feeding | Walking |
| EDS | AK | 10 | 8.4 $^{a}$ | 2.2 $^{ab}$ | 1.2 $^{a}$ | 9.0 $^{a}$ | 8.5 $^{ab}$ | 69.3 $^{a}$ | 22.2 $^{a}$ |
| | EF | 12 | 8.2 $^{a}$ | 1.7 $^{a}$ | 0.4 $^{a}$ | 9.4 $^{a}$ | 3.1 $^{a}$ | 73.0 $^{a}$ | 23.9 $^{a}$ |
| | AD | 10 | 10.5 $^{ab}$ | 2.6 $^{ab}$ | 0.8 $^{a}$ | 9.5 $^{a}$ | 13.4 $^{b}$ | 59.3 $^{a}$ | 27.3 $^{a}$ |
| | MI | 10 | 11.8 $^{b}$ | 2.8 $^{b}$ | 2.6 $^{b}$ | 8.6 $^{a}$ | 6.0 $^{a}$ | 71.1 $^{a}$ | 22.9 $^{a}$ |
| | | | *0.42* | *0.14* | *0.21* | *0.22* | *1.33* | *2.01* | *1.40* |
| LDS | AK | 14 | 11.0 $^{a}$ | 1.9 $^{ab}$ | 1.1 $^{a}$ | 10.2 $^{a}$ | 13.1 $^{a}$ | 62.9 $^{a}$ | 24.0 $^{a}$ |
| | EF | 15 | 9.4 $^{a}$ | 1.8 $^{a}$ | 0.5 $^{a}$ | 9.8 $^{a}$ | 4.6 $^{a}$ | 74.6 $^{a}$ | 20.8 $^{a}$ |
| | AD | 15 | 14.1 $^{b}$ | 3.0 $^{b}$ | 1.9 $^{ab}$ | 10.8 $^{a}$ | 7.0 $^{a}$ | 70.3 $^{a}$ | 22.7 $^{a}$ |
| | MI | 13 | 14.6 $^{b}$ | 3.6 $^{bc}$ | 4.7 $^{b}$ | 10.3 $^{a}$ | 7.0 $^{a}$ | 67.9 $^{a}$ | 25.1 $^{a}$ |
| | | | *0.48* | *0.16* | *0.30* | *0.27* | *1.13* | *1.76* | *1.37* |
| RS | AK | 5 | 10.4 $^{a}$ | 2.0 $^{ab}$ | 1.1 $^{b}$ | 10.5 $^{a}$ | 14.7 $^{a}$ | 64.0 $^{a}$ | 21.3 $^{a}$ |
| | EF | 6 | 8.7 $^{a}$ | 1.6 $^{a}$ | 0.3 $^{a}$ | 10.3 $^{a}$ | 6.3 $^{a}$ | 76.0 $^{a}$ | 17.7 $^{a}$ |
| | AD | 11 | 10.8 $^{ab}$ | 2.0 $^{ab}$ | 0.9 $^{ab}$ | 10.3 $^{a}$ | 12.2 $^{a}$ | 68.3 $^{a}$ | 19.5 $^{a}$ |
| | MI | 12 | 13.0 $^{b}$ | 2.6 $^{b}$ | 1.3 $^{b}$ | 10.5 $^{a}$ | 9.4 $^{a}$ | 66.7 $^{a}$ | 23.9 $^{a}$ |
| | | | *0.37* | *0.11* | *0.10* | *0.22* | *1.21* | *1.78* | *1.05* |
| **Independent variable** | | ***df*** | | | | | | | |
| Site | | 1 | *** | *** | *** | n.s. | * | * | n.s. |
| Season | | 2 | *** | * | ** | *** | n.s | n.s. | n.s. |

walk_dist = total distance of daily trajectories, max_dist = furthest distance of a herd from its night enclosure, dist_water = linear distance between night enclosure and the nearest visited water hole.

EDS = early dry season, LDS = late dry season, RS = rainy season.

AD = Andremba, AK = Ankilibory, EF = Efoetse, MI = Miarintsoa.

$^{a.b.c}$ significant differences between means in the same column within one season according to post-hoc tests.

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, n.s. = non-significant.

Comparing the two livestock species, the daily duration of pasturing was always longer for cattle than for goats, across the two sites and three seasons ($p < 0.001$ in all cases). Livestock species also differed significantly in *walking_dist* ($p < 0.001$) and *max_dist* ($p < 0.01$) on the limestone plateau and in terms of *max_dist* ($p < 0.001$) and *dist_water* ($p < 0.05$) in the coastal plain. Across sites, cattle covered longer distances than goats in all seasons but these differences were only significant in the RS (*walking_dist*: $p < 0.001$, *max_dist*: $p < 0.001$, *dist_water*: $p < 0.01$) and for *max_dist* in the EDS ($p < 0.05$) and LDS ($p < 0.05$).

### 2.3.3 Daily behavior on pasture

The average proportion of time spent on feeding by all cattle was 64% throughout the year. It was followed by 22% of time spent walking and 14% resting time with no significant differences between sites and only for resting ($p < 0.05$) between seasons (Table 2.3). No monitoring of behavior occurred when herds returned to the village at noon and were kept within their enclosures for noon resting time. Such midday breaks were longest during the LDS and then could last 0.8 – 3.7 h (Appendix Table 2.A.1).

Feeding was also the dominant behavior in goats accounting for 69% of the daily observed time, followed by walking (23%) and resting (8%). Activity patterns did not differ between seasons but for resting ($p < 0.05$) and feeding ($p < 0.05$) when comparing flocks from both sites (Table 2.4). Most goat flocks came back to the villages for a noon break lasting 1.3 – 2.7 h during the EDS, 2.0 – 3.4 h during the RS, and 3.0 – 3.7 h during the LDS. No specific differences between regions were found as the length of these interruptions varied more between single villages than between the plateau and the coastal plain. Midday breaks were longest in Efoetse throughout all seasons, followed by Miarintsoa, Anilibory and Andremba. They occurred more regularly and were longer in goat herds than in cattle herds (Appendix Table 2.A.1).

When comparing both species, coastal goats spent a significantly higher proportion of time feeding than coastal cattle ($p < 0.05$) but less time resting ($p < 0.05$). The latter was also the case on the limestone plateau ($p < 0.001$). Across regions, significant differences ($p < 0.05$) between both species were determined for resting ($p < 0.01$) and feeding ($p < 0.001$) activities in the LDS and for feeding in the RS ($p < 0.05$), whereas no such differences were found during the EDS.

### 2.3.4 Land cover preferences of cattle and goat herds

Almost all livestock herds showed a highly dispersed pasture use, infrequently visiting the same grazing ground on consecutive days (see Appendix Figures 2.A.4 – 2.A.12). The proportion of daily time on pasture allocated to different LCC differed widely across sites for both livestock species ($p < 0.001$) and, to a lesser extent, between seasons for cattle herds ($p < 0.05$). This is partly the result of the different distribution of the six LCC across each village territory as depicted in Table 2.4. If water points outside the village area were visited, herd itineraries were already orientated towards these locations. This effect was generally stronger on the plateau in the course of the EDS and during the LDS when animals from Andremba and Miarintsoa occasionally had to walk for more than 6 km every two or three days to reach the still remaining sources of water.

Throughout the year, cattle herds from the coastal plain predominantly grazed on *open area and loose shrubland* of *Euphorbia stenoclada* (73 – 84% of LCC visited). This LCC was the most abundant around Ankilibory and Efoetse as shown in Table 2.2. A disproportionately high share of feeding time as compared to its spatial occurrence was recorded for *cultivated and abandoned cropland* and *settlement areas*, however with no significant seasonal differences. For the limestone plateau, Figure 2.3 shows a high proportion of feeding time spent on *open area and loose shrubland* on rocky ground around Andremba (34 – 57%), on *wooded savanna* for all herds (24 – 61%), as well as on *open savanna and productive grassland* around Miarintsoa and in the transhumance area (13 – 54%). Irrespective of the village, feeding time allocated to a specific LCC varied strongly between seasons ($p < 0.001$). It was highest in the *settlement area*, especially during the LDS, and on *wooded savanna* and *cultivated and abandoned cropland* in the RS for herds from Andremba. In Miarintsoa, the same was true for *savanna and productive grassland* in the LDS and for *open area and loose shrubland* as well as *wooded savanna* in the RS (Table 2.5). For LCC visited by cattle during resting and walking see Appendix Table 2.A.2 as well as Appendix Figures 2.A.13 and 2.A.14.

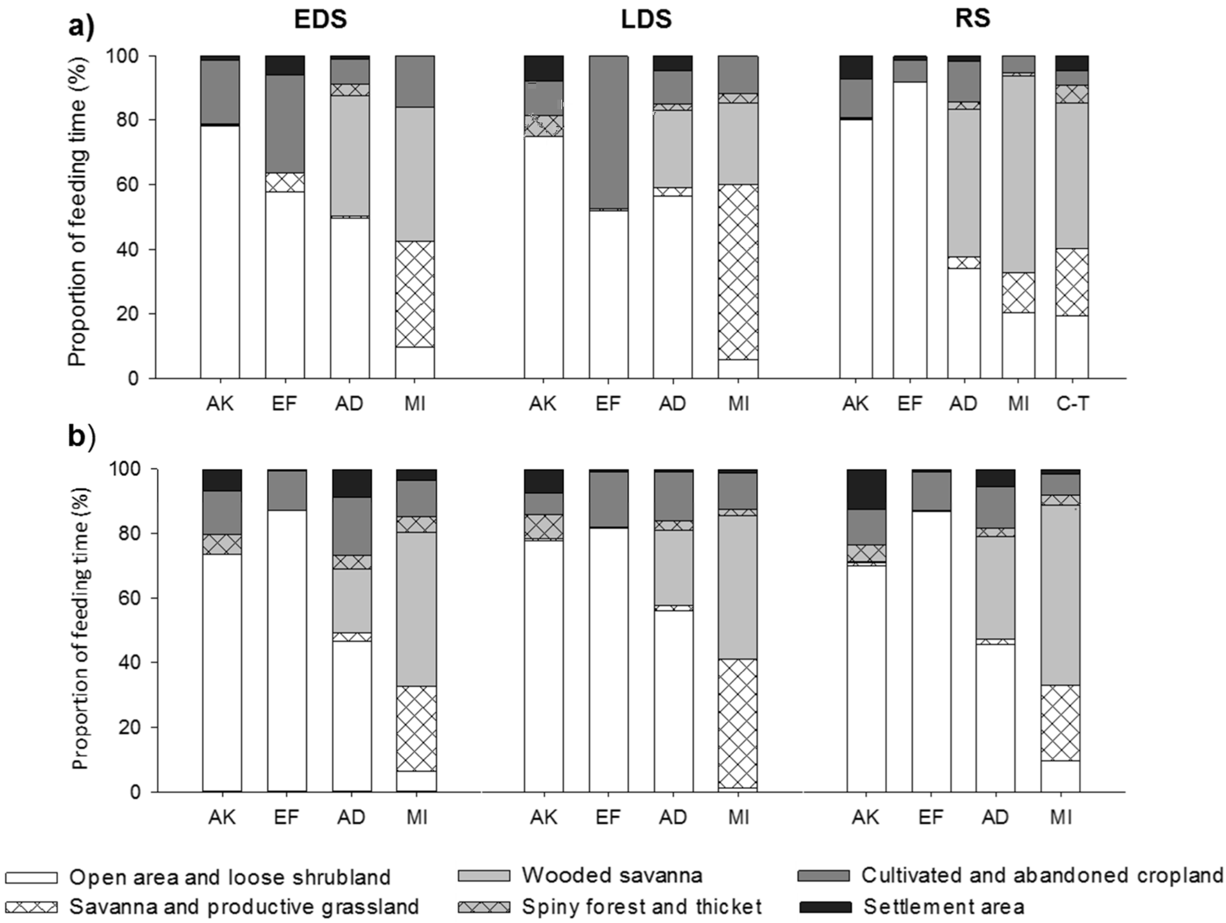


**Figure 2.3.** Proportion of daily feeding time (%) of cattle (a) and goat (b) herds from Ankilibory (AK), Efoetse (EF), Andremba (AD), Miarintsoa (MI), and the transhumance cattle herds (C-T) spent on different land cover classes. Data are shown for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS).

LCC visited by goats for feeding differed marginally from those of cattle (Figure 2.3). Significant differences between species could only be found for *open area and loose shrubland* in Efoetse ($p$ < 0.05) and for *cultivated and abandoned cropland* in Ankilibory ($p$ < 0.05). There, feeding activity was observed more frequently in goats than could be expected from the spatial distribution of the respective LCC. Also, plateau goats from Andremba showed a certain preference for *cultivated and abandoned cropland* and the *settlement area* throughout the year, which is indicated by the high proportion of feeding time spent on these LCC as compared to the proportion of total time spent on the respective LCC. Contrastingly, in Miarintsoa, the animals spent a disproportionately high share of their feeding time on *wooded savanna* and *settlement area* yearlong and on *savanna and productive grassland* during the LDS (Table 2.6). For goats' visits of LCC during resting and walking see Appendix Table 2.A.2 as well as Appendix Figures 2.A.13 and 2.A.14.

**Table 2.5.** Proportion of land cover classes (LCC, details see Table 2.2) within the herds' grazing utilization zones (buffer area) and observed feeding activity per LCC of cattle.

| **Coast** | | | | | | | **Plateau** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LCC** | **I** | **II** | **III** | **IV** | **V** | **VI** | **LCC** | **I** | **II** | **III** | **IV** | **V** | **VI** |
| **Ankilibory** | | | | | | | **Andremba** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 80.8 | 0.4 | <0.1 | 5.0 | 11.9 | 1.8 | Buffer area (%) | 56.7 | 2.8 | 27.3 | 4.1 | 8.5 | 0.6 |
| Feeding (%) | 78.2 | 0.4 | 0.0 | 0.4 | 19.6 | 1.4 | Feeding (%) | 49.5 | 0.9 | 37.3 | 3.5 | 7.6 | 1.2 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 80.7 | <0.2 | 0.1 | 10.7 | 6.3 | 2.0 | Buffer area (%) | 55.7 | 2.7 | 30.0 | 4.1 | 7.0 | 0.5 |
| Feeding (%) | 74.9 | 0.0 | 0.1 | 6.3 | 10.9 | 7.8 | Feeding (%) | 56.6 | 2.4 | 24.1 | 2.0 | 10.2 | 4.7 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 83.7 | 0.2 | 0.1 | 2.5 | 10.3 | 3.2 | Buffer area (%) | 48.2 | 4.0 | 34.6 | 4.6 | 7.9 | 0.7 |
| Feeding (%) | 80.3 | 0.2 | 0.2 | 0.2 | 11.9 | 7.2 | Feeding (%) | 34.1 | 3.4 | 45.8 | 2.3 | 12.7 | 1.7 |
| **Efoetse** | | | | | | | **Miarintsoa** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 74.2 | 0.7 | 0.1 | 2.8 | 21.0 | 1.2 | Buffer area (%) | 9.2 | 27.3 | 34.5 | 12.4 | 15.7 | 0.9 |
| Feeding (%) | 57.9 | 5.6 | 0.0 | 0.1 | 30.4 | 6.0 | Feeding (%) | 9.8 | 32.6 | 41.7 | 0.0 | 15.7 | 0.2 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 73.3 | <0.1 | <0.1 | 1.2 | 24.5 | 0.8 | Buffer area (%) | 8.0 | 33.8 | 37.3 | 5.6 | 14.1 | 1.2 |
| Feeding (%) | 51.9 | 0.0 | 0.0 | 0.5 | 47.5 | 0.1 | Feeding (%) | 5.8 | 54.4 | 25.2 | 2.9 | 11.7 | 0.0 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 82.1 | n/a | n/a | 0.2 | 17.0 | 0.7 | Buffer area (%) | 14.8 | 26.3 | 46.7 | 6.2 | 4.8 | 1.2 |
| Feeding (%) | 91.8 | n/a | n/a | 0.0 | 10.4 | 2.8 | Feeding (%) | 20.4 | 12.5 | 60.9 | 1.0 | 5.0 | 0.2 |
| | | | | | | | **Transhumant cattle herds** | | | | | | |
| | | | | | | | RS | | | | | | |
| | | | | | | | Buffer area (%) | 9.5 | 30.8 | 47.9 | 7.8 | 3.2 | 0.8 |
| | | | | | | | Feeding (%) | 19.4 | 20.7 | 45.1 | 5.5 | 4.6 | 4.7 |

EDS = early dry season, LDS = late dry season, RS = rainy season.

LCC labelling is equivalent to Table 2.2.

**Table 2.6.** Proportion of land cover classes (LCC, details see Table 2.2) within the flocks' grazing utilization zones (buffer area) and observed feeding activity per LCC of goats.

| Coast | | | | | | | Plateau | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LCC | I | II | III | IV | V | VI | LCC | I | II | III | IV | V | VI |
| **Ankilibory** | | | | | | | **Andremba** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 77.1 | 0.7 | 0.2 | 8.9 | 10.0 | 3.1 | Buffer area (%) | 55.0 | 1.7 | 29.3 | 4.5 | 8.9 | 0.6 |
| Feeding (%) | 73.7 | 0.0 | 0.0 | 6.0 | 13.4 | 6.9 | Feeding (%) | 46.7 | 2.3 | 19.8 | 4.2 | 18.2 | 8.8 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 78.5 | 0.7 | <0.1 | 8.5 | 8.9 | 3.3 | Buffer area (%) | 52.2 | 1.8 | 31.7 | 3.5 | 10.4 | 0.4 |
| Feeding (%) | 77.9 | 0.5 | 0.0 | 7.4 | 6.8 | 7.4 | Feeding (%) | 56.1 | 1.7 | 23.4 | 2.8 | 15.1 | 0.9 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 80.5 | 0.8 | 0.3 | 10.0 | 4.8 | 3.6 | Buffer area (%) | 49.0 | 1.9 | 33.0 | 4.1 | 11.2 | 0.8 |
| Feeding (%) | 70.2 | 1.0 | 0.2 | 5.2 | 11.0 | 12.4 | Feeding (%) | 45.8 | 1.4 | 31.9 | 2.8 | 12.7 | 5.4 |
| **Efoetse** | | | | | | | **Miarintsoa** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 75.3 | n/a | n/a | <0.1 | 22.7 | 1.9 | Buffer area (%) | 5.7 | 33.0 | 37.1 | 7.2 | 15.0 | 2.0 |
| Feeding (%) | 87.1 | n/a | n/a | 0.0 | 12.4 | 0.5 | Feeding (%) | 6.3 | 26.2 | 47.7 | 4.8 | 11.4 | 3.5 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 75.7 | n/a | n/a | <0.1 | 22.2 | 2.0 | Buffer area (%) | 4.9 | 33.6 | 36.5 | 4.7 | 18.3 | 2.0 |
| Feeding (%) | 81.9 | n/a | n/a | 0.3 | 16.9 | 0.9 | Feeding (%) | 1.3 | 39.9 | 44.5 | 2.0 | 11.4 | 0.9 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 76.0 | n/a | n/a | <0.1 | 21.8 | 2.1 | Buffer area (%) | 7.6 | 37.6 | 42.3 | 7.2 | 3.3 | 2.0 |
| Feeding (%) | 87.0 | n/a | n/a | 0.3 | 12.0 | 0.7 | Feeding (%) | 9.7 | 23.3 | 55.7 | 3.3 | 6.7 | 1.3 |

EDS = early dry season, LDS = late dry season, RS = rainy season.

LCC labelling is equivalent to Table 2.2.

## 2.4 Discussion

The aim of the present study was to identify spatio-temporal differences in movement patterns and utilization of LCC by livestock on either region of the Mahafaly Plateau research area. Overall, the results indicate a high variation in these variables already between cattle and goat herds from the same village. But different herding strategies, such as in terms of night corralling and free grazing within the nearby national park area, plus the different ecological conditions on both sites of the study area reinforce the clear dissimilarities between the coastal plain and the limestone plateau. The transhumant zebu herds occupy a special position during their time of seasonal migration.

### 2.4.1 Spatial and seasonal differences in movement patterns

The average values of the recorded movement parameters of cattle, and in particular the length of daily trajectories, largely correspond to values reported from similar studies in the Sahel (Schlecht et al., 2006) and East Africa (Butt, 2010b). In contrast, the daily distances travelled by goat herds clearly exceeded those measured by Ouédraogo-Koné et al. (2006) in West Africa and Akasbi et al. (2012) in southern Morocco, though the latter obtained his results in a mountainous region where the animals had to spent a substantial part of their energy on vertical movements. During a survey conducted by Rabeniala et al. (2009) in a coastal area north of our study region, flocks of small ruminants only walked between 4.7 and 6.2 km $d^{-1}$ in the rainy season but 13.7 km $d^{-1}$ when visiting a water point in the dry season. However, these results were based on a low number of samples and the length of the animals' itineraries was only occasionally recorded by an observer from greater distance. Therefore, both studies are not easily comparable. A significantly higher mobility of cattle compared to goats as observed by Turner et al. (2014) could not be generally confirmed. Similar to many other surveys, the present work could, for logistical reasons, not capture night grazing which might have had a non-negligible effect on the total length of itineraries and the animals' performance (Ayantunde et al., 2000; 2002). Nocturnal activities occasionally occurred in both research regions and were slightly more frequent in coastal cattle herds when left on their own within the boundaries of the national park area but also towards the seaside in the course of the dry season.

Herds of both species walked longer ways and were found further away from their night enclosures throughout the year on the limestone plateau compared to the coastal plain. This reflects on the one hand the spatial conditions of each site as westbound livestock itineraries in Ankilibory and Efoetse were limited by the sea but also, in general, by a higher density of cultivated areas around the coastal villages. Another spatial boundary was set by the Tsimanampetsotsa National Park to the east. In the course of the dry season, access to water was the key factor driving the movement of plateau herds. Water supply was significantly better near the coast with a broader network of artificial wells but also water holes with connection to groundwater within or around settlements, most of the latter bearing saline but still palatable water for livestock throughout the year. On the plateau, seasonal aspects affected herd movements to a greater extent. Most watering places around residential zones normally dry out within a few weeks or months after the last rainfall event or, as in Andremba, provide just enough water for humans or small and privileged village herds. In this period of the year, all other herds are forced to travel sometimes long distances towards the remaining water sources. Most herders tend to lead their animals to water in the morning and to get back near their homesteads before the hottest time of the day. These trajectories often showed the typical characteristics that have been described by several authors in the context of piosphere and central-place models (Andrew, 1988; Coppolillo, 2001; Thrash and Derry, 1999), such as soil compaction by trampling and accumulation of livestock feces near water points and resting places.

Despite these seasonal long distance travelling and comparatively shorter grazing days, cattle herds on average walked the longest distances during the rainy season, when water availability was no problem. This contrasts with the results of the vast majority of studies in arid environments, which revealed longer distances traveled to water in the dry season (Adriansen and Nielsen, 2002; Butt, 2010b; Ouédraogo-Koné et al., 2006; Schlecht et al., 2006). Especially for the plateau, this may result from the more heterogeneous landscape and stronger seasonal variation of the vegetation in comparison to the coastal site, which gives plateau herders more choice for selecting pasturing areas with better availability of forage and water and to move their animals more frequently to a new productive grazing ground (Brottem et al., 2014; Little and McPeak, 2014; Scoones, 1995). In addition, long distance dry season travel to water points did not occur on a daily basis, but only every two to four days, depending on the water demand of the particular livestock species. Even though these itineraries proved to be significantly longer than on non-watering days, the total average value was still lower than during the wet season. Furthermore, herds in the coastal plain were slightly less mobile in the course of the dry season when they were preferentially fed with locally available fodder plants such as cacti (*Opuntia sp.*) and Silver Thicket (*Euphorbia stenoclada*) around habitual feeding grounds (Ahlers, 2014). In contrast to cattle, seasonal movement patterns of goat herds observed in the present study corresponded more to literature reports. Even though goats were generally managed in a similar manner to zebu cattle, the fact that young boys were primarily responsible for herding this species did make a difference, as they got tired more quickly than their older, cattle guarding counterparts.

Therefore they led the animals back to the village for longer and more regular midday breaks, especially during the rainy season when temperatures are the highest of the year.

The longest daily grazing itineraries and maximum distance values from night enclosure were recorded for transhumant coastal cattle herds which spent a limited period of time on the limestone plateau during the rainy season. This may be explained by the influence of non-environmental factors, in particular the economic and social circumstances in this temporal environment, on the mobility strategies of these "outside herders" as suggested by Baker and Hoffman (2006) and Turner et al. (2011). Although Battistini (1966) emphasized the equal rights of coastal herders on plateau pastures dating back to ancient agreements between the respective clans and families, transhumant herds were still only temporary visitors and therefore might, to a certain extent, have had less access to the grazing grounds around their temporal homesteads than the residential herds. At the same time, the migrating herds were free to cross the territorial borders between different villages. Consequently they would reach more distant pasture areas while the residential herds were restricted to their own village grazing territory and were only allowed to graze on neighboring ground in times of severe need (Projet SuLaMa, 2011).

### 2.4.2 Spatio-temporal variations in land use

The land cover preference of cattle and goat herds mostly reflected the spatial occurrence of specific LCC within the pasture areas of each village and therefore quite likely differ from other studies. For example, Tsirahamba and Kaufmann (2008) pointed to the importance of spiny forests as zebu pasture for an area just south of the study region, while this LCC was rarely found along the daily itineraries of the monitored herds and therefore was not important for grazing in the present study. However, the preference of both cattle and goat herds to graze on arable land in most villages was surprising. Usually, livestock was not allowed to enter these zones, especially during the cropping season, with some exceptions made for draught oxen and smaller flocks of sheep, and violations were usually punished (Fieloux and Rakotomalala, 1987). However, it must be noted that we grouped together both actively managed fields and abandoned ones, that is fallow areas, in the LCC *cultivated and abandoned cropland*, since they were often hard to distinguish from satellite imagery and even field observations without specific local knowledge. Especially in the coastal zone, former fields were sometimes converted to private pastures which were of great importance for the herds' fodder supply during the dry season. Usually, old living fences composed of cacti and other plant material remained around these private pastures, delineating them. At the same time, fallow fields might have been inadvertently classified as open areas with hardly any vegetation cover (Brinkmann et al., 2014). On the plateau, arable areas are sometimes expanding with a smoother transition into the open savanna, the habitual pasture areas. Together with livestock grazing this expansion of cropland, as observed for the study region by Brinkmann et al. (2014) from their analysis of satellite images for the years 2004 and 2013, is regarded as one of the main threats for the natural vegetation and a major cause of deforestation in southwestern Madagascar (Casse et al., 2004). It also increases the potential for conflicts between crop farmers and livestock keepers due to crop damage as reported from agropastoral societies in other dryland regions (Bassett, 1986; Turner et al., 2014). Transhumant herds are particularly vulnerable to the effects of cropland expansion as this may affect their traditional transhumance corridors and destination areas (Turner et al., 2011).

Especially on the limestone plateau, the avoidance of farmer-herder conflicts was often mentioned by livestock keepers as reason for temporary shifting herds to encampments outside the villages of origin. This was observed for isolated herds of both species, mostly during the rainy and early dry season, when cropping activities were frequent and water was not a limiting factor. On the coastal plain, in contrast, this sort of micro-mobility of herds (Adriansen, 2008) was mostly occurring in the course of the dry season in search of better pastures.

Finally, the comparatively high proportion of time spent feeding within or around settlement areas in relation to the occurrence of this LCC proved a certain importance of these spots for the animals' nutrition. This was especially true for the herds that were moved back to the villages at noon without being corralled. Many of the animals then ranged around freely and sporadically continued to feed on shrubs and the thin turf growing in between the houses before returning to pasture with their herders for the cooler hours of the afternoon. The same was true when herds came back from long distance visits to water points in the dry season. For this reason, the areas closest to the livestock keepers' households are likely to be affected most by the animals, consequently showing certain signs of overgrazing as described by Butt (2010a) for the Maasai in Kenya.

### 2.4.3 Other factors influencing land use and herd management

Apart from seasonal constraints in water and forage availability, the spatial limitations and access restrictions due to the ongoing expansion of agricultural land around the settlement areas, as well as the existence of the Tsimanampetsotsa National Park, a steadily increasing risk of livestock raiding proved to be another important factor influencing the region's system of animal husbandry. Even though this parameter could not be clearly tackled with the experimental approach of this study, reports and occasional observations of frequent changes in pasture grounds due to this menace confirmed its influence on the management and the spatio-temporal distribution of livestock herds throughout the area.

The theft of domestic animals and especially zebus has always been an issue for the region's livestock farmers but was traditionally considered a petty crime and a means of providing masculine prowess (Fieloux and Rakotomalala, 1987; Hoerner, 1982). However, Fauroux (1989a, 1989b) already referred to more organized and violent cattle raids in southwestern Madagascar in the 1940s and 1980s, then even provoking limited military counteractions. Notably in the south of the island, the situation has clearly deteriorated within the past years, reflecting the country's ongoing political and economic crisis (Amnesty International, 2013; Fafchamps and Moser, 2003; Ignace, 2010). Presumably, cattle originating from such raids provided about 30 – 40% of meat on the national beef market a decade ago as reported by Fauroux (2004). For a while, due to its remoteness, the study area was not greatly affected by these serious forms of livestock theft. However, in the more recent past, gangs of sometimes heavily armed cattle raiders (*dahalo* in High Malagasy or *malaso* in the southern dialect) have infiltrated the study region to an increasing degree. Thereby they clearly have a stronger impact on the spacious limestone plateau than on the coastal zone which is less spacious so that crime can easier be prosecuted.

As a result, local pastoralists have been forced to adapt to this increasingly tense security situation by more frequently changing daily grazing grounds and shifting their cattle to outer livestock camps. This includes taking their herds on a sort of "inverse" transhumance towards the presumably safer coastal zones in the course of the dry season (Götter, 2014). Such risk-avoiding strategy, which has also been described by Niamir-Fuller (1999b) for pastoralists in Uganda, is not sufficient to counter the risk of becoming the victim of a raid, though. Transhumant herds from the coastal plain proved to be particularly vulnerable to raids on the plateau during the two years of survey. Several affected transhumant herders were observed to change their grazing grounds and transhumance location in direct response to either actual *malaso* attacks or rumors of such activities. Most of these herds then moved back to their coastal home grounds far earlier than originally planned or reported in the past, accompanied by additional cattle herds originating from the limestone plateau which spent the rest of the rainy and parts of the dry season in the supposedly safer region. This trend in turn currently increases the grazing pressure on the scarce vegetation of the coastal plain which, in the past, was able to regenerate during the absence of the transhumant herds in the rainy season. However, since these cattle plus additional herds now tend to come back earlier, the required regeneration time, especially for the herbaceous vegetation, may not be long enough anymore. Furthermore, the potential for conflict with resident crop farmers is also increased by the early return of transhumant herds but especially by the newcomers from the plateau (Niamir-Fuller, 1999a; Swallow, 1994; Turner et al., 2011). Herd owners are consequently obliged to violate prohibitions, e.g. by conducting their animals at a progressive rate into the protected zones of the Tsimanampetsotsa National Park for grazing. Rising insecurity may therefore severely alter the system of animal husbandry in the whole region where state authorities have little power and livestock keepers can hardly expect any support from the government.

## 2.5 Conclusions

The comparison of two geographically separated study sites within the same area of research, closely linked by the seasonal migration of transhumant cattle herds, illustrates clear trends for differentiation in herding strategies and grazing land use to cope with region-specific constraints. While coastal livestock face limited forage availability in the course of the dry season, leading to increased mobility to gain access to better pasture grounds, cattle and goats on the limestone plateau particularly encounter seasonal water scarcity. Currently, the growing risk of cattle raids, especially on the plateau, leads to a further deterioration of the situation for residential but especially for transhumant herds from the coast. As a consequence, pastoralists are forced to relocate their animals more frequently and to modify their transhumance patterns, resulting in negative consequences for the fragile vegetation of the coastal zone and for the protected area of the national park, while at the same time increasing the potential for farmer-herder conflicts.

Nonetheless, some suggestions for improvement can be made, such as using remote plateau areas that are avoided by the herders due to water scarcity or the risk of assaults to produce hay for livestock kept safely in village confines; a process so far not practiced at all by local pastoralists. In the same region, the construction of further water retention basins for livestock may ensure the animals' water supply and delay the need for traveling to distant water sources in the course of the dry season, when herds are from experience particularly vulnerable to attacks from cattle raiders, for at least several weeks or even months. In the coastal plain, encouraging the systematic plantation of fodder plants, in particular the cuttage-based forestation of *Euphorbia stenoclada*, could at least counteract the problem of overgrazing. However, creating enhanced security in the region would be crucial but firstly requires political and economic stability at the national level to achieve enduring improvements for livestock keepers in southwestern Madagascar.

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## Appendix

**Table 2.A.1.** Duration of cattle and goat herds resting (near villages / corrals) during noontime.

| Cattle | Coast | | Plateau | | |
|---|---|---|---|---|---|
| | Ankilibory | Efoetse | Andremba | Miarintsoa | C-T |
| EDS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 1.7±0.73 | 0.8±0.16 | 0.8±0.25 | n/a | |
| Occurrence on % of grazing days | 28.6 | 48.6 | 57.1 | 0.0 | |
| LDS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 0.8±0.00 | 2.3±0.34 | 1.4±0.31 | 3.7±0.95 | |
| Occurrence on % of grazing days | 5.3 | 48.6 | 50.0 | 8.3 | |
| RS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 1.8±0.69 | 1.6±0.10 | 1.3±0.31 | 1.6±0.33 | 1.5±0.20 |
| Occurrence on % of grazing days | 50.0 | 56.3 | 78.8 | 47.2 | 58.3 |
| **Goats** | **Coast** | | **Plateau** | | |
| | **Ankilibory** | **Efoetse** | **Andremba** | **Miarintsoa** | |
| EDS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 2.0±0.36 | 2.7±0.28 | 1.3±0.21 | 2.2±0.25 | |
| Occurrence on % of grazing days | 71.4 | 58.8 | 81.8 | 86.7 | |
| LDS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 3.4±0.55 | 3.6±0.33 | 3.0±0.48 | 3.7±0.32 | |
| Occurrence on % of grazing days | 62.5 | 62.5 | 91.4 | 71.4 | |
| RS | | | | | |
| Time in / near stable corral (h $d^{-1}$ ± SE) | 2.1±0.49 | 3.4±0.39 | 2.0±0.26 | 2.8±0.42 | |
| Occurrence on % of grazing days | 55.6 | 55.9 | 97.1 | 65.0 | |

C-T = Transhumant cattle herds on limestone plateau, EDS = early dry season, LDS = late dry season, RS = rainy season, SE = standard error, n/a = no recorded noon break.

**Table 2.A.2.** Proportions of land cover classes (LCC, details see Table 2.2) within the herds' grazing utilization zones (buffer area) and observed resting as well as walking time per LCC of cattle. Detailed monitoring of behavior was not performed when cattle herds returned to the village at noon and were kept within their enclosures for noon resting time.

**Coast**

| LCC | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| **Ankilibory** | | | | | | |
| EDS | | | | | | |
| Buffer area (%) | 80.8 | 0.4 | <0.1 | 5.0 | 11.9 | 1.8 |
| Resting (%) | 66.7 | 0.0 | 0.0 | 0.0 | 15.8 | 17.5 |
| Walking (%) | 73.0 | 0.0 | 0.0 | 1.3 | 19.7 | 6.1 |
| LDS | | | | | | |
| Buffer area (%) | 80.7 | <0.2 | 0.1 | 10.7 | 6.3 | 2.0 |
| Resting (%) | 77.6 | 0.0 | 0.0 | 8.1 | 4.3 | 10.0 |
| Walking (%) | 81.8 | 0.7 | 0.0 | 4.3 | 8.0 | 5.3 |
| RS | | | | | | |
| Buffer area (%) | 83.7 | 0.2 | 0.1 | 2.5 | 10.3 | 3.2 |
| Resting (%) | 60.8 | 0.0 | 0.0 | 0.0 | 10.3 | 28.9 |
| Walking (%) | 58.2 | 0.0 | 0.0 | 0.0 | 17.4 | 24.4 |
| **Efoetse** | | | | | | |
| EDS | | | | | | |
| Buffer area (%) | 74.2 | 0.7 | 0.1 | 2.8 | 21.0 | 1.2 |
| Resting (%) | 60.6 | 0.0 | 0.0 | 0.0 | 30.9 | 8.5 |
| Walking (%) | 59.2 | 0.3 | 0.0 | 0.9 | 25.7 | 13.9 |
| LDS | | | | | | |
| Buffer area (%) | 73.3 | <0.1 | <0.1 | 1.2 | 24.5 | 0.8 |
| Resting (%) | 54.7 | 0.0 | 0.0 | 0.0 | 38.5 | 6.9 |
| Walking (%) | 58.1 | 0.0 | 0.0 | 0.2 | 36.8 | 5.0 |
| RS | | | | | | |
| Buffer area (%) | 82.1 | n/a | n/a | 0.2 | 17.0 | 0.7 |
| Resting (%) | 83.3 | 0.0 | 0.0 | 0.0 | 11.1 | 5.6 |
| Walking (%) | 81.8 | 0.0 | 0.0 | 0.0 | 8.1 | 10.2 |

**Plateau**

| LCC | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| **Andremba** | | | | | | |
| EDS | | | | | | |
| Buffer area (%) | 56.7 | 2.8 | 27.3 | 4.1 | 8.5 | 0.6 |
| Resting (%) | 22.7 | 0.0 | 63.7 | 1.2 | 12.5 | 0.0 |
| Walking (%) | 51.1 | 2.1 | 26.0 | 3.2 | 15.2 | 2.4 |
| LDS | | | | | | |
| Buffer area (%) | 55.7 | 2.7 | 30.0 | 4.1 | 7.0 | 0.5 |
| Resting (%) | 48.2 | 0.0 | 39.0 | 0.0 | 6.3 | 6.6 |
| Walking (%) | 40.9 | 5.3 | 24.4 | 3.7 | 19.8 | 4.9 |
| RS | | | | | | |
| Buffer area (%) | 48.2 | 4.0 | 34.6 | 4.6 | 7.9 | 0.7 |
| Resting (%) | 32.4 | 9.4 | 38.5 | 2.4 | 12.7 | 4.6 |
| Walking (%) | 31.3 | 10.9 | 40.2 | 2.0 | 15.4 | 1.8 |
| **Miarintsoa** | | | | | | |
| EDS | | | | | | |
| Buffer area (%) | 9.2 | 27.3 | 34.5 | 12.4 | 15.7 | 0.9 |
| Resting (%) | 14.0 | 41.9 | 28.7 | 0.0 | 15.1 | 0.5 |
| Walking (%) | 7.9 | 22.7 | 46.4 | 7.1 | 11.6 | 4.4 |
| LDS | | | | | | |
| Buffer area (%) | 8.0 | 33.8 | 37.3 | 5.6 | 14.1 | 1.2 |
| Resting (%) | 2.4 | 69.8 | 11.4 | 2.5 | 9.6 | 4.3 |
| Walking (%) | 2.1 | 33.0 | 43.1 | 1.1 | 13.2 | 7.6 |
| RS | | | | | | |
| Buffer area (%) | 14.8 | 26.3 | 46.7 | 6.2 | 4.8 | 1.2 |
| Resting (%) | 15.2 | 3.1 | 67.2 | 3.7 | 10.8 | 0.0 |
| Walking (%) | 19.3 | 12.7 | 54.0 | 2.0 | 5.3 | 5.8 |
| **Transhumant cattle herds** | | | | | | |
| RS | | | | | | |
| Buffer area (%) | 9.5 | 30.8 | 47.9 | 7.8 | 3.2 | 0.8 |
| Resting (%) | 15.8 | 23.6 | 38.6 | 2.3 | 0.8 | 18.8 |
| Walking (%) | 6.2 | 23.0 | 55.7 | 5.5 | 1.2 | 8.4 |

EDS = early dry season, LDS = late dry season, RS = rainy season.

LCC labelling is equivalent to Table 2.2.

**Table 2.A.3.** Proportions of land cover classes (LCC, details see Table 2.2) within the flocks' grazing utilization zones (buffer area) and observed resting as well as walking time per LCC of goats. Detailed monitoring of behavior was not performed when goat flocks returned to the village at noon and were kept within their enclosures for noon resting time.

| **Coast** | | | | | | | **Plateau** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LCC** | **I** | **II** | **III** | **IV** | **V** | **VI** | **LCC** | **I** | **II** | **III** | **IV** | **V** | **VI** |
| **Ankilibory** | | | | | | | **Andremba** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 77.1 | 0.7 | 0.2 | 8.9 | 10.0 | 3.1 | Buffer area (%) | 55.0 | 1.7 | 29.3 | 4.5 | 8.9 | 0.6 |
| Resting (%) | 48.8 | 0.0 | 0.0 | 1.7 | 3.2 | 46.3 | Resting (%) | 33.4 | 0.8 | 42.6 | 0.0 | 17.9 | 5.3 |
| Walking (%) | 57.1 | 0.6 | 0.0 | 3.4 | 14.7 | 23.6 | Walking (%) | 36.5 | 2.1 | 19.9 | 1.8 | 16.7 | 23.1 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 78.5 | 0.7 | <0.1 | 8.5 | 8.9 | 3.3 | Buffer area (%) | 52.2 | 1.8 | 31.7 | 3.5 | 10.4 | 0.4 |
| Resting (%) | 41.6 | 0.0 | 0.0 | 8.3 | 2.8 | 47.3 | Resting (%) | 51.2 | 0.7 | 22.7 | 0.7 | 19.9 | 4.7 |
| Walking (%) | 67.5 | 0.0 | 0.0 | 3.3 | 6.8 | 22.3 | Walking (%) | 39.7 | 3.9 | 30.1 | 3.3 | 13.0 | 10.0 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 80.5 | 0.8 | 0.3 | 10.0 | 4.8 | 3.6 | Buffer area (%) | 49.0 | 1.9 | 33.0 | 4.1 | 11.2 | 0.8 |
| Resting (%) | 49.2 | 0.0 | 0.0 | 1.2 | 5.1 | 44.5 | Resting (%) | 46.4 | 5.7 | 28.1 | 2.3 | 8.5 | 9.0 |
| Walking (%) | 52.6 | 0.0 | 0.0 | 4.0 | 13.1 | 30.3 | Walking (%) | 36.7 | 2.7 | 22.6 | 2.6 | 17.5 | 17.9 |
| **Efoetse** | | | | | | | **Miarintsoa** | | | | | | |
| EDS | | | | | | | EDS | | | | | | |
| Buffer area (%) | 75.3 | n/a | n/a | <0.1 | 22.7 | 1.9 | Buffer area (%) | 5.7 | 33.0 | 37.1 | 7.2 | 15.0 | 2.0 |
| Resting (%) | 83.0 | 0.0 | 0.0 | 0.0 | 10.1 | 6.5 | Resting (%) | 3.7 | 40.2 | 42.7 | 1.9 | 6.1 | 5.6 |
| Walking (%) | 73.4 | 0.0 | 0.0 | 0.0 | 18.4 | 7.4 | Walking (%) | 7.7 | 20.6 | 39.1 | 2.4 | 11.4 | 18.9 |
| LDS | | | | | | | LDS | | | | | | |
| Buffer area (%) | 75.7 | n/a | n/a | <0.1 | 22.2 | 2.0 | Buffer area (%) | 4.9 | 33.6 | 36.5 | 4.7 | 18.3 | 2.0 |
| Resting (%) | 100.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | Resting (%) | 1.4 | 32.5 | 33.9 | 7.4 | 13.8 | 11.0 |
| Walking (%) | 71.0 | 0.0 | 0.0 | 0.0 | 19.6 | 9.4 | Walking (%) | 2.4 | 28.8 | 50.7 | 0.0 | 8.1 | 9.9 |
| RS | | | | | | | RS | | | | | | |
| Buffer area (%) | 76.0 | n/a | n/a | <0.1 | 21.8 | 2.1 | Buffer area (%) | 7.6 | 37.6 | 42.3 | 7.2 | 3.3 | 2.0 |
| Resting (%) | 94.8 | 0.0 | 0.0 | 0.0 | 1.3 | 3.8 | Resting (%) | 9.0 | 43.0 | 34.3 | 0.0 | 0.0 | 13.7 |
| Walking (%) | 70.8 | 0.0 | 0.0 | 0.0 | 15.8 | 13.5 | Walking (%) | 12.8 | 12.7 | 52.2 | 4.2 | 2.4 | 14.6 |

EDS = early dry season, LDS = late dry season, RS = rainy season.

LCC labelling is equivalent to Table 2.2.

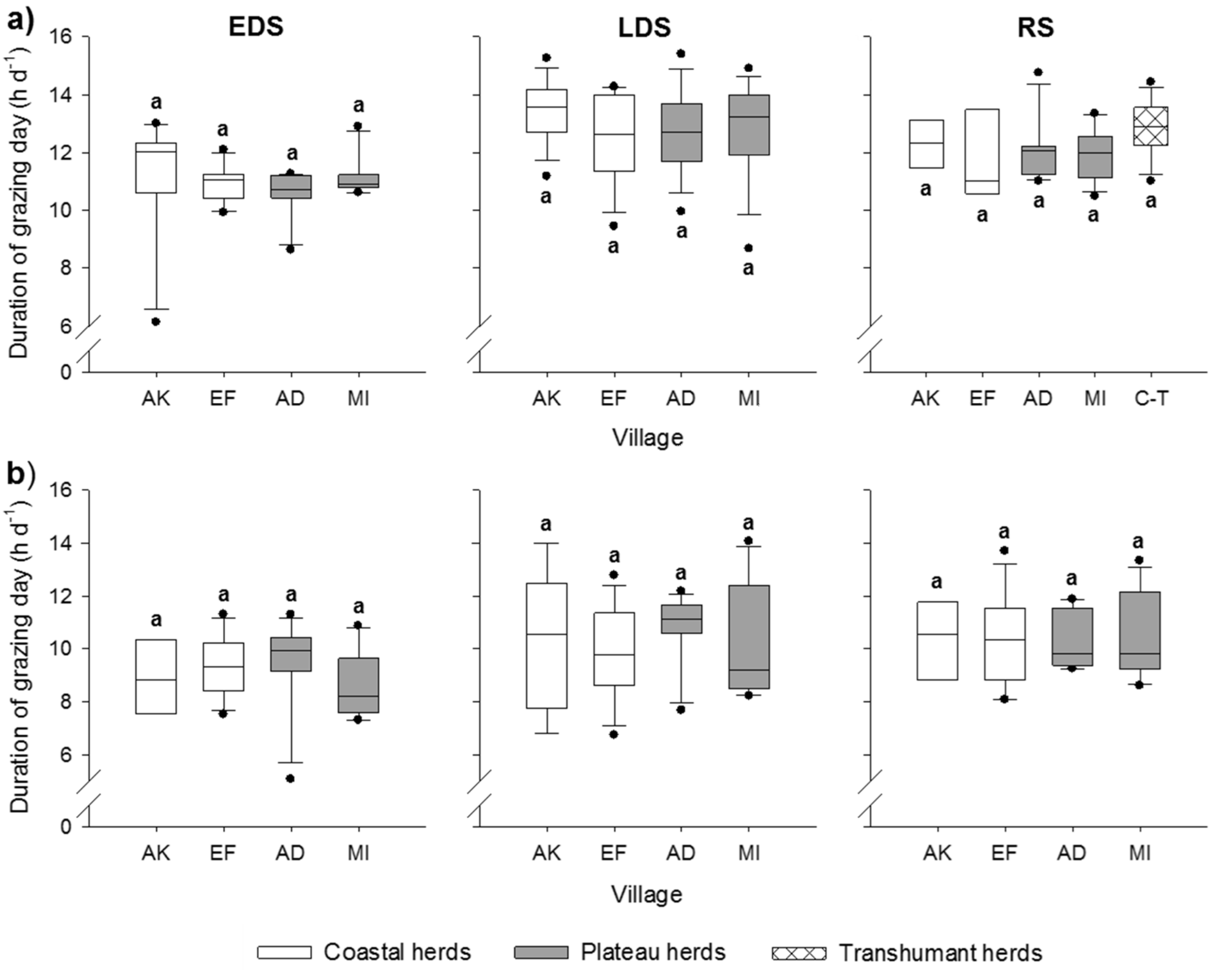


**Figure 2.A.1.** Seasonal variation in the duration of grazing days (h $d^{-1}$) of (a) cattle and (b) goat herds from Ankilibory (AK), Efoetse (EF), Andremba (AD), Miarintsoa (MI), and the transhumance cattle herds (C-T). Data are given for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS). Medians (black lines inside the boxes), interquartile ranges (width of the boxes representing the middle 50% of data), total data ranges (whiskers), and outliers (black dots) are shown. Different letters above and underneath the box plots indicate village differences at $p \leq 0.05$ according to Tukey post-hoc tests.

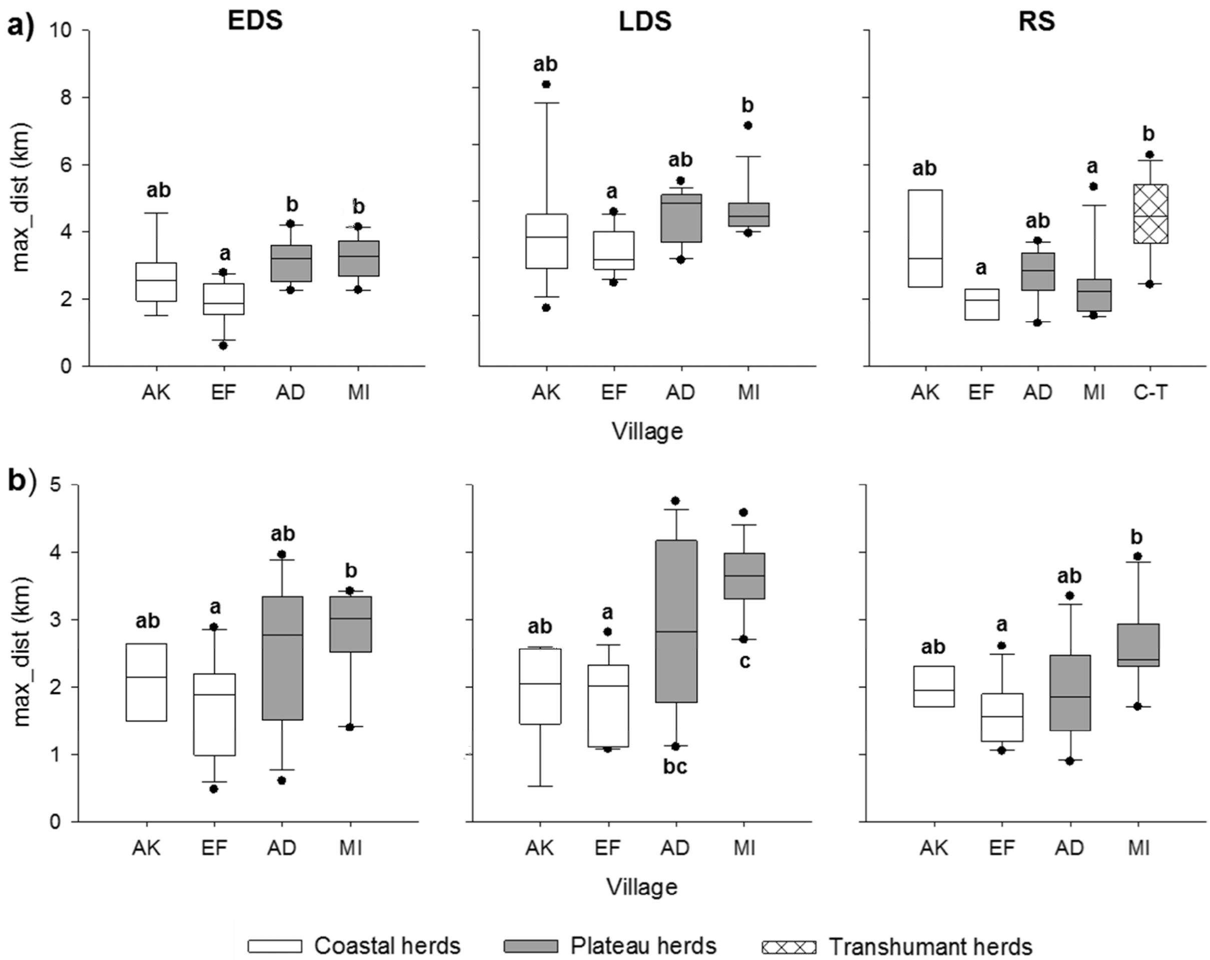


**Figure 2.A.2.** Seasonal variation in the maximum distance to night enclosures (*max_dist*, km) of (a) cattle and (b) goat herds from Ankilibory (AK), Efoetse (EF), Andremba (AD), Miarintsoa (MI), and the transhumance cattle herds (C-T). Data are given for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS). Medians (black lines inside the boxes), interquartile ranges (width of the boxes representing the middle 50% of data), total data ranges (whiskers), and outliers (black dots) are shown. Different letters above and underneath the box plots indicate village differences at $p \leq 0.05$ according to Tukey post-hoc tests. Note the different scaling of Y-axes in a) and b).

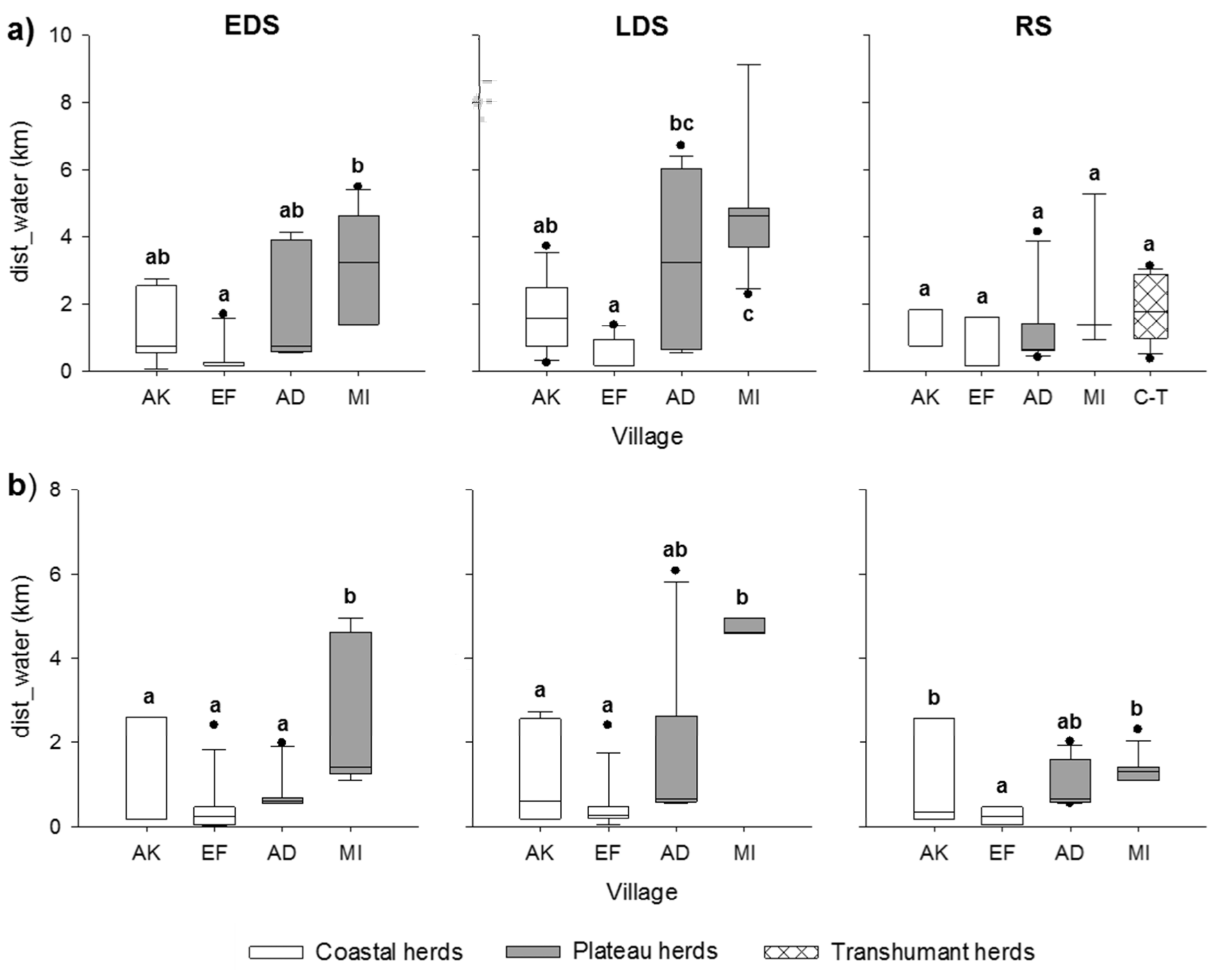


**Figure 2.A.3.** Seasonal variation in the linear distance between the night corral of (a) cattle and (b) goat herds from Ankilibory (AK), Efoetse (EF), Andremba (AD), Miarintsoa (MI), and the transhumance cattle herds (C-T) to the nearest visited water point (*dist_water*, km). Data are given for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS). Medians (black lines inside the boxes), interquartile ranges (width of the boxes representing the middle 50% of data), total data ranges (whiskers), and outliers (black dots) are shown. Different letters above and underneath the box plots indicate village differences at $p \leq 0.05$ according to Tukey post-hoc tests. Note the different scaling of Y-axes in a) and b).

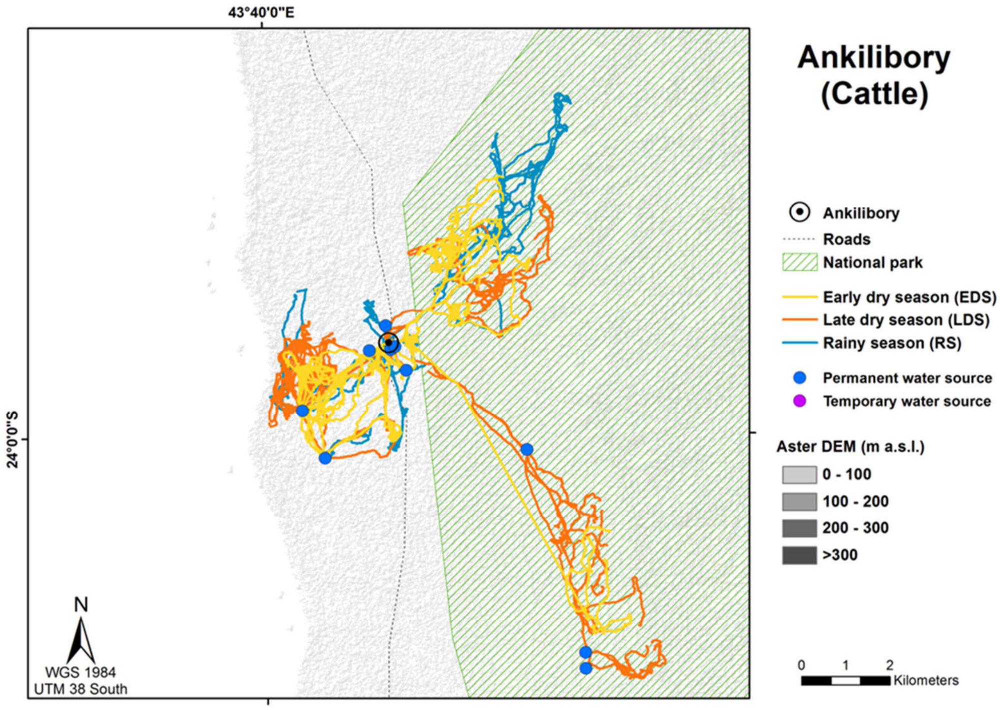


**Figure 2.A.4.** Grazing itineraries of studied cattle herds from Ankilibory between November 2011 and November 2013. Different line colors are used for different seasons (see legend).

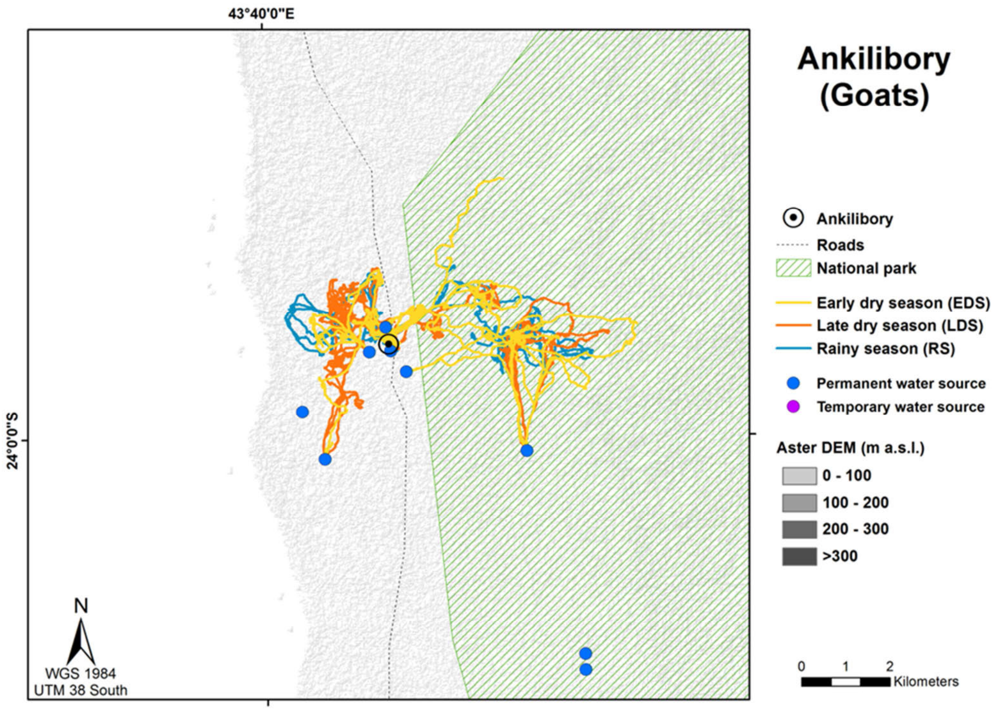


**Figure 2.A.5.** Grazing itineraries of studied goat herds from Ankilibory between November 2011 and November 2013. Different line colors are used for different seasons (see legend).

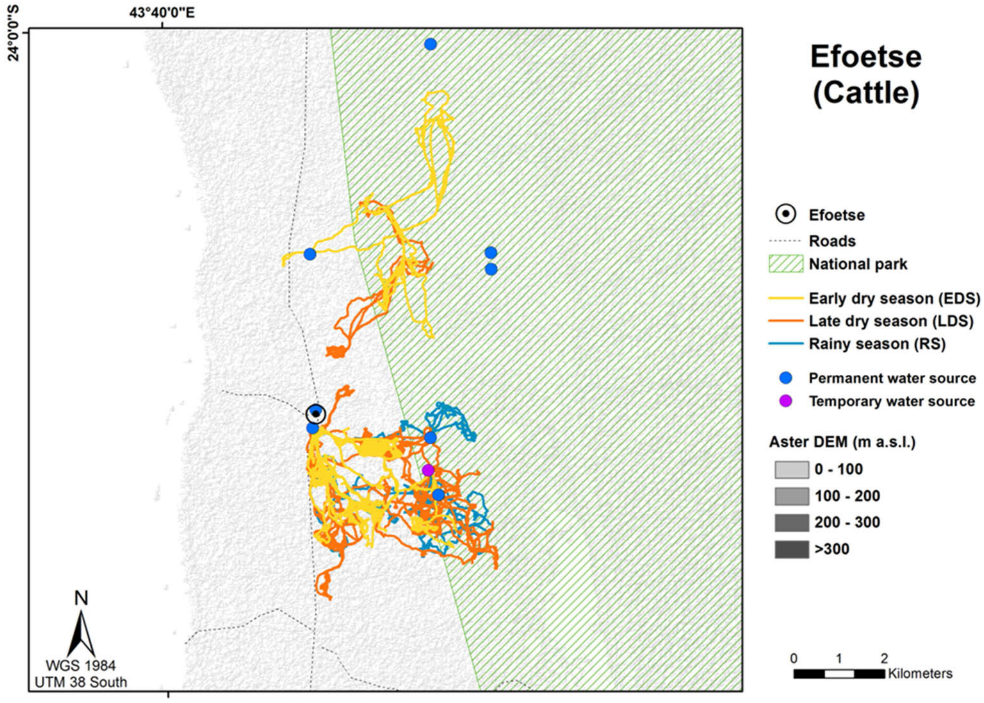


**Figure 2.A.6.** Grazing itineraries of studied cattle herds from Efoetse between November 2011 and November 2013. Different line colors are used for different seasons (see legend).

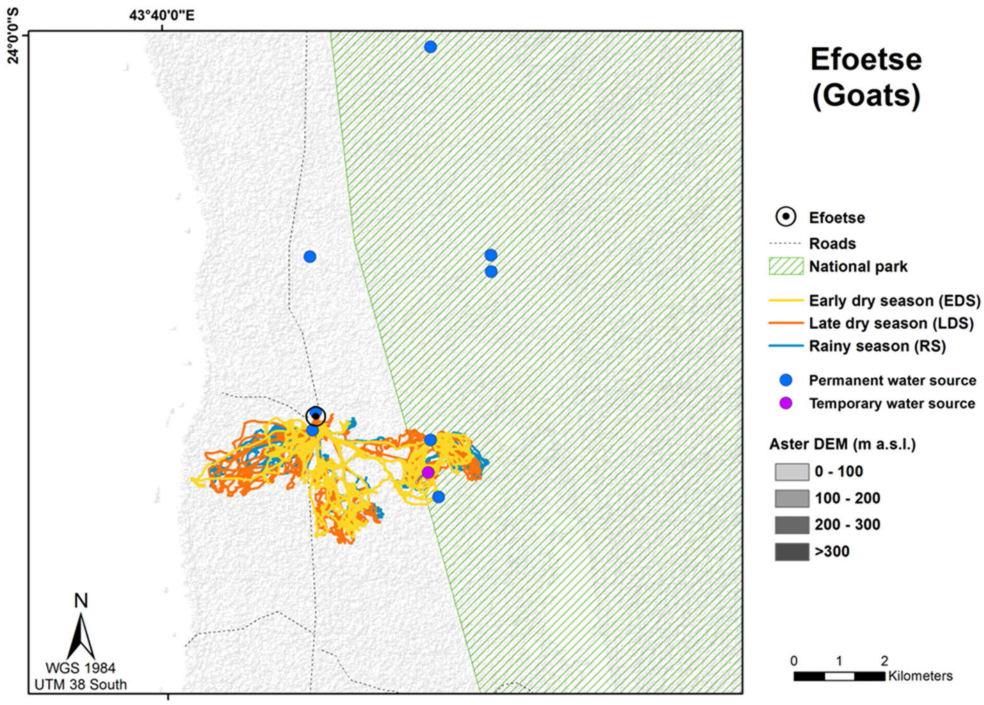


**Figure 2.A.7.** Grazing itineraries of studied goat herds from Efoetse between November 2011 and November 2013. Different line colors are used for different seasons (see legend). A temporal medium-distance dislocation of one herd in 2012 is not shown on the map.

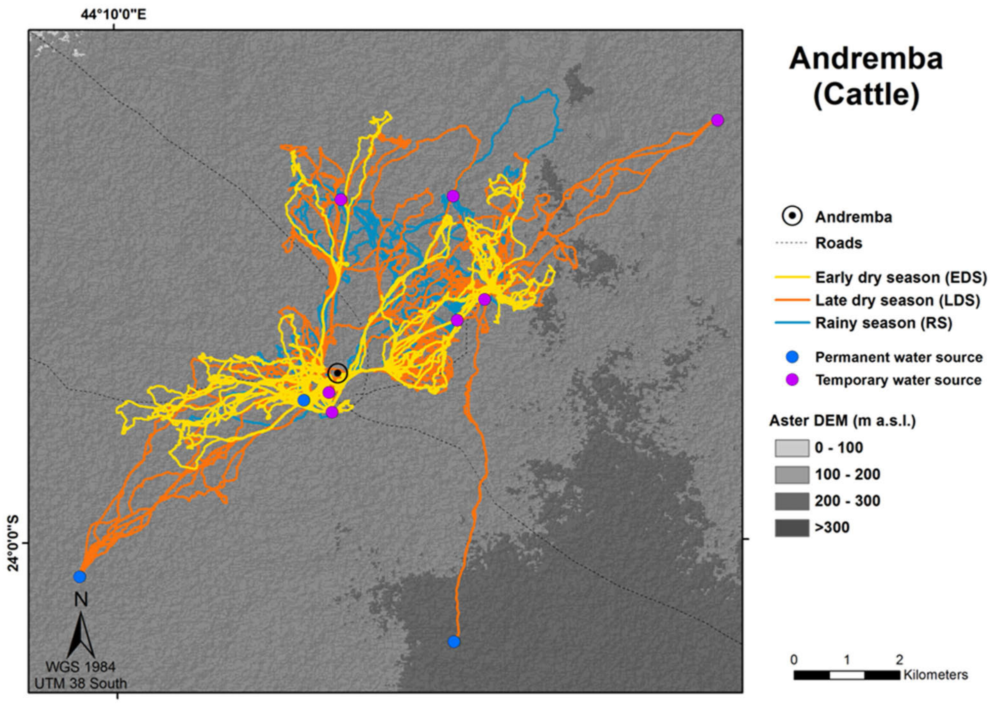


**Figure 2.A.8.** Grazing itineraries of studied cattle herds from Andremba between November 2011 and November 2013. Different line colors are used for different seasons (see legend). A temporal medium-distance dislocation of one herd in 2012 is not shown on the map.

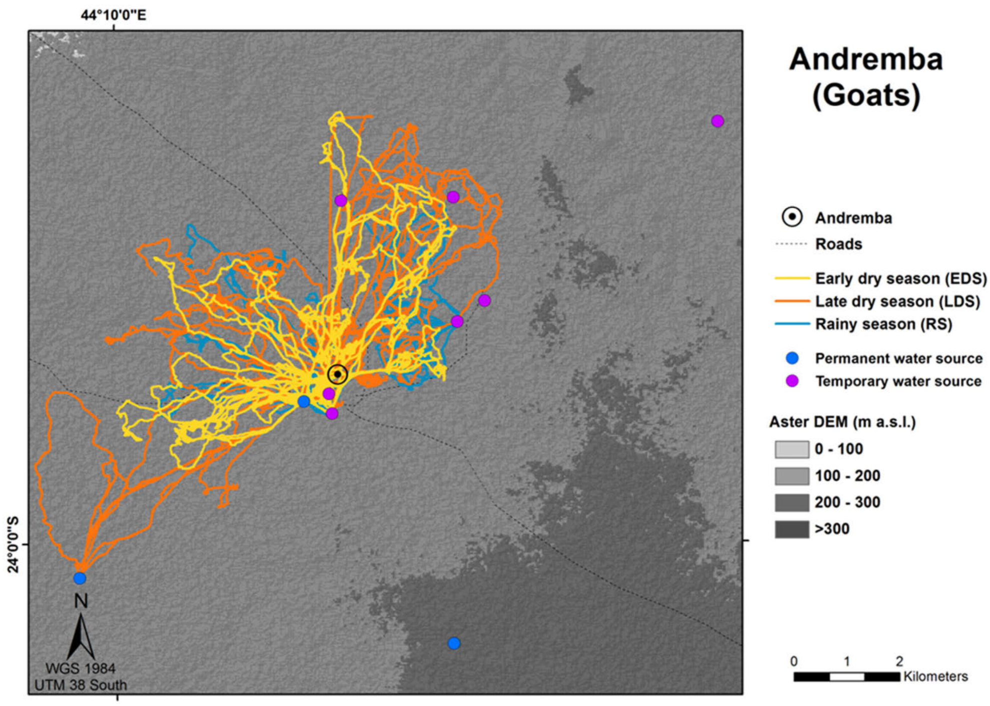


**Figure 2.A.9.** Grazing itineraries of studied cattle herds from Andremba between November 2011 and November 2013. Different line colors are used for different seasons (see legend).

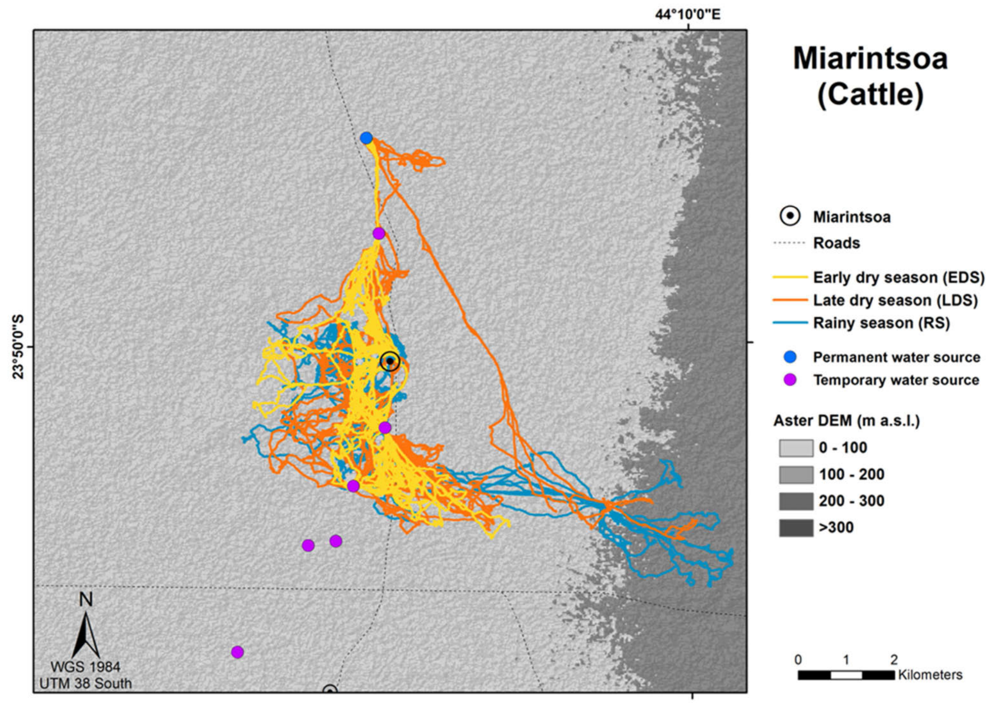


**Figure 2.A.10.** Grazing itineraries of studied cattle herds from Miarintsoa between November 2011 and November 2013. Different line colors are used for different seasons (see legend). A temporal 'in-verse' transhumance movement of one herd in 2012 and in 2013 is not shown on the map.

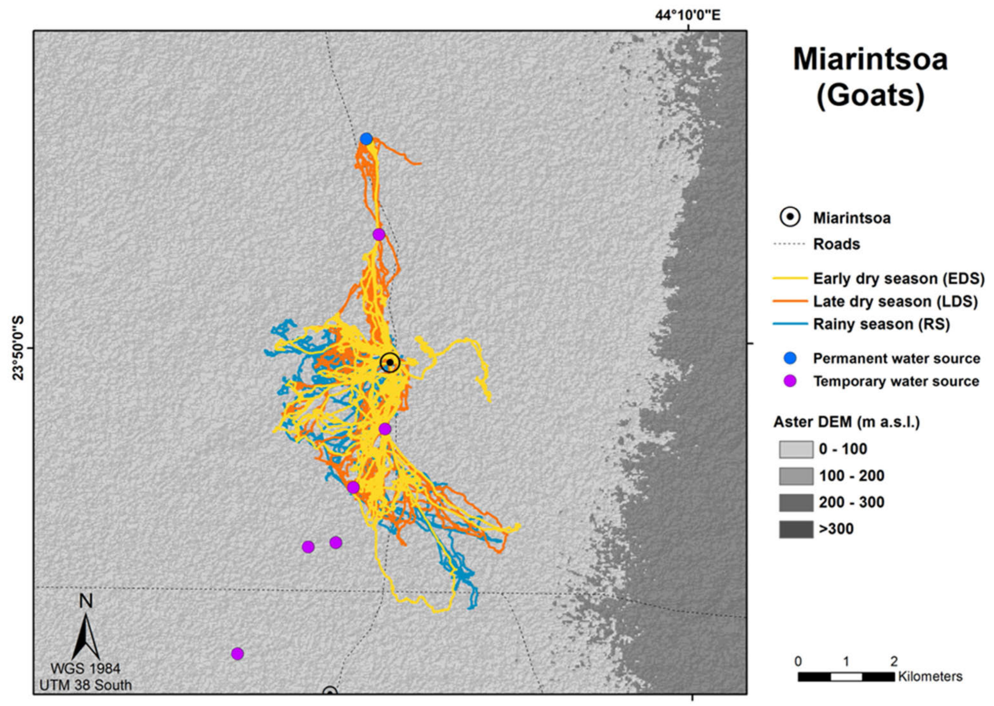


**Figure 2.A.11.** Grazing itineraries of studied goat herds from Miarintsoa between November 2011 and November 2013. Different line colors are used for different seasons (see legend).

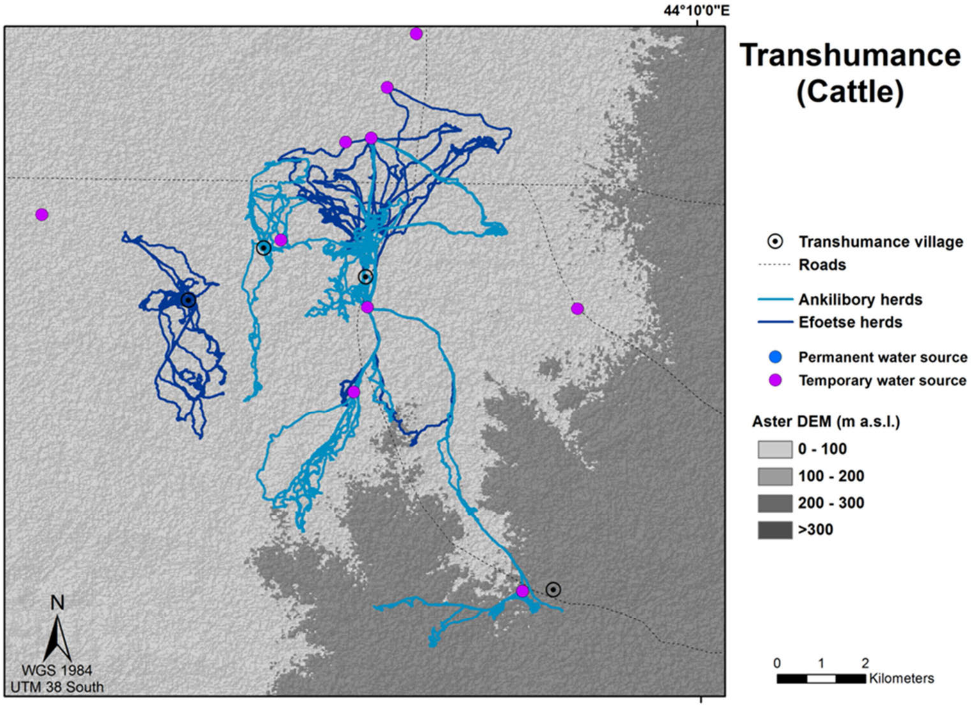


**Figure 2.A.12.** Grazing itineraries of studied cattle herds from Ankilibory and Efoetse during times of transhumance in 2012 and 2013.

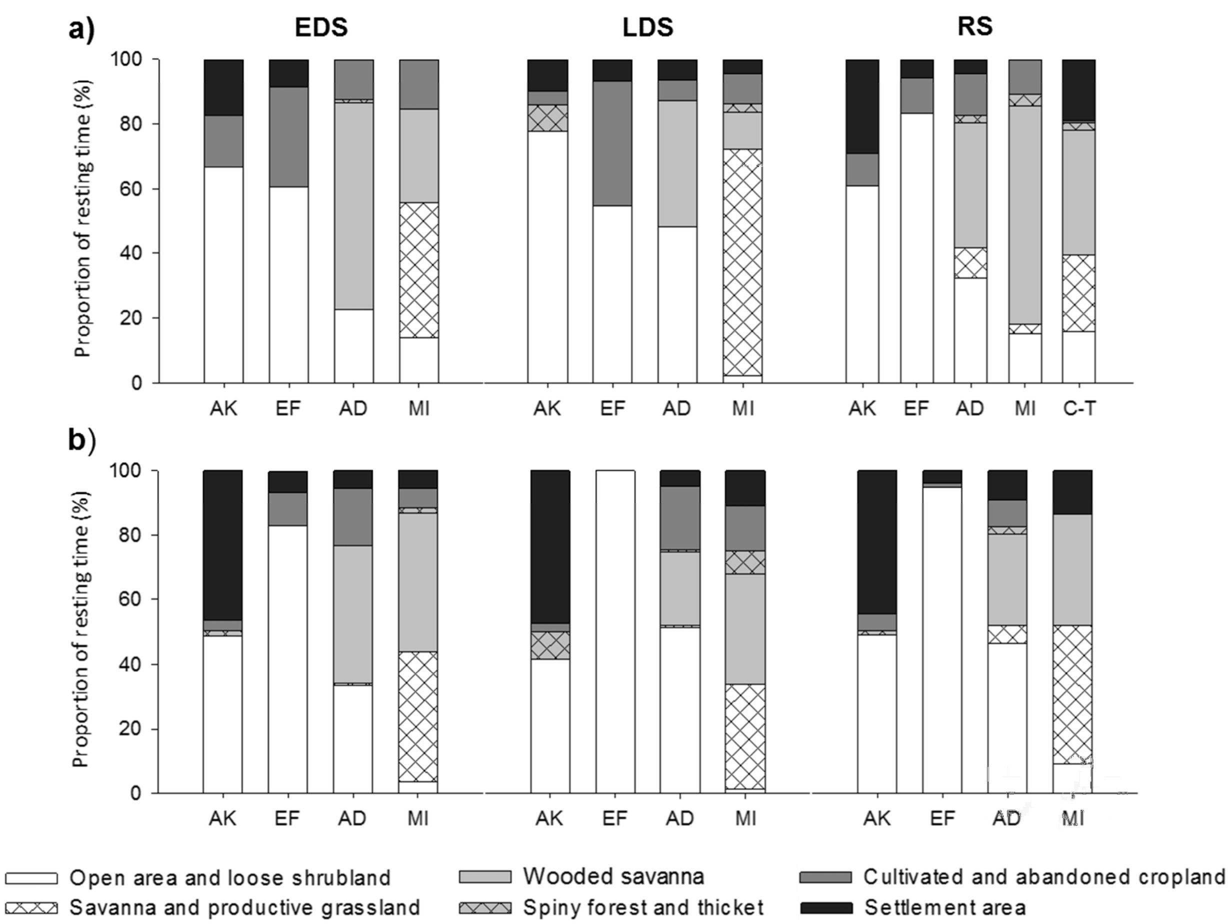


**Figure 2.A.13.** Proportion of daily resting time (%) of (a) cattle and (b) goat herds from Andremba (AD), Ankilibory (AK), Efoetse (EF), Miarintsoa (MI) and the transhumance area (C-T) spent on different land cover classes. Data are shown for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS).

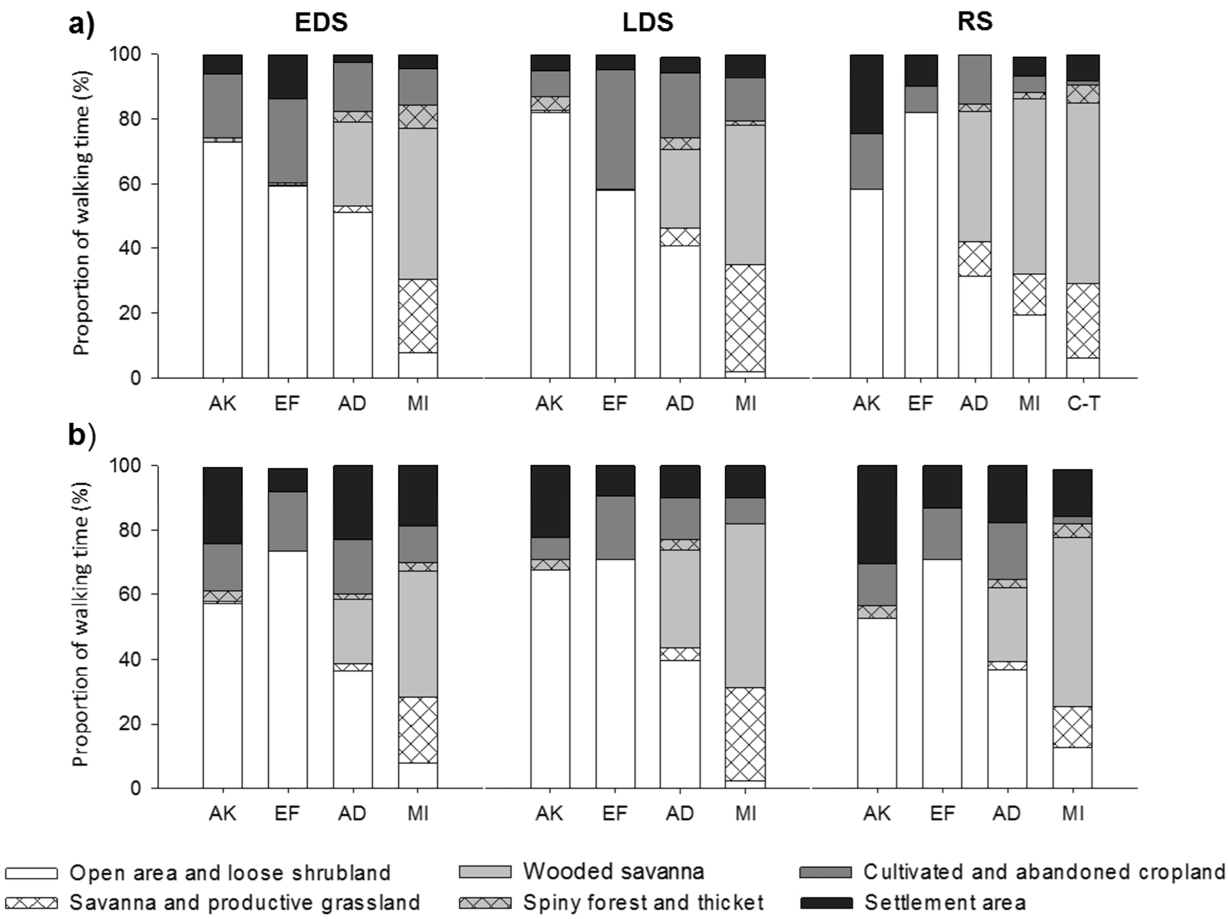


**Figure 2.A.14.** Proportion of daily walking time (%) of (a) cattle and (b) goat herds from Andremba (AD), Ankilibory (AK), Efoetse (EF), Miarintsoa (MI) and the transhumance area (C-T) spent on different land cover classes. Data are shown for the early dry season (EDS), the late dry season (LDS) and the rainy season (RS).

# Chapter 3

## Feed Selection and Diet Quality in Livestock Herds Grazing the Dry Rangelands of Southwestern Madagascar

# Feed selection and diet quality in livestock herds grazing the dry rangelands of southwestern Madagascar

## Abstract

Southwestern Madagascar is well known for its unique vegetation and ecological importance in terms of biodiversity and endemism. At the same time, the region is also home to a significant part of the nation's livestock population, largely grazing on natural pastures. In order to analyze the animals' use of natural forage resources against the seasonal variability and spatial disparities in feed quality and quantity, we investigated the preference of cattle and small ruminants for specific plant species as well as the nutritive value and digestibility of pasture vegetation. The feeding behavior of animals from 12 herds of cattle, goats, and sheep, respectively, originating from two substantially different sites of the research area, was observed. Important forage plants as well as fecal samples were analyzed for nutrient concentration while diet digestibility was assessed from the fecal nitrogen content.

Across sites and seasons, livestock fed on 133 plant species, 13 of which were of major importance for the animals' nutrition. Cattle widely consumed grasses as the principal component of their diet, while small ruminants showed a stronger preference for ligneous vegetation, all substantially decreasing in their nutritive quality and organic matter digestibility over the course of the long dry season. *Euphorbia stenoclada* and *Opuntia* sp. proved to be important supplementary forage species to bypass dry season shortages but also revealed wide Ca:P ratios (18.5:1 to 69.3:1) found characteristic for most forage plants. The results conform to a holistic pastoral regime in which livestock keepers try to make the best out of the available resources. However, the expected amplification of climatic fluctuations and external factors affecting the traditional grazing management threaten the system's balance at the expense of the area's unique nature and therefore require adequate countermeasures.

**Keywords:** *Euphorbia stenoclada*, Feces composition, Feeding behavior, Nutritive value, Pastoral livestock systems, Ruminant husbandry

## 3.1 Introduction

Under traditional management in the arid and semi-arid regions of sub-Saharan Africa, livestock farmers rely extensively on natural pastures as the major feed resource for their animals (Ngwa et al., 2000; Powell et al., 2004; Scoones, 1995). These systems cannot be considered stable in terms of productivity as they are subject to high seasonal and spatial variations in availability and quality of forage (Bezabih et al., 2014; Keba et al., 2013). They are therefore particularly vulnerable to climatic changes as especially reduced rainfall and increased frequency of droughts may limit the primary production of rangelands and increase the risk of overgrazing and degradation, resulting in food insecurity and resource conflicts (FAO, 2009). Seasonal restraints in feed supply are furthermore regarded as one major factor limiting the animals' reproductive performance in traditional pastoral systems (Mgongo et al., 2014; Rooyen and Homann-Kee Tui, 2009). While domestic livestock can react to these difficult conditions to a certain extent by adapting feeding behavior to the available resources (Sanon et al., 2007; Zampaligré et al., 2013), pastoralists have to develop additional risk-management mechanisms such as increased mobility or the use of agricultural byproducts and other supplementary feeds to improve the supply situation for their animals during times of shortage (Ben Salem and Smith, 2008; Niamir-Fuller and Turner, 1999). As long as seasonal variability remains constant, these pastoral systems may thus be kept in balance between the natural productivity of vegetation on the one and the nutritive demand of grazing livestock on the other hand. At the same time, they can easily be unsettled in consequence of extreme weather events and external factors such as changes in access rights to traditional pastures and political instability.

Over the recent past, some of these factors have been gaining importance in southern Madagascar. The dry and poorly developed region is well known for its high climatic variability which is expected to increase further in the future (Tadross et al., 2008), resulting in regular food and water shortages for both humans and livestock (Wüstefeld, 2004). Despite these difficult living conditions, the area is home to a substantial share of the national cattle population and to the majority of the country's domestic goats and sheep (FAO and AGAL, 2005). Most of the animals graze on vast savanna pastures which cover about 68% of the island's total surface (Granier, 1970; Rasambainarivo and Ranaivoarivelo, 2006). Nevertheless, they are also found within the boundaries of protected areas, causing a certain impact on the region's unique and highly endemic dry forest vegetation (Ratovonamana et al., 2013) which has been identified as a target ecoregion for global nature conservation due to its outstanding biodiversity (Olson and Dinerstein, 2002). However, some of these areas are also traditional forest pastures, frequented especially during the long dry season (Kaufmann, 2008). Despite these general insights, little is known to date about the nutritive value of the region's different pasture types and the animals' preference for specific forage plants. The few studies available either exclusively focus on savanna grasses (Rasambainarivo and Razafindratsita, 1987) or discount spatio-temporal variations in the abundance and quality of livestock forage (Randrianariveloseheno, 2004). In the face of low reproductive performance of local livestock, which has been found inferior compared to similar pastoral environments (Chapter 4), but also of climate change and other challenges to the region's livestock farmers, this knowledge on feed selection and diet quality seems all the more important. Aside from seasonal fluctuation in forage and water availability, the increasing number of armed cattle raids and land use conflicts due to the expansion of arable land (Brinkmann et al., 2014) has forced livestock owners to adapt their herd and grazing management (Chapter 2) with largely unpredictable consequences for the region's vegetation.

This study therefore aims to determine (i) the most important forage species for local livestock and (ii) the nutritive value of the natural pasture vegetation, both against the background of spatio-temporal variation. In consideration of recent changes in grazing management, strategies are explored that allow continuing pastoral activities in the area without overstraining its fragile natural resources.

## 3.2 Materials and methods

### 3.2.1 Study location and agricultural system

Field work was carried out in the Mahafaly region of southwestern Madagascar, located about 60 km south of the administrative center of Toliara. The area is characterized by an arid to semi-arid climate with an annual average temperature of 24°C and irregular precipitation of less than 500 mm per year with high seasonal fluctuations (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protegées, 1999). The dry season usually lasts from April to November but regularly extends into late December. The study region can roughly be divided into two substantially different sites, both showing a high level of biological diversity and endemism, especially of plant species (Du Puy and Moat, 1998; Phillipson, 1996). Along the sea, a coastal plain stretches on calciferous sandy soil dominated by a vegetation community described by Razanaka (1996) as *Euphorbia stenoclada*[1] coastal scrubland with loose patches of *Sporobolus* spp. salt meadow communities. Further inland, after a gentle rise in altitude, a limestone plateau of 350 m a.s.l. at maximum opens up with savanna-like landscapes on rocky substrates and grasslands dominated by *Heteropogon contortus* and *Aristida* spp. (Morat, 1973), occasionally interspersed by dense bush- and woodlands.

The area is sparsely populated by agro-pastoral communities with a strong focus on animal husbandry and small-scale agriculture (Battistini, 1966; Kaufmann, 2004), both still conducted in a traditional extensive way. Apart from poultry, people keep zebu cattle, goats, and sheep which define both their owners' economic and social status (Chapter 4). Ruminant herds are usually corralled overnight within the settlements or in separate enclosures up to five kilometers away. They are taken to pasture by boys (normally responsible for small ruminant herds) or young men (cattle herds) in the early morning (usually between 5:30 and 6:30 a.m., depending on season) and return to their homesteads in the evening (usually between 6:00 and 7:00 p.m.), occasionally interrupted by a one to three-hour midday break for herders and animals in the villages (Chapter 2). Livestock is predominantly herded on communal pastures throughout the year, feeding on the local vegetation. In the course of the dry season, when feed supply becomes insufficient, the animals are provided with supplementary forage plants, in particular Prickly Pear Cactus (*Opuntia* sp.) and Silver Thicket (*Euphorbia stenoclada*), the latter restricted to the study area's coastal strip. Crop residues, in contrast, are mostly fed to draft oxen and sick individuals but only sporadically to healthy animals even when natural forage becomes scarce. Throughout the year, livestock spend about two-thirds of daily pasture time on actual feed intake (66.6±1.02%), with some significant differences between animal species but also sites and seasons (Chapter 2). From a livestock keeping point of view, both

[1] For authorities of plant names see Appendix Table A.3.1.

sites of the investigation area are closely linked to one another by annual transhumance movements of predominantly cattle herds. These are, for a period of several weeks or months, migrating from the coastal zone to the plateau at the onset of the rains in the upland region. Recently, also an inverse migration pattern from the plateau to the coastal plain is observed during the dry season, which is due to the increasing risk of armed cattle raids in the plateau area during this time of the year (Chapter 2).

### 3.2.2 Experimental design and data collection

The animals' grazing behavior and selection of forage plants on pasture was studied by observing herds of cattle and flocks of goats and sheep originating from four villages: Ankilibory (23°54'S, 43°41'E; 18 m a.s.l.) and Efoetse (24°04'S, 43°42'E; 17 m a.s.l.) located on the coastal plain as well as Andremba (23°58'S, 44°12'; 273 m a.s.l.) and Miarintsoa (23°50'S, 44°06'E; 183 m a.s.l.) on the limestone plateau. Between November 2011 and November 2013, one adult female individual each from three representative herds per livestock species and village was chosen to be followed on one of three consecutive observation days. Its activities and, in the case of eating at that specific moment, consumed plants and plant parts were monitored by direct observation every 5 minutes from the early morning until the return to the night corral in the evening. At the end of the three days, data from all herds were averaged per species, village, and monitoring period, respectively. The animals to be observed were chosen to be of middle social rank to ensure the representability of their feeding patterns and forage species selection for the whole herd (Moritz et al., 2012; Reinhardt, 1982). The survey was conducted in bi-monthly intervals to depict spatio-temporal variations in pasture use and to illustrate differences between rainy season (RS; December to mid-April), early dry season (EDS; mid-April to July), and late dry season (LDS; August to November). This resulted in a total of 13 surveys for cattle and goats whereas sheep were observed only once per season during the experimental period because of their minor importance to the local animal husbandry system compared to goats, as also indicated by the national stock statistics (FAOSTAT, 2014). With the aid of the herders, most of the selected plant species – and even grasses – could be identified by their local names. Corresponding scientific names were determined using identification keys (Bosser, 1969; Schatz, 2001).

After each monitoring period, leaves and, if also consumed by the animals, twigs of the most important forage plants (importance defined by their share in the feeding observations) per livestock type were collected. Representative samples were clipped from several individual plants and stands at a height reachable by the animals. We thereby abstained from focusing on a fixed number of plant species throughout the period of examination to consider seasonal fluctuations in the abundance and therefore importance as forage of different livestock species, but also to account for the small-scale heterogeneity of the vegetation and the high day-to-day variation in the herds' utilization of pastures described in Chapter 2. In the end, 60 different species of grasses ($n$ = 11), forbs ($n$ = 10), woody plants, i.e. trees, shrubs, and lianas ($n$ = 34), succulents ($n$ = 3), and crops ($n$ = 2) were thus sampled. Furthermore, fecal samples were taken during each monitoring day from the respective animal being followed at the time (once per day in the case of cattle and repeatedly on the case of goats). Feces were collected from the ground immediately after defecation while avoiding collecting soil and debris. If the excreted amount was less than 100 g of fresh matter (FM), additional fecal samples were taken from a second member of the respective herd, being of equal rank, and pooled at the end of the observation day.

### 3.2.3 Data analysis

**Composition and nutritive value of livestock diets**

To calculate the average number of plants consumed by the animals per site ($n$ = 2) and season ($n$ = 3), only species with a share of ≥3% in total feeding observations were considered to reduce the effect of incidental intake. All these forage plants were ranked according to their importance for the specific livestock species based on the results of the monitoring for each location and season. If the number of feeding observations on one plant species was in the 95$^{th}$ percentile of total observations, this species was considered to be of major importance from a quantitative point of view for the nutrition of coastal or plateau cattle, goats, and sheep during the respective time of the year. Plants whose feeding scores were in the 75$^{th}$ percentile were valued as being of substantial importance. Those lying in the 50$^{th}$ percentile were valued as of average and those in the 25$^{th}$ percentile of minor importance.

To determine the nutritive value of the forage plants collected after each herd monitoring event (total sample-*n* = 340), approximate 100 g FM were air-dried and transferred to laboratories in Germany (Witzenhausen and Göttingen). There the samples were ground to pass a 1-mm sieve and subsequently analyzed for total dry matter (DM = air-DM / FM x laboratory DM; g/kg FM), organic matter (OM), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P) following standard procedures (Naumann and Bassler, 2004). NDF and ADF procedure based on the sequential analysis of these two fiber fractions. Crude protein (CP) was calculated from the plants' nitrogen (N) concentration (x 6.25). Due to their particular importance as supplementary forage already indicated by Ahlers (2014) and Kaufmann (2011), metabolizable energy (ME) and digestible organic matter (DOM) concentrations of samples taken from *E. stenoclada* and *Opuntia* sp. were estimated by the Hohenheim gas test according to Menke and Steingass (1988).

To save costs and labor, only one third of all samples were analyzed wet chemically. The results then served as basis for calibration and validation of near infrared spectroscopic (NIRS) data to predict the concentration of all previously notified constituents for the total sample set (Dixon and Coates, 2009). Calibration was developed using WinsISI III (version 1.63) software package (Infrasoft International, Port Matilda, PA, USA). The prediction accuracy of NIRS calibrations for samples of forage plants and feces was assessed by cross-validation using ISIPredict software version 1.10.2.4842 (FOSS North America, Eden Prairie, MN, USA), taking into account the coefficient of determination ($R^2$), the standard error of cross validation (*SECV*), and the coefficient of determination of cross validation (*1-VR*). Model quality for each component was evaluated based on $R^2$-results (<0.7 = poor, <0.9 = good, ≥0.9 = excellent; Shenk & Westerhaus, 1996 in Steyaert et al., 2012).

**Fecal analysis and determination of organic matter digestibility**

Fecal samples (*n* = 322) were processed in a similar manner as the plant samples. They were analyzed for DM, OM, NDF, ADF, N, and P. From the concentration of CP in fecal OM the organic matter digestibility (OMD) of the overall diet was estimated using the equation ( 1 ) established by Lukas et al. (2005):

$$y = 79.76 - 107.7e^{-0.01515x} \quad (Eq.\ 1),$$

where $y$ is the OMD (%) of the ingested diet, $e$ is Euler's number, and $x$ is the determined CP concentration (g/kg DM).

**Statistical analyses**

One goat flock from Ankilibory differed considerably from all others as the monitored doe turned out to be the only adult member of its group, exclusively ranging within the limited village area accompanied by its recent offspring and mostly feeding on crop residues, which was not the case for the other study herds. Thus, fecal samples as well as feeding observations from this flock were excluded from the analyses.

Differences in the respective share of feeding time (recorded grazing and browsing activities in % of total observations) spent by the three livestock species on each functional plant group (grasses, forbs, woody plants, succulents, and crops) and in the number of forage species selected by the animals were analyzed across sites (coastal zone, plateau) and seasons (RS, EDS, LDS). The same was done to determine variations in the average site- and season-specific concentration of OM, NDF, ADF, CP, P, and Ca of the diet as well as in the respective fecal OM, N, NDF, ADF, P, and OMD concentration. Data residuals were first checked for normal distribution, investigating the skewness and kurtosis $z$-values as well as the Shapiro-Wilk test $p$-value, before testing for homogeneity of variance. Pair-wise comparisons of means were then carried out using the independent t-test and one-way ANOVA for normally distributed as well as the Mann-Whitney $U$ and Kruskal-Wallis test for non-normally distributed data sets in case of two and more than two independent variables, respectively. Welch's t-test was used for cases of unequal group variances or sample sizes. All results were expressed as mean ± standard error. Statistical data analyses were performed in SPSS Statistics 20 (IBM Corp., Armok, NY, USA) with a significance level of 0.05 to determine differences between subgroups.

## 3.3 Results

### 3.3.1 Feeding behavior and forage selection of local livestock

Cattle, goats, and sheep grazed and browsed on a total of 133 identified plant species across study sites and seasons (Appendix Table 3.A.1). Grazing activity, i.e.

eating grasses and forbs, expressed as share (%) of total daily time on pasture, was highest for all three livestock species during the RS, apart from plateau goats (higher values in LDS) and sheep (higher values in EDS), while browsing on shrubs and trees occurred mainly during the EDS, apart from plateau cattle (higher values in LDS) and sheep (higher values in RS and LDS; Figure 3.1). Throughout the year, goats fed on a significantly higher number of plant species than the other two livestock species and especially cattle ($p < 0.001$; Figure 3.2). Site-specific differences were discovered for cattle and goats (both $p < 0.05$), with coastal cattle herds and plateau goat flocks consuming significantly more forage species than those from the other site. Seasonal variations were only noted for plateau cattle ($p < 0.01$) and coastal and plateau sheep (both $p < 0.05$).

The share of grasses in the daily diet was highest in cattle in all seasons as compared to goats and, apart from EDS, sheep ($p < 0.001$; Table 3.1). On the plateau, they were the most important functional plant group within this species' diet with regard to feeding time throughout the year, whereas in the coastal area woody and succulent species became more essential in the course of the dry season (EDS and LDS). Goats predominantly browsed on woody plants across the region but the share of ligneous species was significantly higher during the EDS and, only for coastal flocks, LDS compared to RS ($p < 0.01$) when more grasses and forbs were consumed. The feeding behavior of sheep lay between the other two livestock species with graminoids and forbs representing the dominant constituents of their diet but being of lesser importance in view of grasses compared to cattle, except during EDS in the coastal zone.

Across all plant species consumed, 13 were found to be of major importance for at least one livestock species throughout or during a specific time of the year (Table 3.2). Grasses covered the biggest share of cattles' diet with *H. contortus* being of great importance throughout the year for plateau herds. In the coastal area, *Opuntia* sp. and especially *E. stenoclada* proved their high significance as supplementary forage, in particular during the LDS, when cattle spent up to 45% of their feeding time on the latex-rich spurge species. In the LDS, *E. stenoclada* was also increasingly consumed by goats and sheep with a temporal share of about 8% and 17% of feeding time, respectively. Altogether, goats' preference for plant species was broadest throughout the region. With feeding shares of up to 26% for coastal and still

10% for plateau flocks, the shrub *Solanum hippophaenoides* was found to be of high significance for this livestock species, especially during the dry season, confirming its local name as 'goat tree'. Sheep had similar feeding preferences as cattle but additionally relied on two coastal forb species, namely *Heliotropium amplexicaule* and *Indigofera hendecaphylla*.

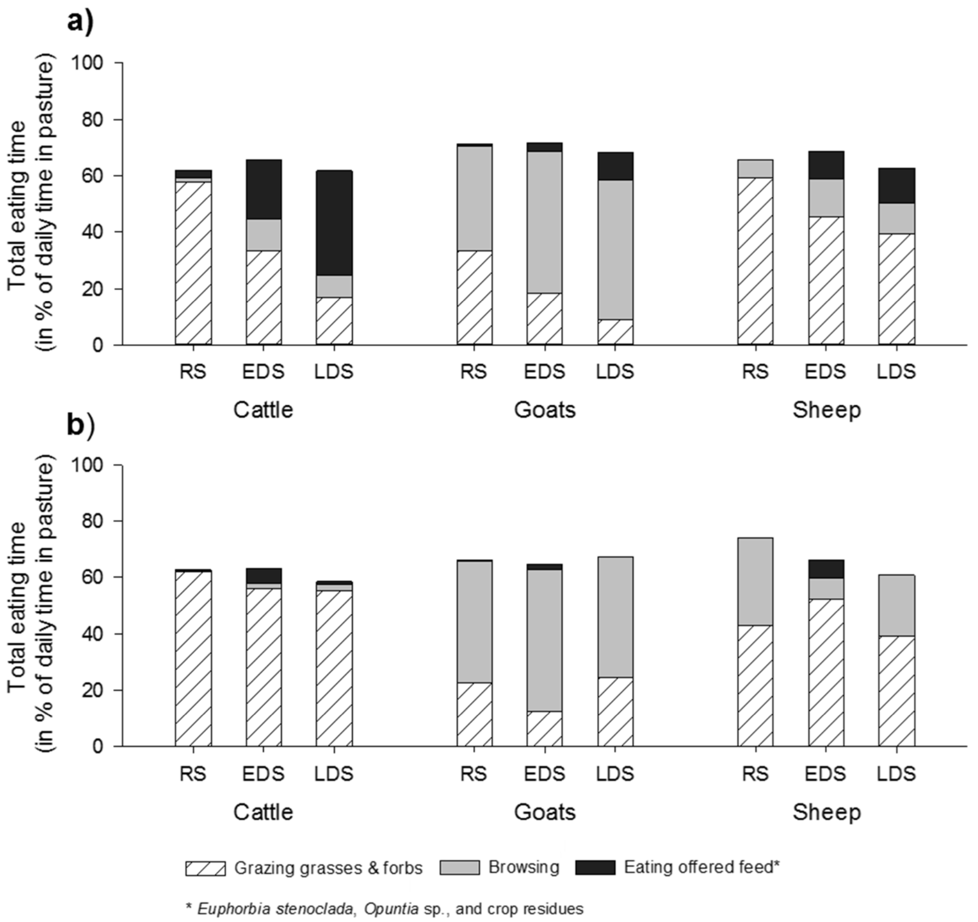


**Figure 3.1.** Share of eating time (in % of daily time on pasture) spent on different forage groups by (a) coastal and (b) plateau cattle, goats, and sheep during the rainy (RS) the early dry (EDS) and the late dry season (LDS). Time in pasture spent by the animals with resting, walking, and other activities is not shown in detail. Number of total eating observations (*n*) per species: cattle = 145, goats = 136, sheep = 35.

**Table 3.1.** Relative contribution (%) of functional plant groups to daily feeding time of cattle, goats, and sheep grouped by study site (*n* = 2) and season (*n* = 3) in the Mahafaly region of southwestern Madagascar. Data are presented as means ± standard errors.

| | Location | Season | Functional plant group | | | | |
|---|---|---|---|---|---|---|---|
| | | | Graminoids | Forbs | Woody plants | Succulents | Crop residues |
| Cattle (*n* = 145) | Coast | RS | $86^{b}$ ±3.1 | $8^{a}$±3.1 | $2^{a}$ ±0.6 | $4^{a}$±2.7 | <$1^{a}$ ±0.1 |
| | | EDS | $44^{a}$ ±6.4 | $7^{a}$±2.1 | $16^{a}$ ±3.5 | $37^{b}$±6.6 | <$1^{a}$ ±0.1 |
| | | LDS | $26^{a}$ ±5.6 | $4^{a}$±1.6 | $12^{ab}$±2.4 | $57^{b}$±6.2 | $1^{a}$ ±0.7 |
| | Plateau | RS | $97^{b}$ ±1.0 | $2^{a}$±0.9 | $1^{a}$ ±0.3 | <$1^{a}$±0.1 | <$1^{a}$ ±0.2 |
| | | EDS | $87^{a}$ ±4.4 | $2^{a}$±0.7 | $3^{ab}$±0.7 | $4^{a}$±4.2 | $4^{b}$ ±1.9 |
| | | LDS | $92^{ab}$±2.2 | $2^{a}$±0.9 | $4^{b}$ ±1.0 | $1^{a}$±0.6 | $2^{ab}$±1.0 |
| | **Independent variable** | | | | | | |
| | Site | | *** | ** | *** | *** | n.s. |
| | Season | | ** | n.s. | *** | *** | * |
| Goats (*n* = 136) | Coast | RS | $31^{b}$±5.7 | $14^{b}$±2.7 | $54^{a}$ ±5.5 | $1^{a}$ ±0.3 | n/a |
| | | EDS | $11^{a}$±2.6 | $12^{b}$±3.2 | $72^{b}$ ±4.2 | $3^{ab}$±0.8 | $1^{a}$±0.5 |
| | | LDS | $11^{a}$±2.6 | $1^{a}$±0.7 | $73^{b}$ ±4.2 | $12^{b}$ ±3.9 | $2^{a}$±2.1 |
| | Plateau | RS | $28^{b}$±3.8 | $6^{a}$±1.5 | $65^{a}$ ±4.0 | <$1^{a}$ ±0.2 | $1^{a}$±0.5 |
| | | EDS | $12^{a}$±2.4 | $7^{a}$±2.3 | $78^{b}$ ±3.8 | <$1^{a}$ ±0.3 | $2^{b}$±0.9 |
| | | LDS | $31^{b}$±4.2 | $4^{a}$±1.5 | $65^{ab}$±4.5 | <$1^{a}$ ±0.1 | n/a |
| | **Independent variable** | | | | | | |
| | Site | | * | n.s. | n.s. | *** | n.s. |
| | Season | | *** | *** | ** | n.s. | n.s. |
| Sheep (*n* = 35) | Coast | RS | $60^{b}$±2.4 | $31^{b}$±1.5 | $9^{a}$ ±2.9 | n/a | n/a |
| | | EDS | $64^{b}$±8.5 | $3^{a}$±2.3 | $18^{a}$ ±4.1 | $1^{a}$±0.8 | 13±7.3 |
| | | LDS | $19^{a}$±4.8 | $45^{b}$±7.0 | $18^{a}$ ±2.6 | $18^{a}$±8.1 | n/a |
| | Plateau | RS | $42^{a}$±3.9 | $17^{a}$±3.5 | $41^{b}$ ±6.3 | n/a | n/a |
| | | EDS | $36^{a}$±20.3 | $37^{a}$±12.5 | $15^{a}$ ±5.8 | n/a | 12±6.9 |
| | | LDS | $52^{a}$±8.0 | $11^{a}$±2.6 | $37^{ab}$±7.9 | n/a | n/a |
| | **Independent variable** | | | | | | |
| | Site | | n.s. | n.s. | ** | n/a | n.s. |
| | Season | | n.s. | n.s. | n.s. | n.s. | n/a |
| | **Effect of livestock species** | | | | | | |
| | by site | Coast | *** | *** | *** | *** | n.s. |
| | | Plateau | *** | *** | *** | n.s. | n.s. |
| | by season | RS | *** | *** | *** | *** | n.s. |
| | | EDS | *** | n.s. | *** | * | * |
| | | LDS | *** | *** | *** | * | n.s. |

RS = rainy season, EDS = early dry season, LDS = late dry season, n/a = no feeding observation / insufficient cases for statistical evaluation (one-way ANOVA and Kruskal-Wallis test).

[a, b, c] significant differences between seasonal means per species and site according to post-hoc tests.

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, n.s. = non-significant.

All animals mostly grazed and browsed on leaves and small twigs, partly made accessible by their herders cutting higher and larger branches of trees and shrubs. Especially small ruminants on the plateau also consumed fallen fruits of trees such as *Pourpartia caffra* and Mango (*Mangifera indica*) during fruiting in the LDS and early RS. However, fruit samples were not taken in this study. In the coastal region, branches of *E. stenoclada* and cladodes of *Opuntia* sp. had to be prepared by chopping (the former) and burning off spines (the latter) before being offered to the animals which were otherwise not able to consume the coral-like spinous branchlets of the spurge and only occasionally fed on the cactus.

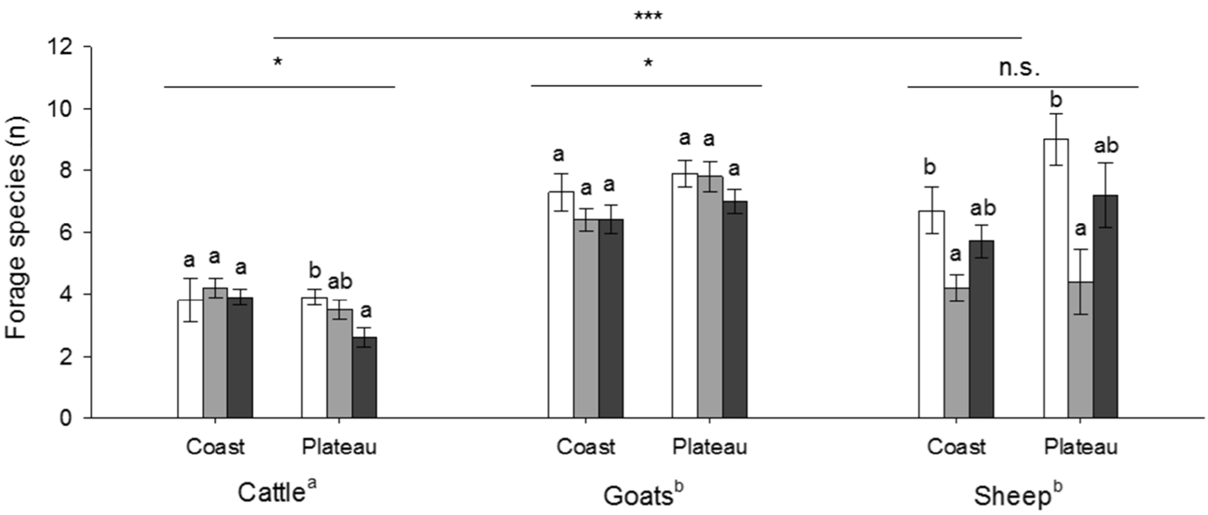


**Figure 3.2.** Number of forage species (means and standard error) consumed by cattle, goats, and sheep in the coastal zone and on the limestone plateau during the rainy (white bars), the early dry (light gray bars) and the late dry season (dark gray bars). Only plant species with ≥3% total feeding observations are considered. Statistical differences between sites per livestock species and across livestock species are shown (* $p \leq 0.05$, *** $p \leq 0.001$). Superscript letters indicate differences between livestock species across sites and seasons as well as seasonal differences per livestock species and site. Number of total eating observations (*n*) per species: cattle = 145, goats = 136, sheep = 35.

**Table 3.2.** Relative share in feeding time (%) of the most frequently selected forage plants in the course of the year. Bold values indicate significance for the respective livestock species in the particular site and season.

| Forage species | Cattle Coastal plain | | | Cattle Plateau | | | Goats Coastal plain | | | Goats Plateau | | | Sheep Coastal plain | | | Sheep Plateau | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| **Graminoids** | | | | | | | | | | | | | | | | | | |
| *Heteropogon contortus* | | | | **53.9** | **40.4** | **79.0** | | | | 5.2 | 5.0 | **17.7** | | | | + | **37.7** | 10.6 |
| *Lepturus humbertianus* | **6.3** | + | + | 7.4 | + | + | + | o | o | + | o | + | o | o | o | 4.5 | o | + |
| *Panicum pseudovoeltzkowii* | **59.0** | **20.3** | **9.3** | | | | **29.6** | **9.2** | 6.7 | | | | **37.5** | **61.3** | 15.6 | | | |
| *P. voeltzkowii* | | | | **18.6** | **21.6** | + | | | | **16.8** | 5.7 | **8.4** | | | | **21.8** | 4.8 | **13.3** |
| **Forbs** | | | | | | | | | | | | | | | | | | |
| *Heliotropium amplexicaule* | + | + | 3.4 | o | + | o | + | + | + | o | + | o | 4.0 | o | **19.7** | 4.9 | o | + |
| *Indigofera hendecaphylla* | + | + | + | o | o | o | 6.0 | **11.6** | + | + | + | o | **21.8** | + | 12.7 | + | o | + |
| **Woody plants** | | | | | | | | | | | | | | | | | | |
| *Acacia viguieri* | | | | o | o | + | | | | **7.7** | **8.2** | 7.8 | | | | 4.0 | 4.0 | + |
| *Alantsilodendron mahafalense* | o | o | + | o | o | o | + | + | + | **7.0** | + | 3.2 | o | + | + | + | o | + |
| *Mundulea stenophylla* | + | 8.9 | 4.7 | | | | 3.4 | 6.1 | **8.5** | | | | o | + | + | | | |
| *Solanum hippophaenoides* | + | o | + | o | o | + | **9.5** | **20.1** | **26.2** | 6.4 | **10.4** | 7.0 | + | + | 9.8 | + | o | + |
| *Ziziphus spina-christi* | o | + | + | o | o | o | + | + | + | 4.8 | **15.7** | 3.6 | o | 5.8 | + | o | 5.6 | + |
| **Succulents** | | | | | | | | | | | | | | | | | | |
| *Euphorbia stenoclada* | o | **21.9** | **44.6** | | | | + | + | **8.4** | | | | o | + | **17.0** | | | |
| *Opuntia* sp. | 4.3 | **10.8** | **12.6** | + | 3.6 | + | + | + | 3.4 | + | + | + | o | o | + | o | o | o |

RS = rainy season, EDS = early dry season, LDS = late dry season, + = <3% of total feeding observations, o = no feeding observations.

Empty cells signify the absence of the specific plant species on one of the two study sites.

### 3.3.2 Quality of pasture vegetation and forage plants

Due to the poor result of the NIRS calibration for P (Appendix Table 3.A.2) and in particular the wide gap between $R^2$ (0.60) and *1-VR* (0.39), it was decided to only refer to the outcome of the wet chemical analysis for this constituent after additionally measuring some 50 samples covering the whole range of P values predicted by NIRS.

Spatio-temporal variations in the nutritive quality of functional forage plant groups are presented in Table 3.3. Across sites and seasons, average CP concentrations (g CP/kg DM) in consumed plant parts were highest in woody species (141±2.9) and lowest in succulents (62±4.0) and grasses (69±3.1). In contrast, NDF and ADF concentrations (both in g/kg DM) were higher in grasses (NDF: 696±7.8; ADF: 406±7.1) than in samples taken from woody vegetation (NDF: 474±6.8; ADF: 328±6.4) and succulents (NDF: 462±16.7; ADF: 324±23.9). Sampled grass species showed clear spatial differences in their NDF ($p < 0.001$) and ADF ($p = 0.001$) concentration, which both were significantly higher on the plateau. In woody vegetation, on the other hand, NDF and ADF concentrations were significantly higher in the coastal zone (both $p < 0.05$). Seasonal variations were distinct in the CP concentrations of grasses, with highest values determined in the RS ($p < 0.001$). Overall Ca concentrations (g Ca/kg DM) ranged between 5.1 and 38.6 for all plant groups but were significantly higher in coastal vegetation ($p < 0.001$). Values for P (g P/kg DM) were low throughout the region (1.0 to 1.9), showing no great differences between locations and seasons.

Among the plant species that were identified as most important according to the animals' selective behavior, the highest CP concentrations (g/kg DM) were found in *S. hippophaenoides* and Christ's Thorn Jujube (*Ziziphus spina-christi*), ranging between 168 (LDS) and 198 (EDS) along the coast and between 154 (LDS) and 183 (RS) on the plateau (Table 3.4). The overall NDF and ADF concentrations (g/kg DM) of these two browse species varied between 340 and 532 and between 188 and 356, respectively, and their Ca:P ratio between 3.4:1 and 12.0:1. On the other hand, grasses such as *H. contortus* and *Panicum pseudovoeltzkowii* showed the lowest CP values: between 25 (EDS) and 113 (RS) on the plateau and between 66 (EDS) and 89 (RS) on the coast. Their NDF concentrations, in contrast, were amongst the highest (600 to 770), also due

**Table 3.3.** Average concentration of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P) in functional plant groups consumed by livestock. Italic values indicate standard errors of the mean.

| Plant group | Location | Season | DM | OM | CP | NDF | ADF | Ca | P |
|---|---|---|---|---|---|---|---|---|---|
| | | | g/kg FM | g/kg DM | | | | | |
| Graminoids (*n* = 119) | Coast | RS | 328 | $896^{a}$ | $83^{a}$ | $638^{a}$ | $359^{a}$ | $6.2^{ab}$ | $1.3^{a}$ |
| | | EDS | 742 | $891^{a}$ | $66^{a}$ | $651^{a}$ | $365^{a}$ | $4.9^{a}$ | $1.0^{a}$ |
| | | LDS | 694 | $878^{a}$ | $65^{a}$ | $607^{a}$ | $379^{a}$ | $12.1^{b}$ | $0.8^{a}$ |
| | | | *92.3* | *4.1* | *4.9* | *8.3* | *8.3* | *0.91* | *0.14* |
| | Plateau | RS | 382 | $898^{a}$ | $81^{b}$ | $686^{a}$ | $392^{a}$ | $5.2^{a}$ | $1.1^{a}$ |
| | | EDS | 721 | $916^{a}$ | $45^{a}$ | $717^{a}$ | $424^{a}$ | $4.1^{a}$ | $0.8^{a}$ |
| | | LDS | 852 | $907^{a}$ | $57^{a}$ | $695^{a}$ | $418^{a}$ | $6.1^{a}$ | $0.9^{a}$ |
| | | | *64.2* | *3.0* | *3.9* | *7.8* | *7.1* | *0.43* | *0.14* |
| **Independent variable** | | Site | | *** | n.s. | *** | *** | ** | n.s. |
| | | Season | | n.s. | *** | n.s. | n.s. | * | n.s. |
| Forbs (*n* = 27) | Coast | RS | 140 | $832^{a}$ | $130^{a}$ | $465^{a}$ | $312^{a}$ | $29.6^{a}$ | $2.0^{a}$ |
| | | EDS | 375 | $831^{a}$ | $148^{a}$ | $504^{a}$ | $294^{a}$ | $31.0^{a}$ | $1.2^{a}$ |
| | | LDS | 604 | $822^{a}$ | $128^{a}$ | $482^{a}$ | $310^{a}$ | $27.4^{a}$ | $1.3^{a}$ |
| | | | *86.8* | *8.8* | *7.4* | *11.6* | *10.5* | *2.6* | *0.2* |
| | Plateau | RS | 232 | $862^{a}$ | $130^{a}$ | $514^{a}$ | $356^{a}$ | $24.1^{a}$ | $2.1^{a}$ |
| | | EDS | n/a | $822^{a}$ | $121^{a}$ | $518^{a}$ | $342^{a}$ | $24.2^{a}$ | $1.5^{a}$ |
| | | LDS | 215 | $878^{a}$ | $123^{a}$ | $498^{a}$ | $343^{a}$ | $14.5^{a}$ | $1.6^{a}$ |
| | | | *43.9* | *13.1* | *8.4* | *13.2* | *9.8* | *2.68* | *0.29* |
| **Independent variable** | | Site | | n.s. | n.s. | n.s. | * | * | n.s. |
| | | Season | | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Woody plants (*n* = 167) | Coast | RS | 392 | $898^{a}$ | $132^{a}$ | $507^{a}$ | $360^{a}$ | $19.1^{a}$ | $1.5^{a}$ |
| | | EDS | 534 | $893^{a}$ | $152^{a}$ | $476^{a}$ | $327^{a}$ | $16.9^{a}$ | $1.4^{a}$ |
| | | LDS | 422 | $891^{a}$ | $144^{a}$ | $469^{a}$ | $334^{a}$ | $16.6^{a}$ | $1.3^{a}$ |
| | | | *20.4* | *5.6* | *4.9* | *11.0* | *10.1* | *1.03* | *0.10* |
| | Plateau | RS | 322 | $912^{a}$ | $147^{a}$ | $486^{b}$ | $337^{a}$ | $17.6^{a}$ | $1.6^{a}$ |
| | | EDS | 563 | $910^{a}$ | $144^{a}$ | $442^{ab}$ | $289^{a}$ | $17.5^{a}$ | $1.2^{a}$ |
| | | LDS | 386 | $916^{a}$ | $130^{a}$ | $469^{a}$ | $323^{a}$ | $16.7^{a}$ | $1.4^{a}$ |
| | | | *24.3* | *2.5* | *3.5* | *8.7* | *8.2* | *0.60* | *0.07* |
| **Independent variable** | | Site | | * | n.s. | * | * | n.s. | n.s. |
| | | Season | | n.s. | n.s. | n.s. | n.s. | n.s. | n.s. |
| Succulents (*n* = 23) | Coast | RS | 343 | 820 | 65 | 470 | 338 | 40.9 | 0.9 |
| | | LDS | 329 | 838 | 58 | 467 | 327 | 32.2 | 1.0 |
| | | | *32.9* | *10.8* | *4.0* | *16.7* | *23.9* | *4.79* | *0.10* |
| **Independent variable** | | Season | | n.s. | n.s. | n.s. | n.s. | n.s. | n/a |
| Crop residues (*n* = 4) | Plateau | EDS | 329 | 864 | 114 | 532 | 380 | 26.2 | 1.9 |
| | | | *31.3* | *20.6* | *21.5* | *37.6* | *31.4* | *2.08* | *0.23* |

FM = fresh matter, RS = rainy season, EDS = early dry season, LDS = late dry season, *n* = number of samples per plant group, n/a = not available, * $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, n.s. = non-significant.

[a, b] significant differences between seasonal means per plant group and site according to post-hoc tests.

to the share in hemicelluloses. Ca:P ratios of this functional group were between 2.9:1 (RS) and 8.3:1 (LDS).

In the direct comparison of *E. stenoclada* and *Opuntia* sp., the spurge species was found to have higher values in CP and P but also in fiber fractions. In contrast, the determined ME (MJ/kg DM) and DOM (%) was higher for the cactus (ME: 9.3±0.30 compared to 8.3±0.53; DOM: 53±2.1 compared to 48±2.6). Both forage plants revealed wide Ca:P ratios across seasons, being considerably higher for *Opuntia* sp. (69.3:1 compared to 18.5:1).

**Table 3.4.** Average concentrations of organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P), in the most important forage plants for livestock collected between 2011 and 2013. Values are given as means ± standard errors.

| | OM | CP | NDF | ADF | Ca | P |
|---|---|---|---|---|---|---|
| | g/kg DM | | | | | |
| **Graminoids** | | | | | | |
| *Heteropogon contortus* | 910 ± 4.2 | 50 ± 5.4 | 724 ± 12.0 | 431 ± 9.7 | 4.0 ± 0.60 | 0.9 ± 0.19 |
| *Lepturus humbertianus* | 897 ± 4.8 | 107 ± 15.8 | 666 ± 13.0 | 358 ± 10.9 | 7.6 ± 1.53 | 1.6 ± 0.72 |
| *Panicum pseudovoeltzkowii* | 896 ± 3.1 | 80 ± 9.0 | 625 ± 14.0 | 351 ± 9.5 | 7.7 ± 1.42 | 1.4 ± 0.26 |
| *P. voeltzkowii* | 889 ± 6.4 | 86 ± 5.6 | 627 ± 9.7 | 350 ± 7.9 | 6.4 ± 0.92 | 1.0 ± 0.04 |
| **Forbs** | | | | | | |
| *Heliotropium amplexicaule* | 842 ± 2.1 | 145 ± 10.4 | 521 ± 13.8 | 341 ± 14.3 | 19.2 ± 0.30 | 1.3 ± 0.11 |
| *Indigofera hendecaphylla* | 815 ± 12.5 | 118 ± 5.3 | 464 ± 9.3 | 302 ± 6.5 | 35.0 ± 2.92 | 1.4 ± 0.07 |
| **Woody plants** | | | | | | |
| *Acacia viguieri* | 926 ± 3.6 | 149 ± 9.5 | 448 ± 18.7 | 310 ± 18.0 | 15.4 ± 1.08 | 1.2 ± 0.07 |
| *Alantsilodendron mahafalense* | 941 ± 3.8 | 101 ± 3.8 | 598 ± 7.9 | 435 ± 8.3 | 16.2 ± 0.77 | 1.1 ± 0.00 |
| *Mundulea stenophylla* | 941 ± 5.6 | 114 ± 6.9 | 602 ± 13.0 | 412 ± 12.8 | 14.7 ± 0.97 | 0.8 ± 0.00 |
| *Solanum hippophaenoides* | 907 ± 3.0 | 170 ± 3.9 | 464 ± 9.0 | 340 ± 7.6 | 11.5 ± 0.80 | 1.6 ± 0.14 |
| *Ziziphus spina-christi* | 904 ± 5.1 | 172 ± 6.1 | 400 ± 13.5 | 243 ± 12.1 | 17.9 ± 0.95 | 1.9 ± 0.15 |
| **Succulents** | | | | | | |
| *Euphorbia stenoclada* | 865 ± 4.1 | 69 ± 3.6 | 518 ± 11.1 | 413 ± 7.2 | 22.0 ± 1.77 | 1.2 ± 0.20 |
| *Opuntia* sp. | 768 ± 8.7 | 50 ± 6.9 | 375 ± 12.2 | 186 ± 11.2 | 64.5 ± 4.51 | 0.9 ± 0.10 |

### 3.3.3 Composition of livestock feces

As in the case for diet P, interpretation of fecal NDF and ADF results was only based on the results of the chemical analysis after the evaluation of the NIRS calibration (Appendix Table 3.A.2). Diet organic matter digestibility (%) as determined from fecal CP concentrations was highest in goats (59±0.8) and lowest in cattle (52±0.8) across locations and seasons (Figure 3.3). The values determined for all three livestock species on the plateau exceeded those of coastal animals (all $p < 0.001$; Figure 3.3) and were generally higher during the RS compared to the EDS and LDS (cattle: $p < 0.001$, goats: $p < 0.01$, sheep: $p < 0.05$). Highest values in goats and lowest in cattle emerged for the concentration of fecal ADF (g/kg DM; goats: 4123±5.1; cattle: 388±6.6) and P (g/kg DM; goats: 2.6±0.05; cattle: 2.5±0.06). In contrast, fecal NDF (g/kg DM) was found higher in cattle (579±6.6) than in goats (556±6.0) with values for sheep lying in between these two livestock species. Similar results were obtained for fecal P (Appendix Table 3.A.3).

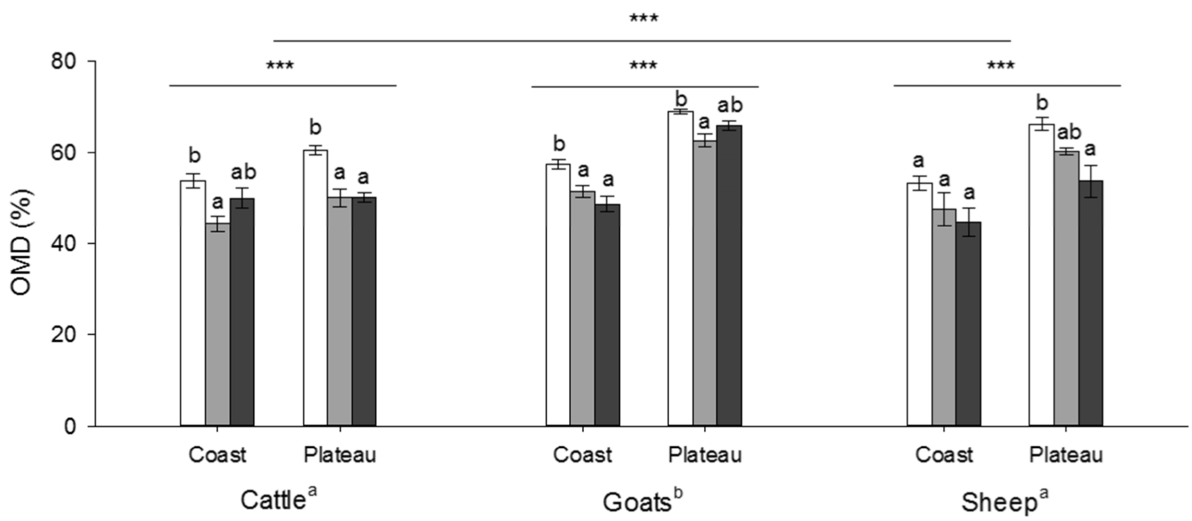


**Figure 3.3.** Organic matter digestibility (OMD, %) of the total diet, derived from fecal crude protein concentration of cattle, goats, and sheep in the coastal zone and on the limestone plateau during the rainy (white bars), the early dry (gray bars) and the late dry season (black bars). Results are depicted as mean values and standard errors. Statistical differences between sites per livestock species and across livestock species are shown (*** $p \leq 0.001$). Superscript letters indicate differences between livestock species across sites and seasons as well as seasonal differences per livestock species and site. Number of total fecal samples ($n$) per species: cattle = 144, goats = 145, sheep = 33.

## 3.4 Discussion

### 3.4.1 Spatio-temporal variation in diet selection

This study revealed the consumption of a considerable number of plant species from different functional groups by local livestock, reflecting on the one hand the area's botanical richness and diversity but also its spatial heterogeneity in terms of plant communities (Antsonantenainarivony, unpubl. data). Many of these species also fulfill other purposes, e.g. as forage and shelter for wild animals (Rasoma et al., 2013) or as medical plants for the local communities (Andriamparany et al., 2014). On the other hand, the observed focus of cattle, goats, and sheep lay on a noticeably smaller number of forage plants with a few species being of major importance throughout the year. This compares to the outcome of research on goats' grazing behavior in the central south of Madagascar (Randrianariveloseheno, 2004). In their review on the foraging ecology of small ruminants, Papachristou et al. (2005) state that these animals usually rely on less than 10 species for the bulk of their diet even if a much more diverse offer of forage species is available, which is in line with our findings.

It is known that the three livestock species studied exhibit different grazing behavior with goats being more selective feeders than sheep and especially cattle (Hofmann, 1989; Van Soest, 1996). In our study, they additionally displayed clear spatio-temporal variation in plant species selection. Across the study region, their temporal share in browsing on woody plants increased in the course of the dry season, being more distinct for coastal animals. This is a typical response of both herded and free-ranging ruminants to the seasonal changes in availability and quality of vegetation especially under sub-humid conditions, and has been reported from similar environments in West Africa (Sanon et al., 2007; Zampaligré et al., 2013). However, it was particularly striking in coastal cattle due to the herders' and livestock keepers' offer of the chopped succulent *E. stenoclada* branches as supplementary forage. The relevance of this species thereby clearly surpassed the dry season feed supply with *Opuntia* cactus which had, for a long time, been attributed greater significance for the coastal region's livestock system in literature, also because of its importance for human consumption and its use as living fences (Kaufmann, 2008; Middleton, 1999). More recent studies (Ahlers, 2014; Kaufmann, 2011) stressed the high value that local pastoralists ascribe to *E. stenoclada*, pointing to both its contribution to dry season livestock feeding but also the overuse of its natural stands. This species does not grow on the limestone plateau and domestic herds on this site therefore have to rely on abundant savanna grasses (cattle) and other ground vegetation (goats). Crop residues which are a major component of dry season livestock feeding in many dryland farming systems (Ben Salem and Smith, 2008) played a minor role for herd nutrition throughout the research area. Mostly leaves and stems of cassava (*Manihot* sp.) were sporadically fed at this time of the year. Sheep, together with draft oxen, thereby enjoyed the privilege of being tolerated on cultivated fields. No specific reasons were given for this exceptional access but one could assume that local crop farmers take advantage of the sheep's occasional preferences for various forb species to counter the region's weed problem (Soavita, unpubl. data), even accepting a certain degree of crop loss due to the animals. Herds of cattle and goats, on the other hand, were only allowed to enter these areas shortly after harvesting to avoid crop damage, which is in agreement with observations by Schlecht et al. (2006) for herded and free-ranging livestock in Western Niger.

### 3.4.2 Nutritive value of rangeland vegetation

Under tropical and subtropical conditions, quantity and quality of vegetation on natural rangelands vary throughout the year because of fluctuations in rainfall, temperature, and light with nutritive values of forage plants being lowest towards the end of the dry period (Van Soest, 1994). Although the animals' rainy season intake may still be sufficient for high daily body weight gain during resource-rich months (Bezabih et al., 2014), overall cyclical nutrient and energy deficits widely limit the productivity of livestock systems in such ecological zones (Kirkman and Faccio Carvalho, 2003). While small ruminants, and especially goats, may compensate these shortcomings to a certain degree by choosing diets higher in CP and DOM than the average of available forage on heterogeneous resources (Animut and Goetsch, 2008), cattle are less selective though better able to cope with feed which is low in protein and high in cell wall due to a different structure of the gastro-intestinal tract (Shipley, 1999; Van Soest, 1994). On the study region's limestone plateau, standing biomass is available yearlong but its quality clearly diminishes in the dry season, becoming largely unpalatable even for this ruminant species. Local pastoralists counter the problem by burning the old vegetation to improve the grazing conditions for their livestock, resulting in approximately 40% of the total savanna area in southern Madagascar being burned down every year (Ranaivoarivelo and

Milleville, 2001), and even more in other parts of the country. These fires cause severe environmental problems when they get out of control (Kull, 2004). This situation does not apply to the coastal strip where only a thin sward grows on the sandy substrate after the short RS before largely disappearing again in the course of the dry season. Thereafter, only few patchy types of grassland remain within private pasture enclosures, mainly reserved for family herds, whereas the majority of the coastal cattle stock increasingly depends on supplementary feeding. However, although being of similar digestibility than the better quality ligneous species analyzed by Dickhoefer et al. (2011) in Northern Oman and by Zampaligré et al. (2013) in Burkina Faso, the concentration of CP and P found in both, *E. stenoclada* and *Opuntia* sp., was lower compared to other local browse species and may not be sufficient to cover the animals' energy and nutrient requirements, if fed exclusively.

Wide Ca:P ratios found in many of the most important forage species from both sites of the study area, resulting as much from high Ca concentration in plants in consequence of the region's calciferous soils as from low P values, suggest an additional problem for the local livestock system. An unbalanced proportion of these two mineral diet components can intensify already existing symptoms of phosphorus deficiency such as reduced growth and poor bone mineralization, leading to bone deformation (NRC, 2000, 2007). For most forage plants, these ratios were widest at the end of the dry season but already clearly exceeded the ideal rate of 1:1 to 2:1 suggested by Wise et al. (1963) during the rest of the year, most obvious in the *Opuntia* cactus. The proportion of Ca and P was best in grasses, which illustrates the consequences of seasonal shortages of this functional group especially for coastal cattle.

Determining the chemical composition and functional properties of the diet of largely free-ranging livestock is regarded as problematic due to the animals' selective grazing behavior. In contrast, results from fecal analyses based on technologies such as NIRS have proved appropriate for estimating dietary attributes (Boval et al., 2004; Dixon and Coates, 2009). Under difficult field conditions, where controlled studies are not feasible, the derivation of the diet's OMD from fecal CP constitutes another reasonable alternative to the use of internal markers or *in vitro* techniques (Schlecht and Susenbeth, 2006). The average OMD of naturally growing forage ingested by cattle, goats, and sheep in the Mahafaly region was found to be considerably lower throughout the area compared to that of 831 types of roughages from various geographical regions summarized by Ketelaars and Tolkamp (1992), who reported an OMD of 65 – 70% for many feeds. The values in the present study were significantly higher for the diet of livestock based on the limestone plateau than for coastal herds, and the spatial effect was more distinct for small ruminants than for cattle. Spatial differences in the consumed diet may explain the higher N concentration in the feces of goats and sheep, which might in part also have been due to increased concentration of condensed tannins from browse forages in their diet (Papachristou et al., 2005). Secondary plant metabolites such as alkaloids and phenolic compounds including tannins certainly affect forage quality, intake, and utilization in herbivores. Simmen et al. (2003) reported a significantly higher occurrence of alkaloids in mature leaves of plant species from the dry spiny forest vegetation of southern Madagascar compared to other forest habitats on the island, but the opposite was observed for phenolic substances. Correspondingly in the survey region, no increased concentrations of condensed tannins were found by Rasoma et al. (2013) in the diet of Radiated tortoises nor by Ahlers (2014) evaluating the quality of *E. stenoclada* as livestock feed. On the other hand, plants known to be rich in tannins such as Tamarind (*Tamarindus indica*) and various *Acacia* species were of certain importance in the diet of small ruminants, but lacked to produce observable negative impact on these animals.

The low P values in the livestock's forage were also reflected in respective low fecal concentrations. Across both study locations they were lower than the values reported by Powell et al. (1999) for West African sheep after conducting a series of feeding trials and by Smith et al. (1994) for cattle grazing on desert rangelands in New Mexico. On the other hand, the present fecal N concentrations were similar to the values reported in these two studies. This has also consequences for the quality of manure which is often found to be poor in smallholder farming systems (Harris, 2002; Lupwayi et al., 2000). In the Mahafaly region, however, its concentrations of P and N were comparable to those in other African farming systems, even though at present manure is hardly used by local farmers for soil amelioration (Hanisch, 2015).

### 3.4.3 New threats to the pastoral system's ecological stability

In the Mahafaly region, the local livestock system has long been regarded as environmentally balanced with regard to the seasonal movements in particular of coastal cattle herds (Barraud, 2006; Kaufmann, 2004). When going on transhumance further inland after the first rainfall events, their feed supply situation improves considerably, though the outcome of laboratory analyses in the recent study indicated that this is not necessarily because of the better nutritive value of plateau pasture plants but has to be rather ascribed to the higher abundance of its resprouting vegetation which, at this moment of the year, offers sufficient food to animals from both the coastal zone and the plateau area. The temporary absence of migratory herds from their coastal home grounds additionally enables the fragile vegetation in that area to regenerate and to provide sufficient quality and quantity forage for returning and sedentary livestock, at least for several dry season months before supplementary forage becomes important. However, the recent increase of armed cattle raids and land use conflicts (Chapter 2) forces livestock owners to adapt their herd management, with expected negative consequences for the system's environmental balance in the near future. Nowadays, early returning migratory herds are moreover joined by additional herds from the plateau whose herders try to avoid the risk of livestock theft. The latter is reported higher during the dry season when long-distance pathways across the plateau are passable and thus provide easy access for thieves. The relatively new phenomenon of inverse transhumance of plateau herds to the coastal area results in higher dry season stocking rates and grazing pressure in the coastal zone, intensifying the pressure on the already scarce vegetation resources and especially accelerating the ongoing depletion of natural stands of *E. stenoclada* (Götter, 2014). Concurrent competition for land resources with local crop farmers, continuously expanding agricultural areas in need to supply the region's continuously growing population (Brinkmann et al., 2014), involves further potential for conflicts and limits the scope for herding activities. As a consequence, pastoralists tend to expand available pasture grounds by increasingly sending their animals into the protected area of the Tsimanampetsotsa National Park where livestock grazing is officially prohibited, notably contributing to a decline in the highly endemic woody vegetation (Ratovonamana et al., 2013).

It therefore seems indispensable to counter these developments, all the more since the expected increase in extreme weather events for the Indian Ocean region may lead to an even higher variation and unpredictability of rainfall (Cai et al., 2014; Ericksen et al., 2013) and thus will additionally compromise pastoral practices within this fragile dry-land system. For the coastal strip, the reforestation of *E. stenoclada* stands appears to be a reasonable measure to take in order to avoid the progressive overexploitation of this important supplementary forage species while at the same time reducing grazing pressure on other vegetation. On the limestone plateau, introducing hay making at a time when grasses are still abundant and in good quality could also contribute to improve the supply situation of especially cattle towards the end of the dry season. This management strategy is so far not practiced at all by local pastoralists, but would not only allow herd owners to dispose of a reliable forage stock but also to keep their animals closer to their villages, except when the herds have to move to far away water holes (Chapter 2). Hay making could therefore also reduce the risk of livestock thefts that are mostly happening further away from settled areas. In addition, the need of temporarily relocating the herds to the coastal zone of supposed security could also be reduced. However, introducing such innovations need of course to be examined from a social and economic point of view and discussed with local pastoralists to assess their willingness to invest time and labor into these measures.

## 3.5 Conclusions

The present study revealed clear spatio-temporal variations in forage selection behavior and plant species preferences by local livestock as well as in the nutritive value of the region's natural rangeland vegetation. The interrelatedness of the two study sites through regular transhumance movements of herds necessitates a holistic analysis of opportunities and constraints of the current pastoral system. By resorting to the abundant feed resources on the limestone plateau when reaching its maximum in quality and quantity during the short rainy season, pastoralists from the coastal zone optimize the nutrient supply for their animals and at the same time allow the vegetation of their home ranges to recover by temporarily lowering the grazing pressure. During the dry season, supplementary forage species help to bridge feed shortages on the coast while plateau herds can still rely on the remaining vegetal biomass although its feeding value is reduced. However, rising insecurity and land use conflicts provoke changes in herd management, which substantially threaten the ecological balance of the current system and may be further pronounced by predicted climatic fluctuations. Therefore, measures have to be taken to sustain the local livestock system and contribute to conserve the region's unique biodiversity. These should be adjusted to people's needs and rely on available on-site resources, and may include the systematic, cuttage-based forestation of *E. stenoclada* for fodder use in the coastal zone and the use of savanna grasses on the plateau for hay production. Yet, their success will certainly depend on the acceptance by the local communities, and accompanying measures such as the determination of the region's total livestock population as well as the number of herds recently utilizing the fragile vegetation in the coastal zone are needed to assess the area's current and future livestock carrying capacity.

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## Appendix

**Table 3.A.2.** NIRS calibration and cross-validation statistics for organic matter (OM), nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), calcium (Ca), and phosphorus (P) concentration (g/kg DM) of forage plants and livestock feces.

| Constituent | n | Mean | SE | SEC | $R^2$ | SECV | 1-VR |
|---|---|---|---|---|---|---|---|
| **Plant samples** | | | | | | | |
| OM | 122 | 88.4 | 0.49 | 1.50 | 0.93 | 2.07 | 0.86 |
| N | 126 | 1.9 | 0.07 | 0.17 | 0.96 | 0.22 | 0.93 |
| NDF | 125 | 50.2 | 1.07 | 3.02 | 0.94 | 4.23 | 0.88 |
| ADF | 124 | 32.1 | 0.86 | 2.32 | 0.94 | 3.30 | 0.88 |
| Ca | 120 | 20.4 | 1.54 | 5.26 | 0.90 | 6.68 | 0.85 |
| P | 127 | 1.3 | 0.05 | 0.33 | 0.60 | 0.41 | 0.39 |
| **Fecal samples** | | | | | | | |
| OM | 170 | 69.0 | 0.82 | 3.58 | 0.87 | 3.93 | 0.87 |
| N | 168 | 1.6 | 0.04 | 0.10 | 0.96 | 0.11 | 0.95 |
| NDF | 174 | 57.2 | 0.47 | 4.26 | 0.53 | 4.89 | 0.39 |
| ADF | 173 | 40.1 | 0.45 | 3.24 | 0.71 | 3.89 | 0.58 |
| P | 166 | 2.5 | 0.06 | 0.36 | 0.79 | 0.41 | 0.72 |

*n* = sample size, SE = standard error, SEC = standard error of calibration, $R^2$ = coefficient of determination, SECV = standard error of cross-validation, 1-VR = coefficient of determination of cross validation.

**Table 3.A.1.** Forage plants and their relative importance for the nutrition of cattle, goats, and sheep in the Mahafaly region of southwestern Madagascar. Plant species were ranked as being of major importance (++) if their share in the total number of feeding observation was in the 95th percentile, as important (+) in the 75th percentile, as average (o) in the 50th percentile, and as of minor importace (-) in the 25th percentile. Empty cells signify the absence of the specific plant species on one of the two study sites.

| Plant species | Cattle | | | | | | Goats | | | | | | Sheep | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal herds | | | Plateau herds | | | Coastal flocks | | | Plateau flocks | | | Coastal flocks | | | Plateau flocks | | |
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| **Graminoids** | | | | | | | | | | | | | | | | | | |
| *Aristida adscensionis* var. *mandrarensis* A. Camus | | | | + | + | + | | | | - | - | - | | | | - | - | - |
| *Cenchrus ciliaris* L. | + | + | + | + | + | - | - | - | - | o | - | - | + | - | o | - | - | - |
| *Chloris boivinii* A. Camus | - | + | - | | | | - | - | - | | | | - | - | - | | | |
| *Chloris* sp. | o | - | - | o | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Cynodon dactylon* (L.) Pers. | - | - | - | o | + | + | - | - | - | o | - | o | o | - | - | - | o | + |
| *Cyperus amabilis* Vahl | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Eragrostis* sp. | o | + | - | + | + | o | - | - | - | + | - | - | o | - | - | + | - | - |
| *Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult. | | | | ++ | ++ | ++ | | | | + | + | ++ | | | | o | ++ | + |
| *Lepturus humbertianus* A. Camus | ++ | o | o | + | o | o | - | - | - | o | - | - | - | - | - | + | - | o |
| *Panicum maximum* Jacq. | - | - | - | o | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *P. pseudovoeltzkowii* Hack. | ++ | ++ | ++ | | | | ++ | ++ | + | | | | ++ | ++ | + | | | |
| *P. voeltzkowii* Mez | | | | ++ | ++ | + | | | | ++ | + | ++ | | | | ++ | + | ++ |
| *Paspalum conjugatum* P.J. Bergius | o | - | - | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Rottboellia cochinchinensis* (Lour.) Clayton | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Sporobolus virginicus* (L.) Kunth | + | + | + | | | | o | o | + | | | | + | o | - | | | |
| Graminoid spp. | - | o | o | + | + | ++ | - | o | - | + | + | + | - | - | - | + | o | + |
| **Forbs** | | | | | | | | | | | | | | | | | | |
| *Abutilon indicum* (L.) Sweet | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Aerva javanica* (Burm. f.) Juss. ex Schult | - | o | + | - | - | - | o | o | - | - | - | - | + | + | + | - | - | - |
| *Alistilus jumellei* (R. Vig.) Verdc. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Blepharis calcitrapa* Benoist | - | - | - | o | - | - | o | o | - | + | o | - | - | - | - | o | - | - |
| *Boerhavia diffusa* L. | + | o | - | o | - | - | o | - | - | o | - | - | - | - | - | - | - | - |
| *Commelina ramulosa* (C.B. Clarke) H. Perrier | | | | - | - | - | | | | - | - | - | | | | - | - | - |

| Plant species | Cattle | | | | | | Goats | | | | | | Sheep | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal herds | | | Plateau herds | | | Coastal flocks | | | Plateau flocks | | | Coastal flocks | | | Plateau flocks | | |
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| *Dioscorea* sp. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Heliotropium amplexicaule* Vahl | o | - | + | - | + | - | o | - | o | - | o | - | + | - | ++ | + | - | o |
| *Hypoestes* sp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Indigofera hendecaphylla* Jacq. | + | o | - | - | - | - | + | ++ | o | - | - | - | ++ | o | + | o | - | o |
| *I. peltieri* Du Puy & Labat | + | o | - | - | - | o | - | - | - | - | - | - | - | - | o | - | - | - |
| *Ipomoea indica* (Burm.) Merr. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Lycium acutifolium* E. Mey. ex Dunal | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Mollugo decandra* Scott-Elliot | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Phyllanthus bathianus* Leandri | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *P. niruroides* Müll. Arg. | | | | - | - | - | | | | o | - | - | | | | + | - | - |
| *Portulaca oleracea* L. | | | | - | - | - | | | | - | - | - | | | | - | o | - |
| *Salicornia pachystachya* Bunge ex Ung.-Sternb. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Senna* sp. | | | | - | o | - | | | | - | o | - | | | | - | o | - |
| *Tribulus cistoides* L. | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - | - | - | - |
| *Tridax procumbens* L. | | | | - | - | + | | | | o | + | + | | | | o | + | + |
| *Waltheria indica* L. | | | | - | - | - | | | | - | o | - | | | | - | - | - |
| *Zygophyllum simplex* L. | + | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Forb spp. | - | o | - | o | + | + | o | o | - | + | + | + | o | - | - | + | o | + |
| **Woody plants** | | | | | | | | | | | | | | | | | | |
| *Acacia bellula* Drake | - | - | - | | | | + | + | + | | | | - | - | - | | | |
| *Acacia.* sp. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *A. farnesiana* (L.) Willd. | | | | - | - | - | | | | + | + | + | | | | - | - | - |
| *A. viguieri* Villiers & Du Puy | | | | - | - | o | | | | ++ | ++ | + | | | | + | o | + |
| *Aerva madagassica* Suess. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Alantsilodendron mahafalense* (R. Vig.) Villiers | - | - | o | - | - | - | o | + | o | ++ | + | + | - | - | - | o | - | o |
| *Albizia atakataka* Capuron | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *A. mahalao* Capuron | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *A. tulearensis* R. Vig. | | | | - | - | o | | | | - | - | - | | | | - | - | - |
| *Androya decaryi* H. Perrier | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Asparagus calcicola* H. Perrier | | | | - | - | + | | | | - | - | o | | | | - | - | - |
| *Azima tetracantha* Lam. | - | - | + | - | - | - | - | o | + | - | - | o | - | - | - | - | - | - |
| *Boscia longifolia* Hadj-Moust. | - | - | - | - | - | o | - | o | o | - | - | - | - | - | - | - | - | - |
| *B. tenuifolia* A. Chev. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Cadaba virgata* Bojer | - | - | - | | | | - | - | - | | | | - | - | - | | | |

| Plant species | Cattle | | | | | | Goats | | | | | | Sheep | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal herds | | | Plateau herds | | | Coastal flocks | | | Plateau flocks | | | Coastal flocks | | | Plateau flocks | | |
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| *Capurodendron androyense* Aubrév. | | | | - | - | - | | | | o | o | o | | | | - | - | - |
| *Cedrelopsis grevei* Baill. & Courchet | | | | - | - | - | | | | o | o | o | | | | - | - | o |
| *Chadsia grevei* Drake | | | | - | - | - | | | | - | o | - | | | | - | - | - |
| *Clerodendrun* sp. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Coffea grevei* Drake ex A. Chev. | | | | - | o | o | | | | o | o | - | | | | - | - | - |
| *Combretum grandidieri* Drake | - | - | - | - | - | - | - | - | - | o | - | - | - | - | - | - | - | - |
| *Combretum* sp. | | | | - | o | + | | | | + | + | + | | | | + | o | + |
| *Commiphora mahafaliensis* Capuron | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | o | - | - |
| *Cordia caffra* Sond. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Croton* sp. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *C. geayi* Leandri | - | - | - | - | o | o | o | - | - | + | o | o | - | - | - | o | - | - |
| *Cynanchum nodosum* (Jum. & H. Perrier) Desc. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *C. perrieri* Choux | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *C. toliari* Liede & Meve | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Delonix boiviniana* (Baill.) Capuron | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Desmodium* sp. | | | | - | - | - | | | | - | o | - | | | | - | - | - |
| *Dicraeopetalum mahafaliense* (M. Peltier) Yakovlev | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Didierea madagascariensis* Baill. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Dicoma incana* (Baker) O. Hoffm. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Diospyros* sp. | | | | - | - | - | | | | - | o | o | | | | - | - | o |
| *Dolichos fangitsa* R. Vig. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Ehretia decaryi* J.S. Mill. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Erythrophysa aesculina* Baill. | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Euphorbia laro* Drake | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Fernandoa madagascariensis* (Baker) A.H. Gentry | - | - | - | - | - | - | - | - | - | - | - | o | - | - | - | - | - | o |
| *Flacourtia ramontchi* L'Hér. | | | | - | - | - | | | | - | - | o | | | | - | - | - |
| *Gonocrypta grevei* (Baill.) Costantin & Gallaud | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Grewia barorum* Capuron | | | | - | - | - | | | | o | - | - | | | | - | - | - |
| *G. grevei* Baill. | - | - | - | - | - | - | o | - | - | - | - | - | - | - | - | - | - | - |

| Plant species | Cattle | | | | | | Goats | | | | | | Sheep | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal herds | | | Plateau herds | | | Coastal flocks | | | Plateau flocks | | | Coastal flocks | | | Plateau flocks | | |
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| *Grewia humbertii* Capuron | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *G. humblotii* Baill. | - | - | - | - | - | o | o | + | - | + | + | o | - | - | - | - | - | - |
| *G. mahafaliensis* Capuron | - | - | - | - | - | o | + | o | - | + | - | - | - | - | - | - | - | o |
| *Gymnosporia linearis* (L. f.) Loes. | - | - | - | | | | - | + | - | | | | - | - | - | | | |
| *Gyrocarpus americanus* Jacq. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Henonia scoparia* Moq. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Indigofera compressa* Lam. | - | o | o | - | - | - | + | + | o | - | - | - | - | - | - | - | - | - |
| *I. diversifolia* DC. | o | - | - | - | o | - | + | - | - | o | o | - | o | - | - | o | - | - |
| *I. mouroundavensis* Baill. | | | | - | - | - | | | | o | o | + | | | | o | - | - |
| *Ipomea* sp. | - | - | o | - | - | - | o | - | - | + | - | - | - | + | o | o | - | - |
| *Karomia microphylla* (Moldenke) R. Fern. | - | o | - | - | - | - | + | + | o | o | - | - | o | - | o | - | - | - |
| *Leptadenia madagascariensis* Decne. | - | - | - | - | - | o | + | o | + | o | + | + | - | o | - | - | o | - |
| *Maerua* sp. | - | o | - | | | | - | - | o | | | | - | - | - | | | |
| *Mangifera indica* L.° | | | | - | - | - | | | | - | - | o | | | | - | - | + |
| *Mundulea micrantha* R. Vig. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *M. pungens* R. Vig. | o | o | - | - | - | - | + | + | + | - | - | - | - | - | - | - | - | - |
| *M. stenophylla* R. Vig. | o | + | + | | | | + | + | ++ | | | | - | o | - | | | |
| *Neobeguea mahafaliensis* J.-F. Leroy | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Olax andronensis* Baker | - | - | - | - | - | - | - | o | o | - | - | - | - | - | - | - | - | o |
| *Paederia grandidieri* Drake | - | - | - | - | o | o | - | - | - | + | + | o | - | - | - | + | - | + |
| *Pentatropis nivalis* ssp. *madagascariensis* (Decne.) Liede & Meve | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Phyllanthus casticum* P. Willemet | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Pluchea grevei* (Baill.) Humbert | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Polygala greveana* Baill. | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Poupartia caffra* (Sond.) H. Perrier° | - | - | - | o | - | - | - | - | - | + | o | + | - | - | - | + | - | o |
| *P. minor* (Bojer) Marchand | | | | - | - | o | | | | + | - | o | | | | - | - | o |
| *Psiadia angustifolia* (Humbert) Humbert | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *Rhigozum madagascariense* Drake | - | - | - | - | - | - | + | o | o | o | - | - | + | - | - | - | - | - |
| *Salvadora angustifolia* Turrill | - | o | o | - | - | - | - | - | + | - | - | + | - | - | - | - | - | - |
| *Secamun* sp. | - | - | - | - | o | - | - | - | - | + | + | - | - | - | - | - | - | - |

| Plant species | Cattle | | | | | | Goats | | | | | | Sheep | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coastal herds | | | Plateau herds | | | Coastal flocks | | | Plateau flocks | | | Coastal flocks | | | Plateau flocks | | |
| | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS | RS | EDS | LDS |
| *Secamun geayi* Costantin & Gallaud | - | - | - | | | | - | - | - | | | | - | - | - | | | |
| *S. tenuifolia* Decne. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Securinega seyrigii* Leandri | | | | - | - | - | | | | - | - | o | | | | - | - | o |
| *Solanum hippophaenoides* Bitter | - | - | o | - | - | o | ++ | ++ | ++ | + | ++ | + | o | - | + | o | - | o |
| *Stereospermum variabile* H. Perrier | - | - | - | - | - | - | o | o | o | - | - | - | - | - | - | - | - | - |
| *Tamarindus indica* L. | - | - | o | - | - | - | - | - | o | o | + | + | - | - | - | - | - | + |
| *Terminalia disjuncta* H. Perrier | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *T. ulexoides* H. Perrier | - | - | - | - | - | - | - | - | o | - | - | - | - | - | - | - | - | - |
| *Tetrapterocarpon geayi* Humbert | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Ximenia perrieri* Cavaco & Keraudren | | | | - | - | - | | | | - | - | - | | | | - | - | - |
| *Ziziphus spina-christi* (L.) Desf. | - | - | o | - | - | - | o | + | o | + | ++ | + | - | + | - | - | + | - |
| *Zygophyllum depauperatum* Drake | - | - | o | | | | + | + | + | | | | - | - | - | | | |
| Woody spp. | - | o | - | o | + | + | o | + | + | + | * | + | - | - | - | + | o | + |
| **Succulents** | | | | | | | | | | | | | | | | | | |
| *Agave sisalana* Perrine ex Engelm | - | - | - | - | - | - | - | - | - | + | - | - | - | - | - | - | - | - |
| *Euphorbia stenoclada* Baill.* | - | ++ | ++ | | | | o | o | ++ | | | | - | - | ++ | | | |
| *Opuntia* sp.* | - | + | ++ | o | + | + | - | - | + | - | - | - | - | - | - | - | - | - |
| *O. stricta* | + | + | + | - | - | - | o | + | + | - | - | - | - | - | - | - | - | - |
| **Crops** | | | | | | | | | | | | | | | | | | |
| *Ipomea* sp. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| *Manihot* sp. | - | - | o | - | + | + | - | - | - | - | + | - | - | - | - | - | - | - |
| *Vigna* sp. | - | - | - | - | o | - | - | - | - | - | - | - | - | - | - | - | + | - |
| *Zea mays* L. | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - |

Binominal nomenclature according to www.tropicos.org (accessed 12/02/15).

RS = rainy season, EDS = early dry season, LDS = late dry season.

* mostly consumed after human preparation, ° also consumption of fruits.

**Table 3.A.3.** Average concentration of dry matter (DM), organic matter (OM), nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), and phosphorus (P) in the feces of local livestock. Bold values indicate standard errors of the mean.

| | Location | Season | DM | OM | N | NDF | ADF | P |
|---|---|---|---|---|---|---|---|---|
| | | | **g/kg FM** | **g/kg DM** | | | | |
| Cattle (*n* = 144) | Coast | RS | 158 | $732^{a}$ | $15^{b}$ | $885^{a}$ | $368^{a}$ | $2.8^{b}$ |
| | | EDS | 231 | $706^{a}$ | $12^{a}$ | $600^{a}$ | $404^{a}$ | $1.9^{a}$ |
| | | LDS | 215 | $672^{a}$ | $15^{ab}$ | $537^{a}$ | $370^{a}$ | $2.1^{a}$ |
| | | | *7.2* | *12.2* | *0.5* | *10.4* | *10.1* | *0.06* |
| | Plateau | RS | 174 | $748^{a}$ | $19^{b}$ | $577^{ab}$ | $356^{a}$ | $3.4^{b}$ |
| | | EDS | 224 | $766^{a}$ | $14^{a}$ | $625^{b}$ | $425^{b}$ | $2.3^{a}$ |
| | | LDS | 290 | $755^{a}$ | $14^{a}$ | $575^{a}$ | $409^{b}$ | $2.1^{a}$ |
| | | | *8.1* | *8.2* | *0.4* | *8.2* | *8.7* | *0.08* |
| **Independent variable** | | Site | *** | *** | n.s. | n.s. | *** | *** |
| | | Season | n.s. | *** | ** | * | *** | *** |
| Goats (*n* = 145) | Coast | RS | 470 | $650^{a}$ | $17^{b}$ | $560^{a}$ | $423^{a}$ | $3.0^{b}$ |
| | | EDS | 500 | $654^{a}$ | $14^{a}$ | $571^{a}$ | $423^{a}$ | $2.2^{a}$ |
| | | LDS | 512 | $621^{a}$ | $13^{a}$ | $535^{a}$ | $391^{a}$ | $2.1^{a}$ |
| | | | *5.8* | *9.4* | *0.3* | *9.1* | *7.7* | *0.07* |
| | Plateau | RS | 459 | $749^{a}$ | $25^{b}$ | $560^{a}$ | $427^{a}$ | $3.1^{b}$ |
| | | EDS | 501 | $753^{a}$ | $20^{a}$ | $533^{a}$ | $394^{a}$ | $2.4^{a}$ |
| | | LDS | 492 | $745^{a}$ | $22^{ab}$ | $573^{a}$ | $417^{a}$ | $2.8^{b}$ |
| | | | *5.3* | *6.6* | *0.4* | *7.5* | *6.5* | *0.07* |
| **Independent variable** | | Site | *** | *** | n.s. | n.s. | *** | *** |
| | | Season | n.s. | ** | n.s. | n.s. | *** | ** |
| Sheep (*n* = 33) | Coast | RS | 469 | $545^{a}$ | $15^{a}$ | $535^{a}$ | $393^{a}$ | $3.2^{c}$ |
| | | EDS | 530 | $651^{a}$ | $13^{a}$ | $542^{a}$ | $364^{a}$ | $2.6^{b}$ |
| | | LDS | 527 | $657^{a}$ | $12^{a}$ | $575^{a}$ | $407^{a}$ | $1.7^{a}$ |
| | | | *15.6* | *24.9* | *0.6* | *10.4* | *10.4* | *0.15* |
| | Plateau | RS | 474 | $708^{a}$ | $22^{b}$ | $572^{a}$ | $408^{a}$ | $3.5^{b}$ |
| | | EDS | 487 | $673^{a}$ | $18^{ab}$ | $635^{a}$ | $449^{a}$ | $2.5^{a}$ |
| | | LDS | 534 | $771^{a}$ | $16^{a}$ | $576^{a}$ | $373^{a}$ | $2.2^{a}$ |
| | | | *12.6* | *16.4* | *0.9* | *14.4* | *17.4* | *0.15* |
| **Independent variable** | | Site | * | *** | n.s. | n.s. | n.s. | *** |
| | | Season | n.s. | ** | n.s. | n.s. | *** | * |

FM = fresh matter, RS = rainy season, EDS = early dry season, LDS = late dry season, *n* = number of fecal samples.

$^{a,\ b,\ c}$ significant differences between seasonal means per plant group and site according to post-hoc tests, , * $p \le 0.05$, ** $p \le 0.01$, *** $p \le 0.001$, n.s. = non-significant.

# Chapter 4

## Reproductive and Economic Performance of Local Livestock in Southwestern Madagascar: Potentials and Constraints of a Highly Extensive System

# Reproductive and economic performance of local livestock in southwestern Madagascar: potentials and constraints of a highly extensive system


## Abstract

In the dry Mahafaly region of southwestern Madagascar, livestock keeping plays a key role in people's livelihoods. Especially zebu cattle and goats are socially and economically important, contributing considerably to the regular income of local households. We therefore analyzed the reproductive performance of local breeds along with herders' culling strategies to determine herd dynamics, opportunities for economic development, as well as potential for future improvements. To illustrate current herd productivity, interviews with herders targeted the progeny history of breeding females (506 cows and 593 does) and their offspring (721 calves and 1,073 kids). Based on the results, reproduction parameters were calculated and then integrated into the PRY Herd Life model to simulate herd development for present management (*status quo*) and two alternate scenarios assuming either ( i ) improved feeding and resulting higher productivity of breeding females or ( ii ) improved culling. Based on prices collected at local markets, a Monte Carlo simulation was used to estimate annual revenues from livestock.

Age at first parturition was 40.5±0.59 months for cattle and 21.3±0.63 months for goats. Females from both species showed long parturition intervals (cattle 24.1±0.48 months, goats 12.4±0.30 months) whereas reported offspring mortality was low with 2.5% of cattle and 18.8% of goats dying before reaching maturity. On the other hand, market dynamics, especially for zebus, were quite high, leading to annual contribution margins of 33 € per cattle unit and 11 € per goat unit. The simulations indicated that improved feeding could support substantial herd expansion and productive offtake rates, whereas improved culling would stabilize livestock numbers and at the same time also increase monetary herd output.

Even though the current livestock husbandry system appears profitable, it might reach its limits in the near future due to the region's restricted carrying capacity. In-

creasing livestock offtake would allow livestock keepers to raise their economic benefit without compromising herd development or enhancing their ecological footprint.

**Keywords:** Herd productivity, Mahafaly Plateau, Monte Carlo model, Progeny history records, PRY Herd Life model, Ruminant husbandry

## 4.1 Introduction

Livestock is of great significance for multiple livelihood objectives in many rural smallholder systems around the globe (Randolph et al., 2007; Upton, 2004). Especially in developing countries, its contribution to food security and as a means of finance and insurance has been subject to numerous studies (Alary et al., 2011; Bosman et al., 1997; FAO, 2011; Little and McPeak, 2014). Furthermore, animals are also important to their owners in view of social status and societal commitments (Weiler et al., 2014). However, many systems continuously run the risk of losses due to poor production and high mortalities brought about by climatic variability, lack of dry season feed supply and poor animal health care (Otte and Chilonda, 2002; Rooyen and Homann, 2008; Thomas et al., 2002). At the same time, restricted market access hampers economic development and poor infrastructure as well as limited availability of natural resources set boundaries to intensification of livestock management.

The depicted situation can also be found on the tropical island of Madagascar, and particularly in its south and southwest, where livestock still forms an integral part of the socio-cultural life and the economy of rural households (Wüstefeld, 2004). A substantial share of the country’s 10 million cattle (estimates for 2013; FAOSTAT, 2014) and the majority of goats and sheep (FAO and AGAL, 2005) are kept by local communities in these dry regions. However, these very extensive and largely grassland-based animal husbandry systems are little productive and susceptible to considerable seasonal constraints, such as dry season forage and water shortages as well as livestock diseases (Rasambainarivo and Razafindratsita, 1987). The increasing number of armed cattle raids, reflecting the country’s ongoing political crisis, and the necessity to conserve this biodiversity hotspot (Myers et al., 2000), which results in the inclusion of natural pastures into protected areas (Ratovonamana et al., 2013), enhance the difficulties livestock farmers face (Chapter 2). Even though pastoralists are considered as relatively effective in coping with external stresses (Harvey et al., 2014; Thornton et al., 2007), the consequences of the current political instability and increasing rainfall variability due to climate change for livelihoods of people in semi-arid southwestern Madagascar and for the region's unique but fragile environment remain uncertain. To identify options of how local livestock keepers can cope with these challenges, including opportunities for increased income generation, an understanding of the livestock system's particularities, its current reproductive performance and economic productivity is crucial. However, very little information on these issues is available (Joshi et al., 1957; Randriamahaleo, 1989; Rasambainarivo and Razafindratsita, 1987; Wüstefeld, 2004), mostly from other areas of Madagascar that do not necessarily match the conditions of the island's southwest (Harvey et al., 2014).

The objectives of the present study were therefore (i) to determine the reproductive performance of the region's two most important livestock species along with current culling strategies, (ii) to assess the system's economic potential based on farmers' annual revenues from cattle and goat keeping, and (iii) to simulate improved feeding and culling strategies and their bio-economic implications so as to identify possible future axes of system improvement without compromising people's livelihoods nor the area's fragile natural resources.

## 4.2 Materials and methods

### 4.2.1 Study area and livestock system

This study was conducted in the Mahafaly region about 60 km south of the administrative center of Toliara in southwestern Madagascar. The terrain is gently rising from a coastal plain on sandy soil at sea level towards a largely open limestone plateau with a maximum altitude of 350 m a.s.l. further inland. The region's arid to semi-arid climate is characterized by strong seasonal and spatial variations in temperature and precipitation, with an annual average of 24°C and irregular rainfall of less than 500 mm per year (Ministère de l`Environnement & Association Nationale pour la Gestion des Aires Protégées, 1999). Most of this rainfall occurs from December to

March when temperatures also reach maxima, whereas water becomes a limiting factor for humans and livestock during the rest of the year (Chapter 2). The vegetation is dominated by loose patches of Silver Thicket (*Euphorbia stenoclada* Baill.) between xerophytic shrub thickets on the sandy soil in the coastal plain and by *Heteropogon contortus* (L) P.Beauv. ex Roem. & Schult. dominated savanna-like grasslands, occasionally interspersed by dense bush- and woodland on the rocky calcareous substrates of the plateau.

Due to its remoteness, a very low level of education of the local population, and the virtual absence of trades and services, the area is amongst the most disadvantaged regions of Madagascar from an economic point of view. Local communities make a living from the cultivation of staple crops (such as cassava, maize, and sweet potato), livestock keeping (indigenous breeds of zebu cattle, goats, and sheep[1], chicken, some turkeys and ducks) and use of timber and non-timber forest products as well as other off-farm activities. Households thereby tend to diversify their activities in order to cope with the high seasonal variability and unpredictability of rainfall and to buffer risks from the underdeveloped social insurance and security system (Neudert et al., in press). The highly extensive animal husbandry system (Kaufmann and Tsirahamba, 2006), plays a vital role in people's livelihoods. With just few exceptions of temporary private grazing grounds in the coastal plain, ruminant livestock is herded on communal pastures throughout the year, feeding on the local vegetation. Their owners make no regular use of concentrate feed and mineral supplements, and crop residues are predominantly fed to draft oxen and sick individuals but only sporadically to healthy animals even when natural forage becomes scarce in the course of the dry season. However, supplementary forage plants, in particular Prickly Pear Cactus (*Opuntia* sp.) and *Euphorbia stenoclada*, the latter restricted to the coastal strip, are provided to animals in times of need (Chapter 3). Veterinary services exist very infrequently due to poor accessibility but also to people's unwillingness to pay for medication and vaccination.

Breeding is mostly uncontrolled, but, especially in cattle, specific animals are preferred based on traits such as a docile character, attractive coat color, and horn size, rather than on reproductive performance (Felius, 2007). From an economic perspective, small ruminants are found more frequently on local markets with goats being the

[1] see Andrianarisoa and Raoliarivelo (2013) and Felius (2007)

only species slaughtered and consumed on-site. In contrast, cattle are important to fulfill social and cultural obligations (Pannoux, 1991) and beef is only consumed during special ceremonies such as funerals and weddings or when an animal dies because of infirmity or disease (Seifert, 1992; Heurtebize, 1997 in Wüstefeld, 2004). Milk yield is low and mainly covers household requirements while sheep milk is considered as a taboo and not consumed at all.

### 4.2.2 Data collection and analysis

Data collection focused on local cattle and goats as pastoralists reported these species to be of major importance as compared to sheep, confirming the national stock statistics (FAOSTAT, 2014).

Data on the livelihood portfolio of local households and basic information on cattle and goat keeping was collected using a structured questionnaire in a survey among 934 households carried out in 2012 (household survey). The interviewed family units were selected in the context of a two-stage sampling design based on village and individual household level. For detailed information on household survey design and its results see Neudert et al. (in press). For the present study, only livestock keeping families ($n$ = 580) were considered. These were grouped into two wealth categories, with households keeping up to 4.3 tropical livestock units (TLU[2]) per adult (older than 14 years) being classified as average and above that as wealthy.

Detailed data on livestock management, sale, and consumption decisions were collected by means of 24 and 31 semi-structured interviews of cattle and goat keepers, respectively. Interviewees were selected in a convenience sampling approach to cover the existing variety of livestock keepers regarding their herd size and age. While qualitative information from these interviews was used to characterize the livestock husbandry system, quantitative data was standardized for statistical analysis and used as input for cost-revenue calculations.

Data on livestock mortality and culling as well as on productivity parameters, i.e. age at first parturition, litter size, parturition interval, and annual parturition rate (litter size x 365 / parturition interval), was obtained from 506 cows and their 721 calves and from 593 does and their 1,073 kids at the end of the 2013 rainy season for goats

[2] Tropical Livestock Unit, TLU: a standard animal of 250 kg live weight. Conversion factors used: 1 cattle = 0.7 TLU, 1 sheep / goat = 0.1 TLU (ILCA, 1993)

and the 2014 rainy season for cattle, using progeny history questionnaires (FAO, 2000; Kaufmann, 2005). The animals belonged in equal shares to herds from three villages located in the coastal zone near Tsimanampetsoa National Park, and three on the limestone plateau (see Appendix Table 4.A.1). For analysis, cattle and goat herds were grouped ( i ) by site, i.e. coastal ($n_{cattle}$ = 20 / $n_{goats}$ = 19) or plateau area ($n_{cattle}$ = 16 / $n_{goats}$ = 18), and ( ii ) by their species-specific size into small to medium (≤33 cattle, $n$ = 17 / ≤38 goats, $n$ = 21) and medium to large herds (>33 cattle, $n$ =19 / >38 goats, $n$ = 16), whereby the latter corresponded to the above classification into average and wealthy livestock owners.

To obtain information on the animals' body weight (BW) at sale and slaughter, a stratified random sample of cattle and goats across pre-selected age classes were weighed in the six focus villages. A wooden platform of 2 m x 1.5 m, linked to an electronic weight scale indicator (SR3000, Tru-Test Inc., Mineral Wells, USA) and four AGRETO weighing feet (AGRETO electronics GmbH, Raabs/Thaya, Austria; nominal load of 1,000 kg per foot, accuracy ±1%) was buried in the ground to weigh cattle; hanging digital scales (range 0 – 50 kg, accuracy 0.5 kg, and range 0 – 100 kg, accuracy 1 kg) were used for light and heavy goats. Measurements were conducted once per livestock species at the end of the rainy season (2013 for goats and 2014 for cattle) when animals were expected to be in optimum body condition (Bezabih et al., 2014), excluding visibly pregnant females. Thus, data from 126 male and 94 female cattle as well as 358 male and 595 female goats were used to determine the animals' average BW in different age and sex classes.

For information on economic performance, prices for live animals and milk were re-corded from local sellers on weekly markets in two coastal and two plateau villages. Monitoring occurred every two weeks from January 2013 to January 2014. Local categories for live animals are very detailed, yet for the present analysis distinction was only made between young males and females (age: 1 to 3 years for cattle, 4 to 18 months for goats) and adult females (1 to 7 parturitions for cattle, 1 to 8 years of age for goats). In total, 558 and 756 price recordings were available for cattle and goats.

All interviews and market surveys were carried out by trained Malagasy assistants fluent in the local dialect and able to understand specific peculiarities and terminologies. Temporal information, e.g. concerning the time of birth or culling of an animal, were derived from the local, season-based calendar in which a year is divided into three parts: rainy season (*asara*; recorded as January), early dry (*asotry*; May) and late dry season (*afaosa*; September). The type and source of all data collected is summarized in Table 4.1.

**Table 4.1.** Type and source of data on reproduction, growth and economic performance of the cattle and goat herds studied, and utilization in biological and/or economic modelling and scenario-testing.

| Parameter | Data source | Purpose | Changed in scenario | |
|---|---|---|---|---|
| | | | IF | IC |
| Livestock-related household characteristics | Household survey[a], additional semi-structured interviews[b] | Description of the local livestock system and management, categorization into subgroups by herd size | | |
| Reproductive performance[c] | Progeny history survey[d] | Scenario modelling (PRY Herd Life) | x | |
| Mortality rate | Progeny history survey[d] | Scenario modelling (PRY Herd Life) | | |
| Culling rate | Progeny history survey[d] | Scenario modelling (PRY Herd Life) | | x |
| Age at culling, sale and slaughter | Progeny history survey[d], additional farmer interviews[e] | Scenario modelling (PRY Herd Life) | | x |
| Animal bodyweight at sale and slaughter | Animal weighing[f], growth curve | Estimation of economic efficiency (Brody model and Monte Carlo simulation) | | |
| Livestock birth season | Progeny history survey[d] | Illustration of seasonal influence on herd productivity | | |
| Prices of animals (per head) and milk (per kg) | Market survey[g] | Calculation of annual herd revenues (Monte Carlo simulation) | | |

* IF = improved feeding scenario, IC = improved culling scenario.

[a] Reference: Neudert et al. (in press).

[b] of *n* = 24 cattle / 31 goats keepers.

[c] age at first parturition, parturition interval, litter size, annual parturition rate.

[d] in six focus villages (*n* = 36 households covering *n* = 506 female cows / *n* = 37 households covering *n* = 593 female goats).

[e] *n* = 20 for cattle / 20 for goats, respectively, in the six focus villages.

[f] of *n* = 220 cattle / 2,429 goats from the six focus villages.

[g] on four local village markets.

### 4.2.3 Calculation of economic performance

In order to assess the profitability of cattle and goat keeping, cost-revenue calculations were computed using a Monte Carlo simulation approach (Brandimarte, 2014; Mußhoff and Hirschauer, 2011; Silva et al., 2011). The calculations included all revenues and costs for which market prices were available, except own household labor and supplementary forage from household-owned sources. Home-consumed and sold animal products were valued with sale market prices. The main indicators of economic performance were contribution margin per cattle unit and year or goat unit and year, as well as the contribution margin per man day. A cattle unit (CU) included a mother cow and all offspring younger than 36 months, while a goat unit (GU) comprised a mother goat and all offspring younger than 22 months. Contribution margins were chosen as indicators instead of profits since fixed costs of capital, land or labour are not relevant in the study area and were not accounted for (Mußhoff and Hirschauer, 2011). Calculations were performed in Malagasy ariary (MGA) and converted to Euro[3].

A Monte-Carlo simulation approach using the Excel®-add-in @RISK 6 (Palisade Corp., Ithaca, NY, USA) was applied to deal with high variation in herd management, knowledge gaps on the livestock production system and uncertainty regarding production and cost factors (Brandimarte, 2014). The Monte Carlo simulation realizes multiple iterations with a deterministic model structure and randomly sampled values from probability distributions of input data, yielding distributions of output data. The approach is suitable to perform analyses under risky or uncertain conditions, displaying the possible range and associated probabilities of results. As input for the cost-revenue calculations, biological herd model data, herd management information from the household survey and semi-structured interviews, as well as animal prices from the market monitoring were used.

To describe the status quo (SQ), three calculations (using all data, coastal herds only, plateau herds only) were run. Economic performance was also modelled for two alternative scenarios of improved livestock management (see section 4.2.4). Where statistical tests of underlying data suggested variation in the model parameters ($p \leq 0.05$), distributions were fitted in @RISK to existing raw data and the best-fitting distribution according to the Akaike Information Criterion was selected for the model. Sampling for the simulations was done with the Latin Hybercube option running 50,000 iterations (Palisade Corp., Ithaca, NY, USA).

[3] (1 € = 3,250 MGA; September 4th 2014, http://www.oanda.com)

### 4.2.4 Herd modeling and scenario analyses

Data on herd productivity, i.e. age at first parturition, parturition interval, litter size, as well as culling rates of females due to poor reproductive performance, and mortality per animal sex and age class, were entered into the species- and system-independent herd model PRY Herd Life (Baptist, 1992) to simulate the development and population dynamics of cattle and goat herds under existing conditions (SQ). Over a given time span, this model computes the potential annual animal offtake for specific culling ages of breeding and surplus females as well as males and calculates the proportion of these three groups in the herd (herd structure), if population size is kept stable.

As little information on mortality and culling rates of adult animals or on their maximum age could be obtained from the progeny history interviews, these data had to be completed from 40 additional farmer interviews (20 per species) and from literature. Based on this information, the animals' maximum life span was determined to be 173 months for cattle and 94 months for goats. These were also set as cull-for-age thresholds for breeding cows and does, since slaughter or sale of cattle older than 84 months and goats older than 48 months do normally not occur. Instead, older animals are kept within the herd and dedicated to special ceremonies and sacrifices, often leading to overaged livestock populations in Madagascar as described in Rasambainarivo and Razafindratsita (1987). Information on productive culling of females, i.e. herd offtakes due to poor breeding performance, was also scarce. As livestock keepers in extensively managed pastoral systems often realize low offtakes (Barrett, 1992; GebreMariam et al., 2010), a share of 3% for cattle and 5% for goats was assumed across all age classes. For surplus females and males, the average age at culling for cattle and at slaughter for goats were chosen as a proxy for offtake age. Mortality rates of mature animals were based on Rasambainarivo and Razafindratsita (1987) for cattle (8%) and Rooyen and Homann-Kee Tui (2009) for local goat breeds raised under similar conditions in Zimbabwe (26%). Mortality was set at 80% for cattle older than 149 months and goats older than 82 months as these were the average ages reported by pastoralists at which the animals' reproductive performance would fall below a critical level.

In order to optimize the culling regime and explore potentials for future development, two scenarios were defined and calculated in PRY, on the one hand to simulate the productivity of local cattle and goat herds under improved management and on the other hand to compute a more market-orientated management. The first scenario (IF = improved feeding) assumed a better feeding regime with locally available additional forage plants and concentrate feed, offered especially during the dry season. For cattle, an exclusive provision with *Euphorbia stenoclada* was assumed for all animals during 5.5 months of the dry season, whereas individual feeding of 500 g $d^{-1}$ of dried cassava tubers over a period of 45 days for does was adopted from Andrianarisoa and Raoliarivelo (2013). As the reproductive performance of breeding females is related to their nutritional status (Berhane and Eik, 2006; Mukasa-Mugerwa, 1989; Peacock, 1996), age at first parturition and parturition interval could be reduced and, at least in the case of goats, prolificacy could be raised slightly under such improved conditions. For scenario IF, age at first calving and calving interval were set to 36 months and 14 months, based on values reported for Madagascar zebus (Joshi et al., 1957; Rasambainarivo and Razafindratsita, 1987). For goats, 17 months was assumed as age of first kidding and 9 months as kidding interval, while the prolificacy was increased to 1.4 kids per parturition corresponding to the average of results from several goat breeds of the Small East African group quoted in Wilson (1991). A higher herd output without compromising herd development was the goal of the improved culling (IC) scenario. For this, offtake rates for poorly performing breeding females were moderately raised to 5% for cows and 10% for does after weaning, and to 15% and 20%, respectively, above the critical reproductive age of 149 and 82 months. These ages were also taken as new cull-for-age thresholds. For the two alternative scenarios, herd development and offtake was only calculated once per species without differentiating between sites or herd size.

### 4.2.5 Statistical analysis

All results based on metric data were specified as mean value ± standard error, apart from the outcome of economic modelling stated as mean value ± standard deviation. Analyses of baseline data were performed in Stata (StataCorp. LP, College Station, TX, USA), taking into account the survey design. For detecting differences between groups, design-based Chi-squared tests were carried out for categorical data, while Mann-Whitney *U* tests were used for comparing groups of metric variables. Statistical data analyses on herd productivity and market monitoring were performed using SPSS Statistics 20 (IBM Corp., Armok, NY, USA) with a significance level of 0.05 to determine differences between subgroups. Pair-wise comparisons of means were carried out using the independent t-test for normally distributed and the Mann-Whitney $U$ test for non-normally distributed data sets after normality was assessed by investigating the skewness and kurtosis $z$-values as well as the Shapiro-Wilk test $p$-value. Welch's t-test was used for cases of unequal group variances or sample sizes.

To determine the animals' BW at the moment of sale and slaughter, growth curves for female and male cattle and goats were established. Age-weight correlation was computed by the Brody function (Eq. 1) which fitted best by comparison of four standard non-linear growth models (Brown et al., 1976; Gbangboche et al., 2008; see Appendix Table 4.A.2).

$$y = A * (1 - b * e^{-k*t}) \qquad \textit{(Eq. 1)},$$

where $y$ is the body weight (kg), $A$ is the asymptote (= adult body weight), $t$ is age in months, $b$ and $k$ are function variables, and $e$ is Euler's number.

Model parameters were optimized by iteration until the relative offset convergence reached values lower than $10^{-5}$. The goodness of fit was assessed by the models' residual weighted sum of squares, and significance of the model parameters was evaluated by their respective $p$-values. The influence of sex and origin of animals (coastal / plateau) was then tested by comparison of the different models through one-way analyses of variance using R version 2.15.2 (R Foundation for Statistical Computing, Vienna, Austria).

## 4.3 Results

### 4.3.1 The livestock system

The household survey revealed systematic differences of the livestock portfolio according to site and wealth category of households (Table 4.2). More households on the plateau kept cattle and draft oxen, while keeping small ruminants was widespread in the coastal region ($p < 0.05$). All wealthy households kept cattle, but other livestock categories (draft oxen, goats and sheep) were also more frequently kept by the wealthy. The relative share of animal species based on total heads of livestock showed that cattle had a higher importance for richer households and goats had a higher overall importance than sheep.

Herding of livestock was carried out mostly by boys (aged 7 – 14 years) and young men. The former herded small stock while zebu cattle were taken to pasture by young men. Herding was mostly done by households members (more than 75% of households), and much less frequently by other persons (relatives outside the household, neighbors) or paid shepherds. The latter were engaged if a household was lacking male members of suitable age for herding, if priority was given to the boys' education, or if herds were large. The employment of paid shepherds was more widespread among wealthy than among average households ($p < 0.01$). The wealthy also engaged more persons in herding than households of average wealth ($p < 0.05$).

On average, 26% of livestock keeping households bought supplementary forage, whereby households having cattle more often purchased fodder than households keeping only small ruminants ($p < 0.05$). Qualitative information confirmed that supplementary forage was of high importance for zebu cattle, while goats were seldom provided with additional resources other than cut branches from shrubs and trees. Among the fodder resources, crop residues and *Opuntia* sp. were most widespread while purchasing *Euphorbia stenoclada* had a far higher importance on the coastal than on the plateau ($p < 0.01$; data not shown).

Milk of goats and cows was used by the overwhelming majority of livestock keepers (cows: 92%; goats: 94%). Milking occurred mainly in the rainy season, but goats were milked more frequently also in the dry season or year-round. According to the herders, average milk offtake per day and goat was 0.5 kg during the primary milking season and 0.3 kg during the dry or late milking season. Milk offtake per cow was reported to range between 0.4 and 4 kg $d^{-1}$ with an average of 1.4 kg $d^{-1}$. The regional coverage with vet-erinary services was low. Despite this, 84% of zebu keepers stated that they had their cattle vaccinated if a veterinarian came to the village, while goats were not vaccinated.

**Table 4.2.** Characteristics of 580 livestock keeping households (HH) in the Mahafaly region, south-western Madagascar, as determined from the 2012 baseline survey. Data for average and wealthy HH[1] show mean values ± standard errors.

| Variable | Coast | | | Plateau | | | Overall | | |
|---|---|---|---|---|---|---|---|---|---|
| | average | wealthy | *p* | average | wealthy | *p* | average | wealthy | *p* |
| **Share (%) of total livestock** | | | | | | | | | |
| Cattle and draft oxen | 18±1.7 | 37±5.0 | *** | 46±3.1 | 53±2.6 | *** | 41±2.7 | 50±3.0 | *** |
| Cattle only | 13±1.7 | 35±4.7 | *** | 28±2.8 | 50±2.6 | *** | 25±2.5 | 47±2.8 | *** |
| Draft oxen only | 5±0.7 | 2±0.4 | n.s. | 18±2.3 | 4±0.3 | n.s. | 15±1.8 | 4±0.3 | n.s. |
| Small ruminants | 82±1.7 | 63±5.0 | *** | 54±3.1 | 47±2.6 | *** | 59±2.7 | 50±3.0 | *** |
| Goats only | 44±4.8 | 34±4.1 | n.s. | 38±3.9 | 24±3.9 | *** | 40±3.3 | 26±3.1 | *** |
| Sheep only | 38±4.5 | 30±1.8 | n.s. | 16±2.5 | 23±5.1 | *** | 20±2.2 | 24±4.4 | *** |
| **HH (%) purchasing additional fodder** | 34±9.4 | 47±11.1 | n.s. | 25±4.2 | 18±2.7 | n.s. | 27±4.0 | 24±3.9 | n.s. |
| **HH (%) investing in herding labor** | 85±3.6 | 100±0.0 | * | 97±1.0 | 98±2.4 | n.s. | 94±1.1 | 98±1.9 | n.s. |

[1] average HH: keeping up to 4.3 tropical livestock units (TLU) per adult (older than 14 years), wealthy HH: keeping >4.3 TLU per adult.

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$, n.s. = non-significant.

### 4.3.2 Reproductive performance and herd structure

Average cattle herds consisted of 37.4% adult females, 11.0% adult males (all older than 22 months), and 20.3% female and 31.3% male offspring. The share of adult cows was higher in coastal (42.9%) than in plateau herds (31.6%), whereas the percentage of females younger than 22 months (30.4%) was about three times higher on the limestone plateau than on the coastal plain (10.7%). The majority (73.5%) of all breeding cows were born within their herds while 21.3% were purchased or exchanged on local markets and 5.2% entered the herds as gifts or compensatory and deficiency payment to reconcile social conflicts (Appendix Table 4.A.3). Generally, animals are often purchased in case a household has some cash available from the sale of crops or casual work, whereas livestock is sold in case a household needs cash.

The average age at first calving was 40.5±0.59 months with no significant differences between coastal and plateau cows nor between herds of different size. Of the breeding females, more than 50% had calved once when they were 36 months old, while only 12.7% were older than 48 months at first parturition (Figure 4.1a). The average calving interval was 24.1±0.48 months, with no differences between sites or herd sizes (Figure 4.2a). A single case of twin births was reported, all others births were single calves. Calving was clearly seasonal with 70.9% of all parturitions occurring during the rainy season compared to 23.6% in the early dry and 5.5% in the late dry season with no significant differences between sites and herd sizes. Abortions and stillbirths were rarely mentioned and therefore not taken into account in further analysis.

Females ($n$ = 348) represented 48.3% and males 51.7% ($n$ = 373) of all offspring recorded from progeny history interviews; only 1.7% females and 2.1% males reportedly died before weaning. Overall, pre-maturity mortality was calculated as 2.5% for both sexes. No significant differences between sites and herd sizes could be determined. Of all offspring, 19.6% were consciously taken out of the herd (= culled) before reaching maturity with a slightly higher share of young males (20.9%) than females (18.1%). Culling was mainly performed as sale or exchange against other goods at local markets (84.3%) or for the purpose of devotement, gift, or compensatory payment (15.7%). The average culling age was 24.7±0.94 months for both sexes across all herd categories. Slaughtering of cattle for own consumption was not reported but many animals were sold to ‘butchers’. As no cattle are slaughtered at village markets in the study area, this term may describe cattle dealers who purchase larger numbers of animals to drive them by foot to trans-regional markets where they enter the national meat trade.

Local goat flocks were composed of 53.5% does and 15.1% bucks (both aged >10 months which was considered as late maturity age), as well as 15.2% female and 16.1% male kids, with no differences between the two sites. The vast majority (75.0%) of breeding does was born within their actual flocks, 23.1% were purchased, and 1.9% gifted or paid to settle conflicts.

Average age at first kidding was 21.3±0.63 months with little variation between sites or flock sizes (Figure 4.1b). Does kidded every 12.4±0.30 months with parturition intervals being significantly higher for plateau goats than for coastal ones ($p < 0.05$). However, no such difference was found between herds of different size (Figure 4.2b). Close to two thirds (67.8%) of all recorded births were single, 30.8% were twins and 1.4% triplets. This resulted in an average annual parturition rate of 1.3±0.02 which was significantly higher for does from small to medium size flocks than for goats from larger flocks ($p < 0.05$), whereas minor differences occurred between the coast and the plateau. Unlike in cattle, kidding of goats followed no clear seasonal pattern: 37.1% of all kids were born during the rainy season, 32.4% during the early dry and 30.5% during the late dry season, showing no significant differences between sites and herd sizes.

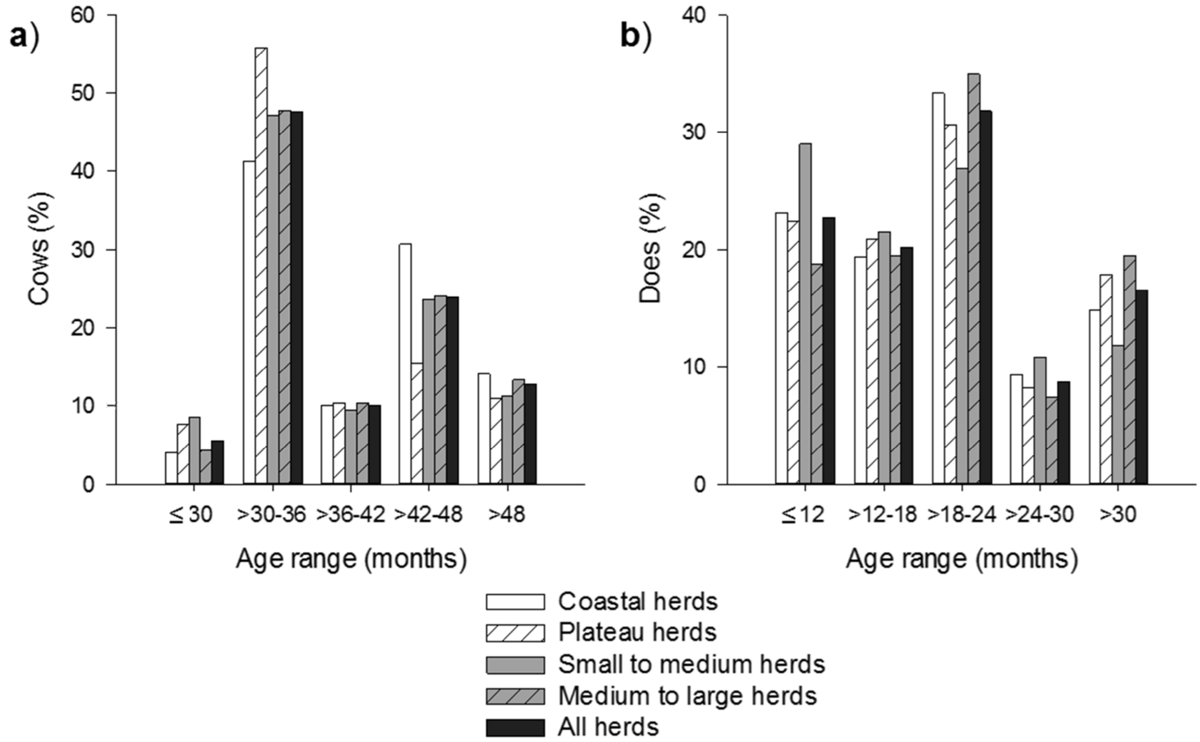


**Figure 4.1.** Age at first parturition of local (a) cows and (b) does in southwest Madagascar as determined by progeny history interviews in six focus villages. Frequency distribution is shown for total and sub-datasets. Note the different scaling of Y-axes.

The ratio of female to male kids was nearly equal ($n_{females}$ = 542, $n_{males}$ = 531). A significantly higher proportion of kids died before weaning (≤4 months) in coastal flocks (18.0%) than on the plateau (9.6%; $p < 0.05$), with an overall average preweaning mortality of 13.3%. Mortality until maturity averaged 18.8% without differences between sites and herds sizes. Diseases were the most frequently named reason for offspring mortality (64.3%). Kids were also stolen or killed by predators (15.9%), mostly by feral dogs, and 4.3% died at birth, while no precise information was given for the remaining 15.5% of cases. A higher portion of weaned male offspring was slaughtered (4.8%) and sold (17.0%) than of weaned female offspring (1.3% and 14.1%, respectively). The majority of culled goats (82.2%) were sold at village markets, 16.9% were slaughtered for own consumption and 0.4% because of physical deficiencies. Slaughter age averaged 12.2±1.23 months and selling age 11.4±0.78 months with no significant differences between sexes, sites, or flock sizes, respectively. Even though the use of goats for sacrifice is common in the region, only 0.5% of all culled animals served this purpose.

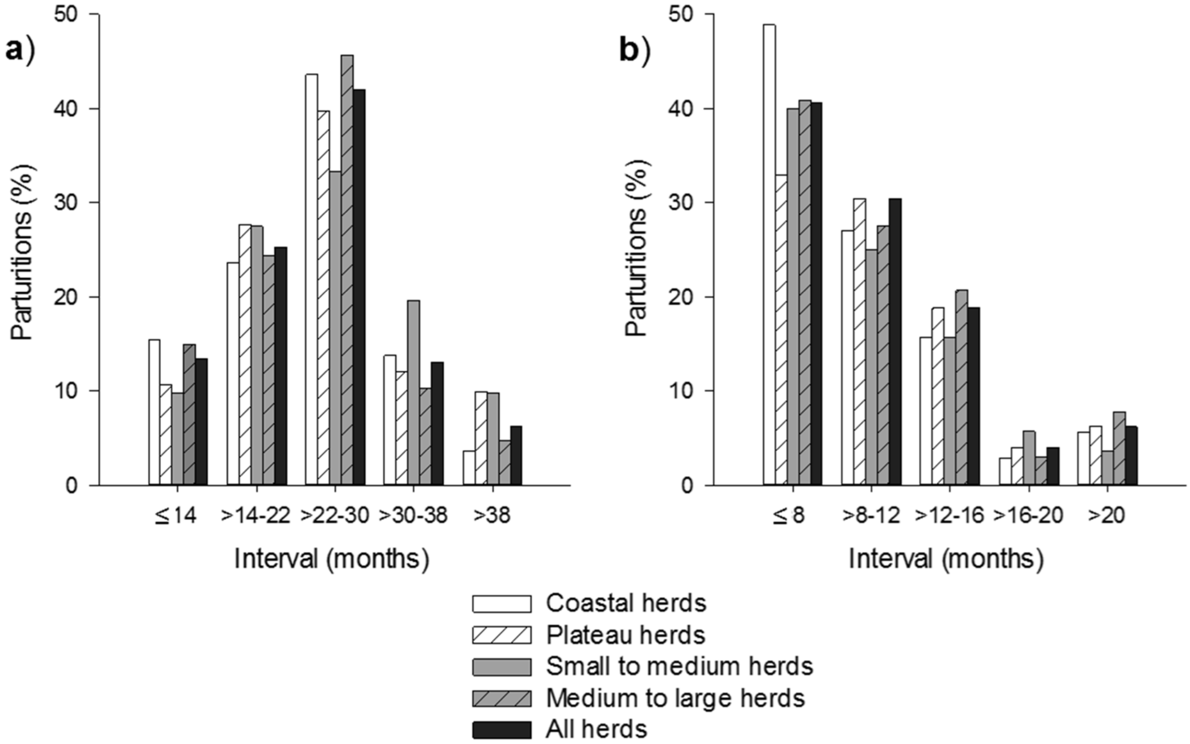


**Figure 4.2.** Parturition interval of local (a) cows and (b) does in southwest Madagascar as determined by progeny history interviews in six focus villages. Frequency distribution is shown for total and sub-datasets.

### 4.3.3 Age dependent bodyweight

The one-time, end-of-rainy-season cattle weighing resulted in an average BW of 205±4.4 kg for adult cows and 268±8.0 kg for adult bulls ($p < 0.001$), with maxima of 267 kg for cows and 405 kg for bulls. There were no statistical differences within these two categories between animals from the coastal plain and the limestone plateau. In the case of adult goats, BW averaged 29 kg for both does (±0.3) and bucks (±0.8), with maxima of 48 kg for empty does and 65 kg for bucks across sites. Animals of both sexes were significantly heavier on the limestone plateau than in the coastal plain ($p < 0.05$, respectively).

The BW for adult animals (*A*) predicted by the Brody model was 211 kg for cows and 343 kg for bulls across sites (Figure 4.3). Predicted BW at culling age was 158 kg and 168 kg for females and males, respectively. The BW of fully grown goats was computed to be 36 kg for does and 41 kg for bucks. According to the model, female animals are culled at a weight of 20 kg and males at 24 kg.

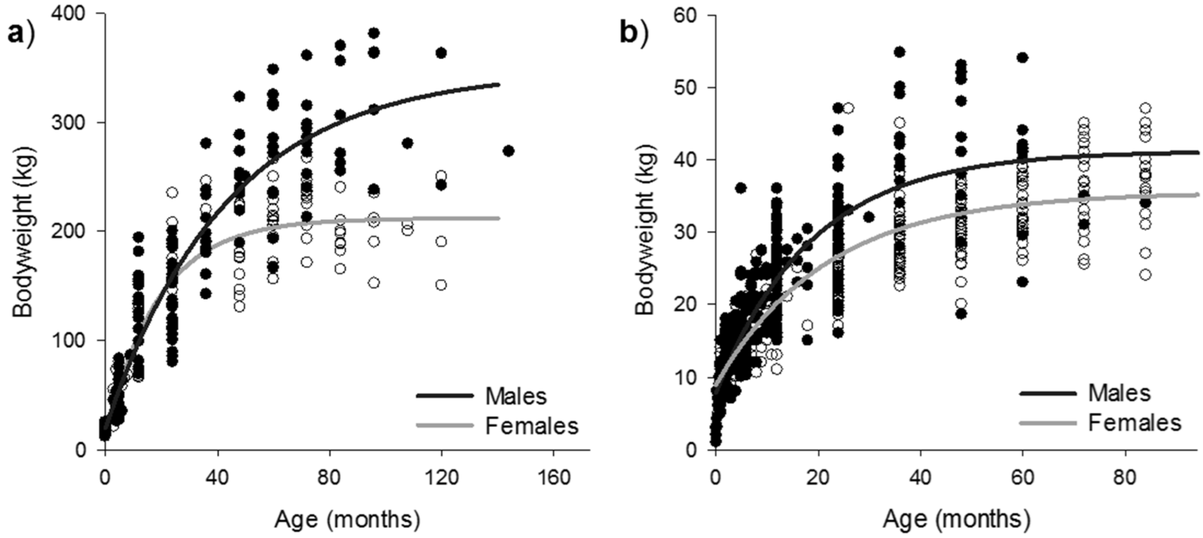


**Figure 4.3.** Bodyweight of (a) 126 male and 94 female cattle and (b) 358 male and 595 female goats until the species-specific cull-for-age threshold (173 months for cattle and 94 months for goats) determined by weighing a stratified random sample of animals across pre-selected age classes in six focus villages at the end of the rainy season 2013 (for goats) and 2014 (for cattle). Regression lines were computed by the Brody function (Eq. 1) fitting best to the weight-age datasets. Filled dots represent male and empty dots female weight data. Note the different scaling of Y-axes.

### 4.3.4 Economic performance and revenues

Prices for categories of livestock as recorded in 2013 are depicted in Table 4.3. Highest prices were achieved for adult females and did do not decrease with older age (data not shown). Regarding regional differences, prices for nearly all livestock categories (except male goat kids) were higher on the plateau than in the coastal region. For cattle, fewer animals were for sale on the plateau, and particularly fewer breeding females. The gathered information was used to compute cost-revenue calculations for cattle and goat herds (Table 4.4). Given the lack of major differences in reproductive performance and management between wealth categories, this factor was ignored.

**Table 4.3.** Prices for live animals recorded in 2013 during regular surveys on four village markets in the Mahafaly region, southwestern Madagascar. Statistical differences are shown in comparison between sites. Monetary data show mean values ± standard errors.

| Livestock category | Coast | | Plateau | | Overall | | *p* |
|---|---|---|---|---|---|---|---|
| | *n* | Price (€) | *n* | Price (€) | *n* | Price (€) | |
| **Cattle** | | | | | | | |
| Young males | 134 | 62.9±1.76 | 80 | 76.9±2.48 | 214 | 68.1±1.51 | *** |
| Young females | 94 | 45.1±1.05 | 79 | 66.5±2.32 | 173 | 55.8±1.49 | *** |
| Adult females | 147 | 80.3±2.83 | 24 | 108.7±3.31 | 171 | 84.2±2.59 | *** |
| **Goats** | | | | | | | |
| Young males | 122 | 7.3±0.19 | 139 | 7.5±0.17 | 261 | 7.4±0.13 | n.s. |
| Young females | 141 | 7.4±0.24 | 180 | 8.5±0.21 | 321 | 8.0±0.16 | *** |
| Adult females | 114 | 10.3±0.22 | 60 | 12.8±0.34 | 174 | 11.1±0.21 | *** |

*** $p \leq 0.001$, n.s. = non-significant.

For cattle, the main differences in input data between the coastal zone and the plateau were prices for live animals, payment of herding labor, additional fodder provision and the share of females in the herd (Appendix Table 4.A.4). Average herding labor costs were higher on the plateau due to a higher share of households employing paid shepherds, while in the coastal region costs for supplementary forage were higher as more households needed to purchase it. With a yearly rearing rate of 0.5 calves / CU, average yearly revenues of 43 € / CU could be achieved, whereby revenues in the coastal region were lower due to lower prices for live animals. Average yearly costs amounted to 11 € / CU, resulting in an average contribution margin of 33 €/ CU per year or 1.5 € per man day. The economic performance of cattle keeping was thereby slightly better on the plateau than along the coast (Appendix Figure 4.A.1).

For goats, differences in input data between the coastal plain and the plateau existed for the parturition interval and the prices for female kids and does (Appendix Table 4.A.5). Thus, the annual rearing rate was 1.3 and 1.1 kids / GU for coastal and plateau herds, with the higher rearing rate having a positive effect on the revenues, although it could not outweigh the higher prices for live animals in the plateau region. On average, yearly revenues of 13 € / GU were achieved. With average yearly costs of 1.9 € / GU, a contribution margin of 11 € / GU per year and 0.6 € per man day was achieved (Appendix Figure 4.A.2).

**Table 4.4.** Results of cost-revenue modelling for cattle and goat keeping households under current management (status quo, SQ, distinguishing sites) and two alternative scenarios (improved feeding, IF, and improved culling, IC; no distinction of sites). Data show mean values ± standard deviations on a yearly basis (except for *).

| Output variable | Unit | SQ | | | Scenarios | |
|---|---|---|---|---|---|---|
| | | Coast | Plateau | Overall | IF | IC |
| **Cattle** | | | | | | |
| Rearing rate[1] | calves / CU | 0.5±0.18 | 0.5±0.18 | 0.5±0.18 | 0.8±0.00 | 0.5±0.18 |
| Female calf revenues[2] | € / CU | 11.8±4.59 | 17.5±7.90 | 14.4±6.84 | 22.1±7.25 | 14.4±6.85 |
| Male calf revenues[2] | € / CU | 17.5±7.96 | 21.5±9.64 | 19.1±8.94 | 29.5±9.43 | 19.2±9.02 |
| Breeding female revenues | € / CU | 7.5±2.96 | 7.5±2.99 | 7.5±3.01 | 7.3±2.71 | 9.2±3.75 |
| Milk revenues | € / CU | 2.2±1.40 | 2.2±1.41 | 2.2±1.41 | 3.3±1.79 | 2.2±1.40 |
| **Total revenues** | **€ / CU** | **39.0±12.36** | **48.7±16.30** | **43.2±14.57** | **62.2±12.31** | **44.9±14.78** |
| Costs for replacement[3] | € / CU | 5.4±1.19 | 8.1±2.48 | 6.6±2.27 | 6.4±2.11 | 7.7±2.74 |
| Costs for herding labor | € / CU | 0.8±3.12 | 1.6±6.45 | 1.1±4.43 | 1.1±4.48 | 1.1±4.60 |
| Costs for additional fodder | € / CU | 3.6±5.52 | 2.1±5.56 | 2.5±5.30 | 13.2±9.62 | 2.5±5.31 |
| Costs for veterinary care | € / CU | 0.3±0.07 | 0.4±0.09 | 0.3±0.08 | 0.3±0.08 | 0.3±0.08 |
| **Total variable costs** | **€ / CU** | **10.1±6.48** | **12.2±8.97** | **10.5±7.40** | **21.1±10.88** | **11.7±7.67** |
| **Contribution margin** | **€ / CU** | **28.9±13.68** | **36.5±17.81** | **32.7±15.59** | **41.0±15.28** | **33.2±15.73** |
| | **€ / man day*** | **1.3±1.73** | **1.7±2.23** | **1.5±1.96** | **1.9±2.33** | **1.6±2.03** |
| **Goats** | | | | | | |
| Rearing rate[1] | kids / GU | 1.5±0.63 | 1.2±0.59 | 1.3±0.61 | 1.4±0.54 | 1.3±0.61 |
| Female kid revenues[2] | € / GU | 4.7±3.03 | 5.0±3.11 | 4.9±3.11 | 5.8±3.08 | 4.8±3.10 |
| Male kid revenues[2] | € / GU | 4.6±2.68 | 4.2±2.53 | 4.4±2.61 | 5.3±2.50 | 4.4±2.59 |
| Breeding female revenues | € / GU | 1.7±0.53 | 2.2±0.65 | 1.9±0.60 | 1.7±0.39 | 2.3±0.69 |
| Milk revenues | € / GU | 2.0±1.55 | 2.0±1.54 | 2.0±1.55 | 2.0±1.56 | 2.0±1.55 |
| **Total revenues** | **€ / GU** | **13.1±5.45** | **13.4±5.49** | **13.2±5.50** | **14.9±5.18** | **13.5±5.48** |
| Costs for replacement[3] | € / GU | 1.5±0.65 | 1.8±0.64 | 1.7±0.66 | 1.6±0.55 | 1.9±0.76 |
| Costs for herding labor | € / GU | 0.2±0.43 | 0.2±0.62 | 0.2±0.56 | 0.2±0.57 | 0.2±0.54 |
| Costs for additional fodder | € / GU | 0.0±0.00 | 0.0±0.00 | 0.0±0.00 | 4.8±0.00 | 0.0±0.00 |
| **Total variable costs** | **€ / GU** | **1.7±0.78** | **2.0±0.89** | **1.9±0.87** | **6.6±0.79** | **2.1±0.93** |
| **Contribution margin** | **€ / GU** | **11.4±5.30** | **11.4±5.38** | **11.3±5.37** | **8.3±5.02** | **11.4±5.32** |
| | **€ / man day*** | **0.6±0.50** | **0.6±0.93** | **0.6±0.82** | **0.4±0.66** | **0.6±0.82** |

Results from Monte Carlo simulation with 50,000 iterations. Annual values based on assumption of steady state herd model.

CU = cattle unit (mother cow and all offspring younger than 36 months), GU = goat unit (mother goat and all offspring younger than 22 months).

[1] Calculated from parturition interval, litter size, and calf / kid mortality. For detailed information on input parameters see model definition in Appendix Tables A.4 and A.5.

[2] Calculated from share of female and male offspring (based on progeny history data) and market prices (see Appendix Tables A.4 and A.5).

[3] Replacement of breeding female, i.e. purchase of female offspring or loss of revenues from the potential sale of a female offspring on the market if the breeding female is replaced by a female offspring from the herd (opportunity costs).

### 4.3.5 Scenario analysis

Under current management (SQ) the annual herd expansion at constant number of breeding females and total herd offtake were slightly higher for coastal than for plateau cattle herds (Table 4.5) due to overall lower mortality and, apart from higher age at first parturition, better reproductive performance. The same result was found for medium to large compared to small to medium size cattle herds. The model calculation for possible herd offtake (in % of animals kept) was generally lower than reported in the progeny history interviews. The predicted share of males in all culls ranged between 60.9% and 65.0% across herds from both sites and sizes (61.2% for total SQ dataset) and was therefore nearly twice as high as the share of culled surplus females (34.4%). By contrast, the progeny history interviews reported a lower share of males (between 54.8% and 59.6% across sites and herd sizes and 57.3% for total dataset) and a higher share of females (42.7%) in all culls.

For goats, a reverse trend was found regarding sites and flock sizes. Here, predicted offtake rates were higher (41.1% modelled compared to 22.0% calculated from progeny history data) and the share of males in all culls lower (58.0% modelled) than reported by their owners (61.4%). However, the results of the progeny history survey included only little information on adult animals.

With regard to the three scenarios, herd expansion and total offtake rates as well as the culling rate of non-breeding females for both species were highest for scenario IF. In the case of herd expansion the rate nearly doubled in comparison to scenarios SQ and IC (Table 4.5). Scenario IF resulted in an average yearly rearing rate of 0.8 calves / CU leading to average revenues of 62 € / CU (Table 4.3). Although there were higher costs for supplementary forage associated with this scenario, the yearly contribution margin could be raised to 41 € / CU compared to yearly SQ performance (33 € / CU). For goats, the yearly kidding rate increased to 1.4 kids / GU, resulting in higher yearly profits of 15 € / GU compared to 13 € / GU in SQ. However, the higher revenues could not outweigh the high costs of additional cassava fodder (4.8 € / GU*year), resulting in a lower average contribution margin of 8 € / GU*year compared to SQ.

For scenario IC, the annual herd expansion rate was lowest compared to the two alternatives, whereas the computed share of breeding females in the herds was highest. Predicted total offtake rates for both species lay between SQ and IF. For cattle, scenario IC resulted in a slightly improved average contribution margin of 33 € / CU*year but could not improve the contribution margin for goats compared to SQ (Table 4.3).

**Table 4.5.** Modeled results of PRY Herd Life for the local cattle and goat husbandry system under current management (status quo, SQ, distinguishing sites and herd sizes*) and two alternative scenarios (improved feeding, IF, and improved culling, IC; no distinction of sites). All data are given in %.

| Output variable | SQ | | | | | Scenarios | |
|---|---|---|---|---|---|---|---|
| | Coast | Plateau | SMH | MLH | Total | IF | IC |
| **Cattle** | | | | | | | |
| Annual herd expansion rate | 12.2 | 10.7 | 11.2 | 12.4 | 12.1 | 21.0 | 10.9 |
| Breeding females (in herd) | 58.8 | 65.0 | 68.6 | 58.8 | 59.5 | 44.0 | 60.8 |
| Surplus females (in herd) | 11.1 | 15.1 | 10.8 | 11.4 | 11.1 | 23.5 | 9.9 |
| Males (in herd) | 29.4 | 19.9 | 20.6 | 29.8 | 29.4 | 32.6 | 29.3 |
| Culls per year, total | 18.4 | 18.4 | 19.6 | 18.7 | 18.4 | 24.7 | 21.7 |
| Culls per year, surplus females | 34.4 | 31.3 | 33.2 | 34.8 | 34.4 | 40.3 | 26.1 |
| Culls per year, males | 61.2 | 65.0 | 63.2 | 60.9 | 61.2 | 56.2 | 51.6 |
| **Goats** | | | | | | | |
| Annual herd expansion rate | 26.9 | 29.8 | 30.3 | 25.9 | 27.4 | 44.5 | 23.5 |
| Breeding females (in herd) | 56.0 | 61.6 | 58.4 | 61.9 | 62.4 | 45.8 | 64.6 |
| Surplus females (in herd) | 12.6 | 15.1 | 20.5 | 14.2 | 14.1 | 23.0 | 12.2 |
| Males (in herd) | 31.4 | 23.3 | 21.2 | 24.0 | 23.5 | 31.3 | 23.2 |
| Culls per year, total | 37.9 | 42.0 | 40.5 | 38.1 | 41.1 | 46.9 | 45.3 |
| Culls per year, surplus females | 34.1 | 37.7 | 36.8 | 35.5 | 35.7 | 40.8 | 28.0 |
| Culls per year, males | 59.0 | 56.4 | 57.9 | 58.9 | 58.0 | 54.3 | 51.8 |

* SMH: small to medium size herds (≤33 cattle / ≤38 goats), MLH: medium to large size herds (>33 cattle / >38 goats).

## 4.4 Discussion

### 4.4.1 Productivity of local livestock herds

Reproductive performance in traditional pastoral systems, where mating is largely uncontrolled, is commonly regarded as poor due to various restraints such as limited dry season forage and water supply, poor animal health, and ineffective breeding management (Mgongo et al., 2014; Rooyen and Homann-Kee Tui, 2009). However, even taking this factor into account, this study's average results for the reproductive performance of cattle and goats in southwest Madagascar appear inferior compared to similar environments. For example, Alberro (1983, cited in Mukasa-Mugerwa, 1989) reported age at first calving at 35.1 months for East African zebu in Ethiopia, and the calving interval for the same type of cattle varied between 16.4 months in Tanzania (Kanuya et al., 2006) and 20.5 months in Kenya (Bekure et al., 1991). Yet, the Madagascar zebu, due to its geographical isolation, has been classified as a distinct breed (Joshi et al., 1957) and may therefore differ from continental *Bos indicus* cattle. The little information available on its performance was primarily obtained from experimental station trials. Reported age at first calving ranges from 30 to 68 months and calving interval from 12.4 to 24 months (Joshi et al., 1957; Randriamahaleo, 1989; Rasambainarivo and Razafindratsita, 1987). With regard to Madagascar goats, Randriamahaleo (1989) described an average age at first kidding of 12 to 18 months. Apart from this report, the respective values obtained in the present study were also higher and kidding intervals were longer than reported for various Small East African goat breeds by Wilson (1991), whereas the determined litter size of 1.3 kids per parturition differed only marginally from findings summarized by the latter author. However, the high number of breeding females showing late age at first parturition and long parturition intervals, especially in cattle, indicate that the overall low performance of local livestock herds may be the consequence of low productive cows and does not being culled, as they continue to play an important role for their owners as a symbol of social status, bank substitute, and insurance in times of need (Bosman et al., 1997; Weiler et al., 2014).

Seasonality seems to have a certain influence on the reproduction of cattle but could not be explicitly determined for goats, confirming the findings of Randriamahaleo (1989) for local livestock in West Madagascar. Although García and Gall (1981) stated that in tropical and subtropical regions breeding occurs throughout the year due to the negligible effect of photoperiodicity compared to temperate zones, authors such as Berhane and Eik (2006) and Hary et al. (2003) emphasized the significant impact of seasonal fluctuations in quantity and quality of available forage resources on individual reproductive traits. These seasonal fluctuations are also distinct within the study region and have a clear site-specific effect on the availability and composition of the natural vegetation which serves as fodder (Chapter 3). Though this leads to some significant differences in grazing management between the coastal zone and the inland plateau (Chapter 2), the consequences for reproductive performance are less explicit. We also observed a minor effect of herd size on reproductive performance, although it could be argued that it is easier for owners of smaller herds to feed and water their animals during the dry season when both resources are scarce (Kanuya et al., 2006). On the other hand, livestock farmers owning medium to large size cattle and goat herds often belong to the most reputable and influential members of their community and may therefore have favored access to high quality grazing grounds year-round, so that advantages and disadvantages are largely balanced in the end.

Surprisingly, the region's unfavorable climatic conditions, the irregular use of supplementary feeding even during the dry season, and the virtual lack of veterinary care did not lead to an elevated livestock mortality rate. In several studies of East African livestock populations compiled by Sieff (1999), total mortality ranged between 5% and 45% for adult cattle and between 10% and 62% for small ruminants. Loss of offspring is normally expected to be high and a major constraint to tropical livestock production (Payne and Wilson, 1999). In contrast, the high survival rate of young cattle and goats recorded in this study was striking. While Desta and Coppock (2002) stressed the episodic development of cattle mortality in the southern Ethiopian rangelands, depending on seasonal and year-specific conditions, this cannot explain the low mortality rates reported for the period covered by the progeny history interviews. Cycles of low annual rainfall and droughts have occurred regularly in southern Madagascar over the decade preceding the survey (Ratovonamana et al., 2011), so higher mortalities due to episodic droughts were to be expected. Furthermore, the low mortality rates contradict the people's perception that their animals suffer a lot from various diseases, as it was regularly communicated during the investigation, but these seemed to only have some impact on the mortality of goats.

However, data on reproductive performance in this and the majority of similar studies resulted from farmer interviews since long-term monitoring providing respective data is typically limited in its practical feasibility, in particular at remote locations. Thus, the outcomes of progeny history approaches clearly depend on the memory, perceptivity, and reliability of the interviewees. Nevertheless, Grandin (1983) argued that in pastoral and agropastoral smallholder production systems, interview-based progeny history generates reliable results as livestock is given a high status. Yet, this depends on the livestock species and its significance for a community. For example, Kaufmann (2005) could retrace the detailed reproductive history of camels in northern Kenya over a period of about 15 years, including a notable amount of data from former breeding females no longer part of the herds. In contrast, Riedel et al. (2014) were not able to gain precise data for more than three past litters of breeding sows in southwestern China. In the current study, several livestock keepers also had problems to coherently recall the productive life history of their animals, which was more problematic for goats than for cattle because of the superior cultural value of zebus. However, the high number of collected animal records and the cleaning of datasets from inconsistent information yielded reliable estimates of reproduction data.

### 4.4.2 Sale and slaughter weight of local livestock

Information on the animals' specific BW at culling are valuable for estimating the economic efficiency of a livestock system, for example to identify optimum offtake weight and optimize use of feed resources (Negassa and Jabbar, 2007). BW for adult cattle as predicted by the Brody growth model was considerably lower for both sexes than given by Felius (2007) and Joshi et al. (1957) for the Madagascar Zebu (on average 320 kg for cows and 475 kg for bulls). For bulls, BW was further at the lower end of a range quoted by Payne (1970) for Madagascar zebus (320 – 450 kg). For goats on the other hand, the BW predicted for does and bucks at the culling age of two years was similar to respective average values of several Small East African goat breeds (28.5 kg for does and 32.7 kg for bucks; summarized by Wilson, 1991).

Significant site-specific differences in BW of adult livestock were only found for goats, which were significantly heavier on the limestone plateau. This may be related to a better availability of feed in this part of the research area during the rainy season as compared to the coastal zone. A regional difference in BW of cattle was not observed and may be due to the fact that most coastal zebu herds move towards the plateau on their annual transhumance movement after the onset of rains (Chapter 2). They thereby gain access to fresh fodder while mixing with the plateau cattle population, and some of the herds surveyed may just have returned from this temporal dislocation shortly before weighing took place.

### 4.4.3 Economic performance

Apart from its cultural functions, this study confirmed the economic and societal importance of livestock in the Mahafaly region. Information from herders regarding inflow and outflow of animals and market data revealed that livestock and its products are sold to satisfy economic needs of households, but an important part is also home consumed (especially milk and goat meat) and animals are given away as presents in the frame of social obligations. Thus, in line with the findings of Fisher (2009) and Wüstefeld (2004), livestock serves as income source, but also as insurance and savings and has cultural value in the study region.

For analyzing the economic performance of goat and cattle keeping, cost-revenue calculations were based on data and knowledge about the local livestock keeping system. This knowledge remained partly incomplete, especially regarding actual fodder supply and demand, and in- and outflow of animals from herds over time. Such insufficient data may have led to shortcomings in the specification of the model. In the calculations we did not include costs for own household labor or opportunity costs of household-generated supplementary forage and use of village pasture resources. Although these costs may be important, it is difficult to value them economically. In general, the aspects not accounted for might lead to a lower economic result than calculated here.

Across sites, and with exception of female zebus, livestock keepers sold their animals before these reached 65% of their mature BW. However, sales at local markets are not based on the weight of animals but exclusively on a price per head, although body condition plays an important role in price negotiations. Additionally, local farmers mostly sell and slaughter their animals in cases of urgent need while otherwise keeping them as livelihood insurance. This selling strategy is similarly found in other little market orientated African smallholder systems (Alary et al., 2011; Bosman et al., 1997; Weiler et al., 2014).

The cost-revenue calculations showed that goat and cattle keeping achieve positive contribution margins. According to the results, under average conditions 33 € / CU*year and 11 € / GU*year is reached for cattle and goat keeping. Minor differences exist between contribution margins of the two sub-regions, mainly due to price differences for live animals and variations in livestock management, whereas differences in reproductive performance were not found to play a major role.

The average remuneration of labor for herding zebu cattle (approx. 1.5 € / man day) is higher than the common agricultural wage in the study region (approx. 0.9 € / man day in 2013). Thus, under the given circumstances, it is economically profitable to employ a person for herding zebu cattle. In contrast, for goats the average remuneration of labor is with approximate 0.6 € / man day lower than the common agricultural wage. Thus, goat herding by adult men, who may find better remunerated labor elsewhere, is not advisable from an economic point of view. Actually, households perceive this relationship as goat herding is often done by boys and employing a goat shepherd is often considered as 'not worth it'. Apart from these general species differences, remuneration of labor strongly depends on herd size.

In the cost-revenue calculations we assumed a steady state of the herd and approximated the potential financial yearly gain from livestock keeping by local households, thus, exploring the income function of livestock keeping. However, to fully value the income function of livestock, information on other income sources is necessary. Wüstefeld (2004) found that livestock keeping in a more southern region of Madagascar contributed 26.1% and 39.0% to household income in a non-drought year and a drought year, respectively. Also in the Mahafaly region, livestock keeping contributed on average 25% to total household income (Neudert, unpubl. data). Part of the potential revenues calculated in this study may not be realized in monetary terms in case the livestock keeper decides to increase his herd. Due to the savings function of livestock, this investment in livestock capital is a regular part of the livestock keeping system in developing countries (e.g. Sieff, 1999). For northern Kenya, McPeak (2005) reported that investment in livestock yielded a higher rate of return than depositing capital in banks.

The economic valuation of the insurance and savings function was explored elsewhere assuming insurance premiums and interest rates for livestock capital (Weiler et al., 2014). However, both valuation approaches can be hardly applied to the situation in southwestern Madagascar due to the absence of practical alternatives to deposit capital in banks or insurances. Yet, especially the insurance function is likely to be of great significance in the study region (Fisher, 2009; Wüstefeld, 2004).

### 4.4.4 Alternative scenarios and implications for improved management

The PRY Herd Life model has been described as a useful tool for comparing the reproductive and growth performance of different livestock species and for testing new and more efficient management options (Dickhoefer et al., 2012; Riedel et al., 2014). In this regard, scenario IF provided the highest herd expansion and offtake rates and, according to the results of the economic cost-revenue calculations, highest annual profits for both cattle and goats by improving reproduction parameters due to better feeding. This scenario seems feasible for livestock keepers in the research area as various studies revealed a certain potential for the cultivation of locally available forage plants and showed positive effects of improved feeding on livestock performance. For example, Ahlers (2014) obtained satisfying results on the voluntary intake and digestibility of a mixed diet of *Euphorbia stenoclada* and *Heteropogon contortus* hay during controlled feeding trials with local sheep, while Andrianarisoa and Raoliarivelo (2013) could improve the reproductive performance of does after systematically feeding dried cassava tubers. Further research has been conducted on the fodder use of *Opuntia* sp. (Rasaon, 1974) and on the plantation of *Ziziphus spina-christi* (Radobarimanajaka et al., 2013), all in the region's coastal area. On the limestone plateau, Fisher (2009) documented the efforts of growing different species of *Brachiaria* grass as cattle fodder. For goats, however, the high costs of supplementary cassava feeding assumed for this scenario (0.2 € / kg cassava) would decrease the overall economic benefit and thus outweigh enhanced revenues from better reproductive performance.

Certainly, it has to be kept in mind that these economic results are only valid if enhanced fodder provision of the stated amount actually leads to the stated economic performance as no information, except the details given in Andrianarisoa and Raoliarivelo (2013), was available from the region to support these assumptions. We additionally used the average market price of cassava as opportunity cost which may be even higher if households face a shortage of this crop, especially in drought years. For cattle, a better supply with additional amounts of the forage plant *Euphorbia stenoclada* appears feasible under the given price relationships. However, hardly any calculations are available on the amount of supplemental feed needed for the local livestock population. Only Ahlers (2014), assuming an average number of 20 TLU per household, estimated that a 1.2 ha of *Euphorbia stenoclada* plantation would be needed per livestock keeping household to feed coastal cattle, goats, and sheep in the course of the dry season. However, it is doubtful whether there would be enough land available for the plantation of forage plants, in particular in view of increasing land use conflicts between pastoralists and crop farmers (Chapter 2). Moreover, if improved feeding would only foster herd expansion without changing the current culling management, this would lead to higher numbers of animals and thus increase the pressure on the fragile vegetation. Especially in the coastal zone such a development may, in the medium term, surpass the system's ability to regenerate its scarce plant cover during the rainy season and therefore lead to an over-exploitation of the natural forage resources.

Therefore it appears reasonable to combine improved feeding with a more stringent culling management as revealed in scenario IC. This would ensure the maintenance of livestock keepers' natural bank accounts (Kaufmann, 2011), since the enhanced offtake of animals will not threaten the herd population, and at the same time increase annual revenues from animal sales. Additionally, it would help to keep the livestock population at a manageable level without exhausting the natural fodder resources to a greater extent than in the current system. However, more detailed data on reproductive performance in relation to the age of adult females would be necessary to fully explore this issue. But finally, the local population's high valuation of especially cattle as a status symbol and capital reserve for times of need may disagree with the concept of increased animal offtake. It is presently further hampered by deficient market opportunities in the structurally weak research area. A better access to trans-regional markets as a consequence of improvements in local infrastructure could consequently be one possible solution and may provide a realistic chance of progressive renunciation of traditional conventions.

## 4.5 Conclusions

The results of this study illustrate the considerable production potential of the local animal husbandry system in southwestern Madagascar, especially if based on improved herd management. In defiance of the region's environmental constraints, cattle and goat keeping appear economically profitable without its full commercial potential being yet exploited. Improved feeding could enhance the low reproductive performance of both species and annual sales revenues of their owners. Nevertheless, a scenario which exclusively relies on herd expansion will enhance feeding costs and, more importantly, conflict with the area's limited natural resources. Against this background, a complementary and substantial increase of herd offtake, especially of poorly performing breeding females, appears more reasonable. However, this would initially imply a fundamental change in local herd management, as keeping large herds is still an important strategy to cope with the high production risks linked to ecological and political constraints and as economization of the livestock system might not necessarily fit people's livelihood requirements. Therefore, an only moderate increase of female culls would correspond better to local needs and customs.

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## Appendix

**Table 4.A.1.** Major characteristics of the six focus villages – Ambory, Andremba, Ankilibory, Efoetse, Marofijery, and Miarintsoa.

| Village | Coastal plain | | | Plateau | | |
|---|---|---|---|---|---|---|
| | Ankilibory | Efoetse | Marofijery | Ambory | Andremba | Miarintsoa |
| Geographical location | 23°54'S, 43°41'E | 24°04'S, 43°42'E | 24°02'S, 43°41'E | 23°58'S, 44°08'E | 23°58'S, 44°12'E | 23°50'S, 44°06'E |
| Altitude (m a.s.l.) | 18 | 17 | 18 | 224 | 273 | 183 |
| Mean annual precipitation (mm)[1] | n/a | 197[a] | n/a | n/a | 451[b] | 773[c] |
| Population, total (2012)[2] | 748 | 1,294 | 642 | 387 | 1,048 | 633 |
| Households, total (2012)[2] | 125 | 216 | 107 | 65 | 175 | 106 |
| TLU*[, 2] | 743 | 1,713 | 802 | 90 | 1,032 | 641 |

m a.s.l. = meters above sea level, n/a = not available.

* TLU = Tropical Livestock Units (1 cattle = 0.7 TLU, 1 goat/sheep = 0.1 TLU).

[1] Hanisch. unpubl. data, [2] Neudert, unpubl. data.

[a] mean value 2011 – 2014, [b] 2012 + 2013, [c] 2013 only.

**Table 4.A.3.** Origin of breeding females and disposal of offspring of local cattle and goats as determined through progeny history interviews in six focus villages in the Mahafaly region, southwestern Madagascar.

| Entry / Disposal reason | Cattle | | Goats | |
|---|---|---|---|---|
| | *n* | % | *n* | % |
| **Origin** | | | | |
| Born in herd | 372 | 73.5 | 445 | 75.0 |
| Market purchase | 108 | 21.3 | 137 | 23.1 |
| Gift / Reconciliation | 26 | 5.2 | 11 | 1.9 |
| **Sum** | **506** | **100.0** | **593** | **100.0** |
| **Disposal (mortality)** | | | | |
| Stillbirth | 2 | 6.5 | 9 | 4.3 |
| Disease | 13 | 41.9 | 133 | 64.3 |
| Theft / Predation | 13 | 41.9 | 33 | 15.9 |
| Other | 3 | 9.7 | 32 | 15.5 |
| **Sum** | **31** | **100.0** | **207** | **100.0** |
| **Disposal (culling)** | | | | |
| Slaughter | 0 | 0.0 | 40 | 16.9 |
| Productive culling | 0 | 0.0 | 1 | 0.4 |
| Market sale | 161 | 84.3 | 194 | 82.2 |
| Gift / Reconciliation | 30 | 15.7 | 1 | 0.5 |
| **Sum** | **191** | **100.0** | **236** | **100.0** |

**Table 4.A.2.** Parameters of optimized growth functions for male and female cattle and goats ($p < 0.001$ for all).

| Growth model | Females[a] | | | | | Males[b] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RSS | Iterations | Parameter[c] | Mean | SE | RSS | Iterations | Parameter[c] | Mean | SE |
| **Cattle** | | | | | | | | | | |
| Brody | 92909 | 5 | *A* | 211.3 | 5.60 | 199439 | 5 | *A* | 343.2 | 19.10 |
| | | | *b* | 0.980 | 0.0790 | | | *b* | 0.944 | 0.0290 |
| | | | *k* | 0.058 | 0.0100 | | | *k* | 0.024 | 0.0040 |
| Logistic | 94245 | 5 | *A* | 207.1 | 4.50 | 203293 | 7 | *A* | 308.7 | 10.10 |
| | | | *b* | 4.407 | 1.1200 | | | *b* | 4.720 | 0.6200 |
| | | | *k* | 0.116 | 0.0190 | | | *k* | 0.062 | 0.0060 |
| Gompertz | 93105 | 7 | *A* | 208.5 | 4.80 | 203293 | 5 | *A* | 319.6 | 12.40 |
| | | | *b* | 1.968 | 0.3070 | | | *b* | 2.000 | 0.1500 |
| | | | *k* | 0.085 | 0.0140 | | | *k* | 0.042 | 0.0050 |
| von Bertalanffy | 92855 | 4 | *A* | 209.3 | 5.00 | 201637 | 4 | *A* | 325.3 | 13.80 |
| | | | *b* | 0.514 | 0.0660 | | | *b* | 0.511 | 0.0290 |
| | | | *k* | 0.076 | 0.0130 | | | *k* | 0.036 | 0.0040 |
| **Goats** | | | | | | | | | | |
| Brody | 10713 | 6 | *A* | 35.5 | 0.49 | 11363 | 3 | *A* | 41.2 | 1.34 |
| | | | *b* | 0.748 | 0.0124 | | | *b* | 0.809 | 0.0165 |
| | | | *k* | 0.046 | 0.0027 | | | *k* | 0.054 | 0.0052 |
| Logistic | 11706 | 10 | *A* | 34.4 | 0.41 | 11591 | 6 | *A* | 39.6 | 1.00 |
| | | | *b* | 2.070 | 0.0961 | | | *b* | 2.771 | 0.1817 |
| | | | *k* | 0.082 | 0.0043 | | | *k* | 0.110 | 0.0084 |
| Gompertz | 11216 | 8 | *A* | 34.8 | 0.43 | 11428 | 5 | *A* | 40.2 | 1.11 |
| | | | *b* | 1.216 | 0.0360 | | | *b* | 1.441 | 0.0575 |
| | | | *k* | 0.063 | 0.0035 | | | *k* | 0.080 | 0.0066 |
| von Bertalanffy | 11045 | 7 | *A* | 35.0 | 0.45 | 11394 | 5 | *A* | 40.5 | 1.16 |
| | | | *b* | 0.343 | 0.0086 | | | *b* | 0.393 | 0.0128 |
| | | | *k* | 0.058 | 0.0032 | | | *k* | 0.071 | 0.0061 |

RSS: residual sum of squares, SE = standard error.

[a] $n_{cattle} = 94$, $n_{goats} = 595$, [b] $n_{cattle} = 126$, $n_{goats} = 358$.

Function descriptions: Brody: $y = A * (1 - b * e^{-k*t})$,

Logistic: $y = A * (1 + b * e^{-k*t})^{-1}$,

Gompertz: $y = A * e^{b*e^{-k*t}}$,

von Bertalanffy: $y = A * (1 - b * e^{-k*t})^3$.

[c] *A*: value (kg) of the asymptote (= adult body weight), *b* and *k*: function parameters.

**Table 4.A.4.** Input data of cost-revenue calculations for cattle keeping households under current management (status quo, SQ, distinguishing sites) and two alternative scenarios (improved feeding, IF, and improved culling, IC; no distinction of sites). Data show mean values ± standard deviations.

| Input variable | Unit | Source | SQ | | | Scenarios | |
|---|---|---|---|---|---|---|---|
| | | | Coast | Plateau | Overall | IF | IC |
| **Production data** | | | | | | | |
| Herd size | heads | HS | 16.4±18.19 | 16.4±18.19 | 16.2±18.19 | 16.4±18.19 | 16.4±18.19 |
| Breeding female share in herd | % | PHS | 42.9 | 31.6 | 37.4 | 37.4 | 37.4 |
| Parturition interval | months | PHS | 23.5±7.80 | 25.2±9.94 | 24.1±8.78 | 14.0±0.00 | 24.1±8.78 |
| Litter size | heads | PHS | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Share of females among offspring | % | PHS | 50.8 | 45.2 | 48.3 | 48.3 | 48.3 |
| Calf mortality | % | PHS | 1.5 | 3.7 | 2.5 | 2.5 | 2.5 |
| Age at first parturition | months | PHS | 41.3±8.37 | 39.6±13.56 | 40.5±11.54 | 36.0±0.00 | 40.5±11.54 |
| Cull-for-age of breeding females | months | AFI | 173.0 | 173.0 | 173.0 | 17.03 | 149.0 |
| Births in rainy season | % | PHS | 77.5 | 62.9 | 70.9 | 70.9 | 70.9 |
| **Management data** | | | | | | | |
| Milking | % of HH | SSI | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Milk production | kg / cow / day | SSI | 1.4±0.53 | 1.4±0.53 | 1.4±0.53 | 1.4±0.53 | 1.4±0.53 |
| Duration of milking season | days | afl | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 |
| Purchase of additional fodder[1] | % of HH | HS | 44.0 | 19.5 | 26.4 | 100.0 | 26.4 |
| Duration of supplementation | months | SSI | 4.0±0.82 | 4.0±0.82 | 4.0±0.82 | 5.5±0.61 | 4.0±0.82 |
| Payment for labor | % of HH | HS | 12.3 | 12.3 | 12.3 | 12.3 | 12.3 |
| Use of vaccination | % of HH | SSI | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Vaccination costs | € / head | SSI | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 |
| **Market data** | | | | | | | |
| Price per female calf | € / head | MMD | 45.0±9.06 | 66.6±19.63 | 54.8±17.97 | 54.8±17.97 | 54.8±17.97 |
| Price per male calf | € / head | MMD | 62.3±18.79 | 76.5±22.21 | 68.2±21.82 | 68.2±21.82 | 68.2±21.82 |
| Price per adult breeding female | € / head | MMD | 82.8±30.98 | 82.8±30.98 | 82.8±30.98 | 82.8±30.98 | 82.8±30.98 |
| Milk price | € / kg | MMD | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Price of additional fodder[1] | € / head / month | SSI | 0.9±0.73 | 0.9±0.73 | 0.9±0.73 | 0.9±0.73 | 0.9±0.73 |

AFI = additional farmer interviews, afl = accepted from literature, CU = cattle unit (a mother cow and all offspring younger than 36 months), HH = household, HS = household survey, MMD = market monitoring data, PHS = progeny history survey, SSI = semi-structured interviews.

[1] consisting of *Euphorbia stenoclada* or *Opuntia* sp..

**Table 4.A.5.** Input data of cost-revenue calculations for goat keeping households under current management (status quo, SQ, distinguishing sites) and two alternative scenarios (improved feeding, IF, and improved culling, IC; no distinction of sites). Data show mean values ± standard deviations.

| Input variable | Unit | Source | SQ | | | Scenarios | |
|---|---|---|---|---|---|---|---|
| | | | Coast | Plateau | Overall | IF | IC |
| **Production data** | | | | | | | |
| Herd size | heads | HS | 18.6±12.16 | 19.1±25.05 | 19.1±22.26 | 19.1±22.26 | 19.1±22.26 |
| Breeding female share in herd | % | PHS | 53.1 | 53.9 | 53.5 | 53.5 | 53.5 |
| Parturition interval | month | PHS | 11.7±5.17 | 13.1±6.14 | 12.4±5.73 | 9.0±0.00 | 12.4±5.73 |
| Litter size | heads | PHS | 1.4 | 1.3 | 1.3 | 1.4 | 1.3 |
| Kid mortality | % | PHS | 19.4 | 13.6 | 15.9 | 15.9 | 15.9 |
| Age at first parturition | months | PHS | 21.0±8.48 | 21.4±10.78 | 21.3±9.80 | 17.0±0.00 | 21.3±9.80 |
| Cull-for-age of breeding females | months | AFI | 94.0 | 94.0 | 94.0 | 94.0 | 82.0 |
| **Management data** | | | | | | | |
| Milking in prime season | % of HH | SSI | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| Milk production in prime season | kg / doe / day | SSI | 0.5±0.29 | 0.5±0.29 | 0.5±0.29 | 0.5±0.29 | 0.5±0.29 |
| Duration of milking in prime season | days | afl | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 |
| Milking in secondary season | % of HH | SSI | 45.0 | 45.0 | 45.0 | 45.0 | 45.0 |
| Milk production in secondary season | kg / doe / day | SSI | 0.2±0.13 | 0.2±0.13 | 0.2±0.13 | 0.2±0.13 | 0.2±0.13 |
| Duration of milking in secondary season | days | afl | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 | 63.3±22.48 |
| Amount of additional fodder[1] | Kg | SSI | 0.0 | 0.0 | 0.0 | 22.5 | 0.0 |
| Payment for labor | % of HH | HS | 19.2 | 19.2 | 19.2 | 19.2 | 19.2 |
| Labor costs | € / herd | SSI | 8.8 | 8.8 | 8.8 | 8.8 | 8.8 |
| **Market data** | | | | | | | |
| Price per female kid | € / head | MMD | 7.4±2.78 | 8.6±2.63 | 8.0±2.80 | 8.0±2.80 | 8.0±2.80 |
| Price per male kid | € / head | MMD | 7.4±2.00 | 7.4±2.00 | 7.4±2.00 | 7.4±2.00 | 7.4±2.00 |
| Price per adult breeding female | € / head | MMD | 10.3±2.07 | 12.8±2.52 | 11.1±2.52 | 11.1±2.52 | 11.1±2.52 |
| Milk price | € / kg | MMD | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Price of additional fodder[1] | € / kg | SSI | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 |

AFI = additional farmer interviews, afl = accepted from literature, GU = goat unit (a mother doe and all offspring younger than 22 months), HH = household, HS = household survey, MMD = market monitoring data, PHS = progeny history survey, SSI = semi-structured interviews.

[1] consisting of cassava root chips.

**Table 4.A.6.** Input data of PRY Herd Life for the local cattle and goat husbandry system under current management (status quo, SQ, distinguishing sites and herd sizes*) and two alternative scenarios (improved feeding, IF, and improved culling, IC; no distinction of sites).

| Input variable | Unit | SQ | | | | | Scenarios | |
|---|---|---|---|---|---|---|---|---|
| | | Coast | Plateau | SMH | MLH | Overall | IF | IC |
| **Cattle**[a, b] | | | | | | | | |
| Age at first parturition | months | 41.3 | 39.6 | 39.8 | 40.9 | 40.5 | 36.0 | 40.5 |
| Parturition interval | months | 23.5 | 25.2 | 25.9 | 23.5 | 24.1 | 14.0 | 24.1 |
| Calves per parturition | heads | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Cull-for-age threshold for breeding females | months | 173 | 173 | 173 | 173 | 173 | 173 | 149 |
| Culling age for surplus females/ males | months | 22.0/26.2 | 25.0/24.6 | 24.0/22.6 | 22.5/25.0 | 23.1/25.5 | 23.1/25.5 | 23.1/25.5 |
| **Goats**[c, d] | | | | | | | | |
| Age at first parturition | months | 21.0 | 21.4 | 20.0 | 22.1 | 21.3 | 17.0 | 21.3 |
| Parturition interval | months | 11.7 | 13.1 | 12.0 | 12.7 | 12.4 | 9.0 | 12.4 |
| Kids per parturition | heads | 1.3 | 1.4 | 1.3 | 1.3 | 1.3 | 1.4 | 1.3 |
| Cull-for-age threshold for breeding females | months | 94 | 94 | 94 | 94 | 94 | 94 | 82 |
| Culling age for surplus females/ males | months | 8.0/14.6 | 14.8/9.4 | 15.0/10.5 | 9.6/13.3 | 11.9/12.1 | 11.9/12.1 | 11.9/12.1 |

SMH: small to medium size herds; MLH: medium to large size herds.

[a] Mortality of female and male cattle was taken as input parameter for five age classes: >0 – 12 months (until reported age of weaning) / >12 – 22 months (until age of maturity) / >22 – 40 months (until average age at first parturition) / >40 – 149 months (until reported age of reduced productivity) / >149 – 173 months (until reported age threshold). It was set according to the sex-specific results of the progeny history interviews for age classes 1 – 3. The share was increased to 8% for age classes 4 and to 80% for age class 5. Total results were adopted for both alternative scenarios.

[b] Productive culling of breeding females was set at 3% across five model-generated age classes (>0 – 25 months / >25 – 40 months / >40 – 84 months / >84 – 149 months / >149 -173 months) for all SQ subgroups and IF. For IC, the share was increased to 5% for age classes 2 – 4 and to 15% for age class 5.

[c] Mortality of female and male goats was taken as input parameter for five age classes: >0 – 4 months (age of weaning) / >4 – 10 months (until age of maturity) / >10 – 21 months (until average age at first parturition) / >21 – 82 months (until reported age of reduced productivity) / >82 – 94 months (until reported age threshold). It was set according to the sex-specific results of the progeny history interviews for age classes 1 – 3. The share was increased to 26% for age classes 4 and to 80% for age class 5. Total results were adopted for both alternative scenarios.

[d] Productive culling of breeding females was set at 5% across four model-generated age classes (>0 – 13 months / >13 – 21 months / >21 – 82 months / >82 – 94 months / >149 -173 months) for all SQ subgroups and IF. For IC, the share was increased to 10% for age classes 2 and 3 and to 20% for age class 4.

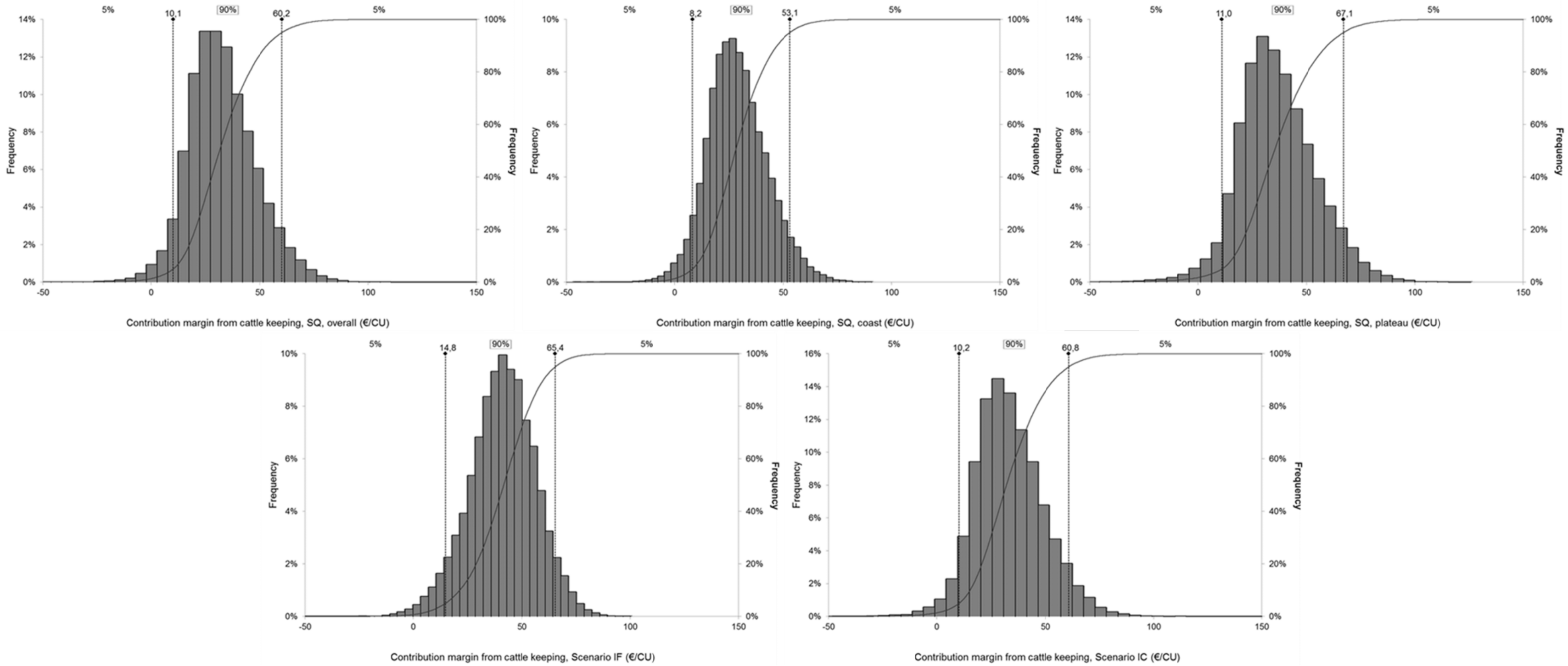


**Figure 4.A.1.** Outcome of Monte Carlo simulations for cattle keeping households in the Mahafaly region, southwestern Madagascar. Results are shown for current management (SQ; upper row: subdivided into total, coastal, and plateau herd) and two alternative scenarios (IF and IC; lower row). Note the different scaling of Y-axes.

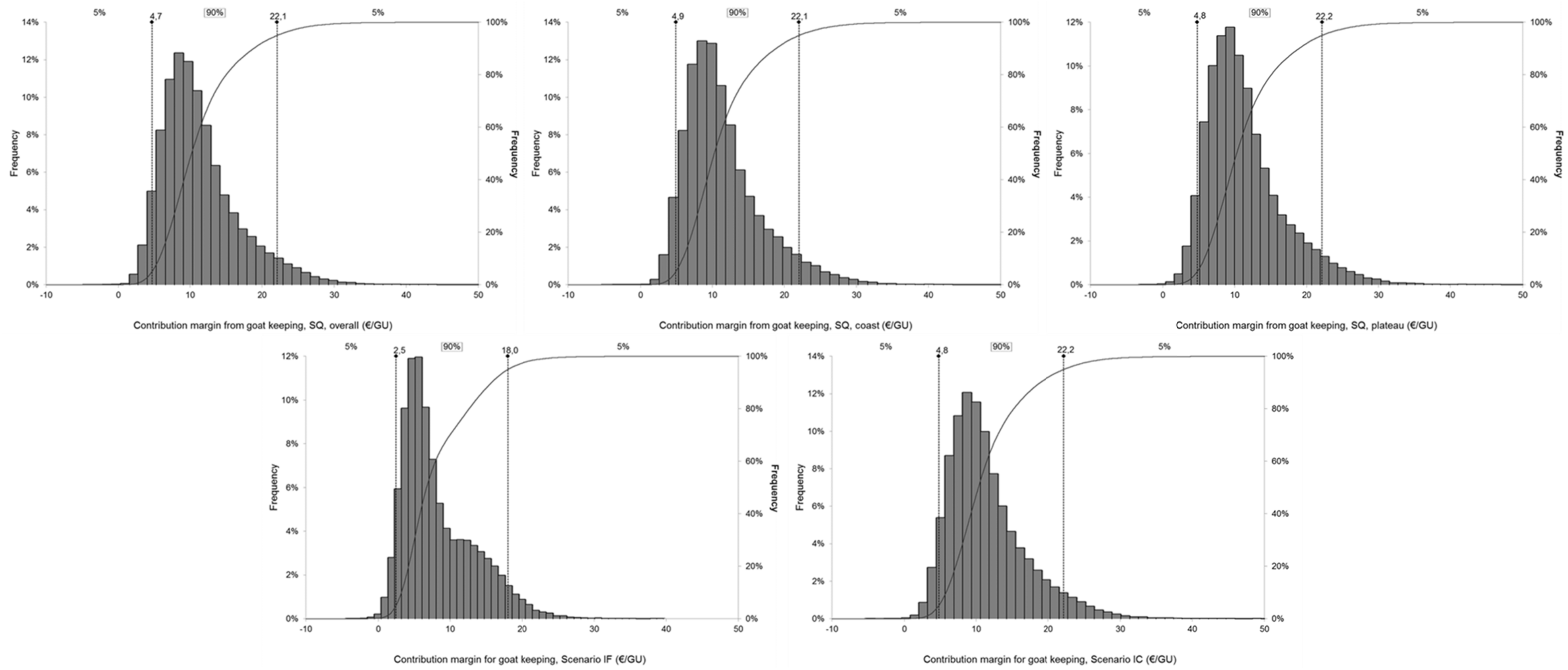


**Figure 4.A.2.** Outcome of Monte Carlo simulations for goat keeping households in the Mahafaly region, southwestern Madagascar. Results are shown for current management (SQ; upper row: subdivided into total, coastal, and plateau flocks) and two alternative scenarios (IF and IC; lower row). Note the different scaling of Y-axes.

# Chapter 5

## General Discussion, Conclusions, and Recommendations

## 5.1 New drivers affecting pastoral decisions and rangeland dynamics

The impact of livestock keeping on rangeland dynamics and environmental degradation in southwestern Madagascar is controversially discussed for a long time. While some authors see the expansion of grazing land and pasture fires as one important cause for deforestation and the spreading of savanna areas (Perrier de La Bathie, 1920 in Morat, 1973); Humbert, 1927 in Morat, 1973), others emphasize the higher importance of different determining factors of human (Brinkmann et al., 2014; Wüstefeld, 2004) and natural origin (Rasambainarivo and Ranaivoarivelo, 2006). A detailed review on this topic is given by Morat (1973).

In this regard, the present study comes to a rather differentiated result. Chapters 2 and 3 reveal the highly extensive and resource driven character of the livestock system in the Mahafaly region and demonstrate the importance of pastoral mobility, being a central element to cope with seasonal shortages in forage and water. This strategy thereby appears the most appropriate in dealing with the strong non-equilibrium dynamics of the region's dry environment. In her review on the two most common paradigms on rangeland ecology and management, Vetter (2005) specifies that these dynamics are predominantly found in arid ecosystems with rainfall coefficients of variation (CV) exceeding 33%. This is clearly the case for southern Madagascar, where the CV of seasonal total precipitation was computed above 40% between 1995 and 2009 (WFP and UNICEF, 2011). Therefore, it can be expected that the impact of rainfall on vegetation composition and biomass yield in the study region is more important than that of grazing, in particular if considering the seasonal migration of herds which locally allows vegetation to regenerate. This conclusion largely corresponds to the outcome of other studies conducted in sub-Saharan Africa by Anderson and Hoffman (2011) and Oba et al. (2001) and to effects stated by Akasbi et al. (2012b) who analyzed decision processes of transhumant pastoralists in southern Morocco.

However, the region's strong spatial and temporal heterogeneity has to be taken into consideration just like the species composition of local livestock herds. Additionally, new key drivers, in particular in terms of the tense state of security in the plateau region and the ongoing expansion of croplands around settlement areas that limit the scope for pastoral activities, are gaining importance and increasingly affect pastoral land use and herd management decisions. Locally resulting in higher livestock numbers and stocking densities during the late rainy and dry season, system dynamics therefore appear to shift as grazing now has an increasing impact on the area's natural rangeland and its productivity with regard to abiotic factors such as rainfall. This enhances the risk of rangeland degradation due to livestock keeping, at least in the area's coastal zone. Similar processes have already been reported from other arid and semi-arid environments and grazing systems in continental Africa (Desta and Coppock, 2002; Illius and O'Connor, 1999). In particular the violent conflicts related to livestock raiding create a strong and omnipresent perception of insecurity and lead to reduced herd mobility and to ineffective resource utilization as it has also been described by Schilling et al. (2012) for pastoral societies in East Africa.

The direct consequences of these developments and their effect on herd mobility and management, however, could only be presented to some degree in the framework of this study. Its methodology focused on the recording of daily grazing itineraries and activities in high temporal resolution while constantly alternating between herds from different locations. As a result, long-distance travels, either reflecting transhumance or evasive movements in answer to raiding activity, were only documented coincidentally and do hardly allow generalization. By regularly repeating measurements in bi-monthly intervals, short-term site relocations of herds could at least be reproduced to some extent. But it failed to give the same detailed illustration of pastoral dynamics as if tracking and observation of animals would have been conducted continuously over several months or years. On the other hand, such approaches, as carried out by Akasbi et al. (2012a) on Moroccan mountain goats or by Butt (2010) who investigated seasonal space-time dynamics of cattle behavior and mobility in Kenya, would have been subject to certain constraints. It would have involved a higher workload, complicated the representative replication of the study design for several villages within the region due to the limited availability of GPS tracking collars, and comprised the risk of loss or damage of these devices and hence the on-board stored data. A possible solution, which would allow to gain continuous data while at the same time reducing the researcher's amount of work, is the stronger involvement of the pastoralists in herd tracking and behavioral observation as done by Adriansen (2008) in Senegal. Nevertheless, this approach also implies the possibility of incomplete data collection and therefore presumes trust and previous training of local herders.

Yet, the role of livestock owners and in particular herders in decision making on which types of land to visit and on the animals' resource utilization represents another knowledge gap as no specific focus was given to these factors within this study. The impact of herding, however, has been given high importance in some research works from pastoral environments. By comparing grazing behavior and land use of free ranging and herded livestock in West Africa, Schlecht et al. (2006) found that herding has a great potential to improve livestock nutrition by increasing forage availability while at the same time distributing grazing pressure on pastured land more regular. Similar effects were confirmed by Turner et al. (2005) in the same region, showing that herding strongly affects the distribution of grazing with respect to forage resources and may therefore improve the sustained productivity of agropastoral landscapes. Behnke et al. (2011) emphasized the important role of herders for migration and transhumance decisions, that is whether or not to move to new pasture grounds. Skilled herding labor therefore has a strong impact on vegetation ecology and livestock performance in pastoral societies and may significantly reduce the effect of overgrazing. At the same time, the systematic integration of local herder knowledge can provide valuable information on temporal shifts in land use and pasture utilization. It therefore would be a useful complement in understanding pastoral dynamics and the impact of new drivers of change in the Mahafaly region and should be taken into account for its future development and implication of management strategies. An attempt to integrate such indigenous knowledge was carried out in an early stage of this study, following an approach of map-based herder interviews as performed by Turner et al. (2005) and Turner and Hiernaux (2002) in West Africa. However, it largely failed to give any utilizable results due to the deficient spatial imagination of local pastoralists while handling the provided maps and their use of non-verifiable place names and distance statements.

## 5.2 The conflict between livestock keeping and nature conservation

The creation and expansion of national parks and protected areas has become a permanent source of conflicts between conservation policies and pastoral interests in many rural regions of the world (Enright and Miller, 2007; Nepal and Weber, 1995;

Turner, 1999). Amongst other reasons, the impact of livestock grazing is seen as major factor negatively influencing vegetation composition and abundance, and the common intellectual separation between 'nature' and 'culture' has led to the perception of park authorities but also tourists that the presence of livestock within these nature conservation areas is a rather disruptive factor (Butt, 2012; Toutain et al., 2004). In southwestern Madagascar, the Tsimanampetsotsa National Park, in particular after its spacious expansion in 2007, imposes a deep change on the life of local livestock farmers. As grazing is largely prohibited within the park and its buffer zone, its existence restricts the access to traditional grazing grounds and forest pastures (Tsirahamba and Kaufmann, 2008) and at the same time significantly reduces the area available for pastoral activities, especially in the limited space of the region's coastal zone. At the same time, its surface overlaps with long-established transhumance routes (Armandine, 1991; Ratovonamana et al., 2013), though special permissions still allow to utilize these paths for annual herd migration during a limited period of time (MNP staff in Efoetse, personal communication). Although the majority of resident pastoralists declares to accept the official regulations (Projet SuLaMa, 2011), frequent transgressions by grazing cattle and other livestock from surrounding settlements are common and have been reported by Brinkmann et al. (2014) and Ratovonamana et al. (2013).

Indeed, the area of the park serves to date as valuable pasture reserve and retreat throughout the year and therefore compensates the limited amount of forage available for domestic herds, at least along its western border. At the same time, local pastoralists still consider their animals to be comparably safe from raiding activities and also rely on the presence of natural water holes within the nature reserve. Consequently, there is a general perception of the negative consequences of livestock for the park's vegetation but also wildlife (Randriamiharisoa et al., 2013; Ranirison et al., 2013; Ratovonamana et al., 2013). Ratovonamana et al. (2013) documented a decrease in plant diversity in correlation with increasing grazing pressure in the degraded dry forest located within the seaward-facing western part of the national park, an area highly frequented by local herds of small ruminants and in particular goats. This livestock species is commonly known for its strong affection of plant communities and structure and hence for modifying the landscape mosaic (Gabay et al., 2011), and their broad diet and preference for woody plants has been illustrated in Chapter 3. However, goats rarely seem to penetrate deeper into the protected area and core zones as they usually return to their night enclosures every day (Chapter 2). Cattle, in contrast, may also range freely and therefore cover longer distances within the national park. If occasional observations within its borders took place during this study, they were mostly found grazing on the herbaceous wetland formations and salt meadow communities dominated by *Sporobolus virginicus* (Antsonantenainarivony, unpubl. data) around the saline Lake Tsimanampetsotsa. The nutritive value of this grass is inferior compared to *Panicum pseudovoeltzkowii*, the otherwise most important graminoid forage species in the coastal zone. According to laboratory results, its annual average concentrations (g/kg DM) were lower in crude protein (67±7.1 versus 80±9.0) and phosphorus (0.8±0.21 versus 1.4±0.26). The concentration of calcium was found higher (8.6±1.74 versus 7.7±1.42), whereas NDF (620±11.0 versus 625±14) and ADF (368±16.9 versus 351±9.5) did not differ considerably. On the other hand, *Sporobolus virginicus* is still available in high abundance during the dry season when the annual *Panicum* grass has already largely disappeared. Thus, the sea plain offers an important forage resource and complement to the predominant feeding of *Euphorbia stenoclada* and *Opuntia* sp. during this time of the year.

Free-ranging cattle were also found to enter the core areas of the national park, both from its western and eastern side. Here, however, their impact on the worth protecting natural spiny forest vegetation is still largely unknown. Ratovonamana et al. (2013), for instance, could not determine any effect of grazing activity on plant communities in these zones. At the same time, the findings of Chapter 3 on the preference of local cattle for particular forage species can hardly be transferred as the composition of different vegetation types within the park deviates significantly from the surrounding areas that have been primary investigated (Antsonantenainarivony, unpubl. data). It therefore could still be possible that livestock, in particular cattle, have a lower impact on the park's unique biodiversity than commonly believed. At least if compared to human influences such as logging for fuelwood and hunting for bush meat, activities also opportunistically carried out in protected areas during the course of herding (Gardner and Davies, 2014).

To clearly evaluate whether or not, and to what extent, livestock and livestock-related human activities are a threat to the vegetation and wildlife of the Tsimanampetsotsa National Park, more information is needed on the effect of animal grazing but also trampling as well as on the spatial and temporal distribution of cattle and small ruminants and, in the first instance, their abundance within the reserve's total area. Such information could only be provided to a limited extent within the framework of this study as a permanent collaring of free-ranging animals within the park would have caused logistical problems in relocating them and furthermore was likely to be refused by the owners, who are well aware that sending their animals into the protected area is illegal. An alternative option would be the use camera traps, a well-established method to determine populations and home ranges of various wildlife species (Maffei et al., 1999; Mugerwa et al., 2012). Initial data on the spatial distribution and abundance of livestock have already been collected using this method but still wait for further analysis (Fust, unpubl. data). Together with the more general outcome of the present work, these new insights could serve as basis to reconsider and, if applicable, modify the recent conservation concept. Instead of a general ban of livestock grazing, limited pasture zones could be designated within the park and its buffer zone. This would allow residential pastoralists to legally graze their animals in some sections of the reserve that may be less worthy of protection from a conservation point of view, without violating existing rules. Herders then could permanently accompany their livestock during grazing days without need to hide themselves or leave the herds on their own for fear of punishment if being spotted. It therefore could result in a higher acceptance of the national park and its regulations by the local population and provide the opportunity for improved grazing management in the region. At the same time, however, such measures would also require more regular controls by the park authorities to prevent violations of the adjusted zonation and negative effects on the park's core areas, in particular in its eastern part.

## 5.3 Further potential for crop-livestock integration

The role of livestock, and in particular zebu cattle, as symbol of wealth and prestige for local communities in southern Madagascar has long time attracted major attention from a scientific perspective (Fauroux, 1989b; Heland and Folke, 2014). It therefore led to the still widespread belief that traditional livestock keeping contributes little to food security or other livelihoods of the population while at the same time posing a serious threat to the environment (Fauroux, 1989a; Réau, 2002). Newer studies slowly cause a transformation of this perception as cattle and small ruminants were found to be an integral part of both, the socio-cultural life and the household economy (Chapter 4). In her study on the importance of livestock as a safety against crop shortfalls in the district of Bekily in the island's extreme South, Wüstefeld (2004) could show that about three quarters of rural household generate regular revenue from domestic animals and their products. While the proportion of income from crop marketing significantly decreased in a year of drought, the livestock-related share held steady and therefore helped considerably to compensate crop failures. In the Mahafaly region itself, Hänke and Barkmann (unpubl. data) found that proceeds from livestock sale compensated for about 60% of cash food expenditures during the rainy and early dry season in 2014 and were the most important income source for local households in this time.

However, livestock keeping still offers further potential within the region's agropastoral system which has not yet been fully exploited, in particular in view of a stronger integration of livestock into crop production. For the semi-arid regions of sub-Saharan Africa, Powell et al. (2004) determined four principal linkages between these two cornerstones of smallholder agriculture: income, animal power, manure, and feed. After the economic connection has already been discussed, deficiencies can still be found in the other three fields. Animal power appears almost exclusively in terms of transport, as ox carts are the only regular way of carrying goods and people over longer distances in the Mahafaly region. In contrast, animals are hardly utilized in the production, harvesting, and processing of crops, that is by drawing ploughs or weeders, as these devices rarely exist on-site (Coral Guerra, 2014). The same applies for manure application to fertilize fields. Its utilization for soil amelioration was specified by only 5% of households interviewed by Coral Guerra (2014). Several reasons for non-use were given by local farmers, such as high labor demands, fear of diseases, and local taboos (Hanisch, 2015). At the same time, the widespread practice of packing animals closely into relatively small enclosures at night, while these are hardly ever cleaned from the animals' feces so that manure may accumulate within the corrals for years, increases the risk of epizootic diseases and parasite infections. Both were found to frequently affect the region's livestock (Ravoavy Randrianasolo, 2015; Seifert, 1992). Therefore, the collection and processing of livestock dung would have a twofold effect by improving hygienic conditions for the animals and at the same time the nutrient inputs to croplands. Finally, the use of crop residues, which normally is a common feeding strategy for ruminant production systems in dry environments (Ben Salem and Smith, 2008), is hardly performed except for draft oxen and weak animals. Herds are also largely kept out from harvested fields (Chapters 3 and 4). Local farmers therefore miss to adequately exploit an available dry season feed resource that would complement natural forages from rangelands as well as *Euphorbia stenoclada* and *Opuntia* sp. as dry season supplementation.

In conclusion, the system of animal husbandry in the Mahafaly region cannot be valued on its own without consideration of the local cropping system. It therefore offers more potential for development than just in terms of livestock production and marketing but may also improve the region's agricultural output. Thus, the stronger integration of these two sectors should be further progressed in future research and development.

## 5.4 General conclusions and recommendations

Until today, livestock keeping is one of the mainstays of livelihoods for the agropastoral communities in the Mahafaly region of southwestern Madagascar. Being traditionally exposed to high climatic variability and seasonal limitations in feed and water availability, local pastoralists successfully adapted over time to these harsh conditions by developing coping strategies helping to bridge temporal resource shortages for their animals. While small ruminants, which have been found of substantial importance for the economic viability of the region's poorer and average wealthy households, tend to be less vulnerable to these natural constraints, annual rainy season herd movements and the use of supplementary forage plants during the long dry season have ensured the maintenance of cattle husbandry. Still, zebu cattle can be considered the central livestock species from a socio-cultural point of view, but they also proved considerable commercial significance and serve as financial reserve for times of need. Thus, pastoral practices can comply with the largely non-equilibrium character of the area's environment while at the same time still offering potential for further productive and economic development beyond the pure role of livestock as status symbol or buffer stock.

In the recent past, however, additional driving factors have gained in importance by increasingly affecting the established system. According to the outcome of this study, a rise in insecurity, expressed by the enhanced danger of becoming the victim of organized livestock raids, has forced local pastoralists to adjust their grazing management by more frequently changing pasture grounds and modifying traditional transhumance patterns. This leads to spatio-temporal shifts in livestock numbers and to the impending risk of local overgrazing and degradation of rangelands, especially in the area's coastal zone, and therefore emphasizes the importance of dry season forage plants such as *Euphorbia stenoclada*. But at the same time, there is a clear tendency of overexploiting the natural stocks of this plant due to unsustainable utilization. Concurrent competition for land resources with local crop farmers, continuously expanding agricultural areas in need to supply the region's continuously growing population, involves further potential for conflicts and limits the scope for herding activities. These developments apparently make livestock keepers falling back to alternative resources by more frequently sending their herds to the supposed safety and feed security of the Tsimanampetsotsa National Park whose area is still considered by local pastoralists as ancestral grazing ground. Yet, the exact consequences of these changes in traditional herd and grazing management for the region's fragile environment and unique nature are difficult to predict, in particular in view of projected climatic fluctuations which may increase the frequency and severity of resource shortages in the future.

This changing situation, together with fundamental deficiencies in livestock hygiene and culling management within the highly extensive livestock system, leads to the following recommendations and implication measures directed to local stakeholders and NGOs but also to national policy makers:

**Feed supply**

- In the coastal area, the considerable exploitation and systematic, cuttage-based forestation of *Euphorbia stenoclada* and *Opuntia* cacti would ensure a sustainable dry season feed supply for livestock. However, the high invasive potential of some *Opuntia* varieties and the need for considerable amounts of fuelwood to burn the cactus' spines before offering its cladodes to the animals has to be taken into account.

- On the limestone plateau, the use of savanna grasses for hay production may help to conserve available biomass before it widely loses its feed quality with advancing maturity during the dry season. At the same time, it would enable the utilization of areas largely avoided by pastoralists due to security concerns while providing their animals with feed without running the risk of raids in further distance from settlements. But certainly this recommendation should be based on a reasonable cost-benefit calculation before being presented to the people.

**Water supply**

- The construction of additional water retention basins to collect rainwater on the limestone plateau could prolong the dispersed water supply for livestock, and humans, for at least several weeks per year before resorting to the few permanent sources. Furthermore, the economical use of water resources also has to be communicated. Surprisingly, this conception is so far hardly found within the local communities.

**Animal health and hygiene**

- A better understanding of animal health and hygiene has to be communicated to local pastoralists, amongst others the need for regular cleaning of livestock enclosures that currently appear to be an important source of diseases.
- The establishment of permanent veterinary services should be promoted for the region. At the same time, local pastoralists must also be encouraged to pay for reasonable veterinary services.
- The use of mineral feed blocks may increase digestion of fibrous feedstuff and improve livestock performance. Such blocks can be produced locally without much effort in cost and labor.

**Herd management and composition**

- In combination with adequate feed supply, enhanced herd offtake, especially of poorly performing breeding females, could substantially improve the performance potential of local livestock herds and increase the annual contribution margins to their owners without severely interfering with culturally conditioned management traditions.

**Improved crop-livestock integration**

- A stronger integration of livestock keeping with crop production may help to counteract growing conflicts between pastoralists and crop farmers. The enhanced use of crop residues would improve the animals' dry season feed supply. The same can be achieved by allowing herds to graze more frequently on harvested fields.
- The processing and application of manure for soil amelioration should be promoted, even against existing cultural taboos. The access of herds to harvested and fallow fields would thereby prove just as functional as the composting of animal dung from night enclosures.

**Policy recommendations**

- The creation of stable state structures in the region has to be the clear purpose of Malagasy authorities to counteract violent livestock raiding and to provide a sense of security for local pastoralists. This would not only benefit the people but also the environment by preventing local overstocking in consequence of a modified but unsustainable grazing management.
- More detailed and reliable information on livestock numbers and their distribution within the region is needed to enable targeted planning of future action strategies and management recommendations.
- To a limited extent, conservation authorities should allow controlled grazing in specified pasture zones within the Tsimanampetsotsa National Park while at the same time ensuring an adequate monitoring by park rangers. This measure may enhance the acceptance of the nature reserve within the local population and imply an improved herd and grazing management. At the same time, more effort should be put into the environmental education of the local population to impart knowledge on the importance of preserving the region's natural resources.

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Hiermit versichere ich, dass ich die vorliegende Dissertation selbständig, ohne unerlaubte Hilfe Dritter angefertigt und andere als die in der Dissertation angegebenen Hilfsmittel nicht benutzt habe. Alle Stellen, die wörtlich oder sinngemäß aus veröffentlichten oder unveröffentlichten Schriften entnommen sind, habe ich als solche kenntlich gemacht. Dritte waren an der inhaltlich-materiellen Erstellung der Dissertation nicht beteiligt; insbesondere habe ich hierfür nicht die Hilfe eines Promotionsberaters in Anspruch genommen. Kein Teil dieser Arbeit ist in einem anderen Promotions- oder Habilitationsverfahren verwendet worden.

Witzenhausen, den 18. Mai 2015 Tobias Feldt

**Affidavit**

I hereby certify that I have written the present dissertation independently, without unauthorized assistance and have not relied on aids other than those mentioned in the dissertation. All points taken literally or paraphrased from published or unpublished writings have been identified as such Third parties were not involved in the creation of content and material of the thesis; in particular I did not enlisted the assistance of a doctoral consultant. No part of this work has been used in another promotion or habilitation.

Witzenhausen, May 18th, 2015 Tobias Feldt

Despite its biological and cultural richness, Madagascar is among the world's poorest countries. A still rapidly growing population in conjunction with increasing poverty, lack of education, and an almost chronic misgovernment and corruption implicate an ongoing exploitation of the island's natural resources and land cover change. Agriculture, mostly subsistence-oriented, is still the mainstay of the national economy. Livestock, and in particular cattle, thereby plays a significant economic, cultural, and social role for local communities – especially in the dry South and Southwest where until today agropastoral groups keep large herds of extensively farmed zebu cattle and small ruminants.

The present study aims to get deeper insight into the highly extensive system of animal husbandry in the Mahafaly region of southwestern Madagascar. It tries to understand the major drivers for pastoral dynamics, land and resource use along a gradient in altitude and vegetation to consider the area's high spatial and temporal heterogeneity. The study also analyzes the reproductive performance of local livestock as well as the owners' culling strategies to determine herd dynamics, opportunities for economic growth, and future potential for rural development.