Towards new agricultural practices to mitigate food insecurity in southern Madagascar

Tiana F. Ralambomanantsoa[1], Mialitiana E. Ramahatanarivo[1], Giuseppe Donati[2], Timothy M. Eppley[3], Jörg U. Ganzhorn[4*], Julian Glos[4], Daniel Kübler[5], Yedidya R. Ratovonamana[4,6], Jacques S. Rakotondranary[1,4]

[1] Mention Anthropobiologie et Développement Durable, Faculté des Sciences, BP 906, Université d'Antananarivo, Madagascar; fifimanantsoa1122@gmail.com, mialitianaerica@gmail.com, jacques.rak@gmail.com
[2] Faculty of Humanities and Social Sciences, Oxford Brookes University, Oxford OX3 0BP, UK; gdonati@brookes.ac.uk
[3] Conservation Science and Wildlife Health, San Diego Zoo Wildlife Alliance, Escondido, CA 92027, USA and Department of Anthropology, Portland State University, Portland, OR 97201, USA; eppleyti@gmail.com
[4] Department of Biology, Universität Hamburg, Martin-Luther-King Platz 3, 20146 Hamburg, Germany; joerg.ganzhorn@gmail.com, julian.glos@uni-hamburg.de
[5] IInstitute for Wood Science-World Forestry and Centre for Earth System Research and Sustainability (CEN), Universität Hamburg, 21031 Hamburg, Germany, and Institute of Forestry, Thünen Institute, Leuschnerstrasse 91, 21031 Hamburg, Germany; daniel.kuebler@thuenen.de
[6] Département de Biologie et Ecologie Végétale, Université d'Antananarivo, Antananarivo, Madagascar; ryrorch@yahoo.fr

* Author for correspondence

Madagascar is known for its exceptionally high endemism and rallying environmental destruction, making it one of the world's most threatened biodiversity hotspots (Myers, Mittermeier, Mittermeier, da Fonseca, & Kents, 2000). Yet, it is also one of the poorest countries in the world with a very poor record of governance and an obvious lack of interest in rural development and nature conservation (Jones, Rakotonarivo, & Razafimanahaka, 2022). Development projects had little impact lasting beyond the actual project timeframes and the majority of measures of success towards the Millennium Development Goals showed negative trends between 2000 and 2015 (Freudenberger, 2010; Waeber, Wilmé, Mercier, Camara, & Lowry II, 2016). As a result, Madagascar ranks 119th out of 121 countries assessed by the Global Hunger Index in 2022 (von Grebmer et al., 2022).

The situation is most precarious in the south of Madagascar. The semiarid region is characterized by recurrent droughts, leading to crop failures and hunger crises. In the driest part of the southwest, people cope with the problem by diversifying their sources of income (Hänke, Barkmann, Coral, Kaustky, & Marggraf, 2017; Narvaez & Eberle, 2021/2022; Neudert, Goetter, Andriamparany, & Rakotoarisoa, 2015; Noromiarilanto, Brinkmann, Faramalala, & Buerkert, 2016) and clearing natural vegetation (the "dry and spiny forest ecosystem") for agriculture (Brinkmann, Noromiarilanto, Ratovonamana, & Buerkert, 2014; Fenn, 2003; Zinner et al., 2014). Yet, increasing the area used for standard agriculture does not mitigate the effects of drought and failure of harvest. On the one hand, increasing the agricultural surface leads to a decrease of the area available for livestock, which are often kept as a sign of wealth and as an "insurance option", while also reducing forest cover with negative impacts on Madagascar's unique biodiversity (Nopper, Riemann, Brinkmann, Rödel, & Ganzhorn, 2018; Scott et al., 2006; von Heland & Folke, 2014). Under drought conditions, people sell livestock and many households resort to the collection of food and other resources in natural forests (Andriamparany, Brinkmann, Jeannoda, & Buerkert, 2014; Feldt, Neudert, Fust, & Schlecht, 2016; Gardner, Gabriel, St John, & Davies, 2016; Hänke & Barkmann, 2017). This leads to the discrepancy that natural forests are cleared for agriculture that provide income during years with sufficient rainfall, but people also need resources from these natural forests to survive periods of drought. The

need to fall back on non-commercial food also illustrates that the current agricultural systems are insufficient to guarantee the survival of people without external assistance.
Malnutrition is widespread in Madagascar and most prevalent among children (Rakotomanana, Gates, Hildebrand, & Stoecker, 2017). Integration of forest resources, including bushmeat, can have a positive effect on human health, though certainly a negative effect on species conservation (Golden, Fernald, Brashares, Rasolofoniaina, & Kremen, 2011; Golden, Vaitla, et al., 2019; Manjoazy et al., 2017; Thompson et al., 2023). This leaves us with the discrepancy that the current economic situation and development approach emphasizes the standard agricultural products with high yields in good years, but a high chance of failure in poor years.
Thus, it would be desirable to add some kind of agricultural insurance options to the common practice. To this end, we used interviews to collect information on the demography, economic situation, standard agriculture, and utilization of forest resources of households from 24 villages in southern Madagascar (Fig. 1). These predictors were then linked to the nutritional state of people. Undoubtedly, data compiled by interviews are hampered by difficulties quantifying the information, but even these data on dietary intake and the nutritional value of food items can help to assess the state of local nutrition in relation to the economic and environmental situation, and derive relevant information on the role of natural food components collected in the forest (Francois, 1962).

Study sites
Southern Madagascar is characterized by semi-arid climatic conditions with irregular rainfall averaging less than 600 mm per year (Armstrong & Goodman, 2022) and often by years below 300 mm (Kasola et al., 2020). Annual mean temperature is about 24°C (Battistini & Richard-Vindard, 1972). The dry season usually lasts 8–9 months, from March to October/November, but locally it may last for several years (Dewar & Wright, 1993; Gould, Sussman, & Sauther, 1999; Kasola et al., 2020). The original ecosystem is assigned to the spiny forest ecoregion (Fenn, 2003; Moat & Smith, 2007), with distinct subtypes of forest distributed in a mosaic-like fashion in relation to edaphic humidity (Andriaharimalala, Roger, Rajeriarison, & Ganzhorn, 2011; Ratovonamana, Rajeriarison, Edmond, & Ganzhorn, 2011).

Cattle herding is the predominant practice in the south. Livestock serves as a sign of wealth but also as insurance for unexpected expenses and crop failure (Feldt et al., 2016; Hänke & Barkmann, 2017). In agriculture, rice cultivation is the most common agricultural practice in Madagascar, the south used to be dominated by the cultivation of cassava / manioc and sweet potatoes (“alimentation type féculents” (Francois, 1962)). Apart from the environmental conditions, people are restricted in their behavioral options by a wide range of taboos (referred to as “fady”) that can vary locally and even within and between families. These taboos can have severe restrictions on the consumption of certain types of food, such as eating lemurs, tortoises, or tenrecs (Jaonasy & Birkinshaw, 2021; Ruud, 1960).

The southwestern study region ranges from the Onilahy River south of Toliara to Tsimanampetsotse National Park (Goodman, Raherilalao, & Wohlhauser, 2018). Apart from the riverine system of the Onilahy, it mostly covers the sandy plains of the coastal region between the sea and the Mahafaly Plateau. Ethnically, the region is dominated by Vezo along the coast who focus on fishing, and by Mahafaly and Tanalana people, who are primarily known as cattle herders. The latter cultivate mainly cassava, maize, legumes, and sweet potatoes (Brinkmann et al., 2014).
The southeastern study region extends between the Mandrare River and Parcel 2 of Andohahela National Park. Ethnically, the region is dominated by Antandroy. Since the region receives slightly more rain than the south-western study region, people try to cultivate rice, especially along river systems. The southeastern study region includes villages bordering the protected area of Lavasoa-Ambatotsirongorongo in the south. Lavasoa-Ambatotsirongorongo is a transitional forest with distinctly more rain than at the other sites (Goodman et al., 2018).

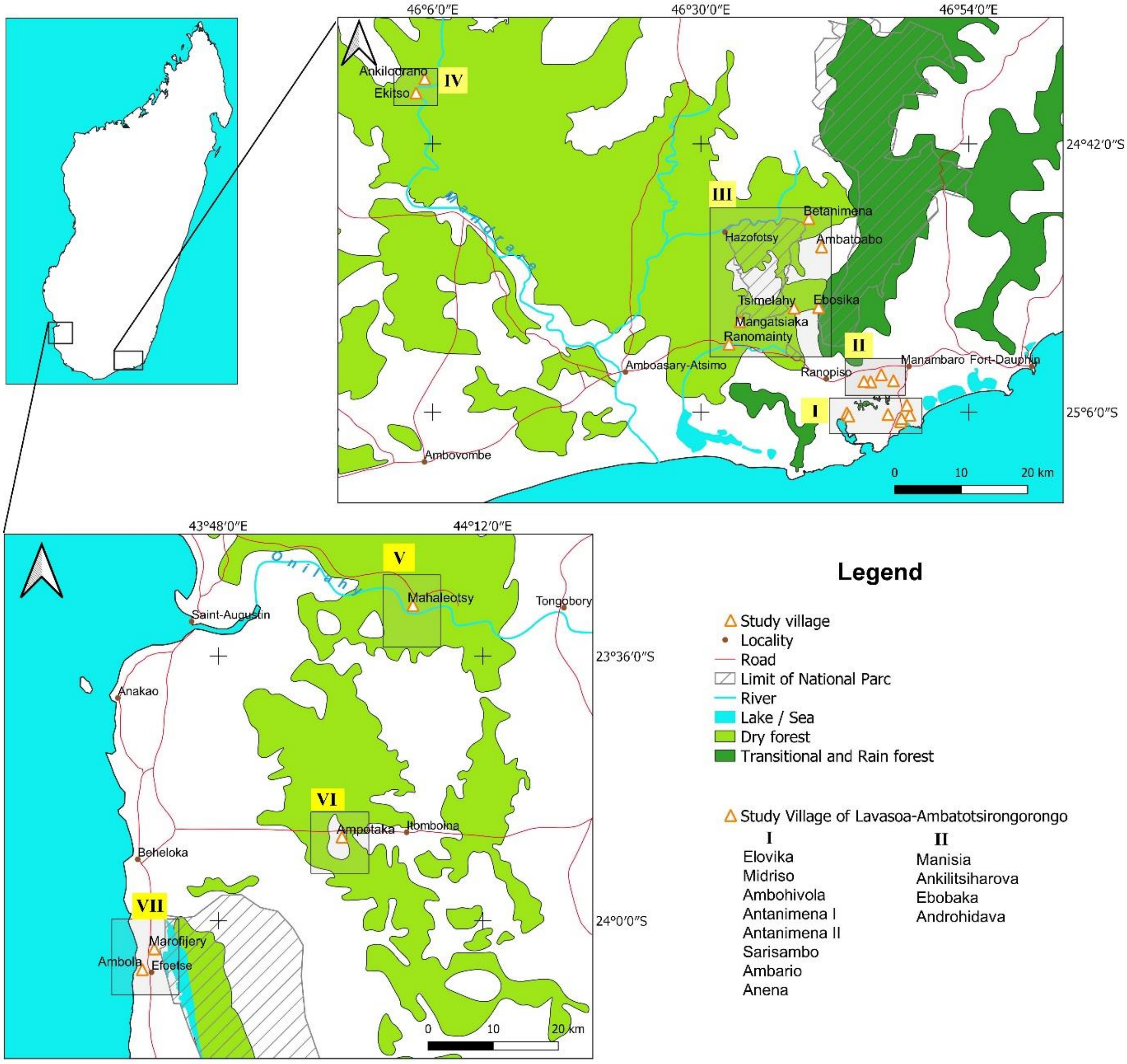


Fig. 1. Location of study sites in southern Madagascar. Roman numbers indicate study regions as listed in Table 1.

Variability of primary production

To illustrate the inter-annual variation of the productivity of the spiny forest ecosystem, we used the southwestern study region as an example. We obtained annual Net Primary Production (NPP) data at 500 m pixel resolution for 2001—2022 from the gap-filled Moderate Resolution Imaging Spectroradiometer (MODIS) MOD17A3HGF product (version 6.1) (Running & Zhao, 2021). We extracted all annual NPP values in the study region and calculated an average across the region for each year (Fig. 2). The average NPP varied considerably between years, ranging from around 420 g C/m²/year in drought years to around 700 g C/m²/year in non-drought years, as the interannual variability in NPP is strongly influenced by droughts in semi-arid ecosystems (L. Huang et al., 2016). The last three years were characterized by low NPP values. As indicated by the comparison of NPP between 2019 and 2020, NPP does not only show very high fluctuations between years, but also high spatial variations at very small scales (Fig. 3).

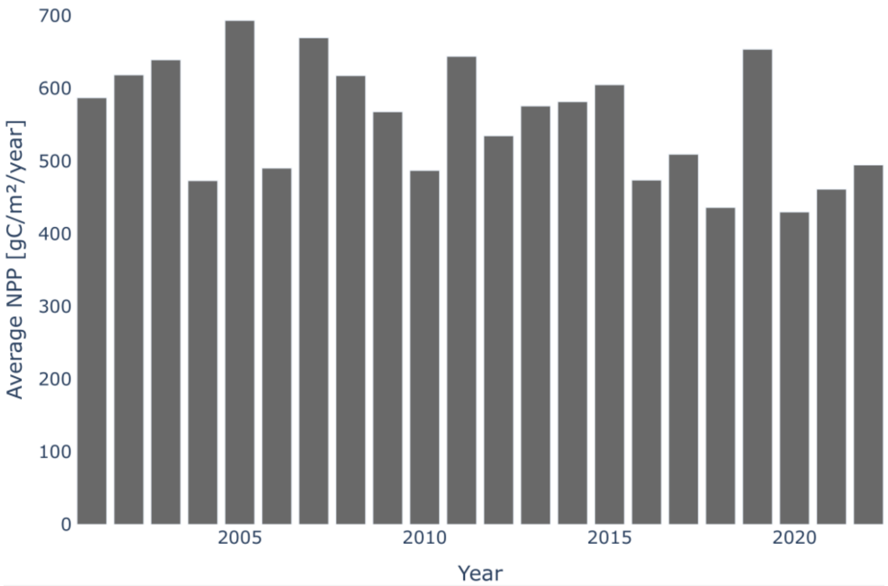


Fig. 2. Average annual Net Primary Production (NPP) in the western study region from 2001 to 2022.

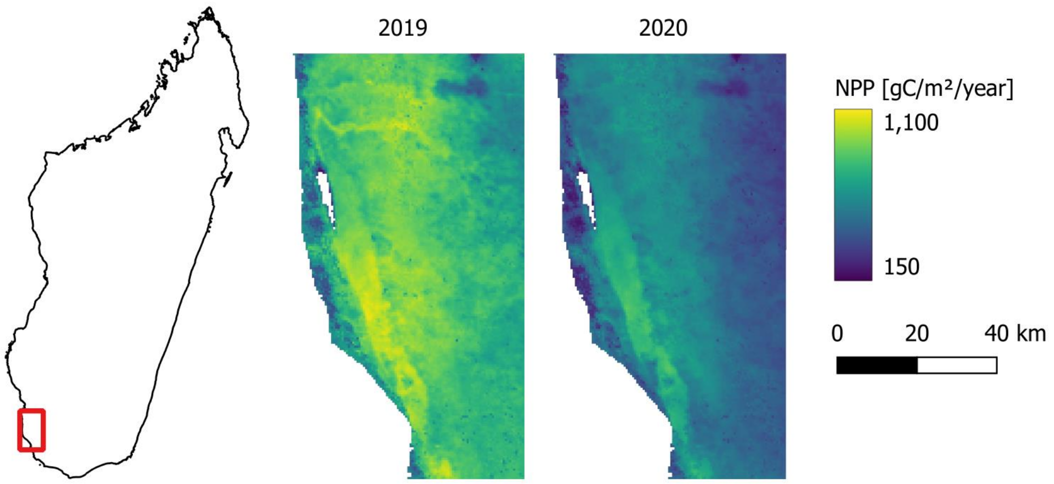


Fig. 3: Annual Net Primary Production (NPP) in 2019 and 2020 in the western study region in and around Tsimanampetsotse National Park, southwestern Madagascar.

Household surveys

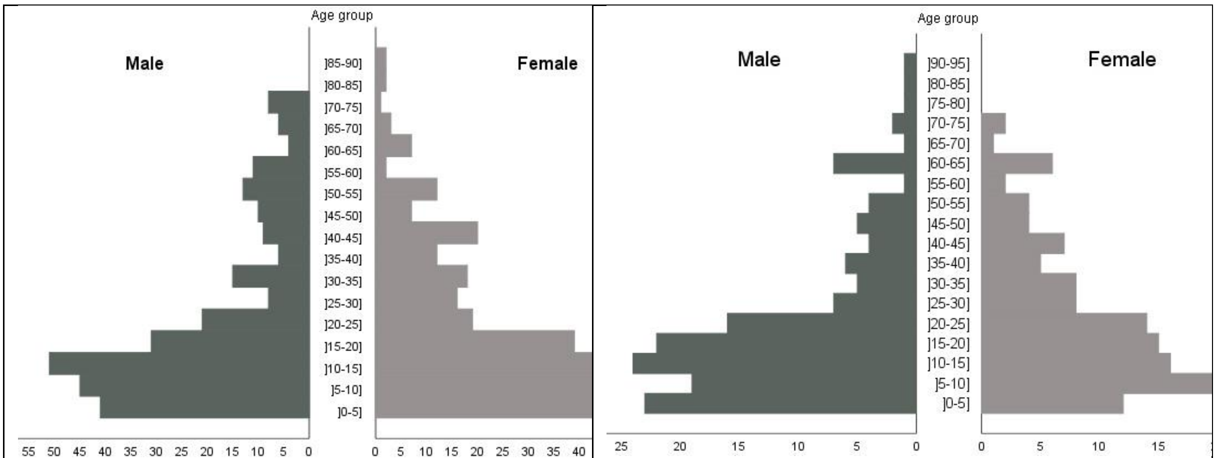
We interviewed 374 households in 24 villages assigned to seven geographic subregions (Fig. 1; Table 1). Interviews followed a questionnaire developed previously for the spiny region (Andriamparany et al., 2014; Neudert et al., 2015) which has since been applied in other regions of Madagascar (Konersmann et al., 2022). Interviews were run by the Malagasy authors in collaboration with local assistants. Since interviews were completed non-concurrently, they cover different seasons of the year. This caveat may not be relevant for the general questions, but has implications for the analyses of food security.

Table 1. Number of households surveyed in 24 villages from seven geographic regions. C = cassava (manioc), SP = sweet potatoes, M = Maize. Number of people per household are means ± standard deviation and minimum and maximum numbers per household in brackets.

Region	Abbreviation	Months and year of survey	Harvest	Number of villages / households	Number of people per household
Southeast					
Lavasoa-Ambatotsirongorongo Sud	I	4, 5 / 2021	None	8 / 92	6.33 ± 2.27 (1 – 14)
Lavasoa-Ambatotsirongorongo Nord	II	4, 5 / 2021	None	4 / 46	5.96 ± 2.87 (2 – 13)
Andohahela	III	6 / 2021	C, SP	6 / 59	5.05 ± 2.18 (1 – 11)
Ebelo	IV	6 / 2021	C, SP	2 / 20	5.35 ± 2.21 (2 – 20)
Southwest					
Amoron'i Onilahy	V	8 / 2022	C, SP, M	1 / 41	5.80 ± 3.33 (1 – 18)
Ampotaka	VI	7 / 2022	C, SP	1 / 37	5.73 ± 2.93 (1 – 13)
Tsimanampetsotse	VII	7, 8 / 2022	C, SP	2 / 79	6.82 ± 2.90 (2 – 15)

Demography

The seven regions show similar demographic structure with a very large proportion of children and young people (Fig. 4). The reduction of age cohorts towards adulthood in the driest regions (Ebelo, Tsimanampetsotse and Ampotaka indicates high child mortality. In most regions, the sudden drop around the age of 20 might reflect emigration of young adults to larger towns and/or cities. Reasons for the demographic structure were not part of the questionnaire. For the compilation of the demography people were simply asked for their age. Thus, the older ages, especially in the southwestern regions, are to be considered personal perceptions of the people interviewed rather than documented ages.



Lavasoa - Ambatotsirongorongo Sud (N=582) | Lavasoa - Ambatotsirongorongo Nord (N=274)

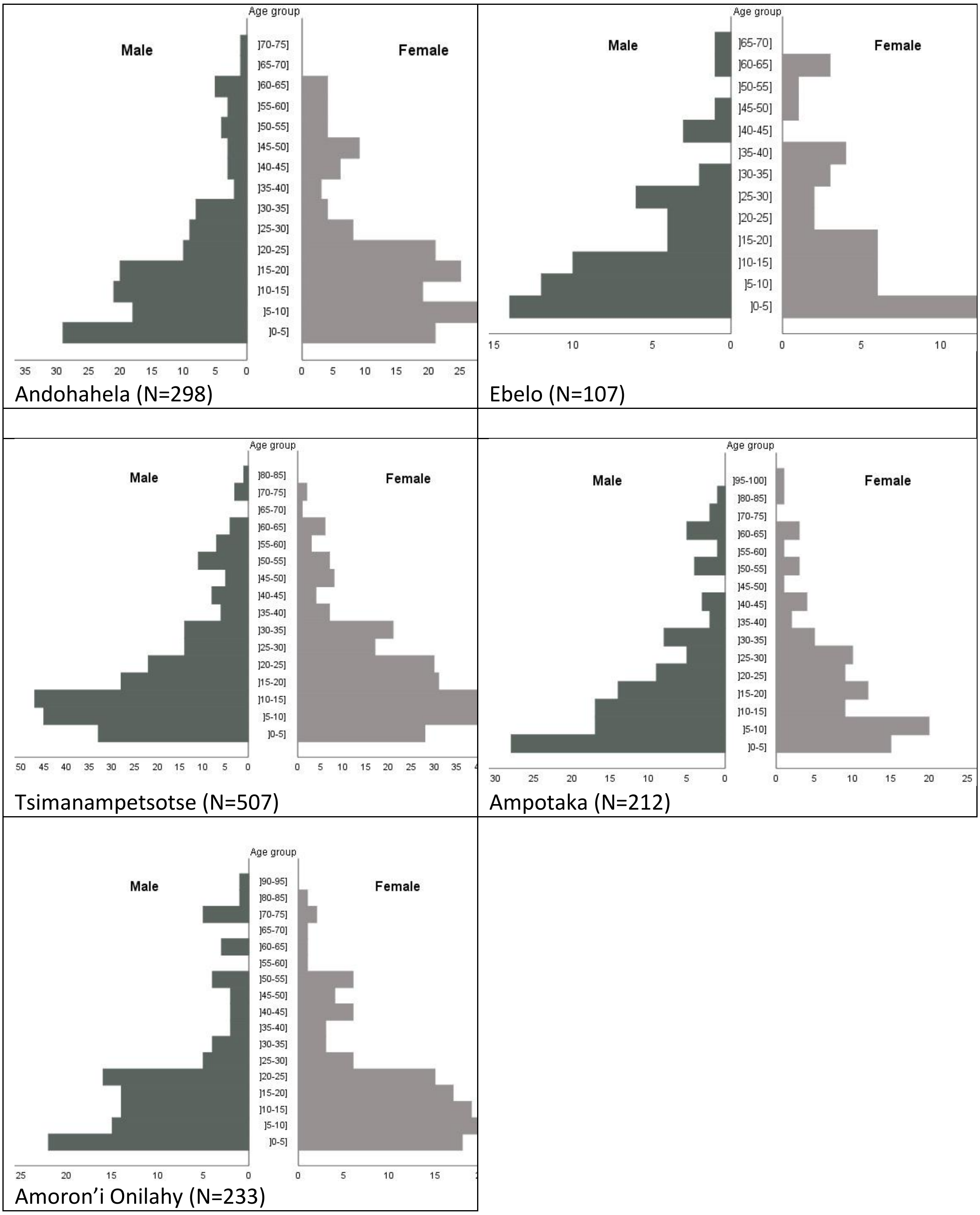


Fig. 3. Age structure of the human population in seven regions with a total of 24 villages and 374 households of southern Madagascar. N indicates the number of people recorded.

Agricultural activities

As already described by Francois (1962) during colonial times, manioc and sweet potatoes are still grown most often. Rice and maize are grown at sites where rivers allow irrigation or have a high groundwater table due to their proximity to rivers (e.g., Andohahela, Ebelo, Amoron'I Onilahy). At Andohahela, creeks are more seasonal than the rivers Mandrare and Onilahy in the other two regions. Due to the lack of rain in Andohahela, rice paddies were not cultivated in the year of survey (2021) and had not been cultivated since 2017. In years of drought, holding rice paddies available in expectation of rain reduces the available arable land that could have been used for other crops, especially those more adapted to dry conditions.

Elsewhere, maize is planted in years assumed to have enough rain. Due to the high unpredictability, this also bears high risk of complete crop failure and the lack of seeds for planting after repeated failure of growth. Sorghum would be better suited for dry conditions, but currently appears to be regionally restricted to the southwest. The region of Tsimanampetsotse contrasts from others as a much smaller proportion of households' plant crops. The low proportions are due to ethnic differences. Though the two villages surveyed in Tsimanampetsotse (Ambola and Marofijery) are adjacent to each other, Ambola is a fishing village inhabited by Vezo who do not practice agriculture, while Marofijery is an agricultural village that only recently increased fishing efforts because agricultural harvests have become too unreliable.

Table 2. Percentage of households with different agricultural activities in the different regions

Region	**Lavasoa-Ambato-tsirongo-rongo Sud N = 92**	**Lavasoa-Ambato-tsirongo-rongo Nord N = 46**	**Andohahela N = 59**	**Ebelo N = 20**	**Amoron'i Onilahy N = 41**	**Ampotaka N = 37**	**Tsimanam-petsotse N = 79**
Agriculture							
Manioc	89.1	91.3	59.3	60.0	65.9	78.4	34.2
Sweet potatoes	91.3	97.8	47.5	40.0	63.4	8.1	32.9
Rice	62.0	73.9	52.5	0.0	0.0	0.0	0.0
Maize	5.4	8.7	20.3	90.0	73.2	24.3	24.1
Sorghum	0.0	0.0	0.0	0.0	31.7	51.4	21.5
Beans	10.9	6.5	5.1	10.0	48.8	91.9	39.2
Fruit	15.2	13.0	3.4	55.0	43.9	29.7	10.1
Vegetable	16.3	10.9	15.3	55.0	56.1	18.9	11.4
Others	3.3	4.3	0.0	5.0	10.0	10.8	1.3
Livestock							
Cattle	22.8	26.1	18.6	30.0	9.8	5.4	7.6
Sheep	0.0	2.2	1.7	15.0	2.4	10.8	11.4
Goats	0.0	0.0	18.6	30.0	22.0	16.2	13.9
Pigs	7.6	13.0	1.7	0.0	0.0	0.0	0.0
Poultry	48.9	39.1	25.4	5.0	24.4	59.5	63.3

Food security

Our measures of food security represent the interview days and therefore should be considered a snapshot in time, while all other data represent the situation over the full annual cycle. Thus, these measures should be taken with caution and only as an indication of the situation.

In "normal years", the months of April and May represent the end of the lean season without regular harvests. June and July are the months when manioc and sweet potatoes are harvested. Rice can be harvested in May, November and December. Thus, the southeastern sites had been surveyed during the lean times of the year at the end of a drought that had lasted from 2017 to 2021. The southwestern sites had been surveyed after the harvest of manioc and sweet potatoes (Table 1).

The nutritional status of households was assessed by three different measures. First, we calculated the caloric intake in kcal per day and person. This measure is based on the quantity of food cooked per day. The caloric values of different food items from the region follow those assigned by Francois (Francois, 1962). The Household Dietary Diversity Score (HDDS) adds a qualitative component to the measure of caloric intake. It is a simple addition of 12 food groups that are consumed by members of a household per day. These groups are: cereals, roots and tubers, vegetables, fruits, meat, poultry, offal, eggs, fish and seafood, pulses, milk and milk products, oil/fat, sugar/honey, miscellaneous (Swindale & Bilinsky, 2006). The Food Consumption Score (FCS) reflects the diversity of food consumed based on only eight categories: cereals, tubers and roots, pulses, vegetables, fruit, meat and fish, milk and other dairy, sugar, oil. As a further development of the HDDS, these categories are weighed differently. The weighted consumption of the different categories are added, resulting in a FCS score that can be used as a measure of food security. Food security is considered to be acceptable above a daily intake of ≥ 2100 kcal or FCS ≥ 5 (J. H. Huang, Nie, & Bi, 2015). For HDDS no definite threshold was defined as the perception of security varies widely in relation to the environmental situation (Hoddinott & Yohannes, 2002). Though the three measures are highly correlated (all with $p < 0.001$), they reflect different strategies to satisfy nutritional needs, as the same caloric intake can be reached either by relying on a staple food source or by combining many different food types (Fig. 5).

Food security was most precarious in the driest regions, i.e., Ebelo, Andohahela, Ampotaka, and Tsimanampetsotse. This is reflected in the average caloric intake as well as in the HDDS and FCS categories. Ebelo was in the center of the food crisis in 2021, recognized globally. Here, 100% of households fell in the lowest FCS category (Table 3). Only Amoron'I Onilahy achieved acceptable food security according to FCS indices, but did not achieve satisfying caloric intakes (Fig. 6).

Table 3. Measures of nutrition and food security. Values for the southeastern regions are based on one day of records. Measures for the southwestern sites were based on 7 survey days. To be comparable with the southeastern sites, HDDS was used only from the first day of survey and FCS was standardized to a single survey day. Values for caloric intake and HDDS are means ± standard deviations; for FCS the percentage of households that fall into one of the categories: poor food security (FCS ≤ 3); borderline (3 < FCS ≤ 5); acceptable (FCS > 5).

Region	**Lavasoa-Ambato-tsirongo-rongo Sud**	**Lavasoa-Ambato-tsirongo-rongo Nord**	**Ando-hahela**	**Ebelo**	**Amoron'i Onilahy**	**Ampotaka**	**Tsimanampetsotse**
Caloric intake [kcal]	1283 ± 654	1443 ± 1093	1117 ± 740	907 ± 814	1297 ± 464	1183 ± 545	1030 ± 390
HDDS	4.0 ± 1.4	3.7 ± 1.4	2.9 ± 1.3	2.2 ± 0.6	4.5 ± 1.8	2.7 ± 1.4	3.9 ± 2.0
FCS: Poor	33.7%	43.5%	57.6%	100.0%	2.4%	37.8%	17.7%
FCS: borderline	50.0%	50.0%	39.0%	0.0%	7.3%	56.8%	35.4%
FCS: acceptable	16.3%	6.5%	3.4%	0.0%	90.2%	5.4%	46.8%

Utilization of forest resources

Type of natural food resources collected

Vegetable resources collected in natural forests include leaves from two plant species, fruits from approximately 33 species, seeds and exudates from one species, and tubers and roots from 15 species. Since some species were listed only by their vernacular names and were not physically available at the time of the household survey, species identity and growth forms were not known for all plant species.

The regions differ markedly in the types of food collected from forests. In the areas with most rain (Lavasoa-Ambatotsirongorongo), people collect mainly fruits from the forest. These can be fruits from native trees (*Strychnos spinosa*, *Flacourtia indica* [Indian plum] or *Canarium madagascariensis*) or introduced species that have invaded forests, such as *Citrus* fruits and *Psidium guajava* (Guava). In most other regions, tubers are collected by most households. These include several species of wild yam and storage organs of other plants. Fruits are also collected, but they come from a larger variety of species than at the more mesic sites (Fig. 5).

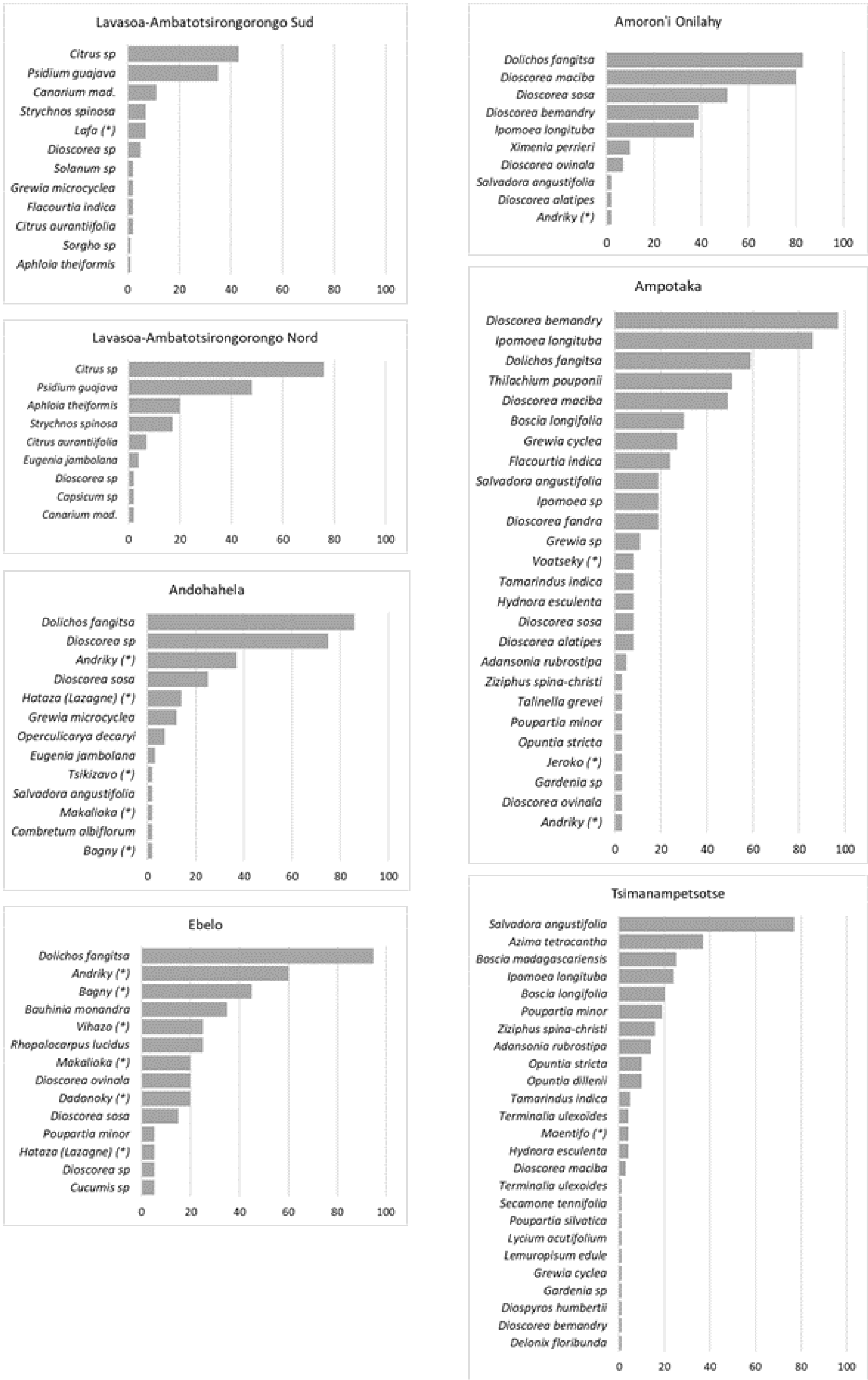


Fig. 4. Percentage of households collecting edible plant resources from forests; * vernacular names.

All plant resources collected for consumption stem from perennial plant species, with the vast majority belonging to woody plants (Table 4). This is in marked contrast to the commercial and standard crops grown in fields which are mostly annual species needing to be replanted after harvest. Commercial annual plants have higher yields when harvests are good, but under southern

Madagascar conditions, their cultivation bears a high risk of complete failure and thus this practice is not sustainable for achieving food security independent from international aid programs. This risk could be mitigated by shifting cultivation towards perennial plants.

Table 4. Type of natural food resources collected in forests. The total number of species is higher than the species with known growth forms because not all plant species recorded with their vernacular names could be identified.

	Fruits	Seeds	Leaves	Exudates	Tubers/Roots
Number of species	33	1	1	1	15
Tree	17	1		1	2
Tree / Shrub	11		1		1
Cactus	2				
Herb / Shrub					1
Herb / Vine					8
Parasite					1

Hunting and fishing

Protein can be a limiting factor in agricultural systems with low food security. Livestock is not affordable for many households (Neudert et al., 2015) and poultry suffer very high mortality due to the lack of vaccination against cholera and newcastle disease, though vaccine options may be available soon (Annapragada et al., 2019). Fishing is a viable option to improve protein supply, as is the alternative, hunting (Golden, Borgerson, et al., 2019; Golden et al., 2011).
Hunting and fishing are mutually exclusive options for the households in southern Madagascar. Of 373 households, 250 neither fish nor hunt, 52 fish but do not hunt, 70 hunt but do not fish, and only 1 is both fishing and hunting. Hunting traditions also vary between villages. Hunting was reported only from households in 10 of the 24 villages surveyed. Guinea Fowl (*Numida meleagris*) was hunted most frequently (Table 5). The various species of Coua (*Coua* spp.) also seem to be taken frequently. Fodies (*Foudia madagascariensis*) are small passerine birds that can occur in large numbers in ripening sorghum fields. Though, except for Guineafowl, bird hunting does not seem rewardable as the small birds weigh only about 10 – 20 g and go up to about 100 g for large passerine species (Rasoma & Goodman, 2007), Fodies and other small birds are not only hunted to protect fields but also serve as actual food for people (Randriamiharisoa et al., 2015).
Insects are consumed as snacks or during mass occurrences (locusts; crickets in bean fields), but not specifically searched for. Therefore, people might not have listed insects as part of their "hunting" practices. Nevertheless, insect farming might become an accepted option in some areas where insects are already part of the human diet and food for insects is available year-round (Borgerson et al., 2021; Fisher & Hugel, 2022).
Bats are collected in large numbers at their roosting sites in caves of Tsimanampetsotse (S. Reher, pers. comm.), but nowhere else. This might be due to the lack of roosting sites where bats can be encountered in large numbers and be caught easily. Tenrecs (*Setifer setosus* and *Tenrec ecaudatus*) are hunted routinely during the wet season. Lemurs seem to be hunted only in Lavasoa-Ambatotsirongorongo. In some villages, lemur hunting is taboo, while in others, lemur hunters simply may not have told, because lemur hunting is prohibited by law. Bushpigs (*Potamochoerus larvatus*) are most rewardable, but require special equipment and skills.
Despite the often small prey, general Linear Models with "village" as random factor and "hunting/fishing" as fixed factor, revealed highly significant improvements of the caloric intake, HDDS and FCS in households that practice either fishing or hunting (Table 6, Fig. 6). These resources thus contribute substantially to diet, and due to their contribution to a more diverse diet, probably also to general human health (Golden et al., 2011; Swindale & Bilinsky, 2006).

Table 5. Number of households hunting different species. People in Lavasoa-Ambatotsirongo Sud (I) do not hunt and therefore this region was omitted from the table. Body length and bodymass according to (Sinclair & Langrand, 2013), (Rasoma & Goodman, 2007) and (Soarimalala & Goodman, 2011).

Region		**Body length / Bodymass**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Insects								
Apis mellifera	Honey bee							1
Birds								
Centropus toulou	Madagascar Coucal	45 cm				1	1	3
Coracopsis spp.	Vasa parrots	35 – 50 cm				1	1	
Coua spp.	Coua : various species	40 cm			1		19	10
Foudia madagascariensis	Madagascar Red Fody	13 cm				1	1	1
Mirafa hova	Madagascar Lark	13 cm				1	1	1
Neomixis spp.	Jery	10 – 12 cm			1	1	2	
Newtonia brunneicauda	Common Newtonia	12 cm					1	
Numida meleagris	Helmeted Guineafowl	60 cm	3	1	1	6	17	11
Oena capensis	Namaqua Dove	28 cm				1		
Pterocles personatus	Madagascar Sandgrouse	35 cm						1
Nesoenas picturata	Madagascar Turtle Dove	28 cm			3		2	2
Turnix nigricollis	Madagascar Buttonquail	15 cm			2	3	4	3
Eggs						1	1	
Mammals								
Bats	Several species	30 – 60 g						1
Setifer setosus	Greater Hedgehog Tenrec	250 g				2	5	11
Tenrec ecaudatus	Common Tenrec	560 g					2	9
Lemur catta	Ring-Tailed Lemur	2200 g	2					

Potamochoerus larvatus	Bushpig	50000 g	2				5	5

Table 6. Effects of hunting or fishing on measures of nutrition and food security. Values are F values based on General Linear Mixed Models with "Village" as random variable and "Hunting/Fishing" as fixed factor; asterisks indicate levels of significance: * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001.

	Fishing or hunting	Village
Caloric intake	9.55**	3.44*
HDDS	12.67***	3.57*
FCS	13.05***	6.56**

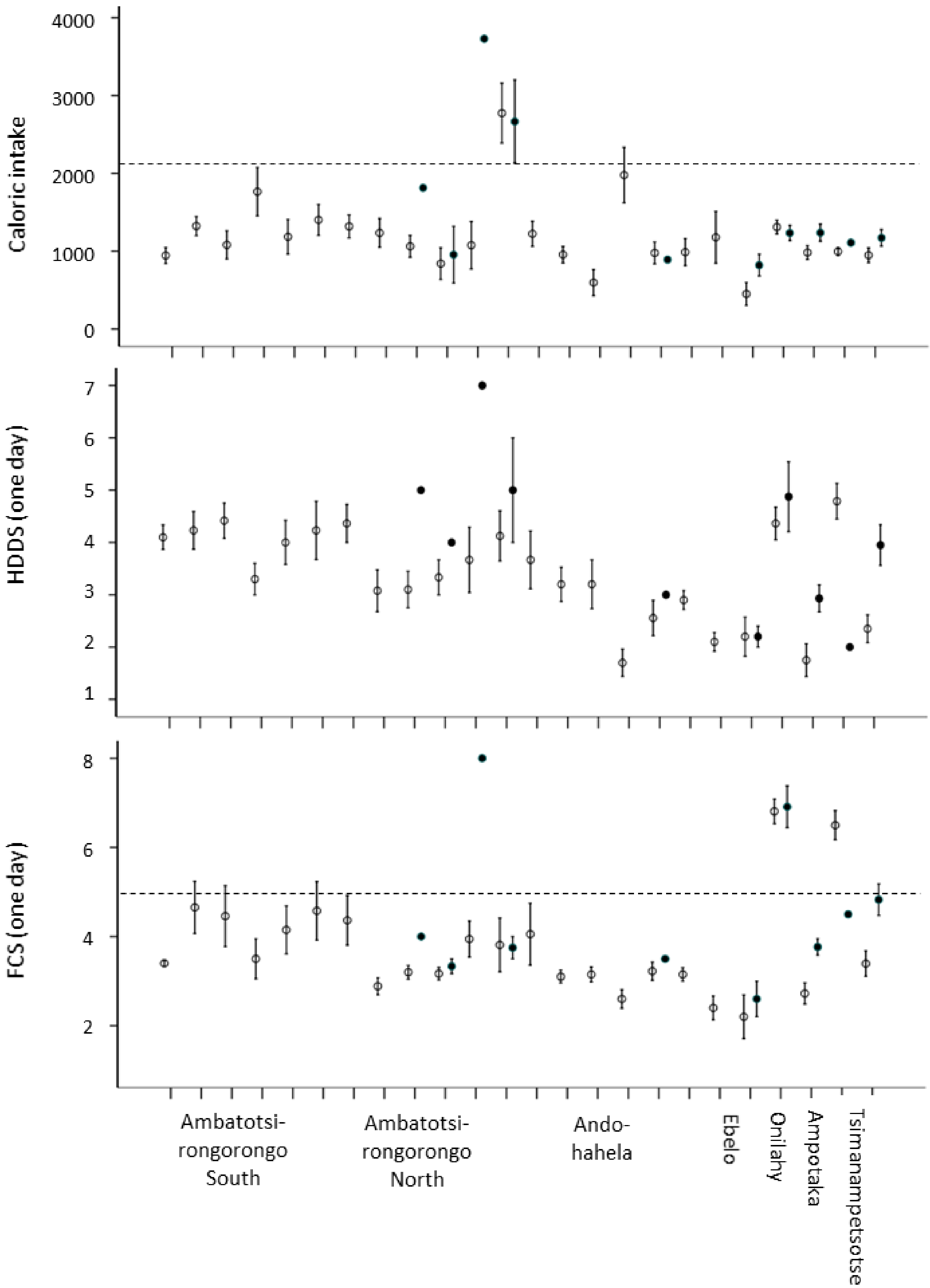


Fig. 6. Nutritional and food security measures for 24 villages of the seven regions. Values are means ± standard errors. White circles indicate households without fishing or hunting. Filled circles indicate households with fishing or hunting. The dashed lines indicate the threshold for acceptable food

security (J. H. Huang et al., 2015). They should be considered as indications rather than absolute thresholds.

Lessons learned

The dry regions of southern Madagascar are subject to recurrent droughts. In previous times, these droughts were reflected in the human demographic structure by an increased death rate of young children and the lack of children born during these years (Jolly, 2004). Today, large portions of this region's population cannot survive without international aid. During periods of food shortage, natural forests provide fallback food resources (Thompson et al., 2023), but the persistent use of these resources is not sustainable and highly destructive (Brinkmann et al., 2014; Zinner et al., 2014). There are many obstacles hindering regional development, ranging from traditions, economic constraints, poor governance, and even crime (Goetter, 2016; Hänke et al., 2017). Many of these obstacles are difficult to overcome, but the traditional use of forest products may provide concepts for new approaches. For the time being, most crops planted are annual plants, and their cultivation resembles a gamble for rain which is too often lost. In contrast, most (if not, all) fallback plant resources are perennial (see also Porcher et al. preprint 2023), thus the logical consequence would be to shift agricultural production from annual to perennial plants. Increasing the emphasis on perennial plants may not only be beneficial for humans, but would have great potential for improving the conservation for endemic animal species. There are a large number of fruit trees and other utilitarian trees that are of value for people and are being used by native animals alike (Gérard, Ganzhorn, Kull, & Carrière, 2015; Konersmann et al., 2022; Rafidison, Rakouth, Carriere, Kjellberg, & Aumeeruddy-Thomas, 2020; Steffens, 2020). These trees could be planted as buffer zones, corridors or hedges. They could provide income and food for people and animals and could also serve as support for planting native yam. While the potential of local knowledge, wild plant foods and agroforestry is being widely recognized (e.g., (Andriamparany et al., 2014; Blanco & Carriere, 2016; Grass et al., 2019; Moore, Alpaugh, Razafindrina, Trubek, & Niles, 2022; Rahman, Jacobsen, Healey, Roshetko, & Sunderland, 2017; Wurz et al., 2022), these concepts have not found their way towards large scale implementation in the south of Madagascar. Implementation would require some thoughts about long-term sustainability and is a matter of perspective (Jones et al., 2022). Options are to extend the exploitation of wild resources into protected areas and bring areas under community-based management decision. This does not seem to work sustainably and so far has resulted in rapid forest degradation in most cases (Gardner et al., 2018; Rafanoharana et al., submitted). Alternatively, plantations of perennial food resources should be extended within the present agricultural areas, combining income for people with biodiversity conservation.

Acknowledgements

The study was carried out under the collaboration between Madagascar National Parks (MNP), the Departments of Animal Biology, Mention Anthropobiologie et Développement Durable, and Plant Biology and Ecology (Antananarivo University, Madagascar) and the Universität Hamburg (Germany). Our special thanks go to the staff of TBSE (Tropical Biology and Social Enterprise) and the Association Analasoa, Charles Kasola, Florent Atrefony, Fisy Louis, German Nicolas Odilon, Romialde Gabriel Ralahinirina, Maritiny, Odilizara Zafinipela. We thank the Malagasy authorities for issuing the research permit. We thank Re:wild and the Postcode Lotterie for financial support.

References

Andriaharimalala, T., Roger, E., Rajeriarison, C., & Ganzhorn, J. U. (2011). Analyse structurale des différents types de formation végétale du Parc National d'Andohahela, habitat de *Microcebus* spp. (Sud-est de Madagascar). *Malagasy Nature, 5*, 39-58.

Andriamparany, J. N., Brinkmann, K., Jeannoda, V., & Buerkert, A. (2014). Effects of socio-economic household characteristics on traditional knowledge and usage of wild yams and medicinal plants in the Mahafaly region of south-western Madagascar. *Journal of Ethnobiology and Ethnomedicine, 10: 82*.

Annapragada, A., Borgerson, C., Iams, S., Ravelomanantsoa, M. A., Crawford, G. C., Helin, M., et al. (2019). Modeling the impact of newcastle disease virus vaccinations on chicken production systems in northeastern Madagascar. *Frontiers in Veterinary Science, 6*, 305.

Armstrong, A. H., & Goodman, S. M. (2022). Forest and grassland ecology: Introduction. In S. M. Goodman (Ed.), *The New Natural History of Madagascar* (pp. 100-104). Princeton: Princeton University Press.

Battistini, R., & Richard-Vindard, G. (1972). *Biogeography and Ecology in Madagascar*. The Hague: Dr. W. Junk B.V., Publishers.

Blanco, J., & Carriere, S. M. (2016). Sharing local ecological knowledge as a human adaptation strategy to arid environments: Evidence from an ethnobotany survey in Morocco. *Journal of Arid Environments, 127*, 30-43.

Borgerson, C., Fisher, B. L., Razafindrapaoly, B. N., Rasolofoniaina, B. J. R., Randriamanetsy, J. M., Razafindrapaoly, B. L., et al. (2021). A nutrient-rich traditional insect for improving food security and reducing biodiversity loss in Madagascar and sub-Saharan Africa. *Conservation Science and Practice, 3*(9), e480.

Brinkmann, K., Noromiarilanto, F., Ratovonamana, R. Y., & Buerkert, A. (2014). Deforestation processes in south-western Madagascar over the past 40 years: what can we learn from settlement characteristics? *Agriculture, Ecosystems and Environment, 195*, 231-243.

Dewar, R. E., & Wright, H. T. (1993). The culture history of Madagascar. *Journal of World Prehistory, 7*, 417-466.

Feldt, T., Neudert, R., Fust, P., & Schlecht, E. (2016). Reproductive and economic performance of local livestock in southwestern Madagascar: Potentials and constraints of a highly extensive system. *Agricultural Systems, 149*, 54-64.

Fenn, M. D. (2003). The spiny forest ecoregion. In S. M. Goodman & J. Bensted (Eds.), *The Natural History of Madagascar* (pp. 1525-1530). Chicago: The University of Chicago Press.

Fisher, B. L., & Hugel, S. (2022). Edible terrestrial arthropod traditions and use on Madagascar. In S. M. Goodman (Ed.), *The New Natural History of Madagascar* (Vol. 1, pp. 218-231). Princeton: Princeton University Press.

Francois, P. J. (1962). *Budgets et Alimentation des Menages ruraux en 1962* (Vol. 2). Tananarive: Ministère des Finances et du Commerce I.N.S.R.E.

Freudenberger, K. (2010). *Paradise lost? Lessons from 25 years of USAID environment programs in Madagascar.* Washington, D.C.: International Resources Group.

Gardner, C. J., Gabriel, F. U. L., St John, F. A. V., & Davies, Z. G. (2016). Changing livelihoods and protected area management: a case study of charcoal production in south-west Madagascar. *Oryx, 50*(3), 495-505.

Gardner, C. J., Nicoll, M. E., Birkinshaw, C., Harris, A., Lewis, R. E., Rakotomalala, D., et al. (2018). The rapid expansion of Madagascar's protected area system. *Biological Conservation, 220*, 29-36.

Gérard, A., Ganzhorn, J. U., Kull, C. A., & Carrière, S. M. (2015). Possible roles of introduced plants for native vertebrate conservation: the case of Madagascar. *Restoration Ecology, 23*(6), 768-775.

Goetter, J. F. (2016). The cattle raiders leave us no choice: New transhumance in the Mahafaly Plateau region in Madagascar. *Madagascar Conservation & Development 11*(1), 12-22.

Golden, C. D., Borgerson, C., Rice, B. L., Allen, L. H., Anjaranirina, E. J. G., Barrett, C. B., et al. (2019). Cohort description of the Madagascar health and environmental research–Antongil (MAHERY–Antongil) Study in Madagascar. *Frontiers in Nutrition, 6*, 109.

Golden, C. D., Fernald, L. C. H., Brashares, J. S., Rasolofoniaina, B. J. R., & Kremen, C. (2011). Benefits of wildlife consumption to child nutrition in a biodiversity hotspot. *Proceedings of the National Academy of Sciences of the United States of America, 108*(49), 19653-19656.

Golden, C. D., Vaitla, B., Ravaoliny, L., Vonona, M. A., Anjaranirina, E. G., Randriamady, H. J., et al. (2019). Seasonal trends of nutrient intake in rainforest communities of north-eastern Madagascar. *Public Health Nutr, 22*(12), 2200-2209.
Goodman, S. M., Raherilalao, M. J., & Wohlhauser, S. (2018). *Les aires protégées terrestres de Madagascar: leur histoire, description et biote / The terrestrial protected areas of Madagascar: their history, description, and biota* Antananarivo: Association Vahatra.
Gould, L., Sussman, R. W., & Sauther, M. L. (1999). Natural disasters and primate populations: the effects of a 2-year drought on a naturally occurring population of Ring-Tailed Lemurs (*Lemur catta*) in Southwestern Madagascar. *International Journal of Primatology, 20*, 69-84.
Grass, I., Loos, J., Baensch, S., Batáry, P., Librán-Embid, F., Ficiciyan, A., et al. (2019). Land-sharing/-sparing connectivity landscapes for ecosystem services and biodiversity conservation. *People and Nature, 1*(2), 262-272.
Hänke, H., & Barkmann, J. (2017). Insurance function of livestock, Farmers coping capacity with crop failure in southwestern Madagascar. *World Development, 96*, 264-275.
Hänke, H., Barkmann, J., Coral, C., Kaustky, E. E., & Marggraf, R. (2017). Social-ecological traps hinder rural development in southwestern Madagascar. *Ecology and Society, 22*(1).
Hoddinott, J., & Yohannes, Y. (2002). *Dietary diversity as a food security indicator. Food and Nutrition Technical Assistance Project, Academy for Educational Development, Washington, D.C.*
Huang, J. H., Nie, F., & Bi, J. H. (2015). *Comparison of food consumption score (FCS) and caloric intake: indicators to measure food security*. Paper presented at the International Conference on Social Science, Education Management and Sports Education (SSEMSE 2015)
Huang, L., Bin, H., Aifang, C., Haiyan, W., L., J., Aifeng, L., et al. (2016). Drought dominates the interannual variability in global terrestrial net primary production by controlling semi-arid ecosystems. *Scientific Reports, 6*, 24639.
Jaonasy, M., & Birkinshaw, C. (2021). Lemur inventories in the Vohidava-Betsimilaho New Protected area. *Lemur News, 23*, 48-51.
Jolly, A. (2004). *Lords and Lemurs*. Boston: Houghton Mifflin Company.
Jones, J. P. G., Rakotonarivo, O. S., & Razafimanahaka, J. H. (2022). Forest conservation on Madagascar: past, present and future. In S. M. Goodman (Ed.), *The New Natural History of Madagascar* (Vol. 2, pp. 2130-2140). Princeton: Princeton University Press.
Kasola, C., Atrefony, F., Louis, F., Odilon, G. N., Ralahinirina, R. G., Menjanahary, T., et al. (2020). Population dynamics of Lemur catta at selected sleeping sites of Tsimanampesotse National Park. *Malagasy Nature, 14*, 69-80.
Konersmann, C., Noromiarilanto, F., Ratovonamana, Y. R., Brinkmann, K., Jensen, K., Kobbe, S., et al. (2022). Using utilitarian plants for lemur conservation. *International Journal of Primatology, 43*, 1026-1045.
Manjoazy, T., Razafimanahaka, J. H., Ronto, W., Randrianavelona, R., Ganzhorn, J. U., & Jenkins, R. K. B. (2017). The supply of illegal tortoise meat to Toliara City, south-western Madagascar. *Oryx, 51*(3), 437-440.
Moat, J., & Smith, P. (2007). *Atlas of the Vegetation of Madagascar. Atlas de la Végétation de Madagascar.* Kew: Kew Publishing, Royal Botanic Gardens.
Moore, M., Alpaugh, M., Razafindrina, K., Trubek, A. B., & Niles, M. T. (2022). Finding food in the hunger season: A mixed methods approach to understanding wild plant foods in relation to food security and dietary diversity in southeastern Madagascar. *Frontiers in Sustainable Food Systems, 6*, 929308.
Myers, N., Mittermeier, R. A., Mittermeier, C., da Fonseca, G., & Kents, J. (2000). Biodiversity hotspots for conservation priorities. *Nature, 403*, 853-858.
Narvaez, L., & Eberle, C. (2021/2022). *Technical Report: Southern Madagascar food insecurity*. Shibuya: United Nations University.
Neudert, R., Goetter, J. F., Andriamparany, J. N., & Rakotoarisoa, M. (2015). Income diversification, wealth, education and well-being in rural south-western Madagascar: Results from the Mahafaly region. *Development Southern Africa, 32*(6), 758-784.

Nopper, J., Riemann, J. C., Brinkmann, K., Rödel, M.-O., & Ganzhorn, J. U. (2018). Differences in land cover - biodiversity relationships complicate the assignment of conservation values in human-used landscapes. *Ecological Indicators, 90*, 112-119.

Noromiarilanto, F., Brinkmann, K., Faramalala, M. H., & Buerkert, A. (2016). Assessment of food selfsufficiency in smallholder farming systems of south-western Madagascar using survey and remote sensing data. *Agricultural Systems, 149*, 139-149.

Rafanoharana, S. C., Andrianambinina, F. O. D., Rasamuel, H. A., Waeber, P. O., Wilmé, L., & Ganzhorn, J. U. (submitted). Projecting forest cover in Madagascar's protected areas to 2050 and its implications for lemur conservation. *Oryx*.

Rafidison, V. M., Rakouth, B., Carriere, S. M., Kjellberg, F., & Aumeeruddy-Thomas, Y. (2020). Multiple values of isolated and clusters of *Ficus* tree species protected by Betsileo farmers in rural landscapes in Madagascar: implications for biodiversity conservation. *Biodiversity and Conservation, 29*(3), 1027-1058.

Rahman, S. A., Jacobsen, J. B., Healey, J. R., Roshetko, J. M., & Sunderland, T. (2017). Finding alternatives to swidden agriculture: does agroforestry improve livelihood options and reduce pressure on existing forest? *Agroforestry Systems, 91*, 185-199.

Rakotomanana, H., Gates, G. E., Hildebrand, D., & Stoecker, B. J. (2017). Determinants of stunning in children under 5 years in Madagascar. *Maternal and Child Nutrition, 13*(4), e12409.

Randriamiharisoa, L. O., Rakotondravony, D., Ranirison, A., Raherilalao, M. J., Wilmé, L., & Ganzhorn, J. (2015). Effects of transhumance trail on the richness and composition of bird communities in Tsimanampetsotse National Park. *Madagascar Conservation & Development, 10*(S3), 110-115.

Rasoma, J., & Goodman, S. M. (2007). Food habits of the Barn owl (*Tyto alba*) in spiny bush habitat of arid southwestern Madagascar. *Journal of Arid Environments, 69*, 537-543.

Ratovonamana, Y. R., Rajeriarison, C., Edmond, R., & Ganzhorn, J. U. (2011). Phenology of different vegetation types in Tsimanampetsotsa National Park, south-western Madagascar. *Malagasy Nature, 5*, 14-38.

Running, S., & Zhao, M. (2021). MODIS/Terra Net Primary Production Gap-Filled Yearly L4 Global 500 m SIN Grid V061.

Ruud, J. (1960). *Taboo*. Oslo: Oslo University Press.

Scott, D. M., Rakotondraparany, F., Brown, D., Mahood, S., Denton, B., & Silburn, A. (2006). The impact of forest clearance on lizard, small mammal and bird communities in the arid spiny forest Southern Domain, Madagascar. *Biodiversity and Conservation, 127*, 72-87.

Sinclair, I., & Langrand, O. (2013). *Birds of the Indian Ocean islands*. Cape Town: Struik Nature.

Soarimalala, V., & Goodman, S. M. (2011). *Les petits mammifères de Madagascar*. Antananarivo: Association Vahatra.

Steffens, K. J. E. (2020). Lemur food plants as options for forest restoration in Madagascar. *Restoration Ecology, 28*(6), 1517-1527.

Swindale, A., & Bilinsky, P. (2006). *Household Dietary Diversity Score (HDDS) for measurement of household food access: Indicator Guide (v.2).* . Washington, D.C.: Food and Nutrition Technical Assistance Project (FANTA).

Thompson, K. E., Borgerson, C., Wright, P. C., Randriamanetsy, J. M., Andrianantenaina, M. Y., Andriamavosoloarisoa, N. N. M., et al. (2023). A Coupled Humanitarian and Biodiversity Crisis in Western Madagascar. *International Journal of Primatology*, 1-28.

von Grebmer, K., Bernstein, J., Resnick, Wiemers, M., Reiner, L., Bachmeier, M., et al. (2022). *2022 Global Hunger Index: Food Systems Transformation and Local Governance*. Bonn, Dublin: Welthungerhilfe and Concern Worldwide.

von Heland, J., & Folke, C. (2014). A social contract with the ancestors—culture and ecosystem services in southern Madagascar. *Global Environmental Change, 24*, 251-264.

Waeber, P. O., Wilmé, L., Mercier, J.-R., Camara, C., & Lowry II, P. P. (2016). How effective have thirty years of internationally driven conservation and development efforts been in Madagascar? *PLoS ONE, 11(8)*, e0161115.

Wurz, A., Tscharntke, T., Martin, D. A., Osen, K., Rakotomalala, A. A. N. A., Raveloaritiana, E., et al. (2022). Win-win opportunities combining high yields with high multi-taxa biodiversity in tropical agroforestry. *Nature Communications, 13*(1), 4127.
Zinner, D., Wygoda, C., Razafimanantsoa, L., Rasoloarison, R., Andrianandrasana, H., Ganzhorn, J. U., et al. (2014). Analysis of deforestation patterns in the Central Menabe, Madagascar, between 1973 and 2010. *Regional Environmental Change, 14*, 157-166.