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Supplementary Information for

Land-use trajectories for sustainable land system transformations: identifying leverage points in a global biodiversity hotspot

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Supplementary Information Text

Sampled land-use types biodiversity and ecosystem functions. We sampled the seven predominant land-use types of north-eastern Madagascar. Large connecting *old-growth forest*, our historic baseline, once covered the study region but is now restricted to protected areas. *Forest fragments* result from fragmentation and degradation of old-growth forest and exist scattered throughout the region. *Forest-derived vanilla agroforests* are established inside forest fragments via thinning of understory shrubs and planting of vanilla (1). However, forests in the region are also cut and burned, thereby entering the shifting hill rice cultivation cycle. The system, referred to as 'tavy' in Malagasy, involves the use of fire directly before rice can be planted at the beginning of the rainy season and rice can be harvested at the end of the rainy season. When sampled for biodiversity and ecosystem functions 6-21 months after harvest, these *hill rice* fields had already turned into herbaceous fallows (Malagasy: 'Matrangy'). Thereafter, shrubs and small trees establish, resulting in *woody fallows* (Malagasy: 'Savoka'). The woody fallows sampled in our study had last burned 4-16 years prior to the onset of our data collection in September 2017. *Fallow-derived vanilla agroforests* are established on such woody fallows, thereby representing open-land-derived agroforests following Martin et al. 2020 (1). Lastly, we sampled irrigated *rice paddies* situated on riverbanks and in plains. This land-use type is usually not directly converted from or converted to one of the other studied land-use types and thus stands outside the trajectory.

Village and site selection biodiversity and ecosystem functions. We selected 10 villages based on several criteria (2) from a sample of 60 villages from a previous household survey (3). Additionally, we chose two old-growth forest sites within Marojejy National park. At each old-growth forest site, we chose 5 plots, leading to 10 replicates. At the village level, we established plots in a semi-blocked design, meaning that we chose one plot per land-use type (forest fragment, hill rice, woody fallow, rice paddy). It was, however, not possible to find suitable forest- and fallow-derived agroforests in each village - leading to one village without fallow-derived vanilla agroforest and three villages without forest-derived agroforest (see **Figure S1** for a schematic overview that shows which plots are represented in which village). Furthermore, fallow-derived vanilla was replicated 20 times, resulting in 80 plots (70 in villages and 10 old-growth forests) overall. These plots form the sampling design for all (endemic) biodiversity, above-ground carbon, soil pH, soil organic carbon, and predation rate. More information on the spatial arrangement of the land-use types is published in Martin et al. 2021 (2).

Ecosystem functions – Above-ground carbon. To calculate above-ground carbon stocks (Mg ha^{-1}) based on above-ground biomass values, we used the pantropical allometric model (4) with diameter at breast height, tree height, and wood density as input data. Therefore, we measured the diameter at breast height and height for each individual tree, following a standardized protocol (5). Additionally, we derived wood density data for all trees, using either a Pilodyn wood tester, or retrieved wood density values from the global wood density database (6). For palms, tree ferns, bananas (*Musa sp.*), and traveller palms (*Ravenala madagascariensis*) we used different allometric equations to estimate above-ground plant biomass, based on literature. We obtained above-ground carbon stocks by multiplying the estimated above-ground plant biomass by 0.5, based on the assumption that plant biomass consists of 50% carbon (7).

Ecosystem functions – Soil organic carbon. To measure soil organic carbon concentrations, we took two mixed soil samples per plot using a soil corer (5 cm diameter, 0-15 cm depth, 295 ml volume). Each mixed sample stemmed from four soil cores taken from four locations. In the laboratory, we dried the soil samples at 70 °C for 48 hours and grounded them to acquire soil organic carbon values of all 160 mixed samples. We then assessed the total organic carbon (C) concentrations (millimole gram dry soil^{-1}) using a C/N elemental analyzer (Vario EL III, Elementar, Hanau, Germany) and calculated the mean of the two mixed samples per plot. Lab methods followed Hertel 2011 (8).

Agricultural productivity. We collected data through a longitudinal survey from October 2017 to October 2018, field measurements of plot sizes, and a recall survey between October 2018 and March 2019. We used data of 109 households located in 10 study villages. These villages are situated in the same region as the 10 villages where we collected plot data, and both sets of 10 villages are a subset of the 60 villages included in Hänke et al. 2018 (3), but only one village is included in both samples. The longitudinal survey used pictogram sheets to facilitate bi-weekly data reporting by household heads for over one year. We further considered one person-day to be equivalent to eight working hours and converted working hours into adult male equivalents (9) This provided information on total family labor as well as expenses and revenues of vanilla and rice farming. We measured the size of each plot of vanilla, paddy rice, and hill rice farmed by the 109 households *in-situ* using a GPS device. During plot visits, we also obtained data on the plot's land-use history. Moreover, we conducted a cross-sectional survey to obtain additional information on farming inputs and outputs.

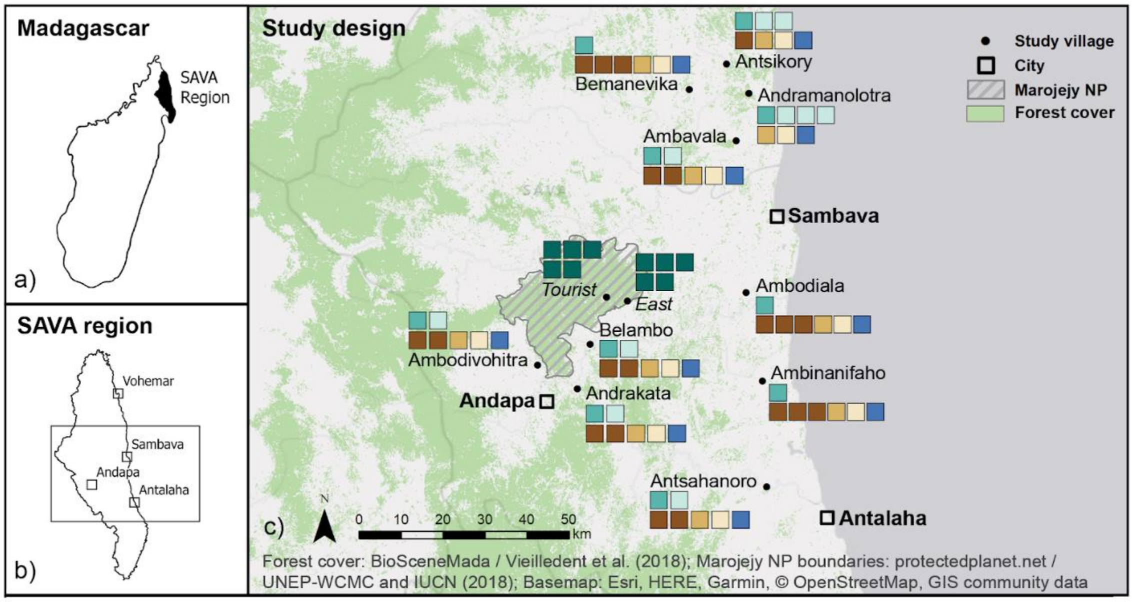

Figure S1. Study design overview. a) The island of Madagascar off East Africa with the SAVA region. **b)** SAVA region with its four main cities and the study area. **c)** Study area with 2017 forest cover (16), roads, rivers and the three major cities Sambava, Antalaha, and Andapa, as well as the 10 study villages and Marojejy National Park where we collected data on biodiversity and ecosystem functions. The colored squares depict the semi-blocked study design with replicated land-use types across 10 villages and two old-growth forest sites. Each square represents one plot, a legend for the colors can be found in **Figure S2**. The 10 villages where we collected data on yields and profits are not displayed.

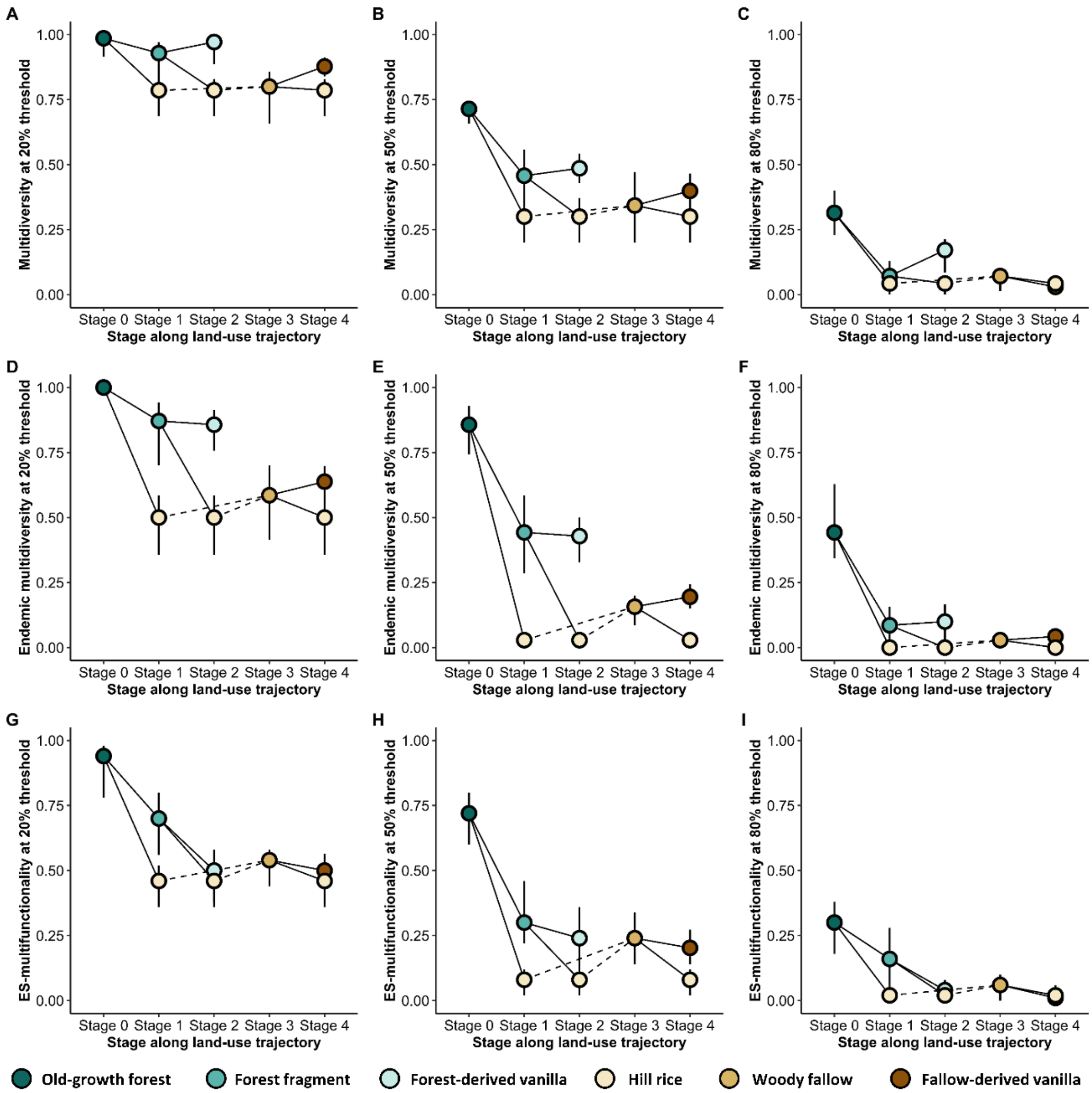

Figure S2. Multidiversity, endemic multidiversity and multifunctionality at stages along a land-use trajectory in north-eastern Madagascar at the 20%, 50% and 80% thresholds. Differences in multidiversity **(A, B & C)** between stages along the land-use trajectory are strongest at the 50% threshold. The leverage point with the strongest potential for biodiversity conservation, i.e., most taxa failing to pass the threshold after conversion, is leverage point 1 (old-growth forest). Differences in endemic multidiversity **(D, E & F)** between land-use types along the land-use trajectory are strongest at the 20% threshold. The leverage point with the strongest potential, i.e., most taxa failing to pass the threshold after conversion, is leverage point 1 (old-growth forest). Multifunctionality **(G, H & I)** shows less pronounced differences between land-use types at the 20% and 80% threshold but is most different at the 50% threshold. Points colored according to the land-use type represent the mean value for each land-use type while error bars are 95% confidence intervals.

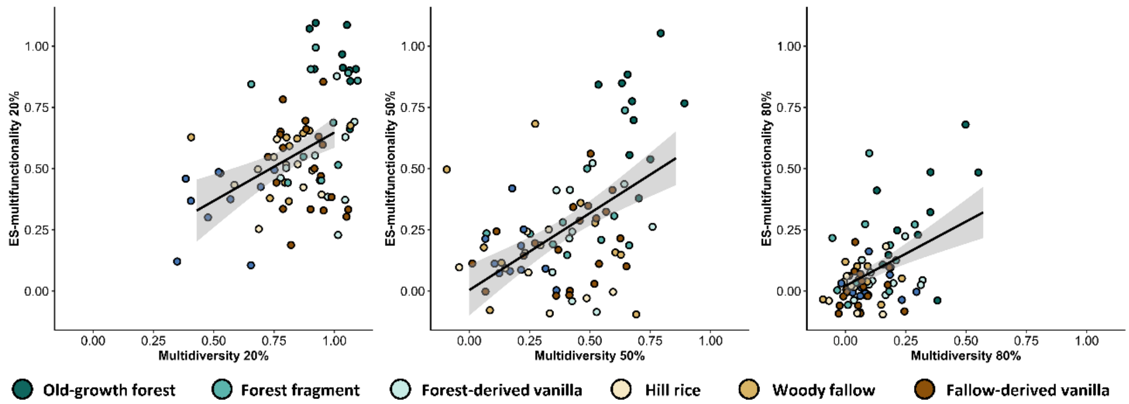

Figure S3. Correlation between multidiversity and multifunctionality at the 20%, 50% and 80% thresholds. Each point represents one plot and lines show the correlation between the two variables. Ribbons represent 95% confidence intervals. Note that the plot employs jittering to avoid overplotting. Spearman correlation coefficients are 0.41, 0.53, and 0.48 for the 20%, 50%, and 80% threshold, respectively.

Table S1. Sources of endemism status across all seven taxa covered

Taxa	**Source**	**Reference**
Trees	Catalogue of the Plants of Madagascar	Missouri Botanical Garden, 2019 (10)
Herbaceous plants	Catalogue of the Plants of Madagascar	Missouri Botanical Garden, 2019 (10)
Birds	BirdLife Species Factsheets	BirdLife, 2018 (11)
Amphibians	Amphibiaweb	Amphibia Web Database, 2020 (12)
Reptiles	Reptile Database	Uetz & Hošek, 2020 (13)
Butterflies	Classification, diversity, and endemism of the butterflies *(Papilionoidea* and *Hesperioidea)*: a revised species checklist; including two updates: *Acraea serena* updated to 'non endemic' based on (15) and *Caropsilia thauruma* updated to 'non endemic' based on (16). Additionally, three species of the *Heteropsis* genus that are not listed in Lees et al., 2003 (14) were classified as endemic since the whole *Heteropsis* genus is endemic to Madgascar (14).	Lees et al., 2003 (14)
Ants	AntWeb Database	Antweb Database (17)

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