Supplementary materials

S.1. Calculation of socioeconomic indicators

The farm household survey data used were collected as part of an interdisciplinary project, the EFForTs (Drescher et al., 2016). To ensure geographical coverage of areas affected by oil palm cultivation in Jambi Province, a multistage random sampling approach was employed to select farm households. It encompassed five lowland regencies: Batanghari, Bungo, Muaro Jambi, Sarolangun, and Tebo. In these regencies, 40 villages were randomly chosen, with an additional five villages included for collaborative studies with other subprojects (Drescher et al., 2016). A total of 701 farm households were selected and interviewed in 2018 (Sibhatu, 2019). However, during the data-processing phase, a few data points were removed because of missing values for important variables, resulting in the exclusion of certain observations. Additionally, only productive plots are included in the analysis. To ensure data accuracy, extreme outliers (values exceeding three times the standard deviation) were trimmed to prevent overestimation. A total of 587 households and 824 plots were used in the final analyses.

Material costs were calculated by multiplying applied quantities (unit $plot^{-1}$ yr^{-1}) of herbicides, fertilizers, and pesticides per plot and year by their respective average output costs per unit (000 Indonesian Rupiah (IDR) $unit^{-1}$). Waged labor costs were determined by multiplying the number of working days required per plot and year (days $plot^{-1}$ $year^{-1}$) by the daily wage rate (000 IDR day^{-1}). Family labor costs were computed by multiplying the average number of hours worked by family members per plot and year (hours $plot^{-1}$ yr^{-1}) by the average wage of agricultural workers (000 IDR $hour^{-1}$), sourced from Statistics Indonesia (https://www.bps.go.id/). For this calculation, an average workday of eight hours was assumed, acknowledging that family labor sometimes involved only a few minutes or hours on specific days. By calculating family labor costs on an hourly basis, overestimation of labor costs arising from shorter work durations was avoided.

The revenue was calculated by multiplying yield harvested per plot (kg $plot^{-1}$) by the average market price (000 IDR kg^{-1}). Profit was subsequently calculated by subtracting material and labor costs from revenue. To ensure comparability, material costs, labor costs, and revenues per plot were standardized for one hectare by dividing the respective values by the plot size. This allowed for consistent analysis across different plot sizes. Profits per hectare (000 IDR ha^{-1}) and profits per invested IDR for labor were computed. The profit per hectare was obtained by deducting the cost of materials and labor from the revenue, whereas the profit per invested IDR was derived by dividing the profit by the labor cost.

The profits were calculated for three land-use types: rubber plantations, palm oil plantations, and jungle rubber. Although jungle rubber was not explicitly recorded in household surveys, it was a significant land-use type in the Jambi Province. To address this, jungle rubber plots were derived from rubber plots using the following definition: rubber plots with less than 400 trees per hectare and no herbicide costs were considered as jungle rubber plots, aligning with the approach employed by Grass et al. (2020). The dataset consisted of 135 jungle rubber plots, 391 rubber plantation plots, and 298 oil palm plantation plots, which formed the basis for calculating the mean values and standard deviations of the five socioeconomic parameters listed in Table 2. All values were converted from Indonesian Rupiah (IDR) to US dollars (USD) using the average exchange rate of 1 USD = 14236.939 IDR in 2018 (OECD, 2023), the year when the Household Survey was conducted.

S.2. Sensitivity analysis

Table S1: Recorded mean values and standard deviation for selected indicators and three land-use types (jungle rubber, oil palm plantation, and rubber plantation) used for the sensitivity analysis. The first eight indicators were used to replace indicators of already existing ecological functions. The last three were used to add another ecological function to the five already used. The superscript letters indicate whether having more or less of an indicator is better. [a] = more is better, [b] = less is better. N = number of plots for measurement.

Indicator	Unit	N	Jungle Rubber	Oil palm plantation	Rubber plantation
Effective Number of Layer (ENL)[a]	-	8	13.10 ± 1.53	7.86 ± 0.64	11.68 ± 0.97
Soil Organic Carbon 0.5-2m[a]	Mg C ha^{-1}	8	115.37 ± 45.88	96.27 ± 29.06	120.95 ± 41.60
Humidity[b]	%	8	93.12 ± 1.44	91.07 ± 1.14	90.15 ± 1.60
Soil Moisture Range[b]	%vol	8	7.60 ± 3.20	5.50 ± 1.40	7.10 ± 3.30
Soil Temp. Range[b]	°C	8	1.20 ± 0.50	1.70 ± 0.60	1.60 ± 0.40
Al[b]	kg ha^{-1} yr^{-1}	8	2.73 ± 1.62	12.95 ± 18.49	3.74 ± 0.97
Ca[b]	kg ha^{-1} yr^{-1}	8	10.32 ± 4.62	28.26 ± 24.80	8.89 ± 1.78
Mg[b]	kg ha^{-1} yr^{-1}	8	3.84 ± 1.78	7.23 ± 3.24	3.80 ± 1.42
Litter Mass Loss[a]	Biomass loss after 6 months (%)	8	27.27 ± 14.89	10.60 ± 5.67	13.51 ± 6.45
N Mineralization[a]	mg N kg^{-1} d^{-1}	8	7.68 ± 4.36	6.77 ± 4.08	6.11± 1.26
Methane (CH_4) [b]	kg C ha^{-1} yr^{-1}	8	-2.14 ± 0.94	-0.95 ± 0.70	-0.61 ± 0.59

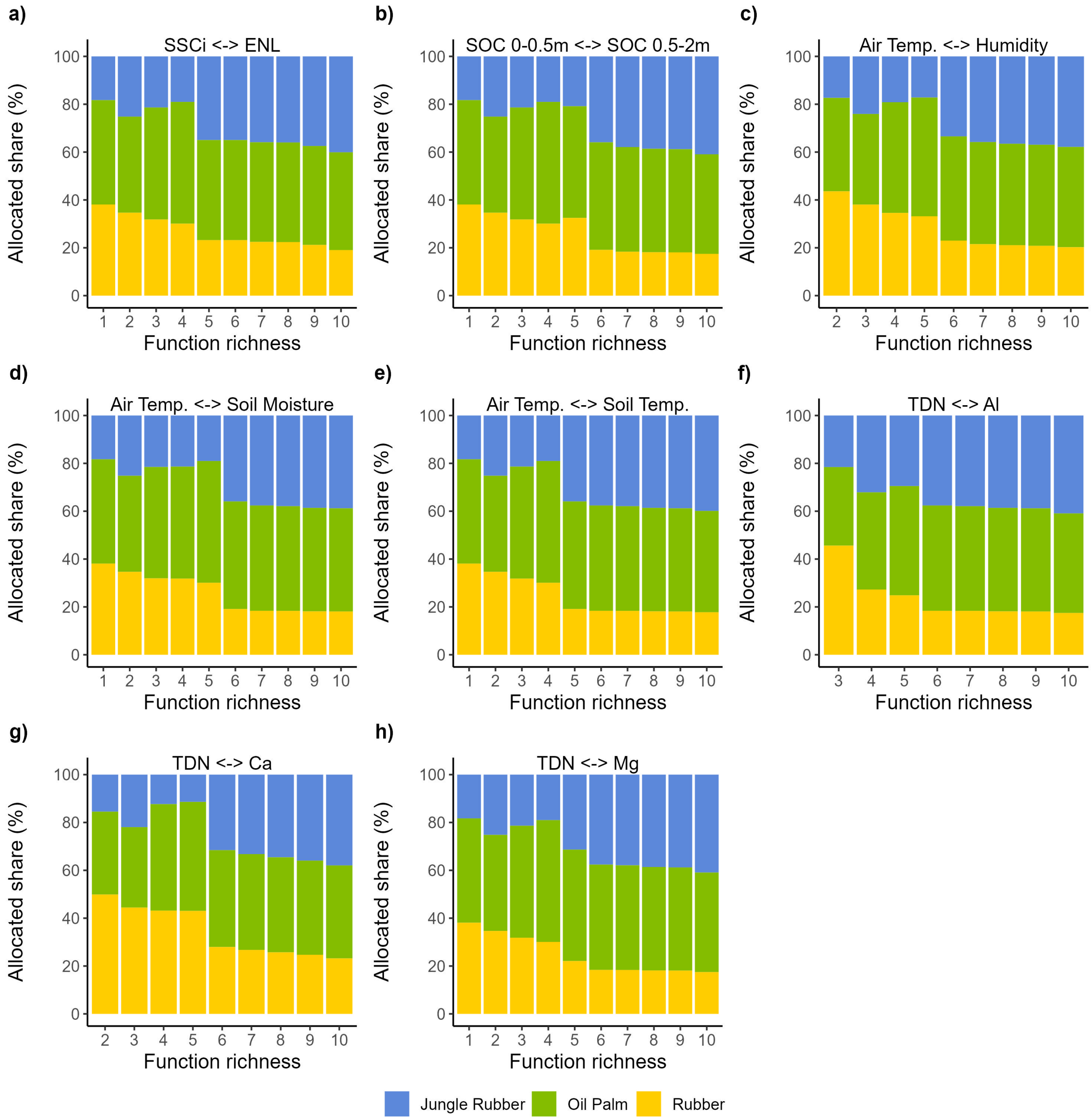

Figure S1: The impact of exchanging indicators for different ecological functions on the optimized land-use composition for different function richness. Optimized portfolios start with the portfolio most closely explaining the currently observed land-use portfolio (function richness 1) and end with the portfolio optimizing all indicators simultaneously (function richness 10). For the intermediate ones, one more indicator is added to the previous portfolio, where the identity of the added indicator is selected according to the lowest BC when compared with the observed land-use portfolio. a) ENL instead of SSCi, b) Soil Organic Carbon 0.5-2m instead of Soil Organic Carbon 0-0.5m, c-e) Humidity/Soil Moisture Range/Soil Temp. Range instead of Air Temperature 95th percentile, f-i) Al/Ca/Mg instead of TDN.

Table S2

The explicit indicator sets and order leading to the respective portfolios shown in Fig. S1, where the indicators for the five ecological functions shown in Table 1 are exchanged. The indicators are added cumulatively; for example, portfolio 5 for plot a) includes Profit, Revenue, Labor Cost, Profit per Labor Cost, and ENL simultaneously in the optimization. Each of these indicators is equally weighted in the optimization. All portfolios were calculated for an uncertainty factor of two.

Function richness	Plot a)	Plot b)	Plot c)	Plot d)	Plot e)	Plot f)	Plot g)	Plot h)
1	Profit	Profit		Profit	Profit			Profit
2	+Revenue	+Revenue	Profit, Humidity	+Revenue	+Revenue		Ca, Profit	+Revenue
3	+Labor Cost	+Labor Cost	+Revenue	+Soil Moisture Range	+Labor Cost	Al, Profit, Revenue	+Revenue	+Labor Cost
4	+Profit per Labor Cost	+Profit per Labor Cost	+Labor Cost	+Labor Cost	+Profit per Labor Cost	+Labor Cost	+Labor Cost	+Profit per Labor Cost
5	+ENL	+SOC 0.5-2m	+Profit per Labor Cost	+Profit per Labor Cost	+TDN	+Profit per Labor Cost	+Profit per Labor Cost	+Mg
6	+TDN	+TDN	+TDN	+TDN	+SOC 0-0.5m	+SOC 0-0.5m	+SSC	+SOC 0-0.5m
7	+Material Cost	+SSC	+SSC	+SOC 0-0.5m	+SSC	+SSC	+Material Cost	+SSC
8	+SOC 0-0.5m	+Material Cost	+SOC 0-0.5m	+SSC	+Material Cost	+Material Cost	+SOC 0-0.5m	+Material Cost
9	+Carbon Total Biomass	+Carbon Total Biomass	+Material Cost	+Material Cost	+Carbon Total Biomass	+Carbon Total Biomass	+Carbon Total Biomass	+Carbon Total Biomass
10	+Air Temp. 95th percentile	+Air Temp. 95th percentile	+Carbon Total Biomass	+Carbon Total Biomass	+Soil Temp. range	+Air Temp. 95th percentile	+Air Temp. 95th percentile	+Air Temp. 95th percentile

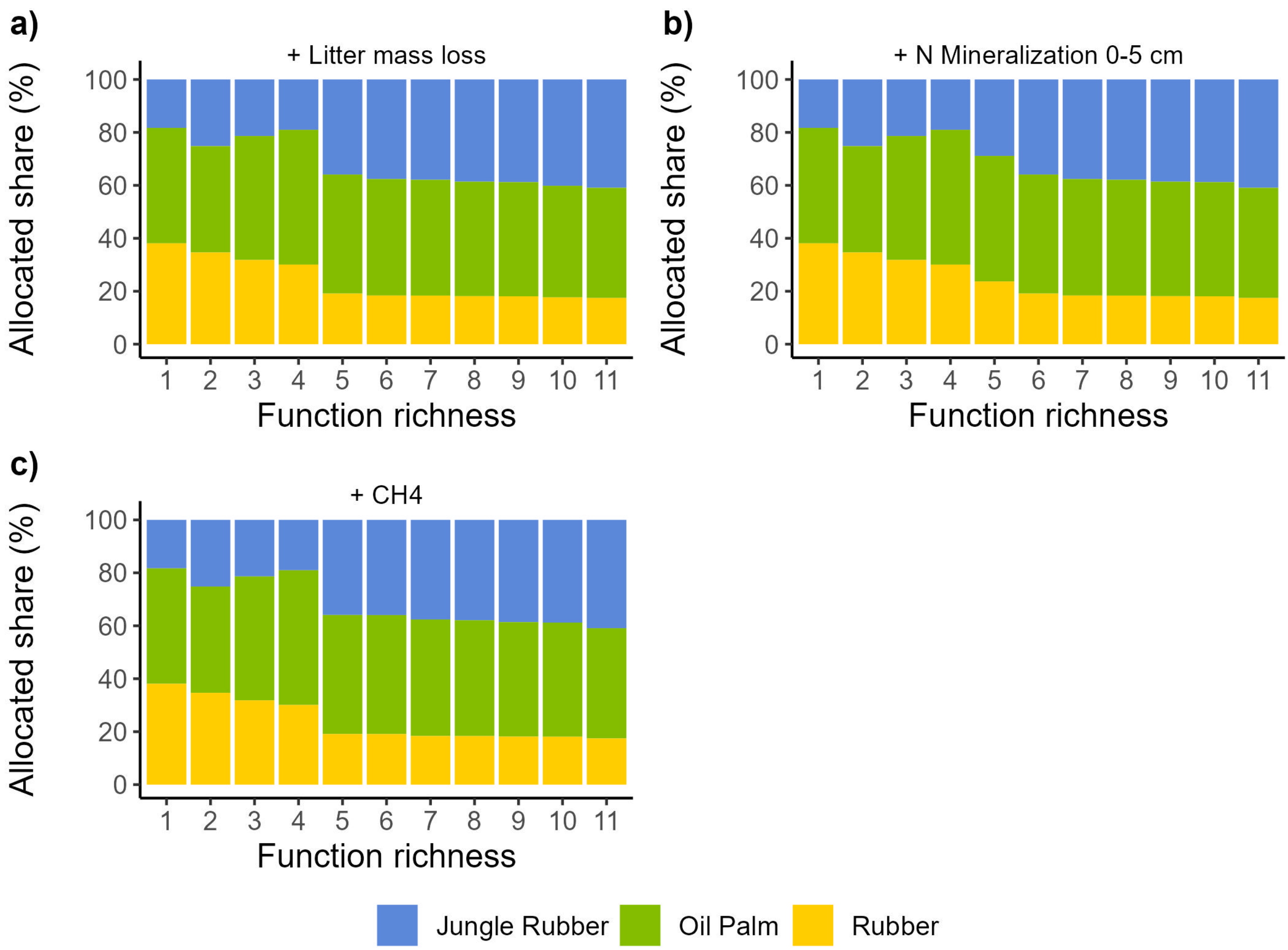

Figure S2: The impact of adding indicators of additional ecological functions on the optimized land-use composition for different function richness. Optimized portfolios start with the portfolio most closely explaining the currently observed land-use portfolio (function richness 1) and end with the portfolio optimizing all indicators simultaneously (function richness 10). For the intermediate ones, one more indicator is added to the previous portfolio, where the identity of the added indicator is selected according to the lowest BC when compared with the observed land-use portfolio. a) Adding indicator Litter Mass Loss (Organic Matter Decomposition), b) adding N Mineralization 0-5 cm (Soil Fertility), c) adding CH4 (Gas fluxes).

Table S3

The explicit indicator sets and order leading to the respective portfolios shown in Fig. S2, where the one indicator of a new ecological function is added to indicators shown in Table 1. The indicators are added cumulative; for example, portfolio 5 for plot a) includes Profit, Revenue, Labor Cost, Profit per Labor Cost, and TDN simultaneously in the optimization. Each of these indicators is equally weighted in the optimization. All portfolios were calculated for an uncertainty factor of two.

Portfolio	Plot a)	Plot b)	Plot c)
1	Profit	Profit	Profit
2	+Revenue	+Revenue	+Revenue
3	+Labor Cost	+Labor Cost	+Labor Cost
4	+Profit per Labor Cost	+Profit per Labor Cost	+Profit per Labor Cost
5	+TDN	+N Mineralization 0-5 cm	+TDN
6	+SOC 0-0.5m	+TDN	+CH4
7	+SSC	+SOC 0-0.5m	+SOC 0-0.5m
8	+Material Cost	+SSC	+SSC
9	+Carbon Total Biomass	+Material Cost	+Material Cost
10	+Litter Mass Loss	+Carbon Total Biomass	+Carbon Total Biomass
11	+Air Temp. 95th percentile	+Air Temp. 95th percentile	+Air Temp. 95th percentile

Table S4

Recorded mean values and standard deviation for selected indicators including primary degraded forest. The superscript letters indicate whether having more or less of an indicator is better. [a] = more is better, [b] = less is better. N = number of measured plots (for ecological indicators) and number of surveyed households (for socioeconomic indicators).

Indicator	Unit	N	Forest	Jungle Rubber	Oil palm plantation	Rubber plantation
SSCi[a]	index	8	6.81 ± 1.14	6.85 ± 0.81	3.50 ± 0.48	4.77 ± 1.14
Air Temperature [b]	95th percentile	8	28.3 ± 0.4	30.20 ± 0.50	31.10 ± 0.11	31.20 ± 0.18
Carbon Total Biomass[a]	Mg C ha^{-1}	8	194.92 ± 35.20	76.12 ± 9.24	43.09 ± 8.21	38.35 ± 11.46
Soil Organic Carbon[a]	Mg C ha^{-1}	8	78.05 ± 26.82	106.47 ± 36.54	80.57 ± 25.84	75.32 ± 29.09
Total Dissolved Nitrogen[b]	kg ha^{-1} yr^{-1}	8	4.70 ± 2.03	5.35 ± 4.97	12.63 ± 12.78	4.63 ± 2.85
Labor Cost[b]	USD ha^{-1} yr^{-1}	824	0 ± 0	500.43 ± 373.06	179.51 ± 151.27	665.40 ± 470.48
Material Cost[b]	USD ha^{-1} yr^{-1}	824	0 ± 0	13.87 ± 15.27	118.29 ± 123.19	29.13 ± 28.07
Revenue[a]	USD ha^{-1} yr^{-1}	824	0 ± 0	707.22 ± 447.09	949.68 ± 628.15	1107.39 ± 715.55
Profit[a]	USD ha^{-1} yr^{-1}	824	0 ± 0	186.80 ± 425.03	634.22 ± 556.88	394.70 ± 728.25
Profit per Labor Cost[a]	USD	824	0 ± 0	0.80 ± 1.11	9.28 ± 18.87	1.31 ± 2.32

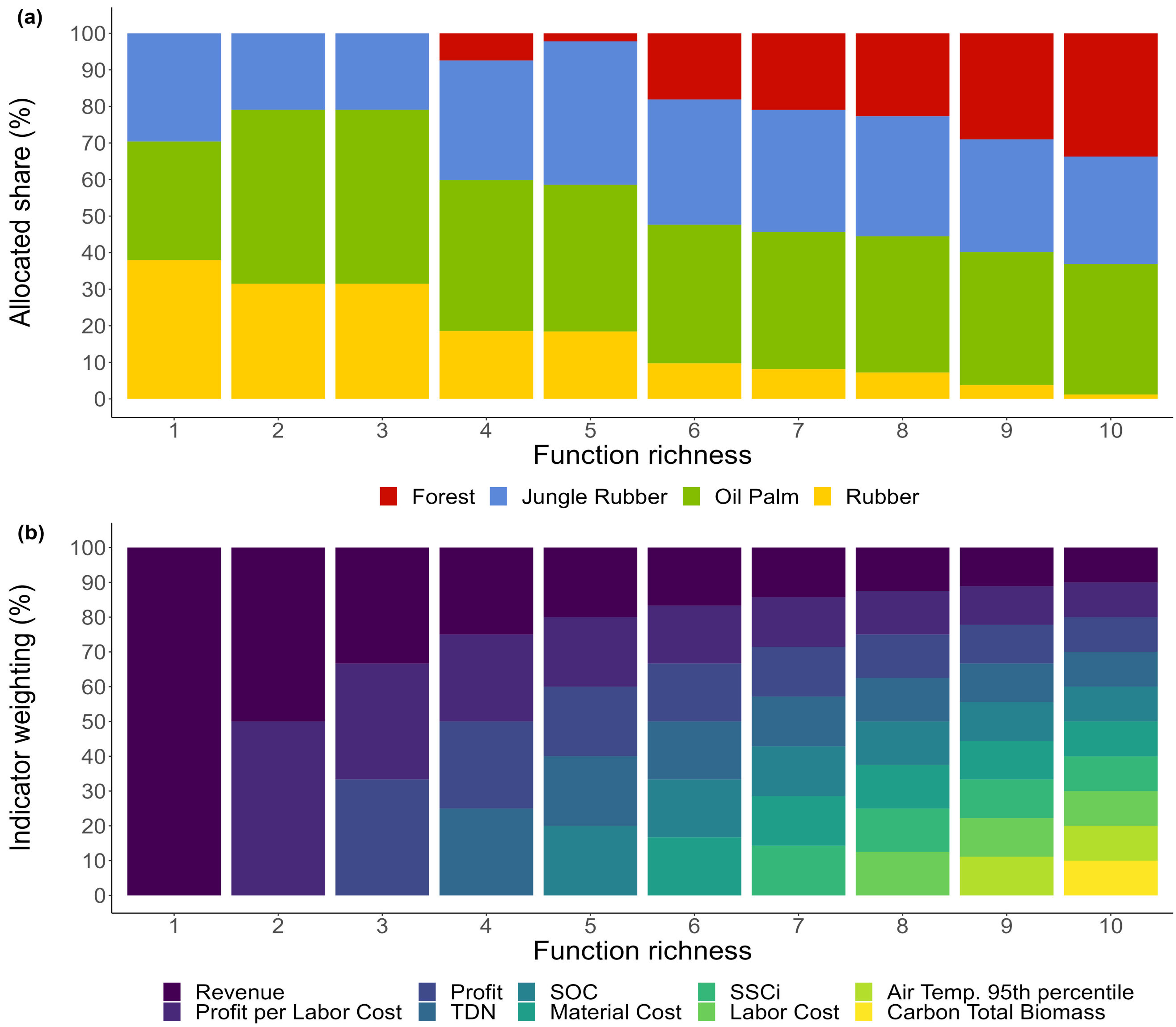

Figure S3: a) Effect of increasing function richness on the optimized land-cover portfolio, including primary degraded forest as an additional land-cover type. Optimized portfolios start with the portfolio most closely explaining the currently observed land-use portfolio (function richness 1) and end with the portfolio optimizing all indicators simultaneously (function richness 10). For the intermediate ones, one more indicator is added to the previous portfolio to increase the function richness, where the identity of the added indicator is selected according to the lowest BC when compared with the observed land-use portfolio. b) The explicit indicator sets leading to the respective portfolios shown in a). Each of these indicators is equally weighted in the optimization. All portfolios were calculated for an uncertainty factor of two.

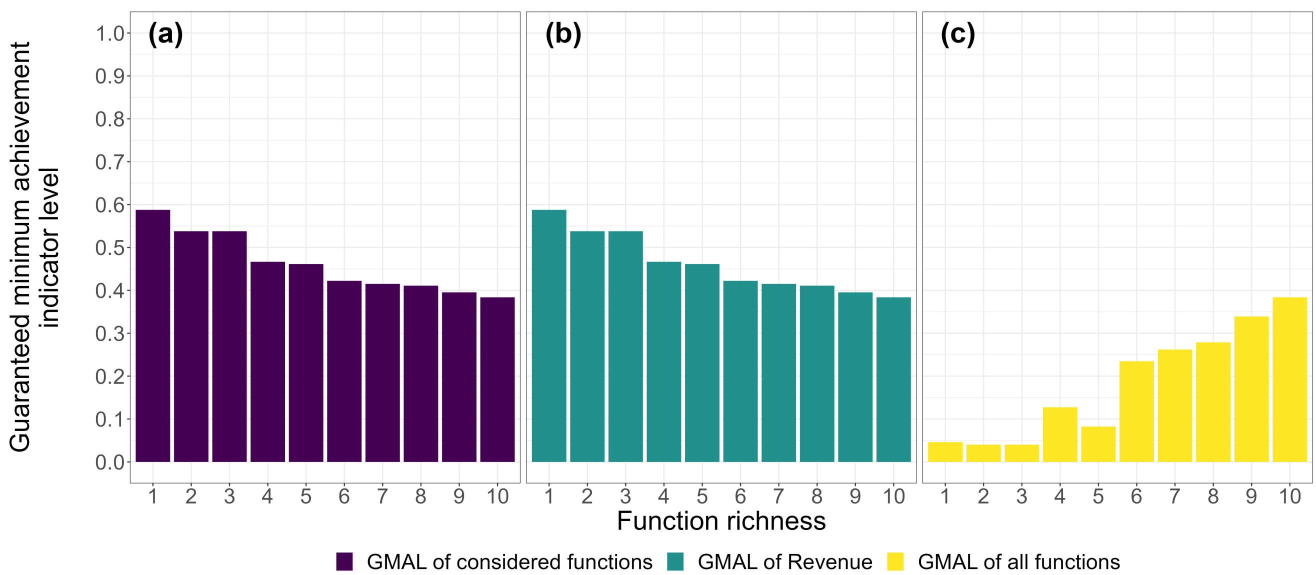

Figure S4: The guaranteed minimum achievement indicator level (GMAL) from three perspectives, including primary degraded forest as an additional land-cover type. a) shows the GMAL for each indicator set used to optimize the portfolios with increasing function richness (robust performance of considered functions)(Fig. S3). b) shows the GMAL of solely the indicator Revenue (robust performance of currently important function). The minimum achievement level of a function richness of 1 is thus equal in a) and b). c) shows the GMAL over all ten indicators for each portfolio with increasing function richness (robust multifunctionality). The GMAL of function richness 10 is thus equal in a) and c).

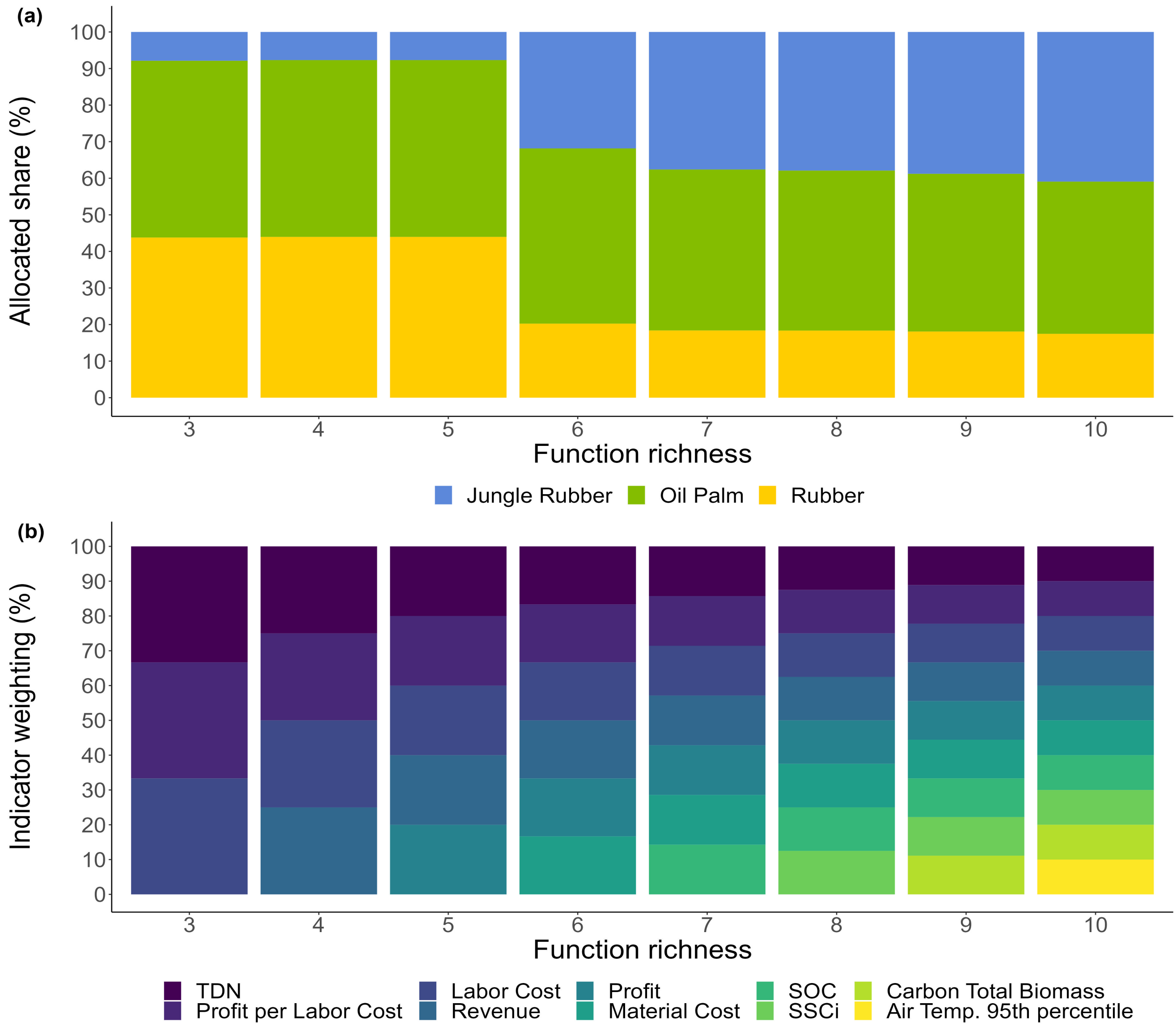

Figure S5: a) Effect of increasing function richness on the optimized land-use portfolio. All portfolios were calculated for an uncertainty factor of zero. Optimized portfolios start with the portfolio most closely explaining the currently observed land-use portfolio (function richness 1) and end with the portfolio optimizing all indicators simultaneously (function richness 10). For the intermediate ones, one more indicator is added to the previous portfolio to increase function richness, where the identity of the added indicator is selected according to the lowest BC when compared with the observed land-use portfolio. b) The explicit indicator sets leading to the respective portfolios shown in a). Each of these indicators is equally weighted in the optimization.

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