Supplementary material

Assessing ecosystem services in rubber dominated landscapes in South-East Asia – a challenge for biophysical modeling and transdisciplinary valuation

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1. Land use change scenarios

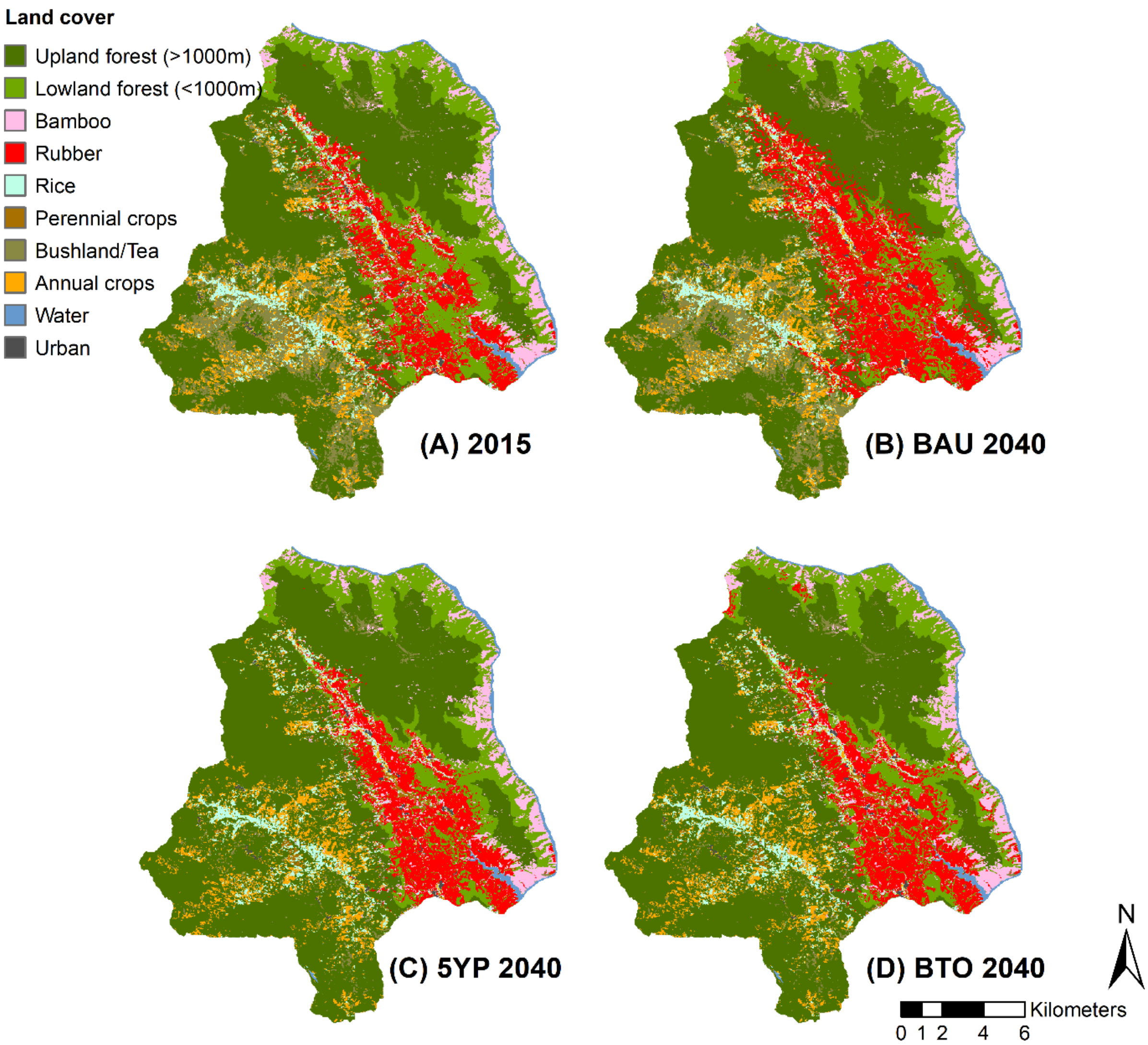

Figure S1. Land cover maps of the NRWNNR (Naban River Watershed National Nature Reserve) of the initial state of 2015 (A) and the final year (2040) of each scenario: Business-as-usual (B), 5-years-plan (C) and Balanced-trade-offs (D).

2. Model parameterization

For detailed descriptions on the manner of functioning for each of the four InVEST model applications used in this study, the reader is referred to the InVEST user guide (http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/). The following chapters provide a list of input parameters and spatial data we used to run the models.

a. InVEST Sediment Retention model

Table S1. Input values for the InVEST sediment retention model for the C- and P-factors of the USLE equation for every land cover category. On the basis of [1] (Sheikh, Palria et al. 2011), values for P are assigned in relation to the slope of the landscape and management measure (no measures, terracing, contouring, strip cropping) on a pixel basis. Elevation data for calculating the slope with ArcGIS (Version 10.3.1) is derived from ASTER Digital Elevation Model Data ("astergtm2_n22e100_dem" (ASTER GDEM is a product of METI and NASA)).

Name	USLE C	Source C	USLE P measures
Upland forest	0.001	[2]	no measures
Lowland forest	0.001	[2]	no measures
Bamboo	0.04	[3]	no measures
Rubber	0.029 (C*P)	[4], 2 herbicide applications per year	terracing
Rice	0.18	[5]	terracing
Perennial crops	0.13	[6]	strip cropping
Bushland/Tea	0.18	From [7] (Primary sources: [8,9])	contouring
Annual crops	0.31	From [7] (Primary sources: [8,9])	strip cropping
Water	0	From [7] (Primary sources: [8,9])	no measures
Urban	0.2	From [7] (Primary sources: [8,9])	no measures

Table S2. Additional parameterization (spatial data and calibration parameters) for the InVEST sediment retention model.

Input	Range	Source of input data	Source of calculation procedure
Rainfall Erosivity R	2911 – 4492 $[MJ*mm*(ha*hr)^{-1}]$	Annual average precipitation (see below)	[10]
Annual average precipitation	1233 – 1631 [mm]	[11] (Resolution ~900*900m)	
Soil Erodability K	0 – 0.035 $[t*ha*hr*(MJ*ha*mm)^{-1}]$	[12] (Resolution ~900*900m)	[4,13]
LS Factor	0.02 – 4579	InVEST internal calculation based on ASTER DEM (mean LS factor=40.7, some few values are extreme outliers), which are capped at 333 according to the InVEST user manual. (Resolution = 30*30m)	[14]
Borselli k	1.096	Calibration parameter	[15]
SDR max	0.8	InVEST default setting	[16]
IC0	0.5	InVEST default setting	[16]
Threshold Flow Accumulation	500	Calibrated to fit the hydrological network in NRWNNR	

b. InVEST water yield

Table S3. Kc coefficients and rooting depth of every land cover category for the InVEST water yield model listed with their sources.

Land use	Kc coefficient	Kc source	Rooting depth [mm]	Rooting depth source
Upland forest (>1000m)	1	[17]	7000	[17]
Lowland forest (<1000m)t	1	[17]	7000	[17]
Bamboo	1.1	[18]	4000	[19]
Rubber	1.1	Own measurements	5000	Own measurements
Rice	1.2	Own measurements	300	Own measurements
Perennial crops	1.2	[20]	400	[21]
Bushland/Tea	1	[20]	3500	[22]
Annual crops	0.65	Own measurements	2100	[23]
Water	1.05	[20]	0	Not applicable
Urban	0.3	[17]	200	[17]

Table S4. Additional input parameters for the InVEST water yield model.

Input	Range	Source of input data	Source of calculation procedure
Annual average precipitation	1233 – 1631 [mm]	[11] (Resolution ~900*900m)	[11]
Annual potential evapotranspiration	1209 – 1610 [mm]	[24] (Resolution ~900*900m)	Direct implementation
Plant available water content (PAWC)	0.115 – 0.138	[12] (Resolution ~900*900m)	Direct implementation
Root restricting layer depth	920.2 – 1130 [mm]	[12] (Resolution ~900*900m)	Direct implementation
Zhang constant Z	23		[25]

c. InVEST carbon storage model

Table S5. Input values for the carbon storage model for each carbon pool and every land use category in Nabanhe Reserve.

Land use	Above ground C [Mg C/ha]	Below ground C [Mg C/ha]	Soil organic C [Mg C/ha]	Dead matter C [Mg C/ha]	Source
Upland forest (<800m)	145	29	82	5	[26]
Lowland forest (>800m)	189	41	79	6	[26]
Bamboo	42	4	72	4	[26]
Highland rubber (<800m)	24	5	62	1.76	[26]
Lowland rubber (>800m)	58	10	56	2.11	[26]
Rice	5	1	39	1	[26]
Perennial crops	15	3	56	1	[26]
Bushland/Tea	6	10	73	0.5	[26]
Annual crops	6	1.67	50	0.5	[26]
Urban	2	1	50	0	[17]
Water	0	0	0	0	[17]

d. InVEST habitat quality model

Table S6. Habitat quality threats for the BAU, the 5YP and the BTO scenario in parenthesis (where applicable). All values are based on Cotter et al. (2017) [27]. Threats are assigned weights concerning their severity in relation to the strongest threat (Urban areas with a value of 1). The weight of all threats decays in an exponential manner until the maximum distance is reached.

Threat	Maximum distance [km]	Weight	Decay
Rubber	0.1	0.27 (0.135)	exponential
Agriculture	0.1	0.3	exponential
Urban	1	1	exponential
Roads	0.1	0.5	exponential

Table S7. Overall habitat scores (vertebrates, invertebrates, flora) and the sensitivity of each land cover category to each threat. All values are based on Cotter et al. (2017) [27].

Land use	Habitat score	Rubber	Agriculture	Urban	Roads
Upland forest (>1000m)	1	0.7	0.6	1	0.8
Lowland forest (<1000m)	1	0.7	0.6	1	0.8
Bamboo	1	0.7	0.6	1	0.8
Rubber	0.57	0	0.1	0.87	0.63
Rice	0.26	0	0.07	0.47	0.33
Perennial crops	0.32	0.13	0.07	0.2	0.2
Bushland/Tea	0.33	0.12	0.17	0.39	0.29
Annual crops	0.33	0.1	0	0.5	0.33
Water	0.73	0.82	0.82	0.97	0.75
Urban	0.1	0	0	0	0

e. ArcGIS rubber yield model

Table S8. Rubber yield estimations based on survey data in Xishuangbanna [28]. Spatially explicit land use data is derived from Beckschäfer (2017) concerning plantation age [29]. Altitude data is derived from ASTER Digital Elevation Model Data (“astergtm2_n22e100_dem” (ASTER GDEM is a product of METI and NASA)). Yields are listed from the first year of plantations being tapped, since plantations have different lengths of establishment phases, depending on elevation. Pixel size is 30x30 m.

	Potential rubber yield [kg/(year*pixel)]		
Elevation	1-5 years	6-10 years	> 10 years
< 800m	124.12	158.20	158.20
800-1000m	124.12	129.55	151.30
> 1000m	58.50	58.50	58.50

3. Additional results

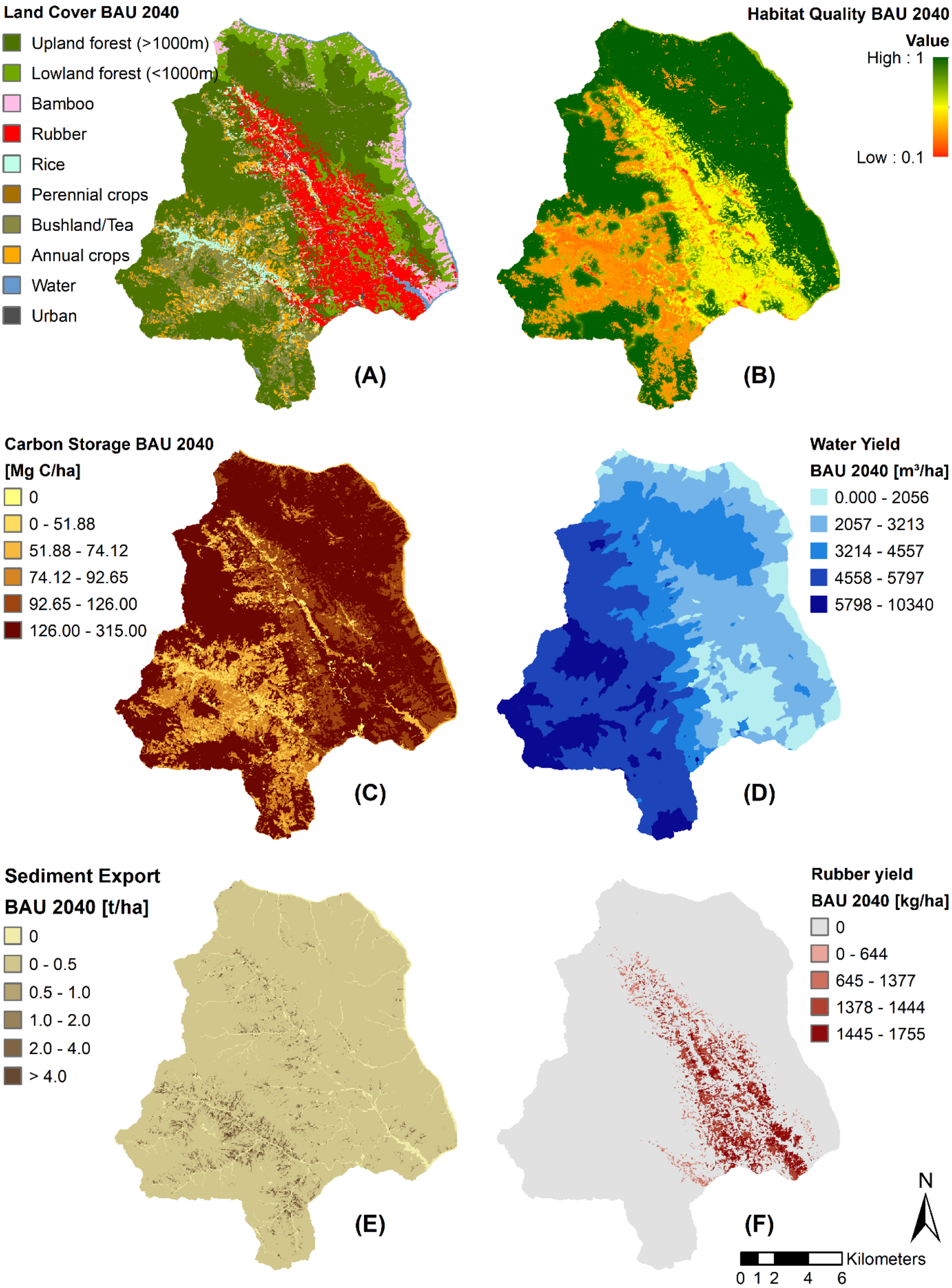

Figure S2. Ecosystem service results at the last year (2040) of the BAU scenario (A) including habitat quality (B), carbon storage (C), water yield (D), sediment export (E) and rubber yield (F).

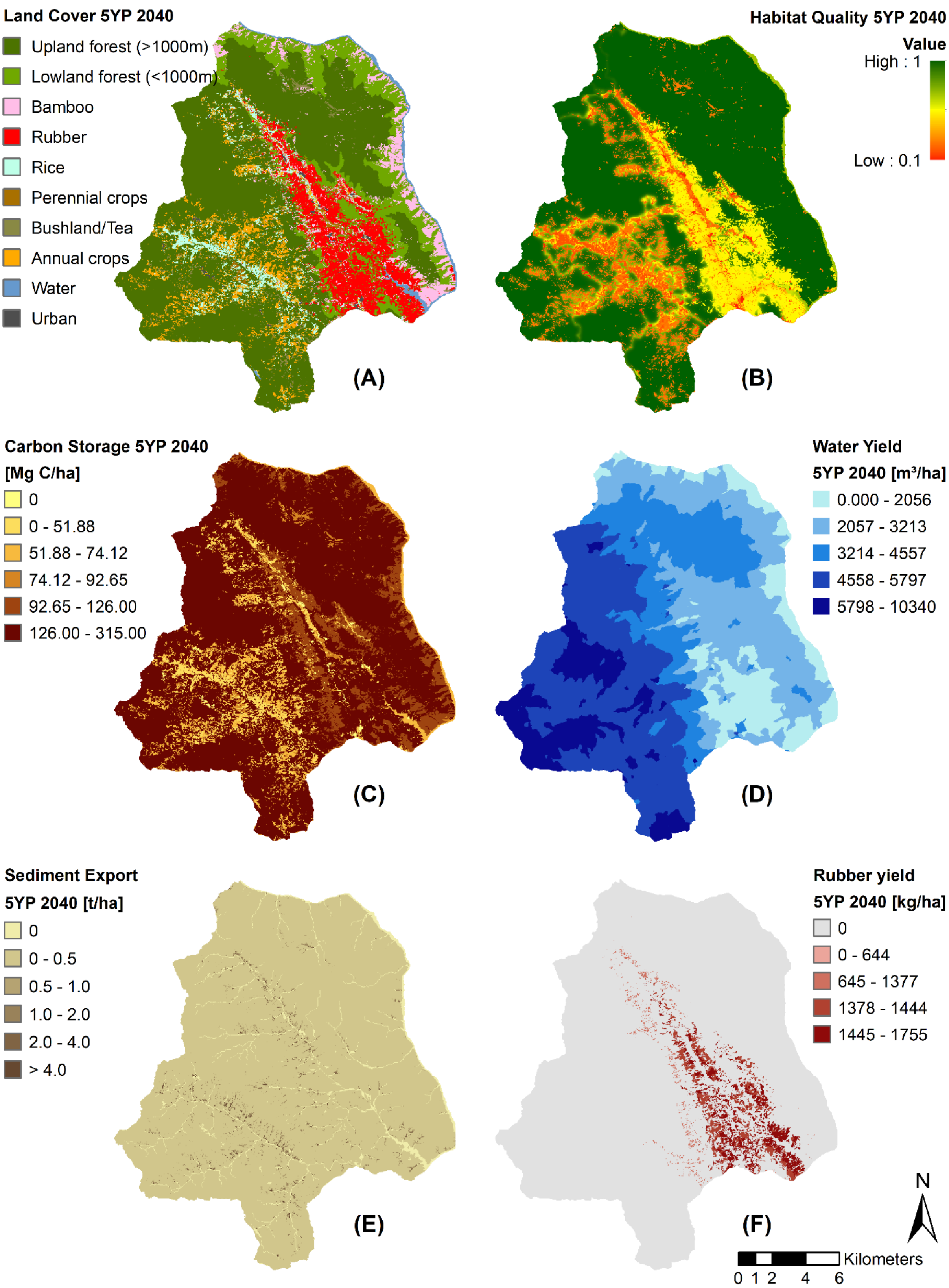

Figure S3. Ecosystem service results at the last year (2040) of the 5YP scenario (A) including habitat quality (B), carbon storage (C), water yield (D), sediment export (E) and rubber yield (F).

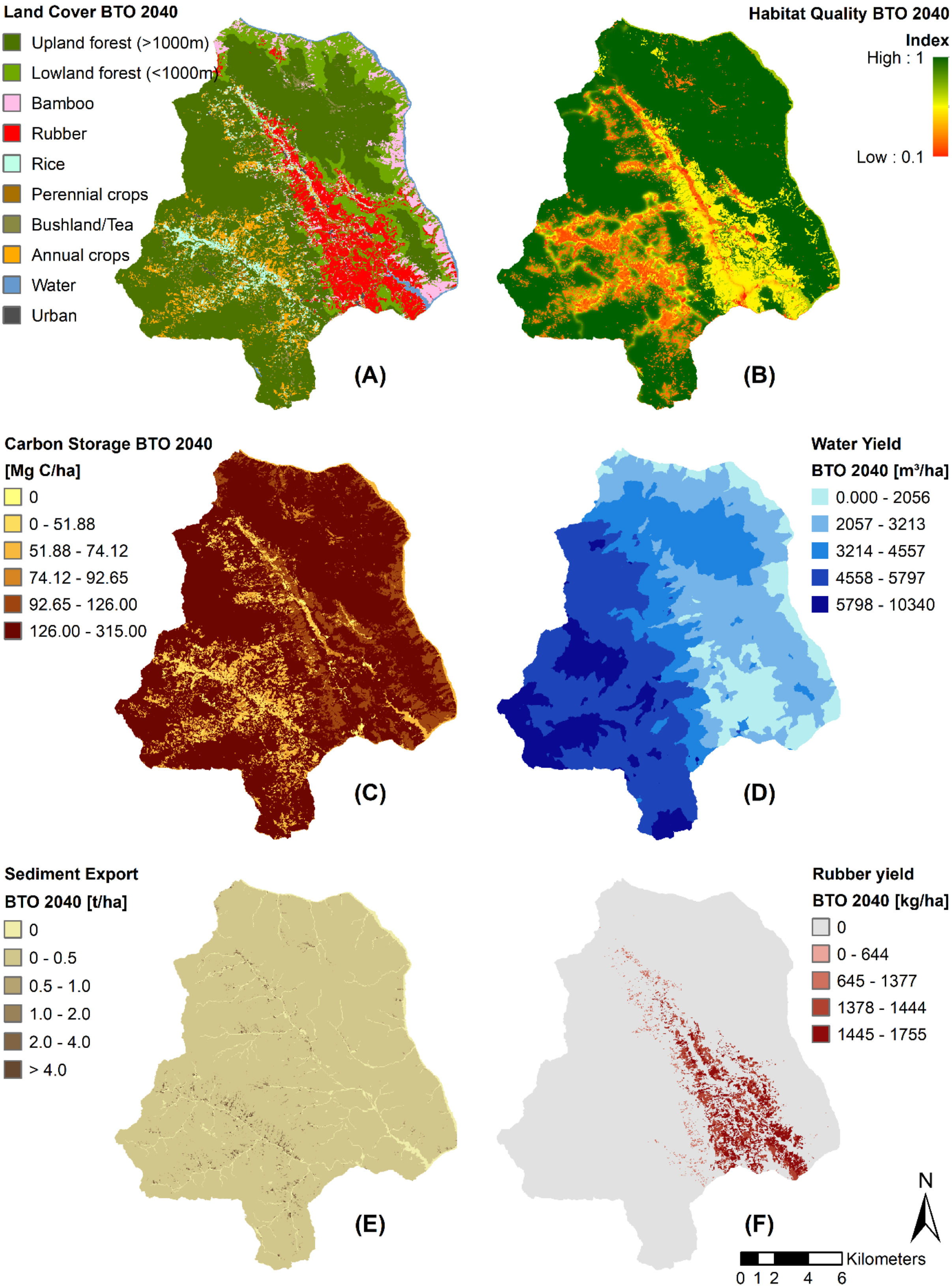

Figure S4. Ecosystem service results at the last year (2040) of the BTO scenario (A) including habitat quality (B), carbon storage (C), water yield (D), sediment export (E) and rubber yield (F).

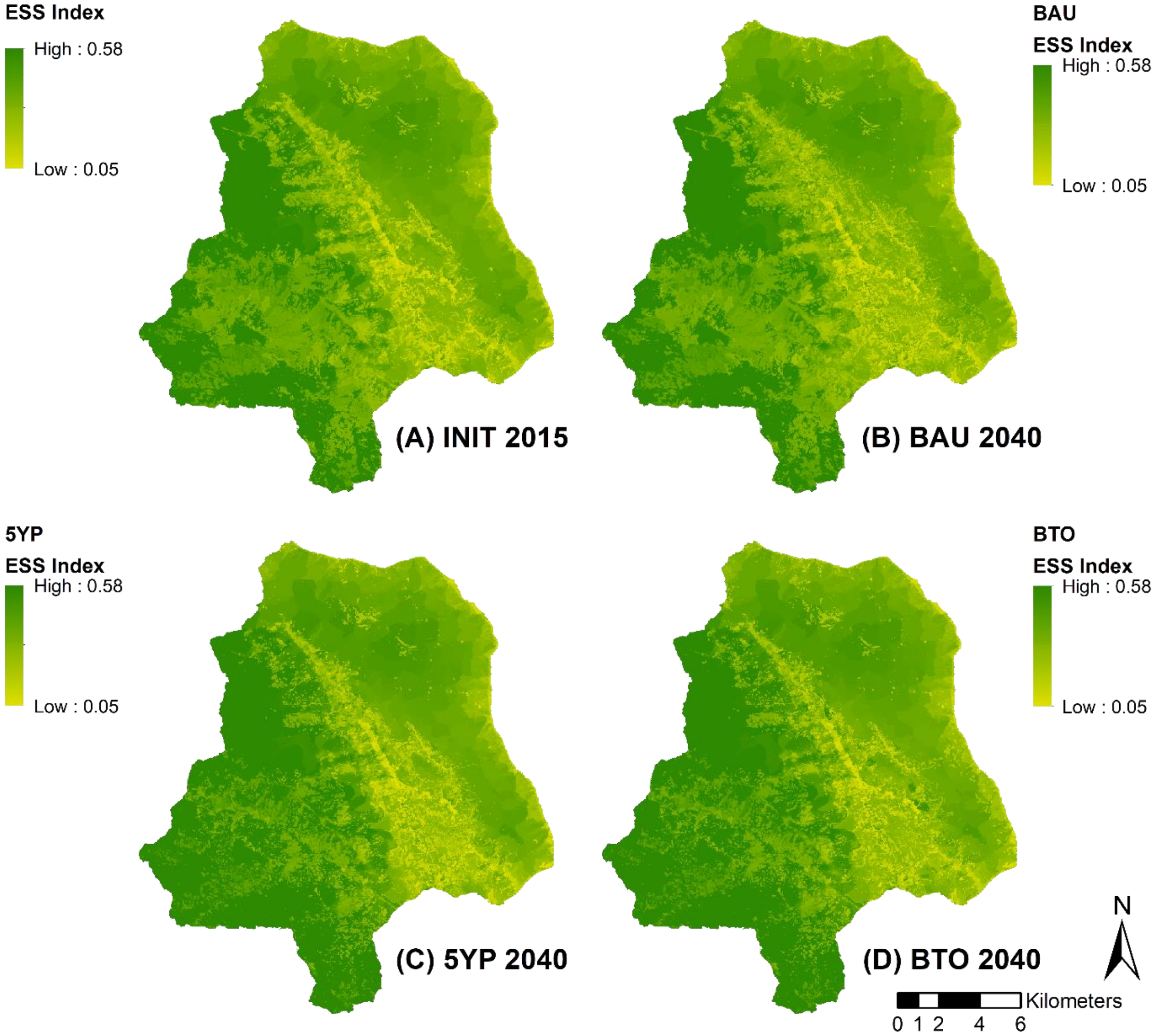

Figure S5. Ecosystem service index integrating the five ecosystem services weighted by Xishuangbanna prefecture administration using the ROC (centroid weight) method for the initial year of 2015 (A) as well as additional results for the final year of each scenario (Business-as-usual (B), 5-years-plan (C) and Balanced-trade-offs (D)).

4. Sensitivity analysis of hydrological models

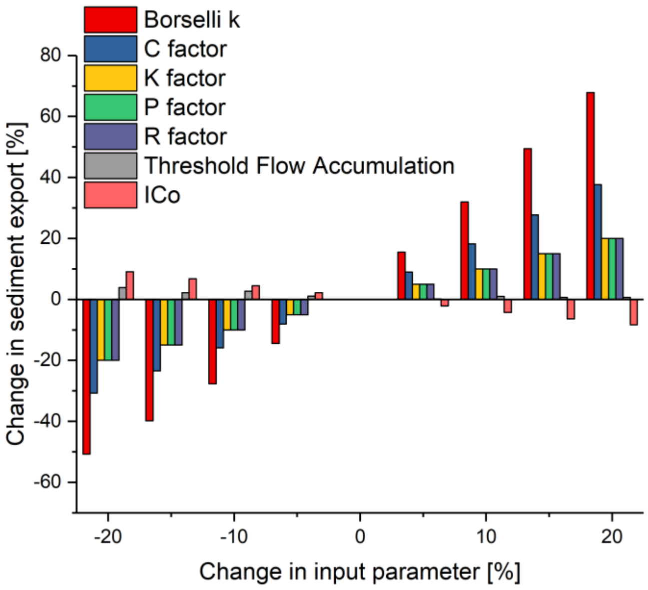

Figure S6. Sensitivity analysis of the InVEST sediment export model.

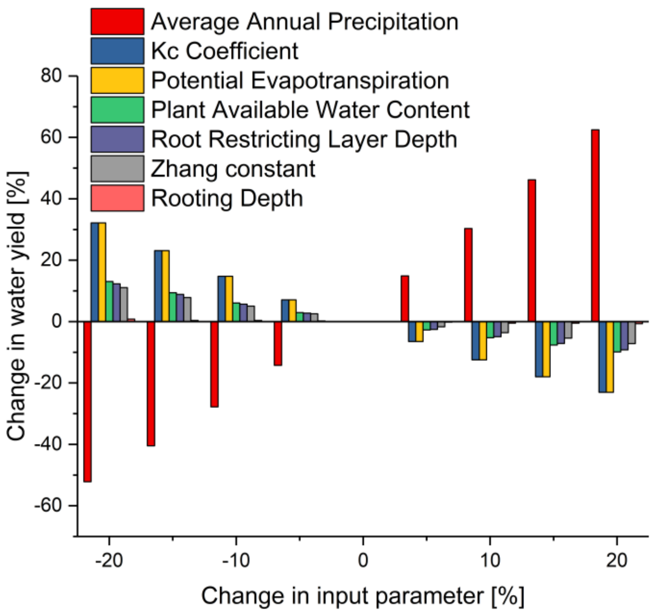

Figure S7. Sensitivity analysis of the InVEST water yield model.

The sensitivity analysis for the sediment export model showed the expected behaviour of a model based on the USLE. Linear relationships between sediment export amounts and changes in the K, R and P factor were found. Sediment exports were more sensitive to changes in the C factor, as it also influences downslope sediment retention in addition to potential soil erosion. The highest sensitivity was identified in respect to changes in the Borselli k parameter, explicitly implemented for calibration purposes.

References

1. Sheikh, A. H.; Palria, S.; Alam, A. Integration of GIS and universal soil loss equation (USLE) for soil loss estimation in a Himalayan watershed. *Recent Res. Sci. Technol.* **2011**, *3*.
2. Yang, D.; Kanae, S.; Oki, T.; Koike, T.; Musiake, K. Global potential soil erosion with reference to land use and climate changes. *Hydrol. Process.* **2003**, *17*, 2913–2928, doi:10.1002/hyp.1441.
3. Zhang, C.; Xie, G.; Liu, C.; Lu, C. Assessment of soil erosion under woodlands using USLE in China. *Front. Earth Sci.* **2011**, *5*, 150–161, doi:10.1007/s11707-011-0158-1.
4. Liu, H.; Blagodatsky, S.; Giese, M.; Liu, F.; Xu, J.; Cadisch, G. Impact of herbicide application on soil erosion and induced carbon loss in a rubber plantation of Southwest China. *Catena* **2016**, *145*, 180–192, doi:10.1016/j.catena.2016.06.007.
5. Liu, Y.; Luo, Z. A study on estimation of the amount of soil erosion in small watershed based on GIS: A case study in the three gorge area of China. In *Proceedings of SPIE - The International Society for Optical Engineering*; 2005; Vol. 6045 II.
6. Shi, Z. H.; Cai, C. F.; Ding, S. W.; Wang, T. W.; Chow, T. L. Soil conservation planning at the small watershed level using RUSLE with GIS: A case study in the Three Gorge Area of China. *Catena* **2004**, *55*, 33–48, doi:10.1016/S0341-8162(03)00088-2.
7. Zhu, Z.; Yu, B. Validation of rainfall erosivity estimators for mainland china. *Trans. ASABE* **2015**, *58*, 61–71, doi:10.13031/trans.58.10451.
8. Cai, C.; Ding, S.; Shi, Z.; Huang, L.; Zhang, G. Study of applying USLE and geographical information system IDRISI to predict soil erosion in small watershed. *J. Soil Water Conserv.* **2000**, *14*, 19–24.
9. Song, X.; Duan, Z.; Niu, H.; Kono, Y. Estimation of the cover and management factor for modeling soil erosion using remote sensing. *J. Beijing For. Univ.* **2009**, *31*, 58–63.
10. Schönbrodt-Stitt, S.; Bosch, A.; Behrens, T.; Hartmann, H.; Shi, X.; Scholten, T. Approximation and spatial regionalization of rainfall erosivity based on sparse data in a mountainous catchment of the Yangtze River in Central China. *Environ. Sci. Pollut. Res.* **2013**, *20*, 6917–6933, doi:10.1007/s11356-012-1441-8.
11. Hijmans, R. J.; Cameron, S. E.; Parra, J. L.; Jones, P. G.; Jarvis, A. Very high resolution interpolated climate surfaces for global land areas. *Int. J. Climatol.* **2005**, *25*, 1965–1978, doi:10.1002/joc.1276.
12. Shangguan, W.; Dai, Y.; Duan, Q.; Liu, B.; Yuan, H. A global soil data set for earth system modeling. *J. Adv. Model. Earth Syst.* **2014**, *6*, 249–263, doi:10.1002/2013MS000293.
13. Fooladmand, H. R. Estimating soil specific surface area using the summation of the number of spherical particles and geometric mean particle-size diameter. *Afr. J. Agric. Res.* **2011**, *6*, 1758–1762.
14. Desmet, P. J. J.; Govers, G. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *J. Soil Water Conserv.* **1996**, *51*, 427–433.

15. Borselli, L.; Cassi, P.; Torri, D. Prolegomena to sediment and flow connectivity in the landscape: A GIS and field numerical assessment. *Catena* **2008**, *75*, 268–277, doi:10.1016/j.catena.2008.07.006.
16. Vigiak, O.; Borselli, L.; Newham, L. T. H.; McInnes, J.; Roberts, A. M. Comparison of conceptual landscape metrics to define hillslope-scale sediment delivery ratio. *Geomorphology* **2012**, *138*, 74–88, doi:10.1016/j.geomorph.2011.08.026.
17. The Natural Capital Project InVEST 3.3.3 User's Guide: Integrated Valuation of Ecosystem Services and Tradeoffs. A Modeling Suite Developed by the Natural Capital Project to Support Environmental Decision Making 2016.
18. Piouceau, J.; Panfili, F.; Bois, G.; Anastase, M.; Dufossé, L.; Arfi, V. Actual evapotranspiration and crop coefficients for five species of three-year-old bamboo plants under a tropical climate. *Agric. Water Manag.* **2014**, *137*, 15–22, doi:10.1016/j.agwat.2014.02.004.
19. Chen, X.; Zhang, X.; Zhang, Y.; Booth, T.; He, X. Changes of carbon stocks in bamboo stands in China during 100 years. *For. Ecol. Manag.* **2009**, *258*, 1489–1496, doi:10.1016/j.foreco.2009.06.051.
20. Allen, R. G.; Pereira, L. S.; Raes, D.; Smith, M. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO Rome* **1998**, *300*, D05109.
21. Carr, M. K. V. The water relations and irrigation requirements of banana (Musa SPP.). *Exp. Agric.* **2009**, *45*, 333–371, doi:10.1017/S001447970900787X.
22. Bhagabati, N. K.; Ricketts, T.; Sulistyawan, T. B. S.; Conte, M.; Ennaanay, D.; Hadian, O.; McKenzie, E.; Olwero, N.; Rosenthal, A.; Tallis, H.; Wolny, S. Ecosystem services reinforce Sumatran tiger conservation in land use plans. *Biol. Conserv.* **2014**, *169*, 147–156, doi:10.1016/j.biocon.2013.11.010.
23. Canadell, J.; Jackson, R. B.; Ehleringer, J. R.; Mooney, H. A.; Sala, O. E.; Schulze, E.-D. Maximum rooting depth of vegetation types at the global scale. *Oecologia* **1996**, *108*, 583–595.
24. Global Aridity and PET Database | CGIAR-CSI. Available online: http://www.cgiar-csi.org/data/global-aridity-and-pet-database (accessed on Oct 20, 2017).
25. Redhead, J. W.; Stratford, C.; Sharps, K.; Jones, L.; Ziv, G.; Clarke, D.; Oliver, T. H.; Bullock, J. M. Empirical validation of the InVEST water yield ecosystem service model at a national scale. *Sci. Total Environ.* **2016**, *569–570*, 1418–1426, doi:10.1016/j.scitotenv.2016.06.227.
26. Yang, X.; Blagodatsky, S.; Lippe, M.; Liu, F.; Hammond, J.; Xu, J.; Cadisch, G. Land-use change impact on time-averaged carbon balances: Rubber expansion and reforestation in a biosphere reserve, South-West China. *For. Ecol. Manag.* **2016**, *372*, 149–163, doi:10.1016/j.foreco.2016.04.009.
27. Cotter, M.; Häuser, I.; Harich, F. K.; He, P.; Sauerborn, J.; Treydte, A. C.; Martin, K.; Cadisch, G. Biodiversity and ecosystem services-A case study for the assessment of multiple species and functional diversity levels in a cultural landscape. *Ecol. Indic.* **2017**, *75*, 111–117, doi:10.1016/j.ecolind.2016.11.038.
28. Waibel, H.; Min, S.; Huang, J. Small scale rubber farming and income risk in Xishuangbanna, China. In *World Congress on Agroforestry*; Delhi, 2014.

29. Beckschäfer, P. Obtaining rubber plantation age information from very dense Landsat TM & ETM + time series data and pixel-based image compositing. *Remote Sens. Environ.* **2017**, *196*, 89–100, doi:10.1016/j.rse.2017.04.003.