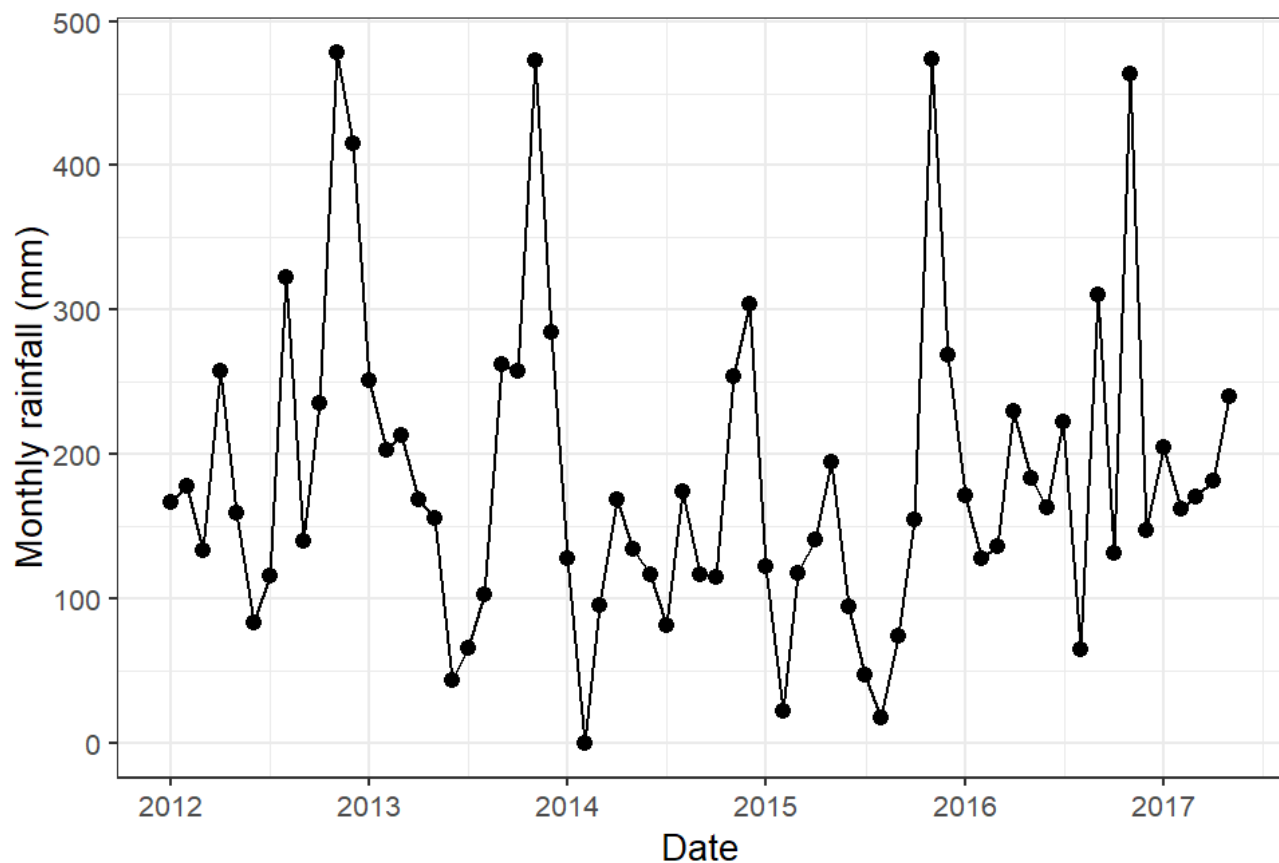


Managing oil palm plantations more sustainably: large-scale experiments within the Biodiversity and Ecosystem Function in Tropical Agriculture (BEFTA) Programme

Supplementary Material



Supplementary Figure 1- Mean monthly rainfall (mm) calculated from measurements taken from multiple rain gauges across three SMARTRI estates (Kandista, Libo, and Ujung Tanjung) between January 2012 and May 2017. Each rain gauge had a 100 cm² collecting area.

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Supplementary Table 1- Details of plot name, location, original planting dates, and understory vegetation treatment for each of the BEFTA Understory Vegetation Project plots. For details of estate locations refer to Figure 1, and for information about understory vegetation treatments refer to Figure 3 and main text.

Estate	Triplet	Plot name	Understory vegetation treatment	Date planted
Ujung Tanjung	1	C10	Reduced	1988
	1	C11	Enhanced	1988
	1	C12	Normal	1988
	2	C17	Enhanced	1989
	2	C18	Normal	1989
	2	C19	Reduced	1989
	3	D28	Enhanced	1989
	3	D29	Reduced	1989
	3	D30	Normal	1989
Kandista	4	F04	Enhanced	1992
	4	F05	Reduced	1992
	4	F06	Normal	1992
	5	G07	Enhanced	1992
	5	G08	Normal	1992
	5	G09	Reduced	1992
	6	G14	Reduced	1993
	6	G15	Normal	1993
	6	G16	Enhanced	1993

Supplementary Table 2- Details of plot names, location, original planting dates, replanting dates, and riparian treatment types for each of the RERTA treatments. For details of estate locations refer to Figure 1, and for information about riparian treatments refer to Figure 4 and main text.

Estate	RERTA replicate name	Treatment name	Riparian treatment type	Date mature palm was planted	Date of replanting and creation of buffer treatment
Palapa	RERTA 1	A	Mature palms and native tree enrichment planting	1987	2018
		B	Mature palms only	1987	2018
		C	No mature palms and nature tree enrichment planting	1987	2018
		D	Control – replanting to river edge	1987	2018
Kandista	RERTA 2	F	Mature palms and native tree enrichment planting	1988	2019
		G	Mature palms only	1988	2019
		H	No mature palms and nature tree enrichment planting	1988	2019
		I	Control – replanting to river edge	1988	2019

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Supplementary Table 3- Details of native tree species planted in the enrichment planting RERTA riparian restoration treatments.

Common name	Species name	Family	Native distribution	Traits
Sungkai	<i>Peronema canescens</i>	Lamiaceae	Sumatra, Riau Islands, West Java, Kalimantan, Peninsular Malaysia	Pioneer species
Meranti tembaga	<i>Shorea leprosula</i>	Dipterocarpaceae	Sumatra, Borneo, Southern Thailand, Peninsular Malaysia	Climax species
Bintangur	<i>Calophyllum inophyllum</i>	Clusiaceae	Large areas of SE Asia, Australia, India, Japan, Madagascar	Water-tolerant
Pulai	<i>Alstonia scholaris</i>	Apocynaceae	Large areas of SE Asia, Australia, India, China	Shade plant
Cempedak	<i>Artocarpus integer</i>	Moraceae	Indonesia, Myanmar, Thailand, Vietnam, Malaysia	Fruit
Sengon	<i>Albizia chinensis</i>	Fabaceae	Indonesia, Cambodia, China, India, Laos, Myanmar, Thailand, Vietnam	Legume

Supplementary Table 4- Results of lsmeans tests to show estimated differences in mean temperature (5cm underground) at different times of day between plots within Buffer Core and OP Core microhabitats within RERTA 1 sites during the pre-treatment time period.

Response	Microhabitat comparison	Estimated magnitude of temperature difference between treatments (°C)	Which plot type was warmer?	SE	df	t	p-value
00:00 mean temperature	BC-OPC	0.03	BC	0.19	38.37	0.156	0.8769
03:00 mean temperature	BC-OPC	0.09	BC	0.19	38.37	0.484	0.6308
06:00 mean temperature	BC-OPC	0.15	BC	0.19	38.37	0.767	0.4481
09:00 mean temperature	BC-OPC	0.05	BC	0.19	38.37	0.236	0.8147
12:00 mean temperature	BC-OPC	-0.33	OPC	0.19	38.37	1.695	0.0982

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15:00 mean temperature	BC-OPC	-0.35	OPC	0.19	38.37	1.839	0.0737
18:00 mean temperature	BC-OPC	-0.21	OPC	0.19	38.37	1.083	0.2855
21:00 mean temperature	BC-OPC	-0.05	OPC	0.19	38.37	0.269	0.7894

Supplementary Table 5- Results of mixed effects models to test for impacts of the three different BEFTA Understory Vegetation Project treatments (Enhanced, Normal, and Reduced vegetation) on a range of vegetation and temperature metrics. A significant interaction between understory treatment and time point in the experiment (Treatment:PrePost) indicates that one or more of the experimental treatments had an effect on the response variable. Results of lsmeans tests then show which treatments showed a significant change pre- and post-treatment, and which treatments differed from one another post-treatment. Asterisks are used to highlight significant results: ***= $p < 0.001$, **= $p < 0.01$, and *= $p < 0.05$. Refer to Figure 7 and Figure 8 to see the direction of the changes.

Response	When there is a significant interaction between understory treatment and pre- and post-treatment time point:								
	Effect of interaction between understory treatment and time point in the experiment (Treatment:PrePost)			Which treatments have shown a difference between pre- and post-treatment values? (results of lsmeans test)			Which treatments are the post-treatment differences between? (results of lsmeans test)		
	χ^2	df	p	Enhanced	Normal	Reduced	E-N	E-R	N-R
Vegetation height	46.731	2	<0.001 ***	<0.001 ***	<0.001 ***	<0.001 ***	0.7158	<0.001 ***	<0.001 ***
Arc fern cover	66.540	2	<0.001 ***	0.3081	0.1208	<0.001 ***	0.8888	<0.001 ***	<0.001 ***
Arc other plants cover	68.389	2	<0.001 ***	0.0279 *	0.1136	0.0094 **	0.0590	<0.001 ***	<0.001 ***
Arc frond cover	18.336	2	<0.001 ***	0.8043	0.7605	0.0016 **	0.8712	<0.001 ***	<0.001 ***
Arc bare ground cover	62.269	2	<0.001 ***	<0.0041 **	0.3895	<0.0030 **	0.0043 **	<0.001 ***	<0.001 ***
Arc canopy openness	1.6222	2	0.4444	NA	NA	NA	NA	NA	NA
Mean temperature	5.4564	2	0.0653	NA	NA	NA	NA	NA	NA
Maximum temperature	2.8432	2	0.2413	NA	NA	NA	NA	NA	NA
Minimum temperature	0.1501	2	0.9277	NA	NA	NA	NA	NA	NA

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Daily range in temperature	1.4045	2	0.4955	NA	NA	NA	NA	NA	NA
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Supplementary Table 6- Results of lsmeans tests to show estimated differences in post-treatment mean temperature at different times of day between BEFTA Understory Vegetation Project plots with different understory vegetation treatments (E=Enhanced, N=Normal, and R=Reduced). Asterisks are used to highlight significant results: *=p<0.05.

Response	Treatment comparison	Estimated magnitude of temperature difference between treatments (°C)	Which plot type was warmer?	SE	df	t	p-value
00:00 mean temperature	E-N	0.034	N	0.15	53.42	0.225	0.9726
	E-R	0.11	E	0.15	53.42	0.729	0.7474
	N-R	0.15	N	0.15	53.42	0.954	0.6091
03:00 mean temperature	E-N	0.000083	E	0.15	53.42	0.001	1.0000
	E-R	0.19	E	0.15	53.42	1.251	0.4288
	N-R	0.19	N	0.15	53.42	1.251	0.4291
06:00 mean temperature	E-N	0.022	E	0.15	53.42	0.147	0.9882
	E-R	0.24	E	0.15	53.42	1.540	0.2805
	N-R	0.21	N	0.15	53.42	1.393	0.3516
09:00 mean temperature	E-N	0.04	E	0.15	53.42	0.259	0.9638
	E-R	0.10	E	0.15	53.42	0.662	0.7866
	N-R	0.061	N	0.15	53.42	0.403	0.9146
12:00 mean temperature	E-N	0.067	N	0.15	53.42	0.441	0.8986
	E-R	0.33	R	0.15	53.42	2.184	0.0831
	N-R	0.27	R	0.15	53.42	1.743	0.1987
15:00 mean temperature	E-N	0.0054	E	0.15	53.42	0.035	0.9993
	E-R	0.40	R	0.15	53.42	2.596	0.0321 *
	N-R	0.40	R	0.15	53.42	2.631	0.0294 *
18:00 mean temperature	E-N	0.070	N	0.15	53.42	0.458	0.8912
	E-R	0.22	R	0.15	53.42	1.463	0.3165
	N-R	0.15	R	0.15	53.42	1.006	0.5765
21:00 mean temperature	E-N	0.065	N	0.15	53.42	0.425	0.9053
	E-R	0.011	R	0.15	53.42	0.074	0.9970
	N-R	0.054	N	0.15	53.42	0.351	0.9342

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Supplementary Table 7- Results of lsmeans tests to show estimated changes in temperature pre- and post-treatment across different BEFTA Understory Vegetation Project treatment plots. No significant interaction was found between treatment and pre- and post-treatment time point (Table S5), indicating that the experimental manipulation of treatment had no effect on temperature. Rather, the changes observed were happening anyway, caused by a factor independent of our experimental manipulation. Asterisks are used to highlight significant results: ***= $p < 0.001$, **= $p < 0.01$, and *= $p < 0.05$.

Response	Treatment	Estimated change from pre- to post-treatment (°C)	SE	df	t	p-value
Mean temperature	Enhanced	+ 0.27	0.12	21.55	2.30	0.032 *
	Normal	+ 0.62	0.11	21.31	5.58	<0.001 ***
	Reduced	+ 0.36	0.11	21.31	3.25	0.004 **
Maximum temperature	Enhanced	+ 5.80	3.18	21.50	1.82	0.082
	Normal	+ 7.76	2.97	20.95	2.61	0.016 *
	Reduced	+ 12.51	2.97	20.95	4.21	<0.001 ***
Minimum temperature	Enhanced	- 2.19	0.60	26.00	3.67	0.001 **
	Normal	- 1.95	0.56	26.00	3.49	0.002 **
	Reduced	- 2.19	0.56	26.00	3.92	<0.001 ***