

Selective logging in tropical forests decreases the robustness of liana-tree interaction networks to the loss of host tree species

Supplementary Online Material

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Extended Methodology

Liana and tree biomass estimations

For each plot, we calculated both liana and tree biomasses. For liana biomass we used the following equation [1]:

$$AGB = \exp[-1.484 + 2.657 \ln(D)], \quad [\text{Eqn. 1}]$$

where AGB is the predicted aboveground oven-dry weight of the liana in kilograms and D is the diameter in cm at 130 cm from the roots. For tree biomass we applied the following equation proposed for moist forest stands [2]:

$$(AGB)_{est} = \rho * \exp(-1.499 + 2.148 * \ln(D) + 0.207 * \ln(D))^2 - 0.0281 * \ln(D))^3) \quad [\text{Eqn. 2}]$$

where AGB is aboveground biomass, ρ is wood density measured in g/cm^3 and D is the DBH measured at 130 cm from the forest ground.

We obtained estimates of wood density for the tree species surveyed from the Global Wood Density Database [3]. For species that did not appear in the dataset or individuals only identified to genus level, we used the average for the nearest taxonomic group available for the region (genus or family). We then calculated average tree and liana biomasses per plot as well as the percent of the total biomass (tree and liana) contributed by lianas.

Table S1: List of tree and liana species (or morphospecies) used in quantitative interaction networks with code for figure depicting network structure, Fig. 3.

a)

Tree species	ID network figure
<i>Primary forest</i>	
<i>Adinandra dumosa</i> Jack	
<i>Aglaia elliptica</i> Blume	T1
<i>Aglaia macrocarpa</i> (Miq.) Pannell	T2
<i>Aglaia odoratissima</i> Bl.	T3
<i>Aglaia</i> sp.	T4
<i>Alangium javanicum</i> (Bl.) Wang	
<i>Aporusa elmeri</i> Merr.	T5
<i>Aporusa grandifolia</i> Merr.	T6
<i>Aporusa grandistipula</i> Merr.	T7
<i>Aporusa nitida</i> Merr.	T8
<i>Aquilaria malaccensis</i> Lamk.	
<i>Ardisia elliptica</i> Thunb.	
<i>Ardisia</i> sp.	
<i>Artocarpus</i> sp.	
<i>Baccaurea macrocarpa</i> Müll.Arg.	T9
<i>Baccaurea</i> sp.	
<i>Baccaurea stipulata</i> J.J.Sm.	T10
	T11
<i>Baccaurea tetrandra</i> (Baill.) Mull.Arg.	
<i>Barringtonia macrostachya</i> (Jack) Kurz	T12
<i>Blumeodendron tokbrai</i> (Bl.) Kurz	T13
<i>Brownlowia peltata</i> Benth.	
<i>Canarium denticulatum</i> Blume	T14
<i>Canarium odontophyllum</i> Miq.	
<i>Canarium</i> sp.	
<i>Castanopsis mottleyana</i> King	T15
<i>Chionanthus pluriflorus</i> (Knobl.) Kiew	
<i>Chisocheton patens</i> Blume	
<i>Chisocheton</i> sp.	
<i>Cynometra elmeri</i> Merr.	T16
<i>Dehaasia</i> sp.	
<i>Dillenia excelsa</i> (Jack) Martelli	
<i>Dimocarpus longan</i> Lour.	
<i>Diospyros frutescens</i> Blume	
<i>Diospyros macrophylla</i> Blume	
<i>Diospyros</i> sp.	T17
<i>Diospyros tuberculata</i> Bakh.	T18
<i>Dipterocarpus caudiferus</i> Merr.	
<i>Dryobalanops lanceolata</i> Burck	
<i>Elaeocarpus stipularis</i> Bl.	
<i>Endospermum diadenum</i> (Miq.) Airy Shaw	
<i>Eugenia</i> sp.	

<i>Eusideroxylon zwageri</i> Teijsm. & Binn.	T19
<i>Ficus</i> sp.	
<i>Ficus variegata</i> Bl.	
<i>Fordia</i> sp.	
<i>Fordia splendidissima</i> (Miq.) Buijsen	
<i>Garcinia parvifolia</i> (Miq.) Miq.	
<i>Garcinia</i> sp.	
<i>Glochidion borneensis</i> Boerl.	T20
<i>Gluta</i> sp.	
<i>Hopea ferruginea</i> Parijs	
<i>Hopea nervosa</i> King	
<i>Hopea sangal</i> Korth.	T21
<i>Hydnocarpus borneensis</i> Sleum.	
<i>Ixora grandifolia</i> Zoll. & Moritz	T22
<i>Kibara obtusa</i> Bl.	
<i>Knema laurina</i> (Bl.) Warb.	T23
<i>Knema</i> sp.	
<i>Koilocarpus longifolium</i> Hook. F.	T24
<i>Lansium domesticum</i> Corrêa	T25
<i>Lithocarpus gracilis</i> (Korth.) Soepadmo	
<i>Litsea caulocarpa</i> Merr.	
<i>Litsea</i> sp.	T26
<i>Lophopetalum javanicum</i> (Zoll.) Turcz	T27
<i>Ludeckia borneensis</i> Ridsdale	
<i>Luvunga heterophylla</i> Merr.	
<i>Maasia sumatrana</i> (Miq.) Mols, Keßler & Rogstad	T28
<i>Madhuca kingiana</i> (Brace ex King & Gamble) H.J. Lam	
<i>Madhuca motleyana</i> (de Vriese) J.F. Macbr.	
<i>Madhuca</i> sp.	T29
<i>Magnolia montana</i> (Blume) Figlar	
<i>Mallotus lackeyi</i> Elmer	
<i>Mallotus penangensis</i> (Müll.Arg.) S.E.C. Sierra, Kulju & Welzen	T30
<i>Mallotus</i> sp.	T31
<i>Mallotus wrayii</i> King ex. Hook	T32
<i>Mangifera</i> sp.	
<i>Microcos crassifolia</i> Burret	T33
<i>Neesia</i> sp.	
<i>Nephelium maingayi</i> Hiern	
<i>Nephelium ramboutan-ake</i> (Labill.) P.W. Leenhouts	
<i>Ochanostachys amentaceae</i> Mast.	
<i>Paranephelium xestophyllum</i> Miq.	
<i>Parashorea malaanonan</i> (Blanco) Merr.	
<i>Parashorea tomentella</i> (Symington) Meijer	
<i>Payena acuminata</i> (Blume) Pierre	
<i>Pentace laxiflora</i> Merr.	T34
<i>Polyalthia insignis</i> (Hook. F.) Airy Shaw	
<i>Polyalthia rumphii</i> (Bl.) Merr.	
<i>Polyalthia</i> sp.	T35
<i>Polyalthia xanthopetala</i> Merr.	
<i>Popowia pisocarpa</i> (Blume) Endl.	
<i>Pterospermum javanicum</i> Jungh.	

<i>Pterospermum stapfianum</i> Ridley	
<i>Ryparosa acuminata</i> Merrill	T36
<i>Semecarpus borneensis</i> Merrill	T37
<i>Semecarpus</i> sp.	
<i>Scorodocarpus borneensis</i> Becc.	
<i>Shorea agamii</i> P.S. Ashton	
<i>Shorea argentifolia</i> Symington	
<i>Shorea beccariana</i> Burck	
<i>Shorea faguetiana</i> F. Heim	T38
<i>Shorea gibbosa</i> Brandis	
<i>Shorea johorensis</i> Foxw.	T39
<i>Shorea leprosula</i> Miq.	
<i>Shorea leptoderma</i> Meijer	
<i>Shorea macroptera</i> Dyer	
<i>Shorea mecistopteryx</i> Ridl.	
<i>Shorea ovata</i> Dyr ex Brandis	
<i>Shorea pahangensis</i> Foxw.	
<i>Shorea parvifolia</i> Dyer	
<i>Shorea pauciflora</i> King	T40
<i>Shorea superba</i> Symington	T41
<i>Spathiostemon javanicum</i>	T42
<i>Sympetalandra borneensis</i> Stapf	
<i>Syzygium napiforme</i> (Koord. & Valet.) Merr. & Perry	
<i>Syzygium</i> sp.	T43
<i>Urophyllum glabrum</i> Wall.	
<i>Vatica albiramis</i> Slooten	
<i>Vatica dulitensis</i> Sym.	T44
<i>Xanthophyllum affine</i> (Korth. ex Miq.) Kuntze	T45
<i>Xanthophyllum ellipticum</i> Korth. ex Miq.	
<i>Xanthophyllum</i> sp.	
<i>Ziziphus angustifolius</i> (Miq.) Hatusima ex van Steenis	
<i>Logged forest</i>	
<i>Adinandra dumosa</i> Jack	
<i>Aglaia elliptica</i> Blume	T1
<i>Aglaia macrocarpa</i> (Miq.) Pannell	T2
<i>Aglaia odoratissima</i> Bl.	T3
<i>Aglaia</i> sp.	T4
<i>Alangium javanicum</i> (Bl.) Wang	
<i>Aporusa elmeri</i> Merr.	
<i>Aporusa grandistipula</i> Merr.	
<i>Aporusa nitida</i> Merr.	
<i>Aquilaria malaccensis</i> Lamk.	
<i>Ardisia</i> sp.	
<i>Ardisia dumetosa</i> Tutcher	
<i>Artocarpus elasticus</i> Reinw. ex Blume	T5
<i>Artocarpus</i> sp.	
<i>Baccaurea lanceolata</i> (Miq.) Mull. Arg.	T6
<i>Baccaurea stipulata</i> J.J.Sm.	T7
<i>Baccaurea tetrandra</i> (Baill.) Mull.Arg.	T8
<i>Barringtonia macrostachya</i> (Jack) Kurz	
<i>Beilschmiedia micrantha</i> Merr.	

<i>Blumeodendrum tokbrai</i> (Bl.) Kurz	T9
<i>Brownlowia peltata</i> Benth.	T10
<i>Callicarpa pentandra</i> Roxb.	
<i>Canarium denticulatum</i> Blume	T11
<i>Canarium odontophyllum</i> Miq.	
<i>Castanopsis motleyana</i> King	
<i>Chionanthus pluriflorus</i> (Knobl.) Kiew	
<i>Chisocheton</i> sp.	T12
<i>Cratoxylum cochinchinense</i> (Lour.) Blume	T13
<i>Cratoxylum formosum</i> Benth. & Hook. F. ex Dyer	
<i>Cynometra elmeri</i> Merr.	
<i>Dehaasia</i> sp.	
<i>Dendrocnide elliptica</i> (Merr.) Chew	
<i>Dendrocnide</i> sp.	
<i>Dillenia excelsa</i> (Jack) Martelli	T14
<i>Dimorphocalyx murinus</i> Elmer	
<i>Diospyros ellipticifolia</i> (Stokes) Bakh.	
<i>Diospyros elliptica</i> P.S. Green	T15
<i>Diospyros frutescens</i> Blume	
<i>Diospyros macrophylla</i> Blume	T16
<i>Diospyros</i> sp.	T17
<i>Diospyros tuberculata</i> Bakh.	T18
<i>Dipterocarpus caudiferus</i> Merr.	T19
<i>Dryobalanops lanceolata</i> Burck	T20
<i>Duabanga moluccana</i> Blume	
<i>Durio kutejensis</i> Hassk. & Becc.	
<i>Elaeocarpus stipularis</i> Bl.	T21
<i>Endospermum diadenum</i> (Miq.) Airy Shaw	T22
<i>Endospermum</i> sp.	
<i>Eusideroxylon zwageri</i> Teijsm. & Binn.	T23
<i>Ficus</i> sp.	
<i>Ficus virgate</i> Reinw. ex Blume	
<i>Ficus variegata</i> Bl.	
<i>Garcinia parvifolia</i> (Miq.) Miq.	
<i>Glochidion borneensis</i> Boerl.	T24
<i>Glochidion</i> sp.	T25
<i>Gluta</i> sp.	T26
<i>Gluta wallichii</i> (Hook.f.) Ding Hou	
<i>Hopea ferruginea</i> Parijs	T27
<i>Hydnocarpus borneensis</i> Sleum.	
<i>Ixora grandifolia</i> Zoll. & Moritz	
<i>Knema laurina</i> (Bl.) Warb.	T28
<i>Knema pulchra</i> (Miq.) Warb.	
<i>Koilocarpus longifolium</i> Hook. F.	T29
<i>Koompassia excelsa</i> (Becc.) Taub	T30
<i>Lansium domesticum</i> Corrêa	T31
<i>Lithocarpus gracilis</i> (Korth.) Soepadmo	T32
<i>Litsea caulocarpa</i> Merr.	T33
<i>Litsea micrantha</i> Merr.	
<i>Litsea</i> sp.	T34
<i>Lophopetalum javanicum</i> (Zoll.) Turcz	

<i>Ludeckia borneensis</i> Ridsdale	T35
<i>Maasia sumatrana</i> (Miq.) Mols, Keßler & Rogstad	
<i>Macaranga digyna</i> (Wight) Müll. Arg.	
<i>Macaranga gigantea</i> (Rchb.f. & Zoll.) Müll.Arg.	
<i>Macaranga gigantifolia</i> Merr.	
<i>Macaranga hypoleuca</i> (Rchb.f. & Zoll.) Müll.Arg.	
<i>Macaranga pearsonii</i> Merr.	
<i>Macaranga</i> sp.	
<i>Madhuca kingiana</i> (Brace ex King & Gamble) H.J.Lam	
<i>Madhuca motleyana</i> (de Vriese) J.F. Macbr.	T36
<i>Madhuca</i> sp.	T37
<i>Mallotus penangensis</i> (Müll.Arg.) S.E.C. Sierra, Kulju & Welzen	T38
<i>Mallotus</i> sp.	
<i>Mallotus wrayii</i> King ex. Hook	T39
<i>Mangifera</i> sp.	T40
<i>Microcos crassifolia</i> Burret	T41
<i>Nauclea subdita</i> (Korth.) Steud.	
<i>Neesia</i> sp.	
<i>Neesia synandra</i> Mast.	
<i>Neolamarckia cadamba</i> (Roxb.) Bosser	T42
<i>Nephelium maingayi</i> Hiern	
<i>Nephelium ramboutan-ake</i> (Labill.) P.W. Leenhouts	
<i>Ochanostachys amentaceae</i> Mast.	T43
<i>Octomeles sumatrana</i> Miq.	
<i>Paranephelium xestophyllum</i> Miq.	T44
<i>Parashorea malaanonan</i> (Blanco) Merr.	T45
<i>Parashorea tomentella</i> (Symington) Meijer	T46
<i>Pentace laxiflora</i> Merr.	T47
<i>Pleiocarpidia sandakanica</i> Bremekamp	
<i>Polyalthia cauliflora</i> Hook.f. & Thomson	T48
<i>Polyalthia insignis</i> (Hook. F.) Airy Shaw	
<i>Polyalthia rumphii</i> (Bl.) Merr.	T49
<i>Polyalthia</i> sp.	T50
<i>Polyalthia sumatrana</i> (Miq.) Kurz	
<i>Polyalthia xanthopetala</i> Merr.	T51
<i>Popowia pisocarpa</i> (Blume) Endl.	T52
<i>Pternandra coerulescens</i> Jack	
<i>Pterospermum javanicum</i> Jungh.	
<i>Ryparosa acuminata</i> Merrill	T53
<i>Semecarpus borneensis</i> Merrill	
<i>Semecarpus</i> sp.	
<i>Saurauia</i> sp.	
<i>Scorodocarpus borneensis</i> Becc.	
<i>Shorea agamii</i> P.S. Ashton	
<i>Shorea beccariana</i> Burck	
<i>Shorea fallax</i> Meijer	
<i>Shorea gibbosa</i> Brandis	
<i>Shorea johorensis</i> Foxw.	T54
<i>Shorea leprosula</i> Miq.	
<i>Shorea ovata</i> Dyr ex Brandis	
<i>Shorea parvifolia</i> Dyer	

<i>Shorea pauciflora</i> King	T55
<i>Shorea superba</i> Symington	T56
<i>Sindora irpicina</i> de Wit	T57
<i>Spathiostemon javanicum</i>	T58
<i>Symplocos fasciculata</i> (Kuntze) Zoll.	T59
<i>Syzygium</i> sp.	T60
<i>Terminalia citrina</i> (Gaertn) Roxb. Ex Fleming	T61
<i>Urophyllum</i> sp.	
<i>Xanthophyllum affine</i> (Korth. ex Miq.) Kuntze	T62
<i>Xanthophyllum ellipticum</i> Korth. ex Miq.	T63
<i>Ziziphus angustifolius</i> (Miq.) Hatusima ex van Steenis	

b)

Liana species	ID network figure
<i>Primary forest</i>	
<i>Aglaia borneensis</i> Merr.	
<i>Artabotrys roseus</i> Boerl.	L1
<i>Bauhinia</i> sp.	L2
<i>Caesalpinia oppositifolia</i> Hattink	L3
<i>Caesalpinia</i> sp.	
<i>Cissus hastata</i> Miq.	
<i>Luvunga heterophylla</i> Merr.	
<i>Luvunga</i> sp.	
<i>Mucuna</i> sp.	
<i>Omphalea malayana</i> Merr.	
<i>Spatholobus macropterus</i> Miq.	L4
<i>Spatholobus</i> sp.	L5
<i>Spenodesme triflora</i> Wight	L6
<i>Strychnos</i> sp.	L7
<i>Tetracera scandens</i> (L.) Merr.	L8
<i>Tetrastigma borneensis</i>	
<i>Uncaria cordata</i> (Lour.) Merr.	
<i>Uncaria</i> sp.	L9
<i>Uvaria sorzogonensis</i> (Presl)	L10
<i>Uvaria</i> sp.	
<i>Wilughbeia</i> sp.	L11
<i>Logged forest</i>	
<i>Aglaia borneensis</i> Merr.	L1
<i>Artabotrys roseus</i> Boerl.	L2
<i>Bauhinia integrifolia</i> (Roxb.) Benth.	
<i>Bauhinia</i> sp.	L3
<i>Caesalpinia latisiliqua</i> (Cav.) Hattink	L4
<i>Caesalpinia oppositifolia</i> Hattink	L5
<i>Caesalpinia parviflora</i> Prain ex King	L6
<i>Caesalpinia scortechinii</i> (F.Muell.) Hattink	L7
<i>Caesalpinia</i> sp.	
<i>Celastrus</i> sp.	

<i>Cissus hastata</i> Miq.	
<i>Combretum nigrescens</i> King	L8
<i>Erycibe borneensis</i> (Merr.) Hoogl.	L9
<i>Jacquemontia tomentella</i> Hallier f.	
<i>Luvunga heterophylla</i> Merr.	
<i>Mucuna</i> sp.	
<i>Omphalea malayana</i> Merr.	L10
<i>Spatholobus macropterus</i> Miq.	L11
<i>Spatholobus</i> sp.	L12
<i>Spenodesme triflora</i> Wight	L13
<i>Strychnos ignatii</i>	L14
<i>Strychnos</i> sp.	L15
<i>Tetracera scandens</i> (L.) Merr.	L16
<i>Tetrastigma borneensis</i>	
<i>Tetrastigma</i> sp.	
<i>Uncaria cordata</i> (Lour.) Merr.	
<i>Uncaria</i> sp.	L17
<i>Uvaria sorzogonensis</i> (Presl)	L18
<i>Uvaria</i> sp.	L19
<i>Wilughbeia</i> sp.	L20

Table S2. Proportions of each of the types of climbing mechanisms for lianas and families in the case of trees present within the two types of forests surveyed.

Lianas	Tendrils	Scramblers	Twiners
Logged	0.22	0.32	0.46
Primary	0.03	0.26	0.67

Trees	Euphorbiaceae	Dipterocarpaceae	Meliaceae	Rubiaceae
Logged	0.13	0.14		0.18
Primary	0.13	0.12	0.12	0.02

Table S3. Characterization of the topology of plant-liana networks in primary and logged forests. “Null model” were obtained using 1000 permutations of the Patefield null model [4].

*: < 0.05, **: < 0.01, ***:

LOGGED				
	Observed (mean ± SE)	Null Model (mean ± SE)	z	P
Weighted Connectance	0.18 ± 0.03	0.21 ± 0.03	-2.96	0.003**
Nestedness (weighted NODF)	23.02 ± 6.47	26.70 ± 5.21	-1.69	0.04*
Complementary specialization (H2')	0.33 ± 0.08	0.19 ± 0.03	6.16	<0.001***
PRIMARY				
Weighted Connectance	0.16 ± 0.03	0.19 ± 0.02	-2.99	0.003**
Nestedness (weighted NODF)	16.28 ± 7.40	19.39 ± 7.94	-3.86	<0.001***
Complementary specialization (H2')	0.35 ± 0.08	0.21 ± 0.03	7.24	<0.001***

Table S4. Selection of best models evaluating the effect of logging, species richness and abundance on three descriptors of tree-liana network topology at the network level and two at the guild level, analysed by means of GLMMs. Factor significance is based on Likelihood Ratio Tests. *: < 0.05, **: < 0.01, ***:

	Metric	Variable	Estimate ± S.E.	z-value
<i>Network level metrics</i>	Weighted Connectance	Intercept	-1.69 ± 0.06	-28.95***
		Logging (primary)	-0.21 ± 0.05	-3.85***
		Liana sps richness	-0.06 ± 0.03	-2.46*
	Nestedness (weighted NODF)	Intercept	2.99 ± 0.07	42.31***
		Tree sps richness	-0.19 ± 0.09	-2.04*
		Liana abundance	0.25 ± 0.09	2.72**
	Complementary specialization (H₂)	Intercept	0.31 ± 0.03	8.89***
		Logging (primary)	0.07 ± 0.03	2.35*
		Tree sps richness	0.02 ± 0.02	1.25
<i>Guild level metrics</i>	Tree specialization	Intercept	0.14 ± 0.03	4.48***
		Tree sps richness	0.02 ± 0.01	1.85
		Liana abundance	-0.03 ± 0.01	-2.80**
	Liana specialization	Intercept	0.15 ± 0.02	9.31***
		Liana abundance	-0.03 ± 0.02	-1.85

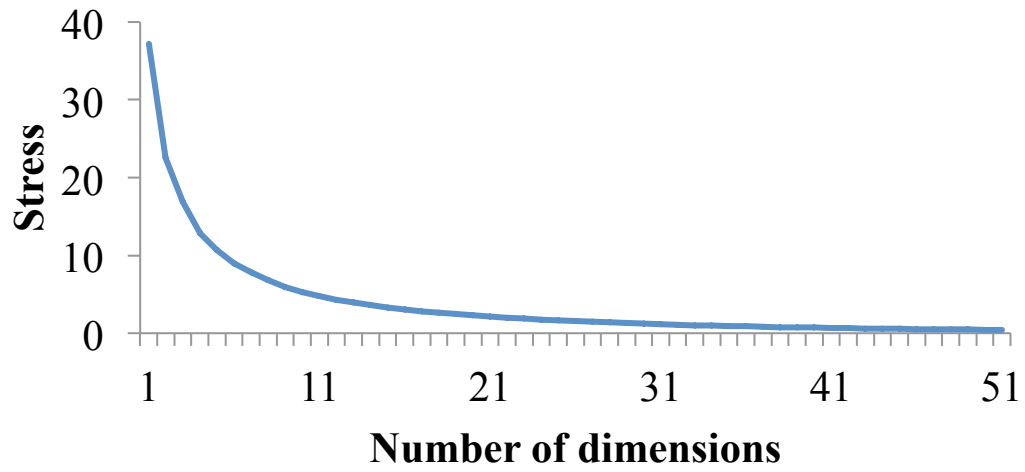


Figure S1. Relationship between number of dimensions used in the non-metric multidimensional analysis (NMDS) and output stress values.

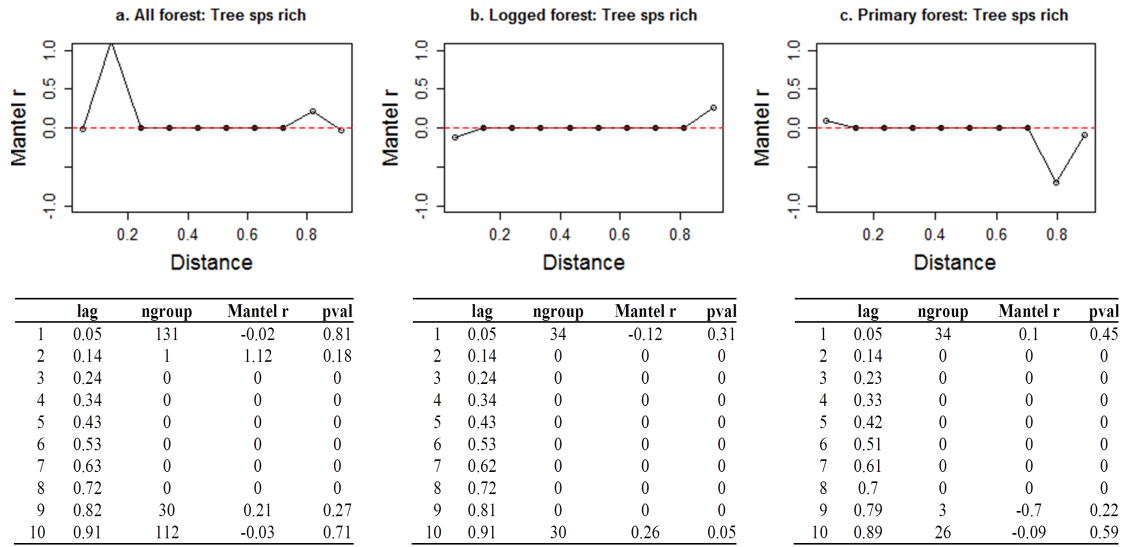


Figure S2. Partial Mantel correlograms and Mantel r value tables for the linear regression residuals of tree species richness against locations for (a) the whole sample, (b) within logged forests and (c) primary forest.

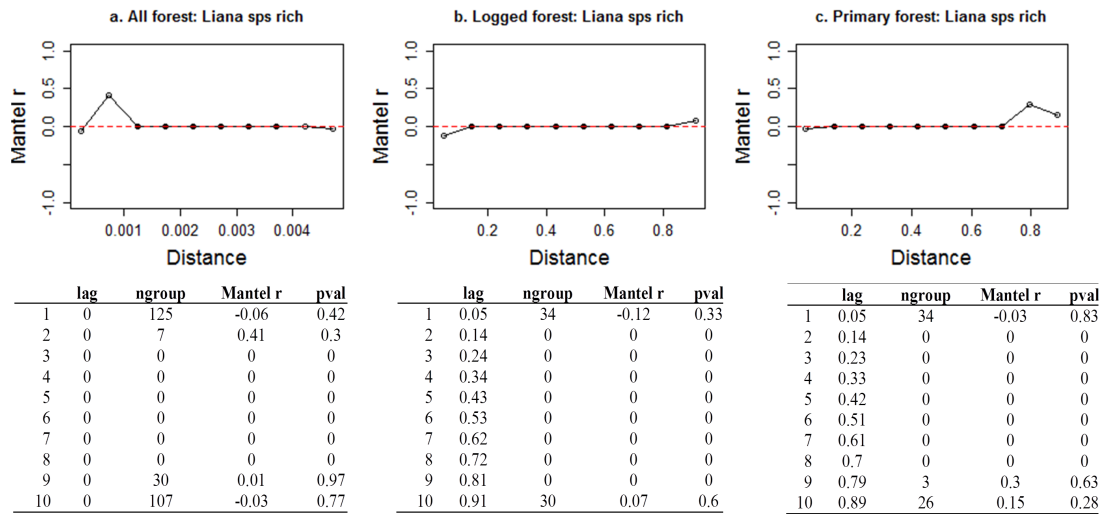


Figure S3. Partial Mantel correlograms and Mantel r value tables for the linear regression residuals of liana species richness against locations for (a) the whole sample, (b) within logged forests and (c) primary forest.

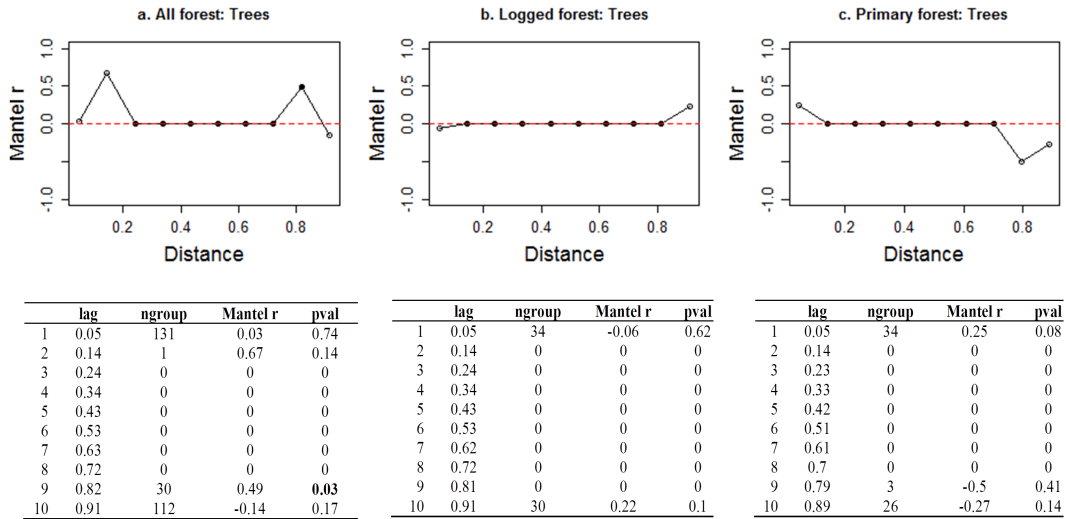


Figure S4. Partial Mantel correlograms and Mantel r value tables for the linear regression residuals of tree species composition against locations for (a) the whole sample, (b) within logged forests and (c) primary forest.

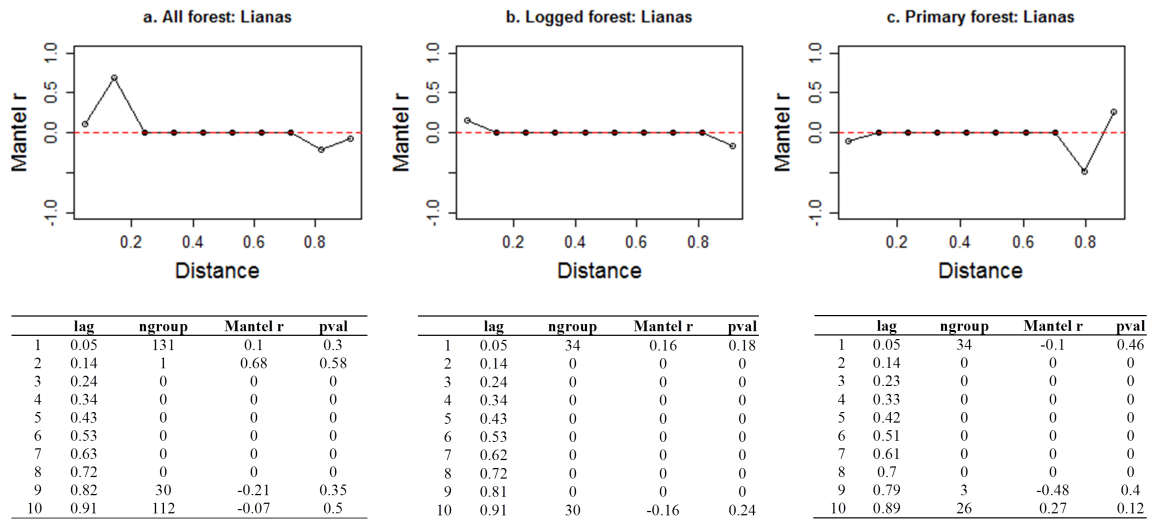


Figure S4. Partial Mantel correlograms and Mantel r value tables for the linear regression residuals of liana species composition against locations for (a) the whole sample, (b) within logged forests and (c) primary forest.

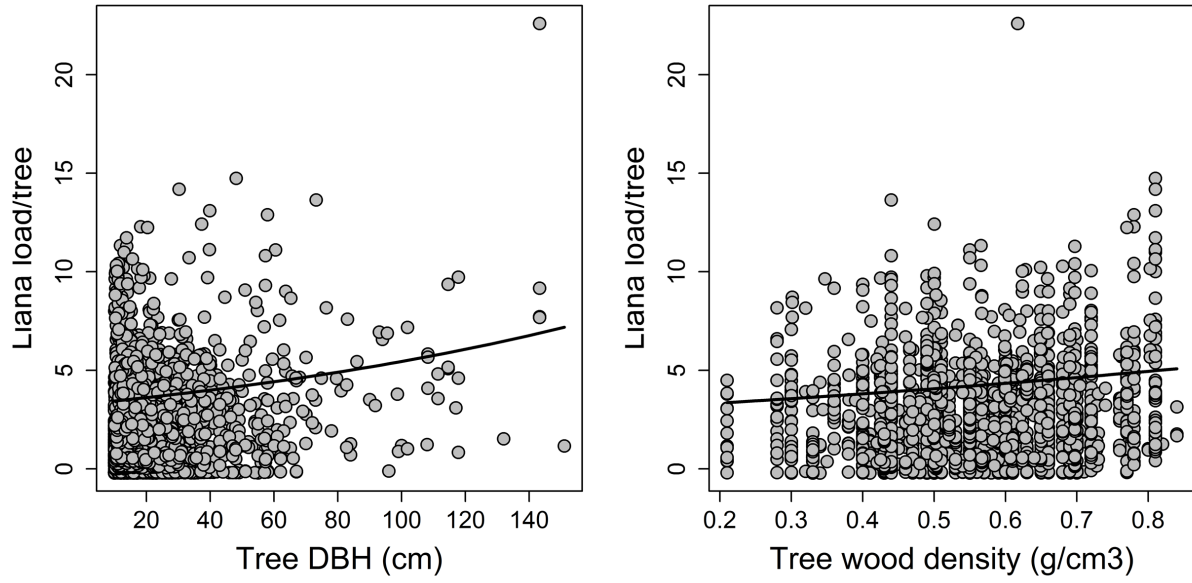


Figure S6. Partial residual plots showing results of GLMM models analysing the effect of tree host DBH and tree host wood density on liana load per tree.

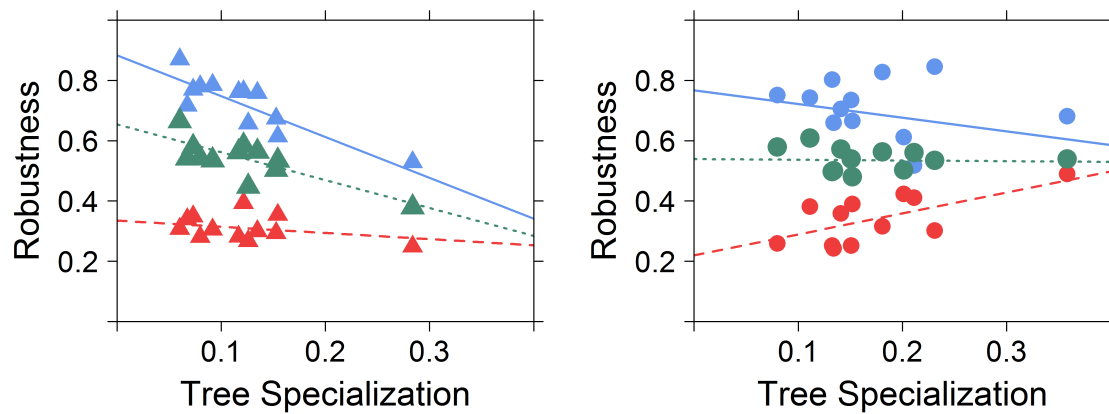


Figure S7. Partial residual plots showing how tree specialization relates to network robustness to the local species loss of selected host trees in logged (triangles) and primary (circles) forests and under three species loss scenarios. Blue points and solid lines represent the rare species loss scenario, green points and dotted lines the random species loss scenario and red points and dashed lines the connected species loss scenario.

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