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***New Phytologist* Supporting Information**

Article title: **Individual tree damage dominates mortality risk factors across six tropical forests**

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The following Supporting Information is available for this article:

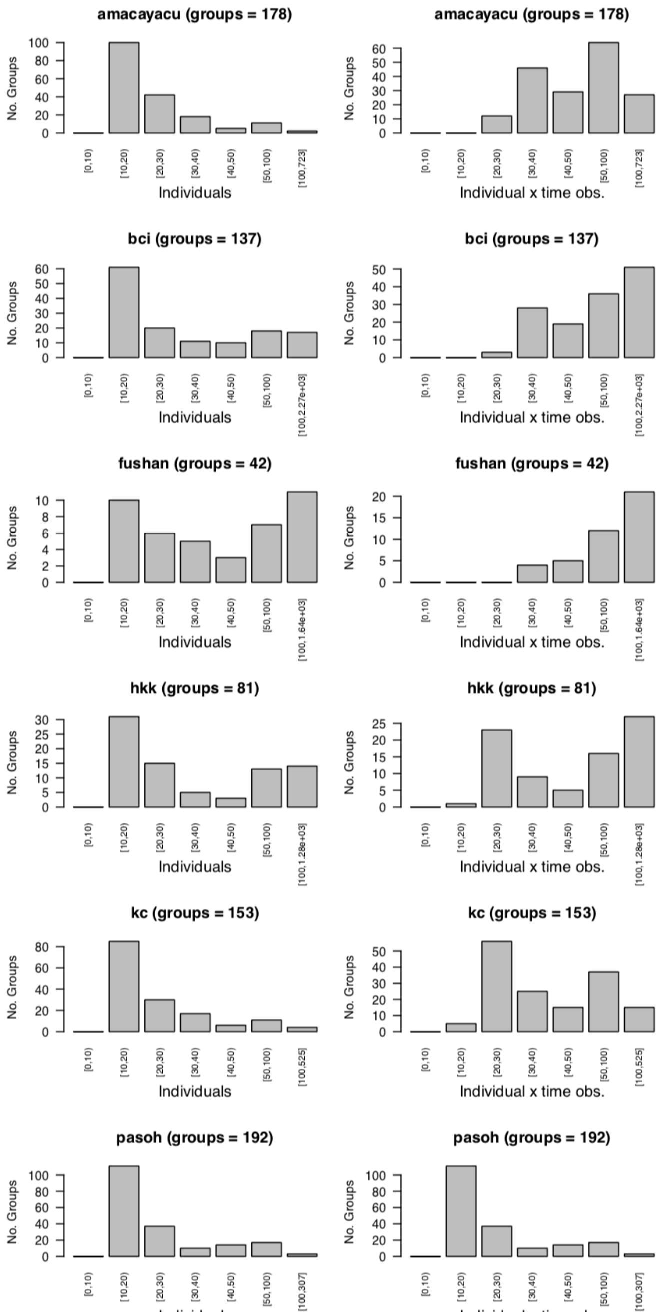

Fig. S1 No. individuals and observations in GLMM random-effect groups.

Distribution of the number of individuals (first column) and individual × interval observations (second column) included in taxonomic groups for which random intercepts and slopes were fit in each of the condition × site GLMMs. Species with less than 10 individuals were grouped into larger taxonomic groups at the level of genera, families, or a single residual group. A sensitivity analysis including different minimum taxonomic group sizes is presented in Fig. S12.

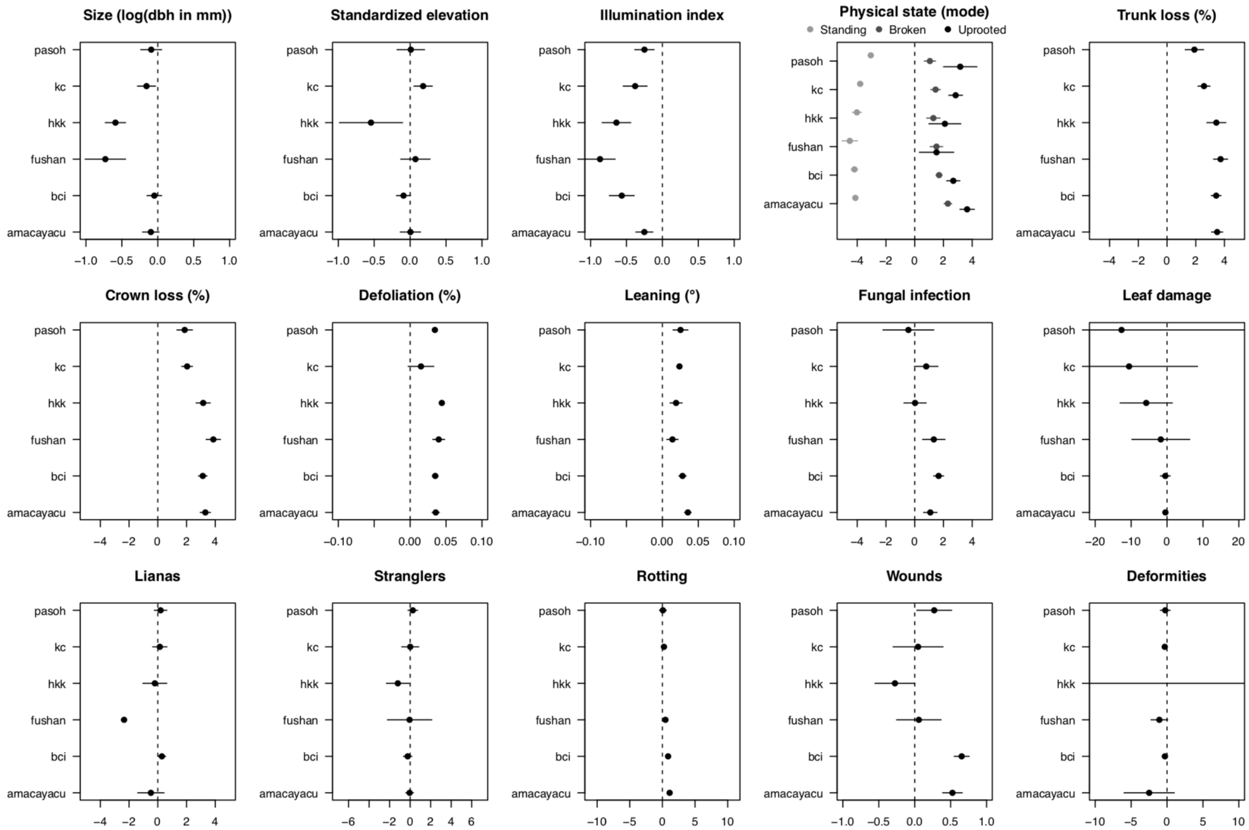

Fig. S2 Site-level GLMM coefficients for each condition.

Population averaged slopes for the mortality GLMMs (x-axis) based on the 15 conditions evaluated in each of the six tropical forests. Error bars represent the Wald confidence interval for the slope. Note that in some cases the confidence intervals are larger than the total range of the x-axis presented here, which represents the high variability of the estimated parameter in a given site. Estimated slope for HKK in deformities is not shown as it is -230.65. GLMMs summary statistics and analysis of residuals are presented for each site in File S2.

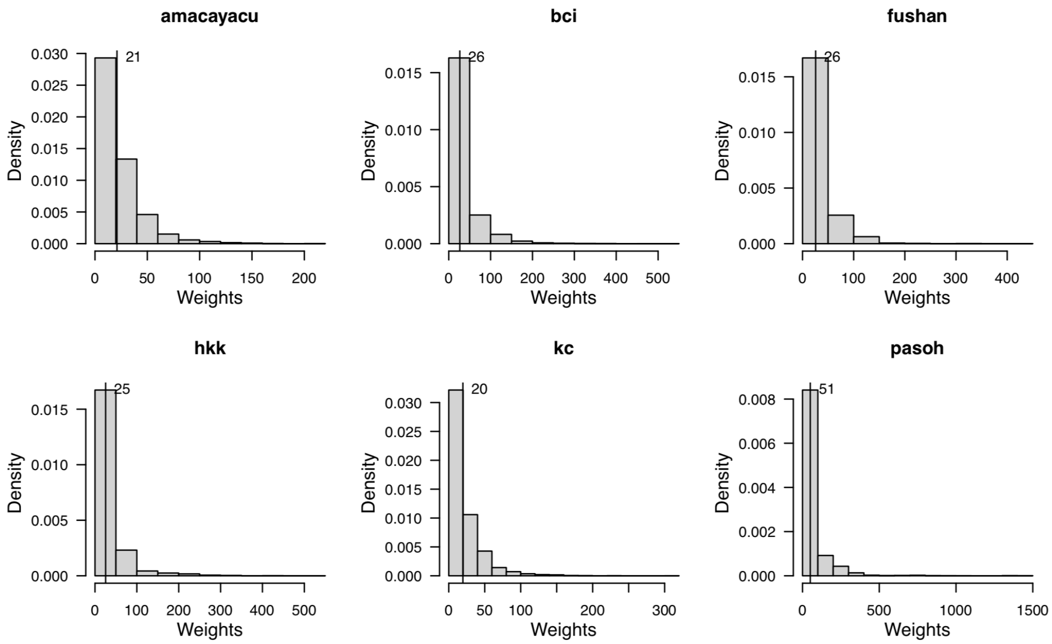

Fig. S3 Distribution of weights used to upscale results to the forest level.
Distribution of weights used at the individual level in each of the six tropical forest plots studied. Vertical line and number represent the mean weight. These weights are interpreted as the number of trees in the full forest plot that each individual in the sample represents and are used in our analyses to obtain forest-wide estimates.

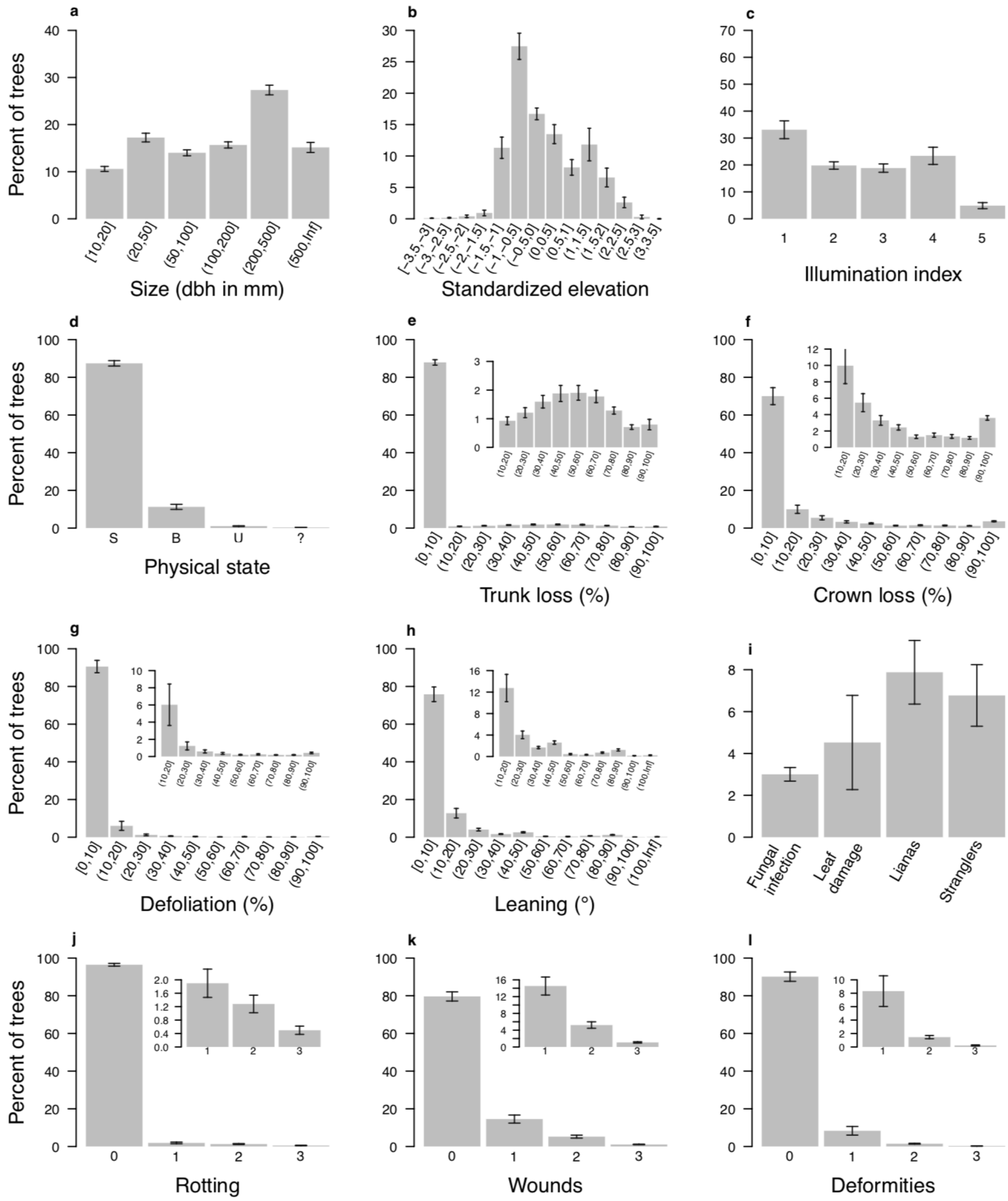

Fig. S4 Sample-based conditions.

Sample-based frequencies of tree-level conditions on living trees, with means (bars) and standard errors (whiskers) calculated over 14 site by interval combinations (from six tropical forest sites). Inset figures show the distribution of a given condition from the second class (i.e., removing the first, most common class) and are presented to improve visualization of condition distributions. In (b), values refer to the standard normal deviations of the elevation within the plot. In (d), “S” refers to standing; “B” to broken, “U” to uprooted, and “?” to unidentified physical states in living trees. Trees found “B” and “U” were grouped into the “U” category. In (j-l), “0” refers to absence, “1” to small, “2” to large, and “3” to massive (Arellano et al. 2021).

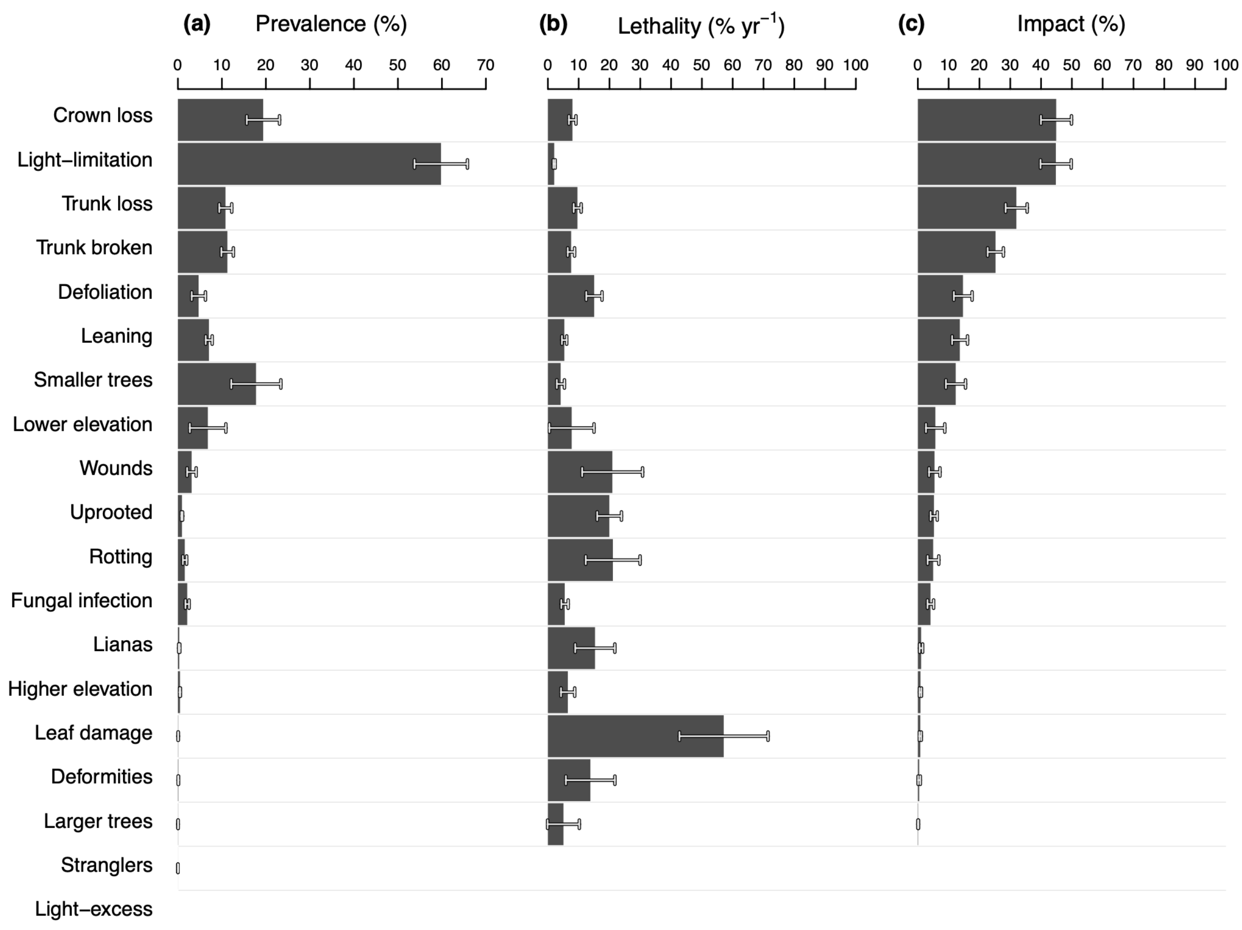

Fig. S5 Sample-based prevalence, lethality, and impact of risk factors.

Sample-based prevalence, lethality, and impact of 19 risk factors assessed during 14 one-year census intervals in six tropical forests. Prevalence (a) is the estimated proportion of individuals in the forest with the risk factor at the beginning of the interval. The lethality (b) is the difference between the mortality rate of individuals with a given risk factor and the mortality rate of individuals without the risk factor. The impact (c) is the proportion of overall mortality in the forest that is associated with the risk factor, i.e., the percent of mortality that would not have occurred if the risk factor is not present in the forest. Note that having a risk factor means that the tree both had the condition and was estimated to have a mortality rate elevated more than two-fold the baseline because of it. Risk factors are ranked by the total contribution to overall mortality. Error bars are standard errors estimated from the 14 site by census interval combinations among the six sites. “Sample-based” means this is based on patterns in the sampled trees alone, rather than based on upscaling to the whole forest using weighting factors, as in main text. *See* Materials and Methods for details.

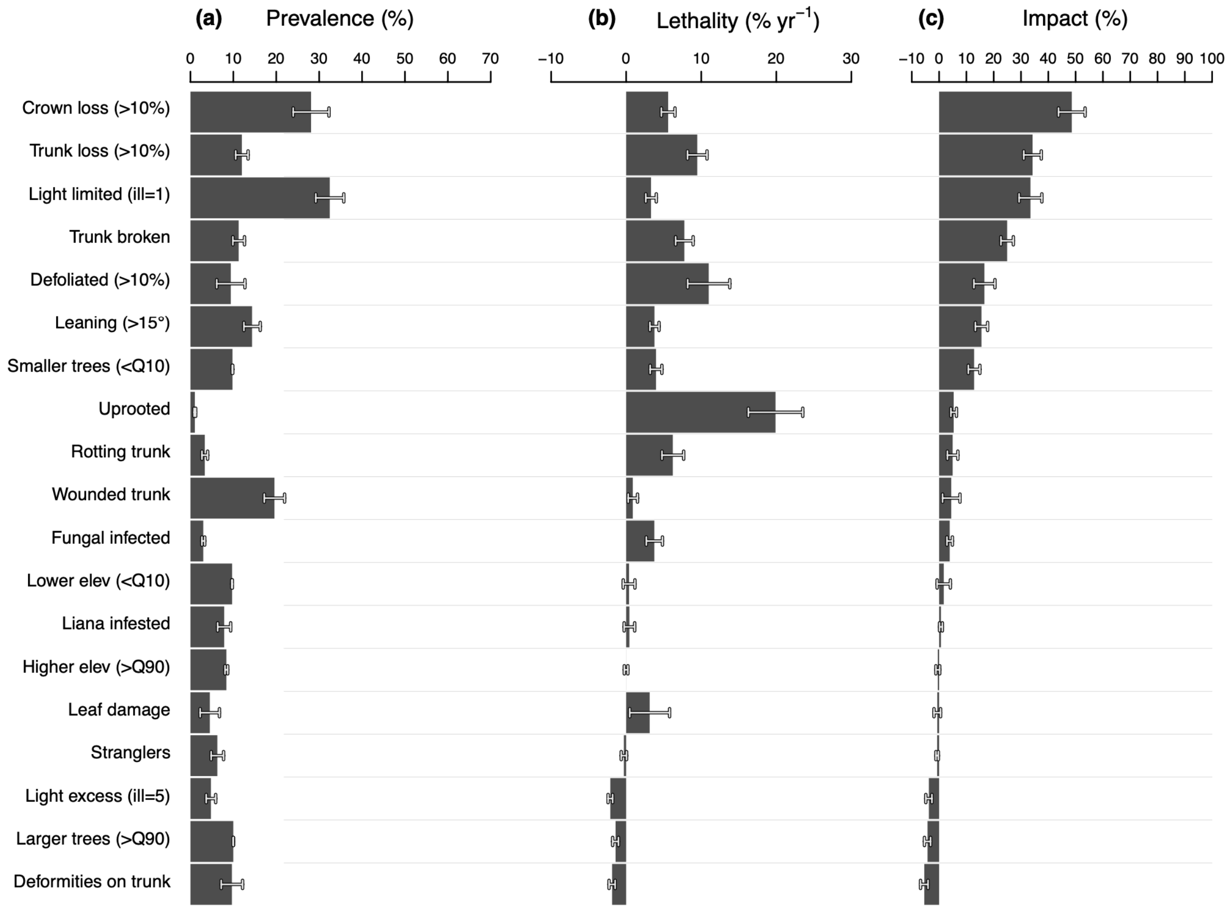

Fig. S6 Sample-based prevalence, lethality, and impact of *risky* conditions.
Sample-based prevalence, lethality, and impact of 19 risky conditions assessed during 14 one-year census intervals in six tropical forests. Risky conditions are arbitrarily defined in the sample, but not based on model-informed risk factor assignments. Prevalence (a) is the proportion of individuals in the sample with the risky condition at the beginning of the interval. The lethality (b) is the difference between the mortality rate of individuals with a given risky condition and the mortality rate of individuals without the risky condition. The impact (c) is the proportion of overall mortality in the forest that is associated with the risky condition. Risky conditions are ranked by impact. Error bars are standard errors estimated from the 14 site by census interval combinations among the six sites. The risky conditions were defined as follows: Crown loss, trees with >10% loss in the crown; Trunk loss, trees with >10% loss in the trunk; Light limited, trees with a value of "1" in the illumination index; Trunk broken, trees recorded as broken "B" in the physical state; Defoliated, trees with >10% defoliation; Leaning, trees with more than 15° of leaning from vertical; Smaller trees, trees smaller than the 10th dbh percentile in the site x census interval; Uprooted, trees recorded as uprooted "U" in the physical state; Rotting trunk, trees with presence of rotting in the trunk (degree ≥ 1); Wounded trunk, trees with presence of wounds on the trunk (degree ≥ 1); Fungal infected, trees with presence of

fungal infections; Lower elev.; trees located at sites that are lower than the 10th elevation percentile in the plot; Liana infested; trees with >50% of their crown covered with lianas; Higher elev.; trees located at sites that are higher than the 90th elevation percentile in the plot; Leaf damage, trees with >25% lamina loss; Stranglers, trees with presence of stranglers on the trunk; Light excess, trees with a value of “5” in the illumination index; Larger trees, trees larger than the 90th dbh percentile in the site x census interval; Deformities on trunk, trees with presence of deformities on the trunk (degree ≥ 1).

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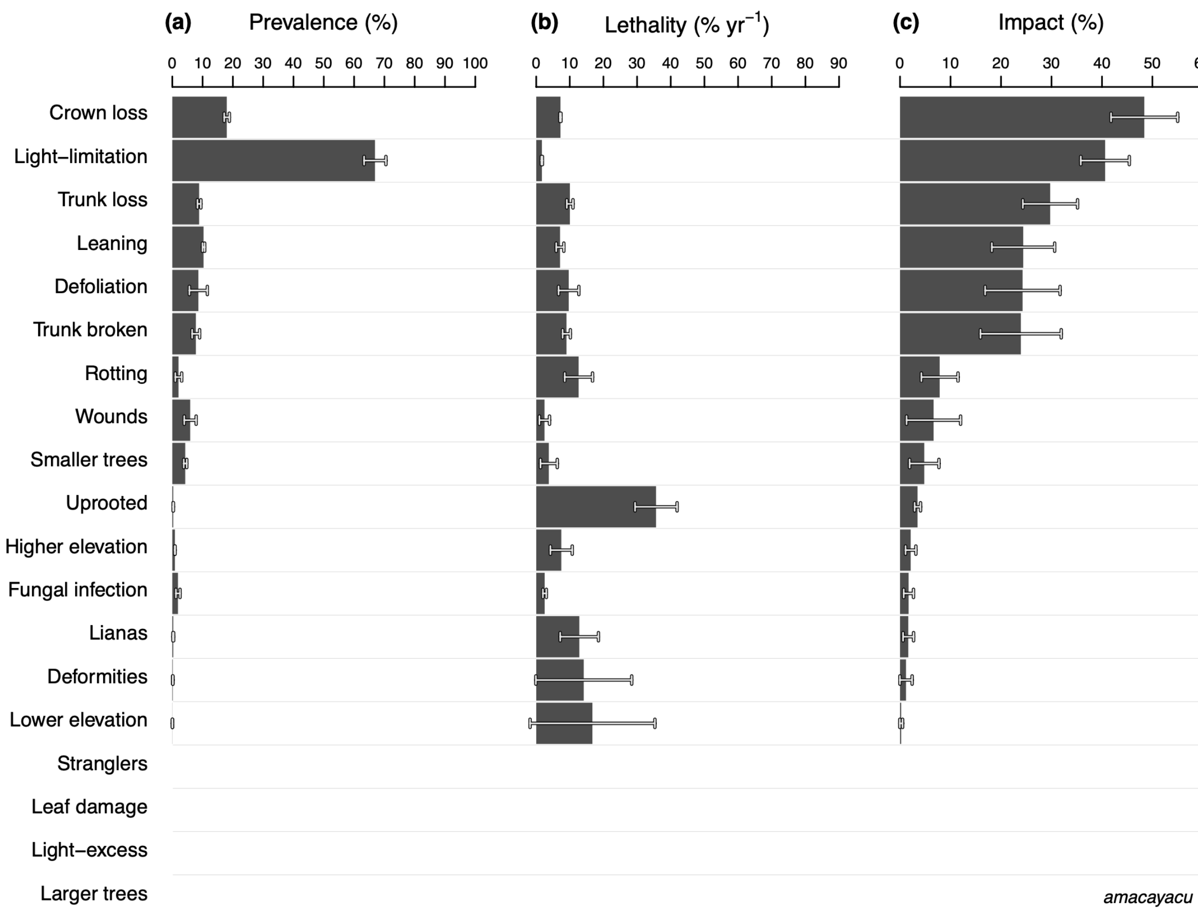


Fig. S7 Site-specific forest-wide prevalence, lethality, and impact of risk factors.
Site-specific forest-wide prevalence, lethality, and impact of 19 risk factors assessed in six tropical forests: (a-c) Amacayacu, (d-f) BCI, (g-i) Fushan, (j-l) HKK, (m-o) KC, and (p-r) Pasoh. Prevalence (a) is the estimated proportion of individuals in the forest with the risk factor at the beginning of the interval. The lethality (b) is the difference between the mortality rate of individuals with a given risk factor and the mortality rate of individuals without the risk factor. The impact (c) is the proportion of overall mortality in the forest that is attributed with the risk factor, i.e., the percent of mortality that would not have occurred if the risk factor is not present in the forest. Note that having a risk factor means that the tree both had the condition and was estimated to have a mortality rate elevated more than two-fold the baseline because of it. Risk factors are ranked by impact. Error bars are standard errors estimated from the census interval combinations within each site. All values are based on extrapolating from the observed sample to all trees ≥ 10 mm dbh in the forest as a whole, with extrapolation based on weighting factors accounting for differences in abundances across classes defined by combinations of dbh and taxonomic group. *See* Materials and Methods for details.

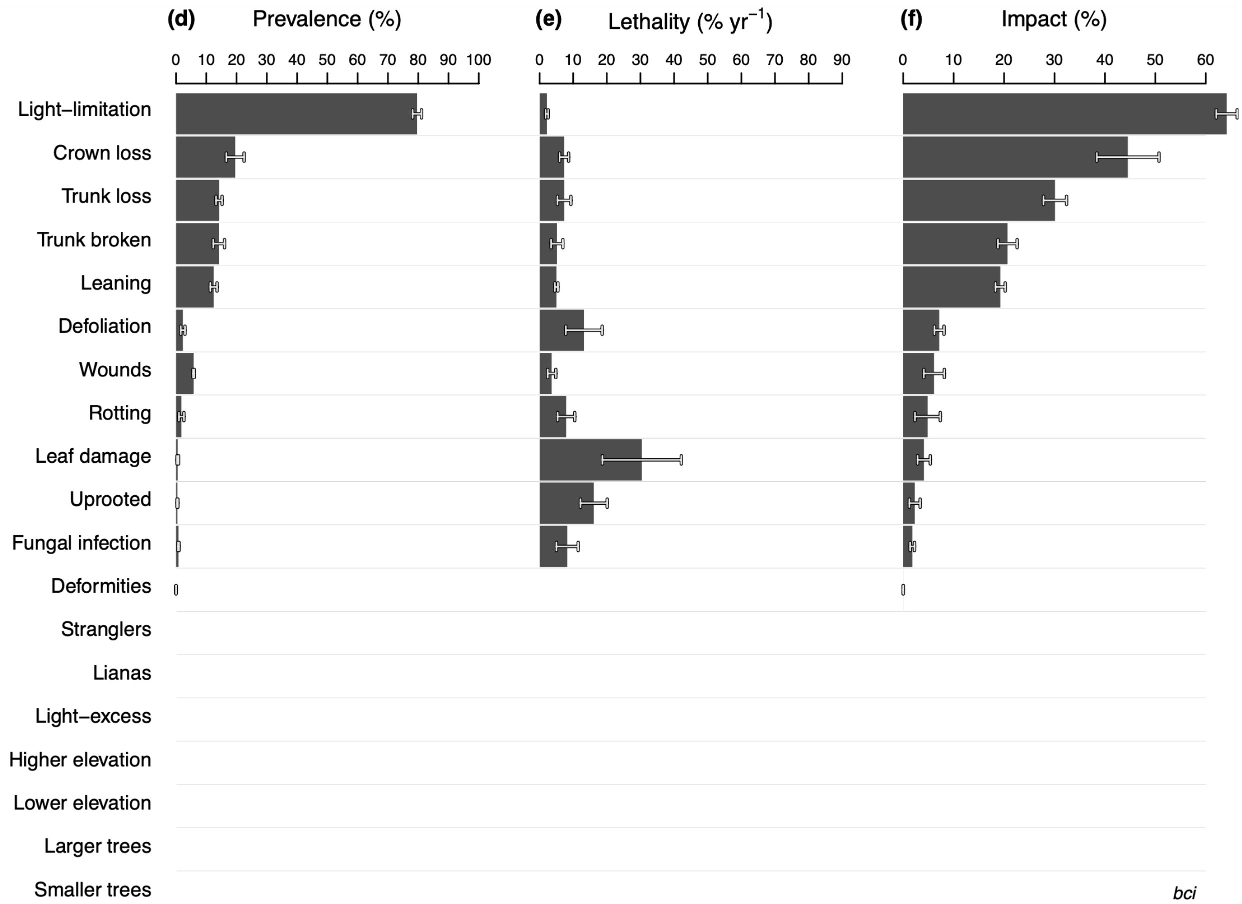
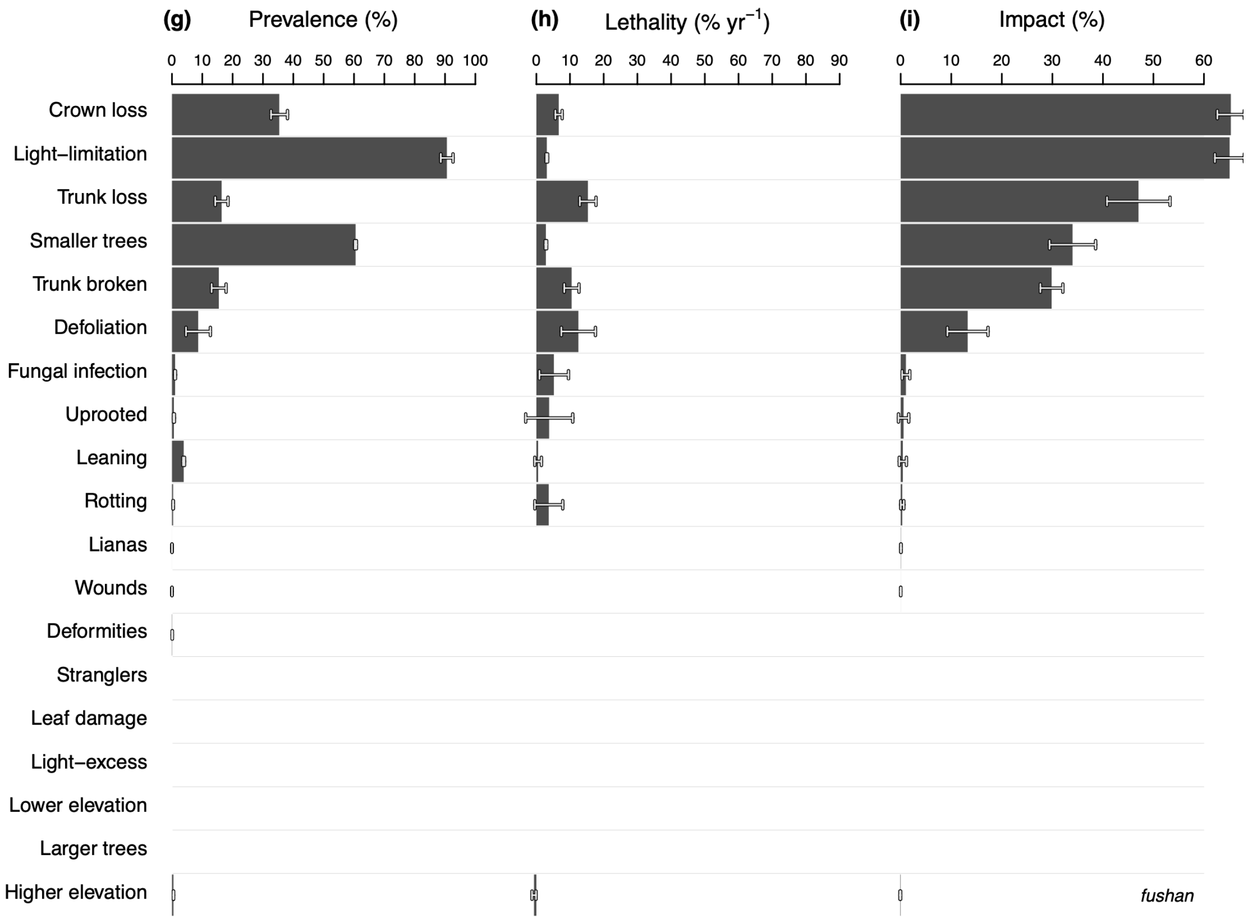


Fig. S7 (continued)



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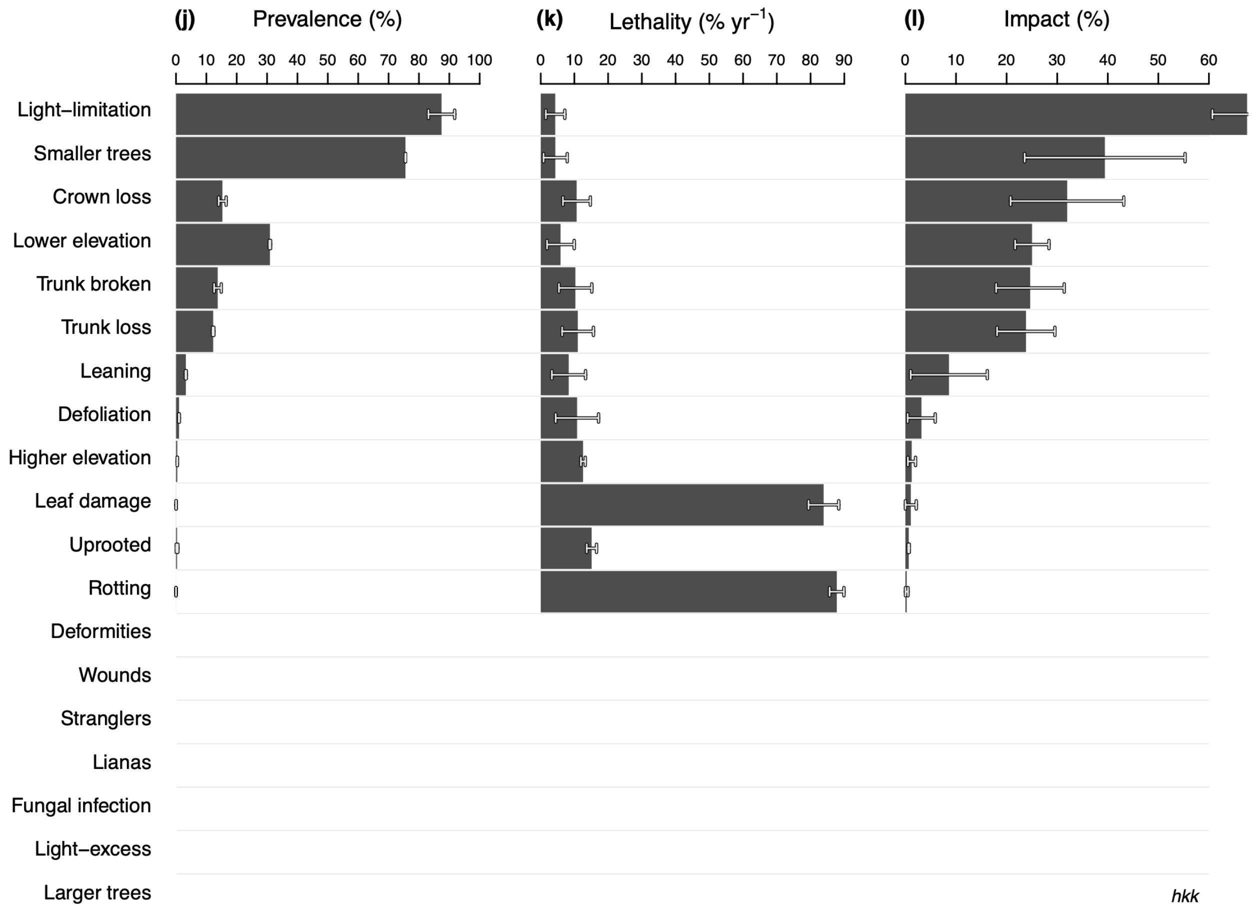

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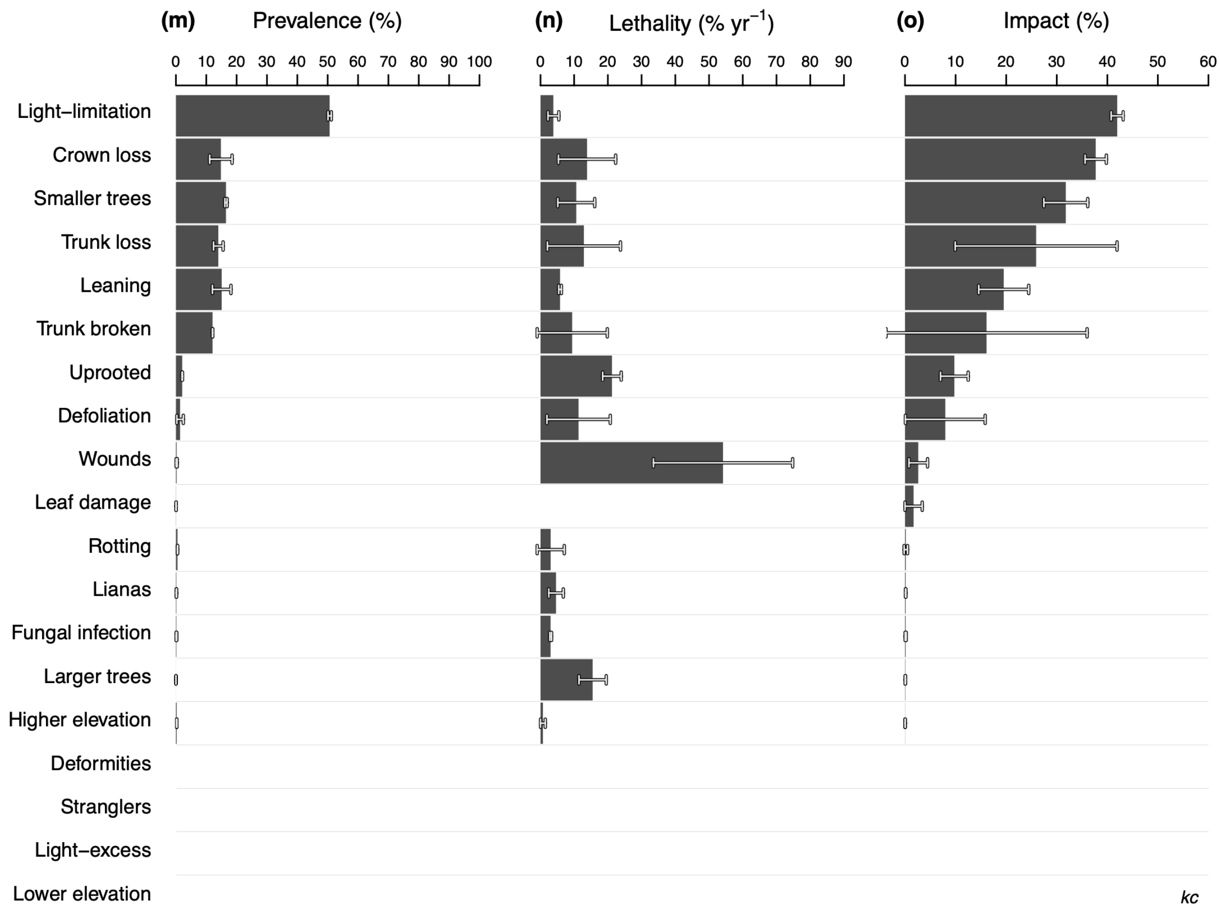

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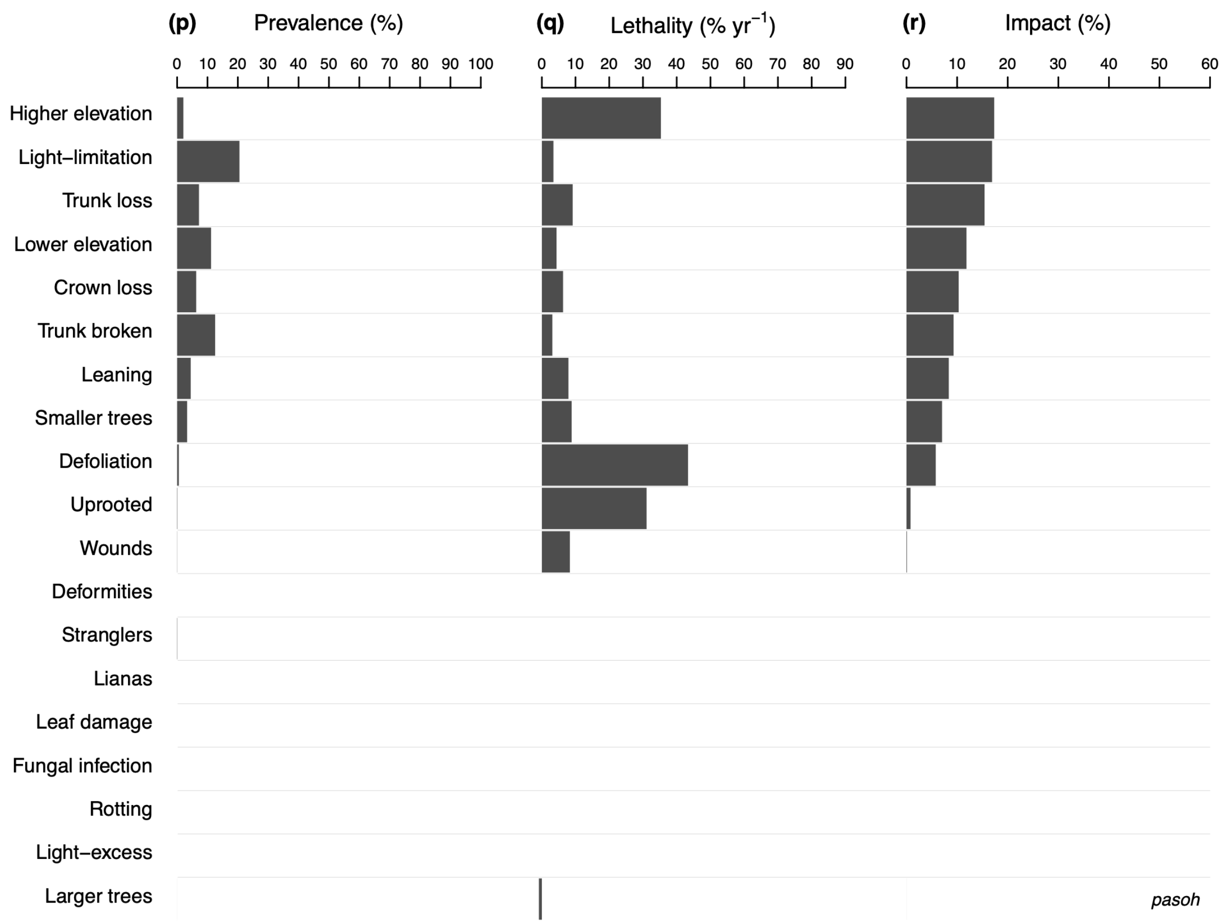

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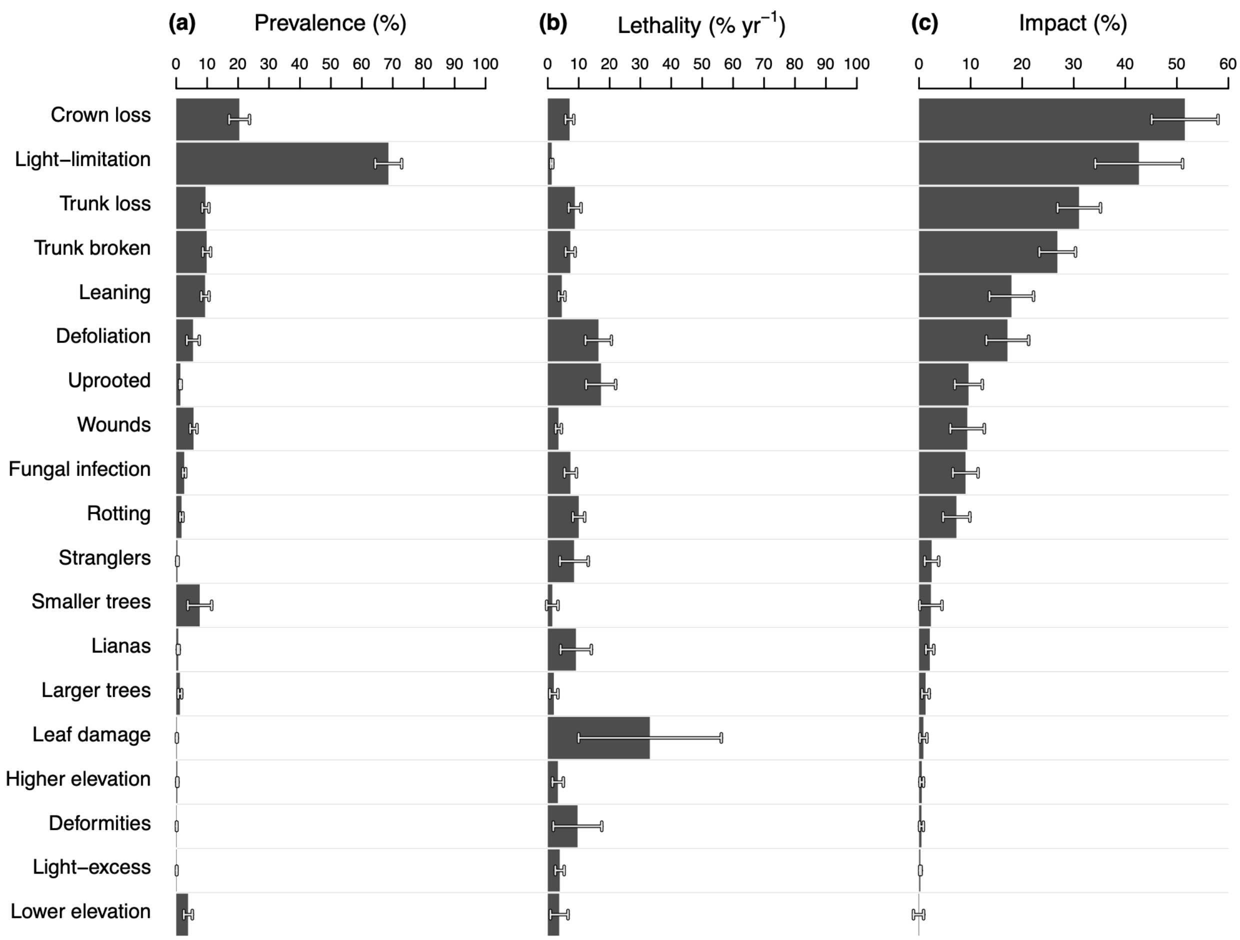

Fig. S8 Forest-wide prevalence, lethality, and impact of risk factors on trees ≥ 100 mm dbh. Estimated forest-wide prevalence, lethality, and impact of 19 risk factors on large trees (≥ 100 mm dbh) assessed during 14 one-year census intervals in six tropical forests. Prevalence (a) is the estimated proportion of individuals in the forest with the risk factor at the beginning of the interval. The lethality (b) is the difference between the mortality rate of individuals with a given risk factor and the mortality rate of individuals without the risk factor. The impact (c) is the proportion of overall mortality in the forest that is associated with the risk factor, i.e., the percent of mortality that would not have occurred if the risk factor is not present in the forest. Note that having a risk factor means that the tree both had the condition and was estimated to have a mortality rate elevated more than two-fold the baseline because of it. Risk factors are ranked by impact. Error bars are standard errors estimated from the 14 site by census interval combinations among the six sites. *See* Materials and Methods for details.

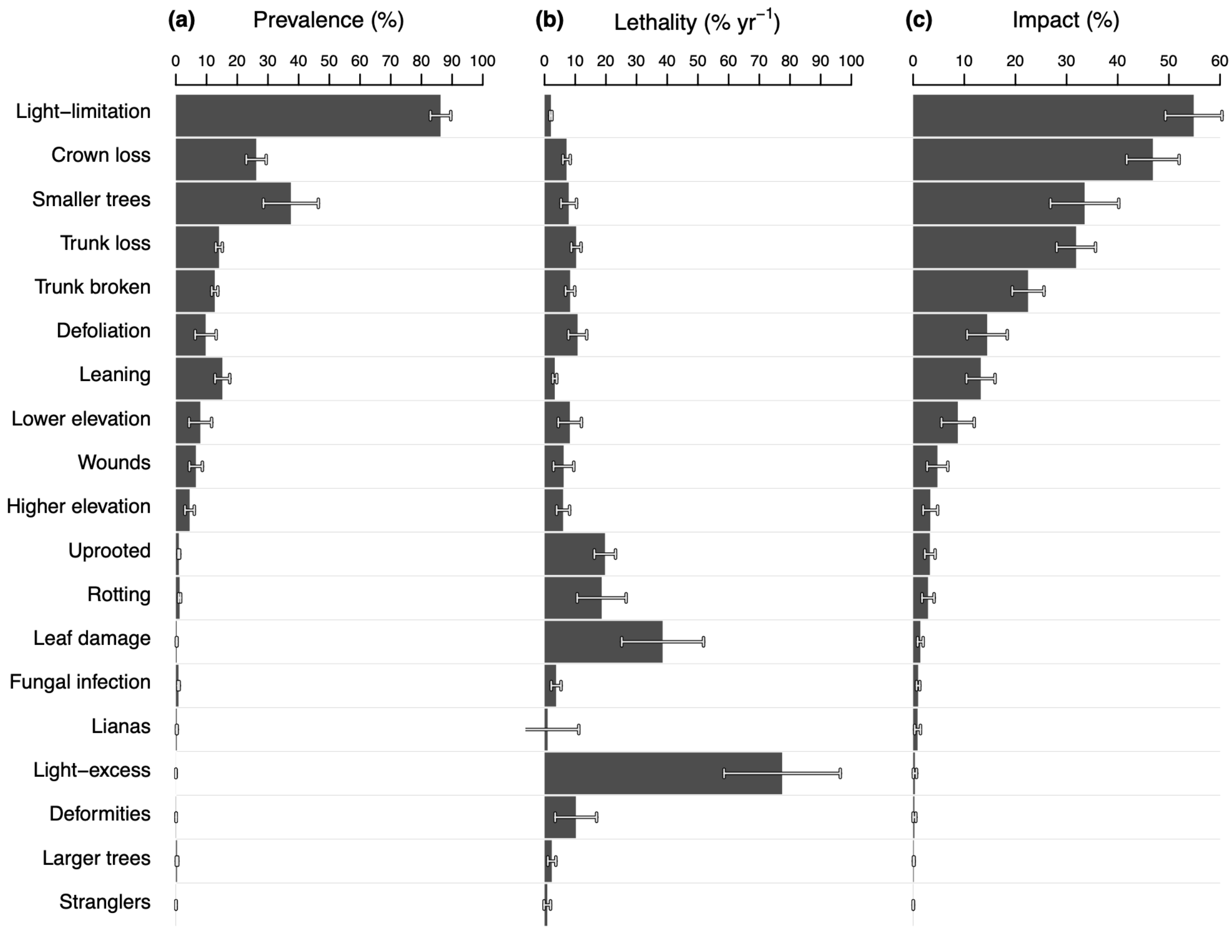

Fig. S9 Forest-wide prevalence, lethality, and impact using a 1.5-fold threshold to define risks. Estimated forest-wide prevalence, lethality, and impact using a 1.5-fold threshold to define risks (see main text). The 19 risk factors were assessed during 14 one-year periods in six tropical forests. Risk factors are ranked by the total contribution to overall mortality. Error bars are standard errors estimated from the 14 site by census interval combinations among the six sites. See main text for a detailed description. *See* Materials and Methods for details.

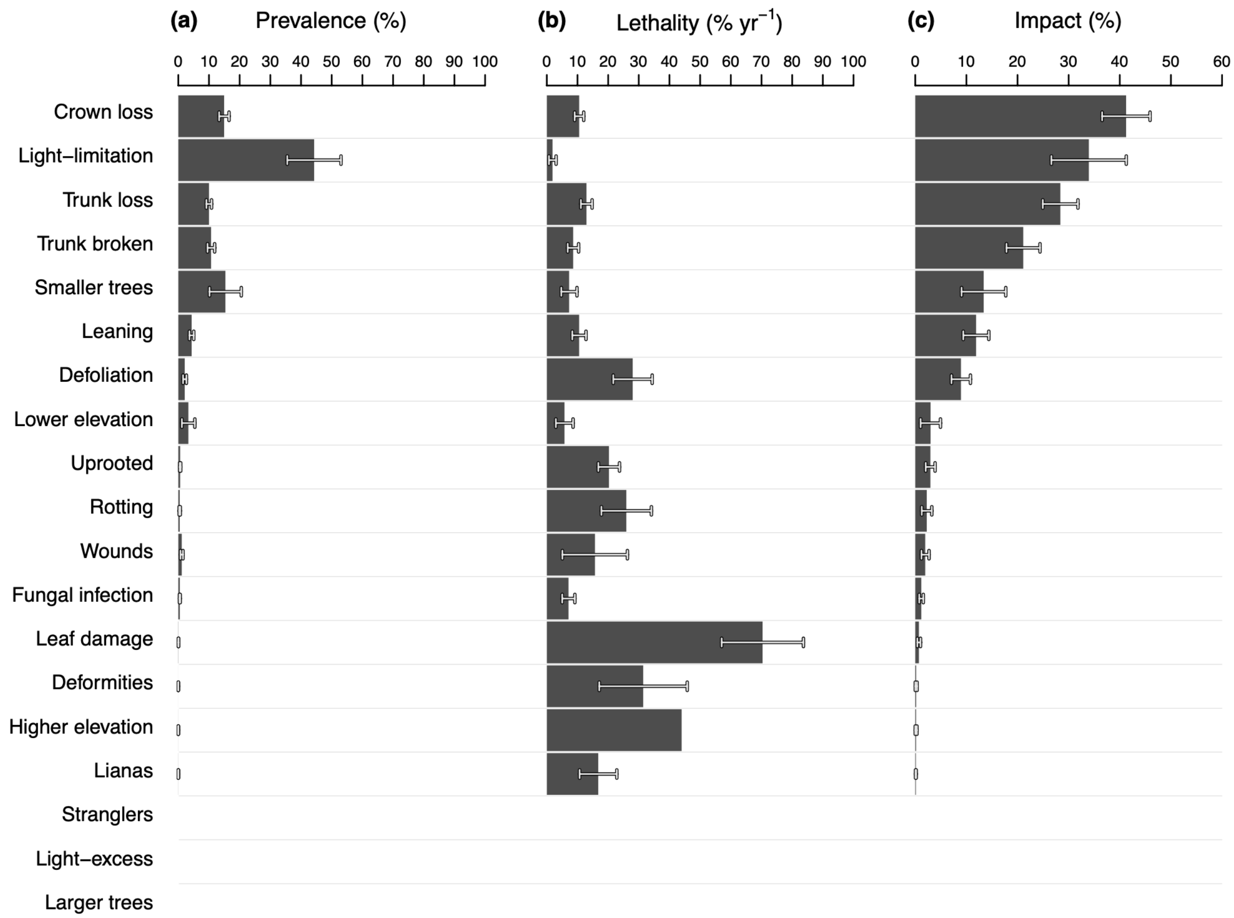

Fig. S10 Forest-wide prevalence, lethality, and impact using a three-fold threshold to define risks.

Estimated forest-wide prevalence, lethality, and impact using a three-fold threshold to define risks (see main text). The 19 risk factors were assessed during 14 one-year periods in six tropical forests. Risk factors are ranked by the total contribution to overall mortality. Error bars are standard errors estimated from the 14 site by census interval combinations among the six sites. See main text for a detailed description. *See* Materials and Methods for details.

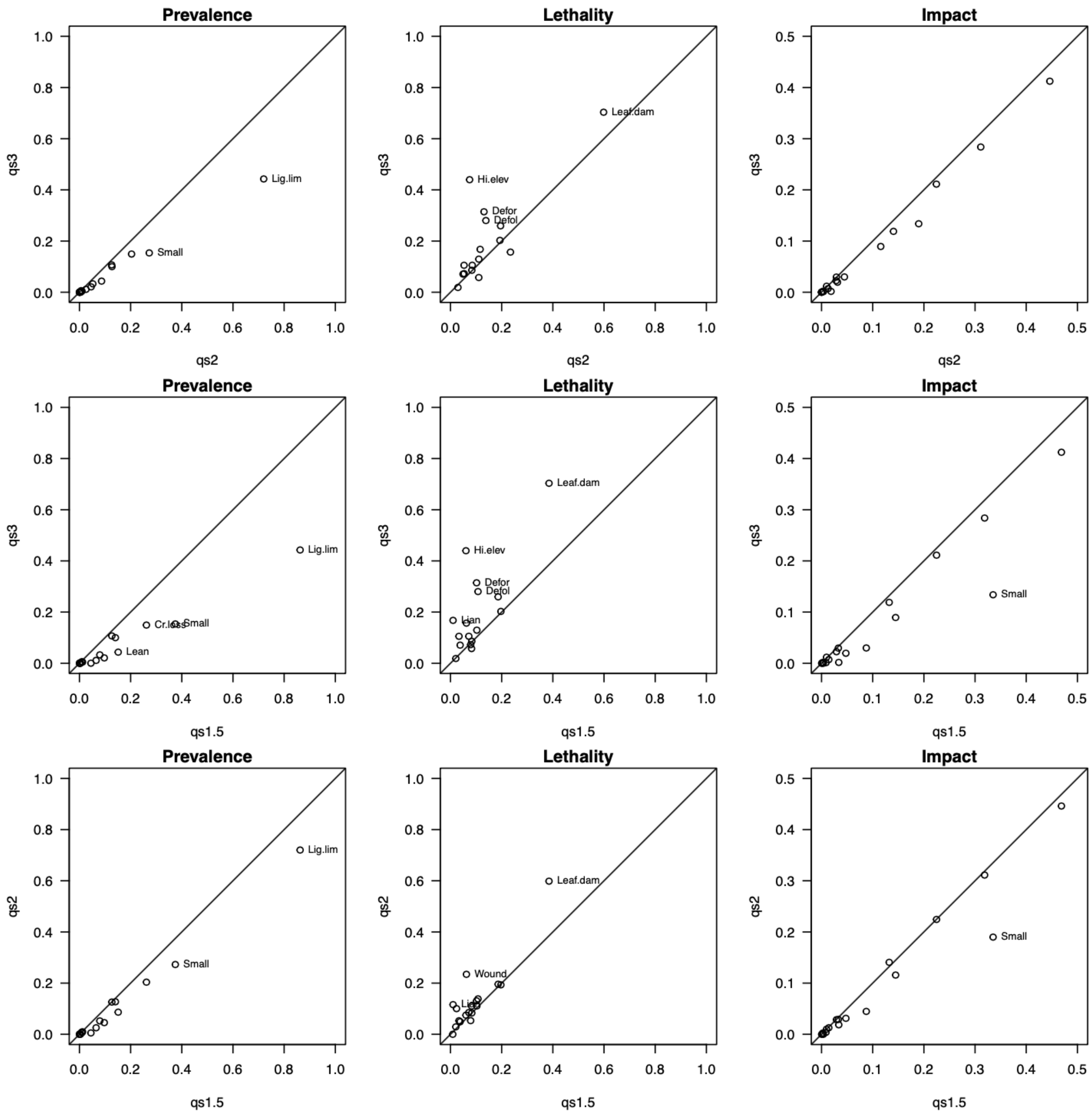

Fig. S11 Sensitivity analysis using different thresholds in the risk definitions.
Sensitivity analysis for results on the average prevalence, lethality, and impact across 14 census intervals when using different thresholds in the risk definitions in six tropical forests. An individual tree *i* is defined as 'at risk' under a condition *c* if $\left(mp_{c,s,i,t}/mq_{c,s}\right) > \ threshold$, i.e., if its probability of mortality was more than two-fold higher than the corresponding baseline mortality for its species in its site. Results are shown for thresholds = 2 (qs2, the one used in the main text), 3 (qs3), and 4 (qs4). Names of risks factors are shown for those with differences larger than |0.1|. By definition, the lower the threshold the higher the number of trees assigned a risk factor; therefore, higher averaged values of prevalence, impact, and lower values of lethality are expected. *See* Materials and Methods for details.

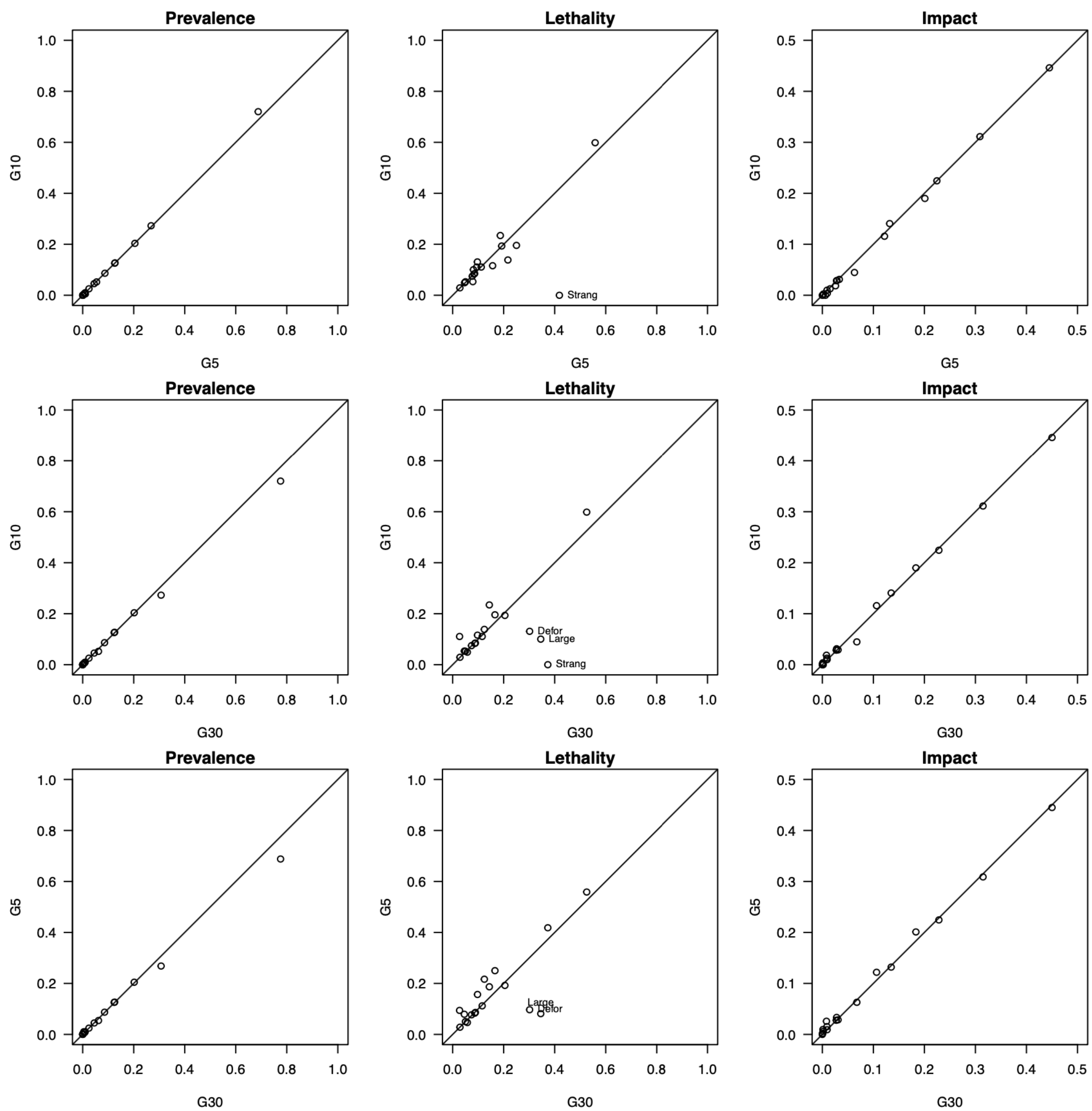

Fig. S12 Sensitivity analysis using different minimum taxonomic group sizes.
Sensitivity analysis for results on the average prevalence, lethality, and impact across 14 census intervals from mortality models using different minimum taxonomic groups sizes in six tropical forests. Results are shown for taxonomic groups with a minimum of 5 individuals (G5), 10 individuals (G10, the one used in the main text), and 30 individuals (G30). Names of risks factors are shown for those with differences larger than |0.1|. *See* Materials and Methods for details.

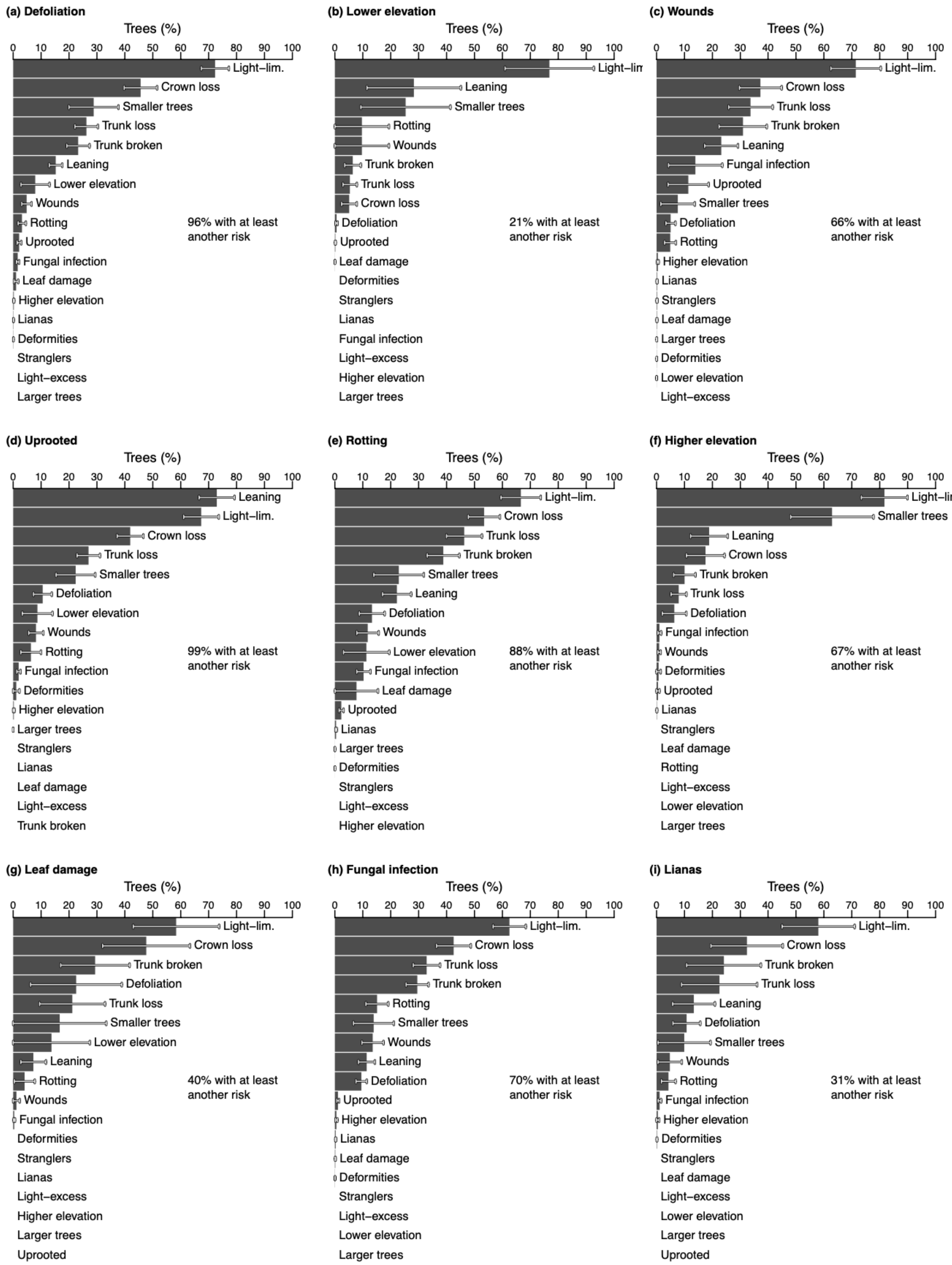

Fig. S13 Co-occurrence of risk factors in the rest of risks (complementary to Fig. 4).

Co-occurrence of risk factors in each of the following nine risks in importance. For each risk, bars in each panel show the percentage of trees (from higher to lower) that were also assigned other risks. Error bars are standard errors estimated from the 14 periods. Co-occurrence for the six most important risks is shown in the main text. The rest of the risks are not shown due to their low prevalence.

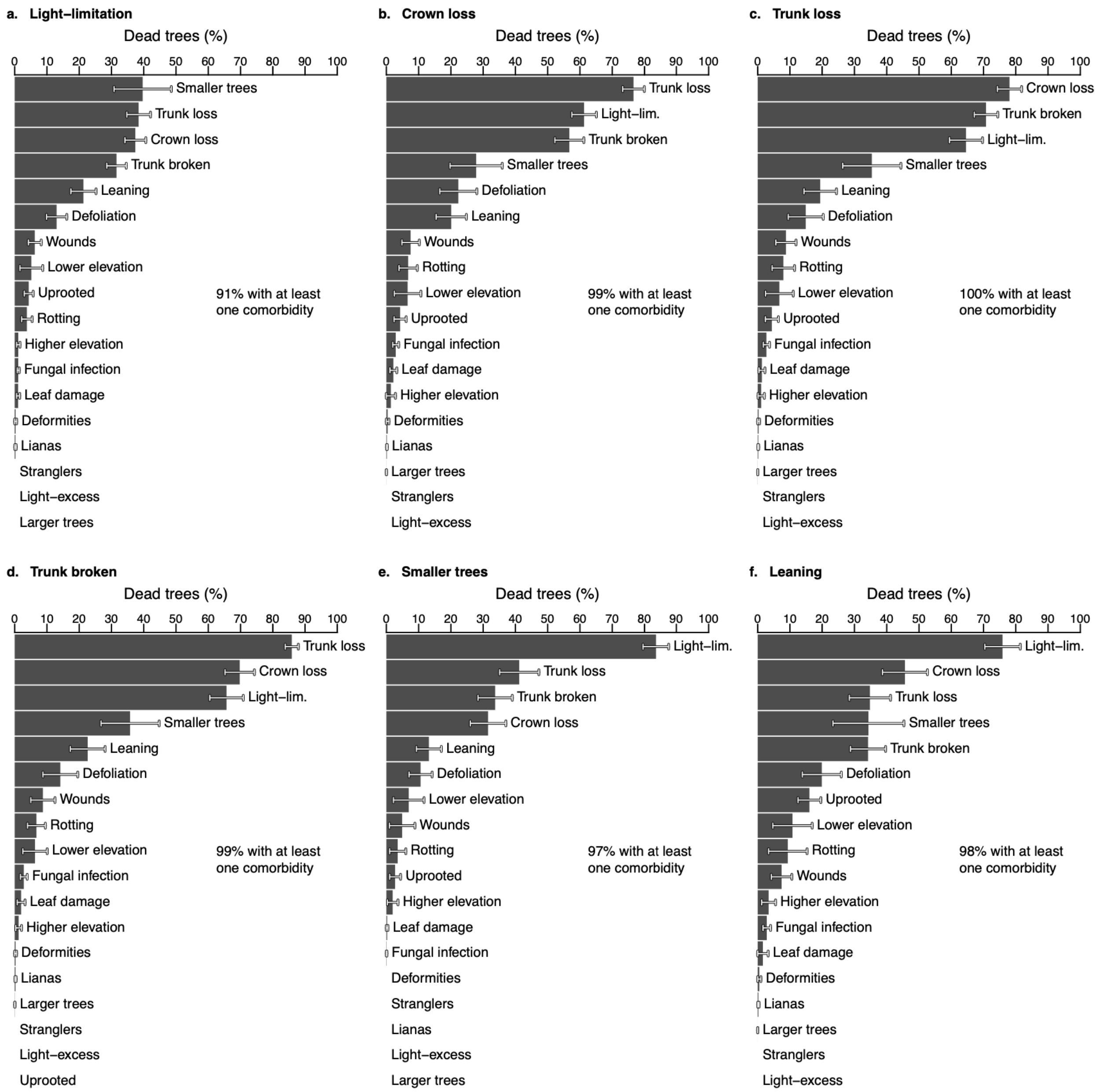

Fig. S14 Co-occurrence of risk factors in trees that subsequently *died*.
Co-occurrence of risk factors in trees that subsequently died (commonly referred to as multimorbidity). For each risk, bars in each panel show the percentage of trees (from higher to lower) that were also assigned other risks. Error bars are standard errors estimated from the 14 periods.

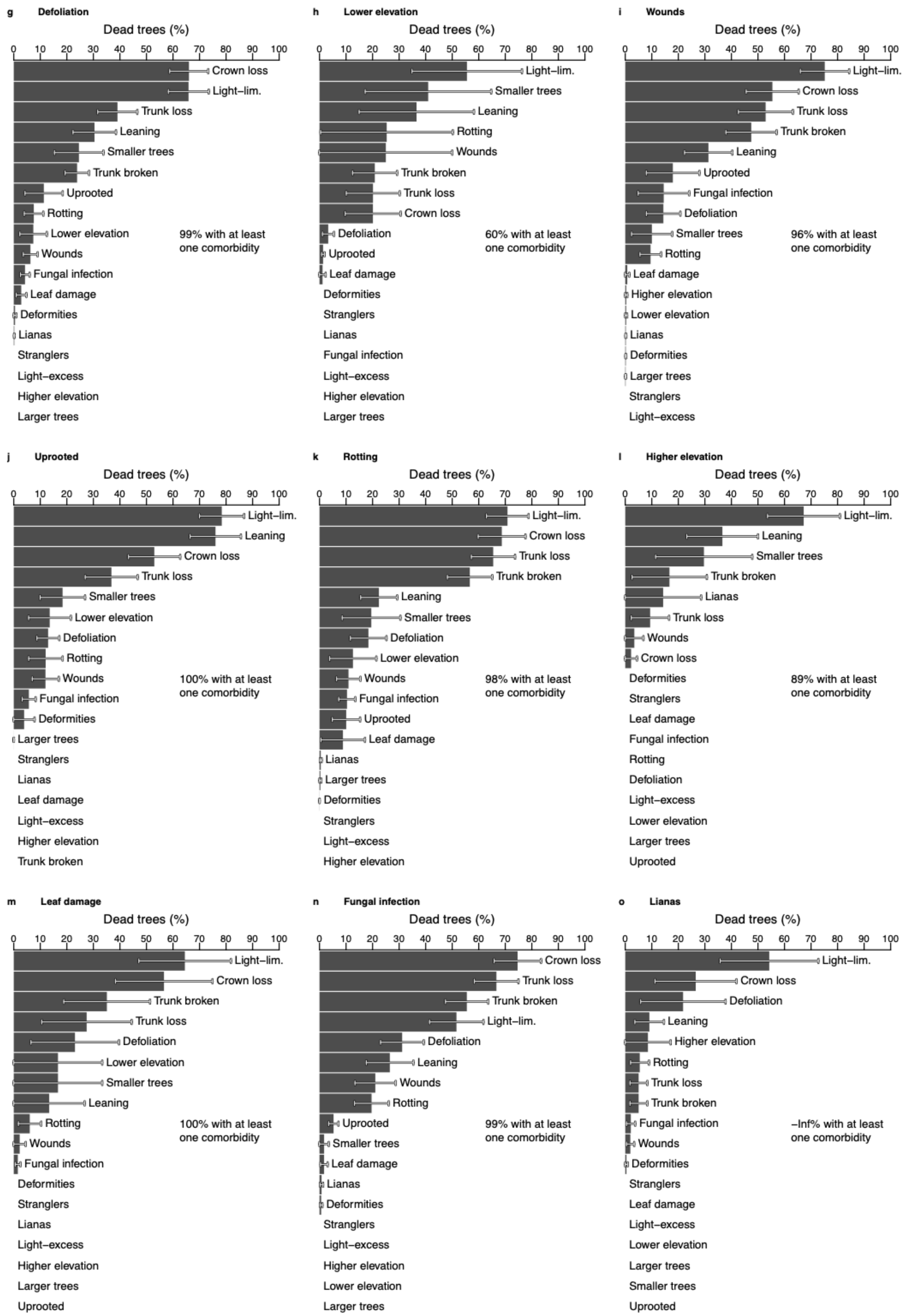

Fig. S14 (continued)

Methods S1 Crown damage estimates.

We estimated crown loss as the reduction from the "ideal" crown. We used a model that describes the cumulative relative volume (0-1) of tree trunk vs. crown at a relative height *r* (Ver Planck and Macfarlane, 2014). In this model, the total accumulated relative volume,$V_{whole}(r)$, is$V_{whole}(r) = V_{trunk}(r)$ below the crown base height (i.e., just the cumulative volume of the trunk) and$V_{whole}(r) = V_{trunk}(r) + V_{crown}(r)$ above the crown base height (i.e., the cumulative volumes of the trunk and the crown combined). The models are based on a solid of revolution and are described by McFarlane (2010) as:

$$V_{trunk}(r) = p_{trunk} \times (1 - (1 - r)^{a})$$
$$V_{crown}(r) = \beta \times (1 - (1 - (r - rC))^{b})$$

where p_{trunk} is the overall proportion of volume in the trunk, $rC$is the relative position of the base of the crown, parameters *a* and *b* are tapering factors that describe the accumulation rate of volume as height increases, and $\beta = \frac{1-V_{trunk}(r)}{1-rC^{b}}$. $p_{trunk}$was set to ⅔ based on empirical data from 611 harvested tropical trees (Chambers et al., 2001; Duque et al., 2017). $rC$was set to 1.30 m divided by the ideal tree height to match our definition of "crown" in the field (Arellano et al., 2021). We set *a* = 5 and *b* = 3.

Crown biomass was estimated as the proportion of crown volume above and below a given height multiplied by the total aboveground biomass of the tree, based on the species wood density, the stem dbh, and the same site-specific environmental stress used for height estimates (Chave et al., 2014; Réjou-Méchain et al., 2017). Total crown biomass loss was estimated as [crown biomass above the remaining living length] + [[estimated crown biomass below the living length] ×[1 - estimated proportion of remaining crown within the living length]].

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Methods S2 Instantaneous mortality rates.

We calculated the conventional annual mortality rates for each census interval in each forest using sample bins as ‘subpopulations’ *sensu* Sheil and May (1996). Specifically, we took Eq. 8 in Sheil and May (1996) and calculated the annual mortality rate in the forest (*m*) by replacing the species term by species × size ‘bins’ (*b*) and the number of individuals *n* by the weight that each bin in the forest (w_b):

$$m \; = 1 - \left\{ \sum_{b\,=\,1}^{B} [w_{b0}\;(1 - m_b)^t] \,/\, \sum_{b\,=\,1}^{B} w_{b0} \right\}$$

, where, B is the total number of bins in the forest, w_{b0} is the weight of the bin *b*, and *t* is the time census interval. m_b is the annual mortality rate for bin *b* calculated as 1–(N_s/ N_0)^(1/t), where N_0 is the number of living trees in the initial census, N_s is the number of those trees still alive in the final censuses (Kohyama et al. 2018).

Notes S2 ForestGEO site-specific acknowledgements.

Amacayacu: The 25-ha Long-Term Ecological Research Project of Amacayacu is a collaborative project of the Instituto Amazónico de Investigaciones Científicas Sinchi and the Universidad Nacional de Colombia Sede Medellín, in partnership with the Unidad de Manejo Especial de Parques Naturales Nacionales and the Forest Global Earth Observatory of the Smithsonian Tropical Research Institute (ForestGEO). We acknowledge the Director and staff of the Amacayacu National Park for supporting and maintaining the project in this National Park as well as coworkers from the Palmeras Indigenous Community for their assistance in fieldwork. This project is possible thanks to the commitment of S. Sua, A. Barona, N. Castaño, and the administrative crew at Sinchi. We also thank A.F. Jimenez, L. Gómez, and hundreds of technicians and students of forest engineering at Universidad Nacional de Colombia that have worked on data collection and cleaning.

Barro Colorado Island (BCI): The BCI forest dynamics research project was made possible by National Science Foundation grants to Stephen P. Hubbell: DEB-0640386, DEB-0425651, DEB0346488, DEB-0129874, DEB-00753102, DEB-9909347, DEB-9615226, DEB-9615226, DEB9405933, DEB-9221033, DEB-9100058, DEB-8906869, DEB-8605042, DEB-8206992, DEB7922197, support from the Forest Global Earth Observatory (ForestGEO), the Smithsonian Tropical Research Institute, the John D. and Catherine T. MacArthur Foundation, the Mellon Foundation, the Small World Institute Fund, numerous private individuals, and through the hard work of over 100 people from 10 countries over the past two decades.

Fushan: Fushan: The Fushan Forest Dynamics plot (FDP) is supported by the Taiwan Forestry Bureau, the Taiwan Forestry Research Institute and the Ministry of Science and Technology of Taiwan. We would like to express our gratitude to all field technicians and students who helped with the implementation and recensus of the Fushan FDP. We also thank the Fushan Research Center staff for providing logistic support.

Huai Kha Khaeng (HKK): We thank the many people who helped to create the permanent research plot in Huai Kha Khaeng. The administrative staff of Huai Kha Khaeng Wildlife Sanctuary helped with logistical problems of the plots on many occasions. The Huai Kha Khaeng 50-hectare plot project has been financially and administratively supported by many institutions and agencies. Direct financial support for the plot has been provided by the Royal Thai Forest Department and the National Parks Wildlife and Plant Conservation Department, the Arnold Arboretum of Harvard University (under NSF award #DEB-0075334, and grants from USAID and the Rockefeller Foundation), the Smithsonian Tropical Research Institute, and the National Institute for Environmental Studies, Japan. We acknowledge the Royal Thai Forest Department and the Department of National Parks, Wildlife and Plant Conservation for supporting and maintaining the project in Huai Kha Khaeng Wildlife Sanctuary, Thailand.

Khao Chong (KC): We thank the many people who helped to create the permanent research plot in Khao Chong. The administrative staff of Khao Chong Botanical Garden helped with logistical problems of the plots on many occasions. Direct financial support for the plot has been provided by the people of Thailand through the Royal Forest Department (1991-2003) and the National Parks Wildlife and Plant Conservation Department since 2003, the Arnold Arboretum of Harvard University, the Smithsonian Tropical Research Institute, and the National Institute for Environmental Studies, Japan, as well as grants from the US National Science Foundation (grant #DEB-0075334 to P.S. Ashton and S.J. Davies), US-AID (with the administrative assistance of WWF-USA), and the Rockefeller Foundation. Administrative support has been provided by the Arnold Arboretum, the Harvard Institute for International Development, the Royal Forest Department, and the National Parks Wildlife and Plant Conservation Department. In addition, general support for the ForestGEO program has come from the Arnold Arboretum of Harvard University, the Smithsonian Tropical Research Institute, the John D. and Catherine T. MacArthur Foundation, Conservation, Food and Health, Inc., and the Merck Foundation. All of these organizations are gratefully acknowledged for their support.

Pasoh: The 50-ha forest plot at Pasoh FR is an ongoing project of the Malaysian Government, directed by the Forest Research Institute Malaysia through its Director-General, Dr Ismail bin Parlan. The project was initiated under the leadership of Drs. N. Manokaran, P. S. Ashton and S. P. Hubbell. The project is now a collaboration of the Forest Research Institute Malaysia and ForestGEO of the Smithsonian Tropical Research Institute. The late Dr. K. M. Kochummen, while on a fellowship at STRI, supervised the species identification and personally examined all trees over 100 mm dbh. Funds for the project are gratefully acknowledged from: the National Science Foundation, USA (BSR Grant No. INT-84-12201 to Harvard University through Drs. P. S. Ashton and S. Hubbell), Conservation, Food and Health Foundation, Inc., USA, the United Nations, through the Man and the Biosphere program (UNESCO-MAB grant Nos. 217.651.5, 217.652.5, 243.027.6, 213.164.4, and also UNESCO-ROSTSEA grant No. 243.170.6), the Center for Tropical Forest Science-Arnold Arboretum Asia Program at Harvard University, USA, and the National Institute for Environmental Studies, Japan.

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