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Wind Shapes the Growth Strategies of Trees in a Tropical Forest

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ABSTRACT

In tropical forests, trees strategically balance growth patterns to optimise fitness amid multiple environmental stressors. Wind poses the primary risk to a tree's mechanical stability, prompting developments such as thicker trunks to withstand the bending forces. Therefore, a trade-off in resource allocation exists between diameter growth and vertical growth to compete for light. We explore this trade-off by measuring the relative wind mortality risk for 95 trees in a tropical forest in Panama and testing how it varies with tree size, species and wind exposure. Surprisingly, local wind exposure and tree size had minimal impact on wind mortality risk; instead, species wood density emerged as the crucial factor. Low wood density species exhibited a significantly greater wind mortality risk, suggesting a prioritisation of competition for light over biomechanical stability. Our study highlights the pivotal role of wind safety in shaping the life-history strategy of trees and structuring diverse tropical forests.

1 | Introduction

As a tree grows from the sheltered understory into the wind-exposed forest canopy its growth pattern changes. Its trunk diameter growth rate increases faster than its height growth, resulting in curved allometric relationships. One explanation for this curvature is that when trees are in the understory they prioritise competition for light, but when they reach the forest canopy and are exposed to stronger winds they prioritise mechanical stability. Experimental studies have shown that trees can respond to wind by increasing their diameter growth rates within days of a simulated extreme wind event (Bonnesoeur et al. 2016), but this acclimation incurs a resource cost implying trade-offs with other priorities (Telewski 2006). The results of wind-acclimation are particularly clear in areas with strong prevailing winds, where trees are shorter and grow streamlined

crowns which reduce their risk of damage (Telewski 2012). In these windy environments, angiosperms will often grow tension wood on the upwind side of their trunk, which has a higher cellulose content and resists tension better than the rest of their trunk (Gardiner, Flatman, and Thibaut 2014; Scurfield 1973). To date, most of the data on the effects of wind acclimation come from saplings or even-aged planted forests containing only one species. We therefore do not know what role wind acclimation plays in a diverse tropical forest. Given the link between wind acclimation and tree growth patterns, this knowledge gap has important implications for our understanding of tropical forest structure and carbon storage (Ennos 1997).

It is generally assumed that wind mortality risk will increase with tree height (Gora and Esquivel-Muelbert 2021) because (a) taller trees with exposed crowns will experience a stronger

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wind force and (b) the bending moment at the tree base is proportional to wind force applied to the crown multiplied by the tree height (Gardiner et al. 2008). This assumption was supported by a post wind-damage survey in Brazil (Rifai et al. 2016). However, the resistance to snapping scales with the cube of the trunk diameter (Niklas 2016) and resistance to uprooting scales with the square of the trunk diameter (Peltola et al. 2000), so tall trees may balance their increased exposure by growing thicker trunks. Finally, the risk of snapping will also depend on the wood material properties, specifically its modulus of rupture. This is usually well quantified for timber species and is strongly correlated with wood density (Niklas and Spatz 2010). Direct field measurements to support the role of height over other traits in controlling wind mortality risk are limited. Most studies focus on conifer plantations (e.g., Gardiner et al. 1997), so we do not understand how wind mortality risk varies in tropical forests across steep topography and large variation in wind exposure. Only Jackson et al. (2020) has directly measured wind strain in tropical trees and this study was limited to 17 individuals.

In a diverse tropical forest, different tree species follow different life-history strategies, classified on a spectrum from 'acquisitive' low wood density species to 'conservative', high wood density species (Chave et al. 2009; Salguero-Gómez et al. 2016). High wood density species usually have longer lifetimes and are more resistant to stressors such as drought (Chave et al. 2009; Oliveira et al. 2021). We expect wind acclimation ability to align with these life-history strategies, because acclimation generally incurs a resource cost for trees. For example, species which prioritise vertical growth to compete for light may invest fewer resources in wind acclimation and therefore have a greater wind mortality risk. This also extends to the size and shape of the tree crown, since a large tree crown would capture lots of sunlight, but also increase the wind exposure of the tree (Nicoll, Connolly, and Gardiner 2019).

In this study, we present novel data to explore the importance of biomechanical stability in a tropical forest. Previously research in this field has been limited by the availability and high cost of the necessary sensors. We have changed this by designing a low-cost sensor allowing us to directly measure the bending strains in the trunks of 95 trees in a tropical forest in Panama, the largest data set of its kind. We use this field data to calculate the relative wind mortality risk for each tree and address the following research questions:

Q1: Does the risk of wind mortality increase with tree height? This will depend on tree growth patterns, and whether the higher wind exposure of tall trees is balanced by their larger trunk diameters and other traits such as crown shape.

Q2: Do low wood density species have a greater risk of wind-induced mortality? If yes, this would suggest that tree life-history strategy is related to wind mortality risk, consistent with predictions related to the wood economics spectrum (Chave et al. 2009).

Q3: Do trees fully acclimate to their local wind conditions? If yes, then wind mortality risk would be independent of wind

exposure. Alternatively, other priorities such as competition for light may lead to imperfect acclimation to the wind.

2 | Methods

2.1 | Study Site and Sampling Design

Barro Colorado Island is a 1543 ha lowland tropical rainforest site in central Panama (9°09' N, 79°51' W), with elevation ranging 26–171 m above sea level. The island has been protected since it was isolated from the mainland in 1914 by the creation of Gatun Lake. Mean annual precipitation is 2660 mm year⁻¹ (1925–2023) and mean annual temperature is 25.9°C (1988–2023). It has a 4-month dry season, with precipitation less than 100 mm per month from January to April. The wind direction is predominantly from the north in both the dry and wet seasons (Paton 2024).

We monitored 75 trees across a steep peninsula oriented perpendicular to the prevailing northerly winds and surrounded by Lake Gatun (Figure 1). This provided a 'natural experiment' with trees on the north side exposed to the prevailing Northerly winds, while those on the south side of the peninsula are sheltered. We also monitored a further 20 trees on the western side of the island because this area has greater natural disturbance rates (Cushman et al. 2022). We measured the diameter at breast height (dbh) and height of the trees in the field using a laser rangefinder (Nikon Forestry Pro II, Tokyo, Japan).

We selected species commonly found in the canopy across the entire island. We monitored 61 low wood density trees (22 *Virola* spp., 14 *Jacaranda copaia* and 25 *Anacardium excelsum*) and 34 high wood density trees (24 *Dipteryx oleifera* and 10 *Handroanthus guayacan*). The wood density values given in (Chudnoff 1984) were similar to locally measured wood density (Rutishauser et al. 2020) (S1). Henceforth, we refer to these taxa simply as 'species' and reference them individually using their genus names. These species have been historically used for timber so their green wood mechanical properties are well documented (S1). Crucially, this gives us the breaking strain, the strain at which the trunk would snap, calculated as the ratio of the modulus of rupture to the modulus of elasticity (Lavers 1983; Chudnoff 1984). These material properties were measured by the UK Forest Products Research Laboratory using three-point bending tests on green wood and the data were collated by Chudnoff (1984) We compare our measured strain to these breaking strains to calculate the risk of wind-induced mortality.

2.2 | Relative Wind Mortality Risk Using BioMech Sensors

We measured the relative wind mortality risk using novel field data. We designed and built biomechanical sensors (hereafter *BioMech*) to measure the bending strains in tree trunks. This bending strain varies in real time as the tree sways back and forth in the wind (Figure 2A). We based our design on a sensor used in the forestry industry (Blackburn 1997; Moore et al. 2005), with some modifications to enable low-cost batch production for use in ecology. The *BioMech* sensor is based on a

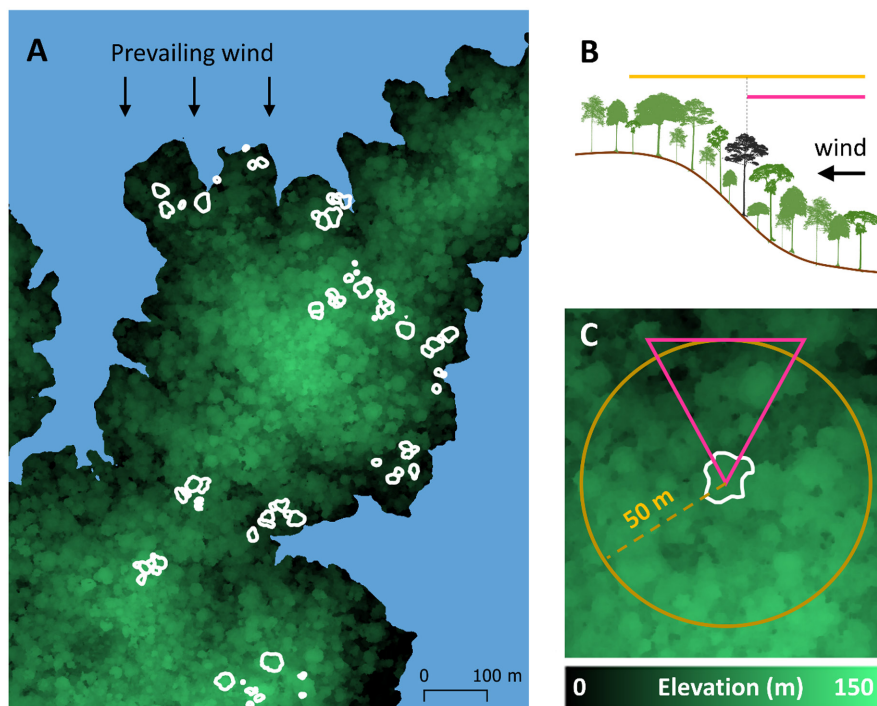


FIGURE 1 | Sampling design. (A) Map of the main study area on Barro Colorado Island showing the canopy surface (black to green by height) and the monitored trees (white polygons). The peninsula is surrounded by Lake Gatun and the trees on the northern edge are exposed to the prevailing wind. (A) Full map of the island is given in S7. (B, C) Show how we calculated wind exposure as the extent to which the tree overtops the surrounding canopy surface. The overall wind exposure (1) is given in orange, and the upwind wind exposure (2) in pink. B is a profile view while C is a zoom in of the top-down view in panel A.

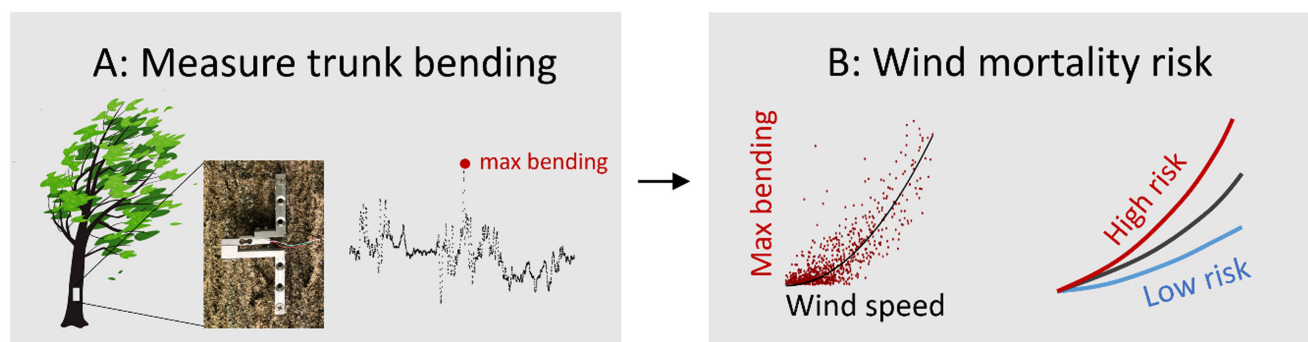


FIGURE 2 | (A) A BioMech sensor attached to a tree trunk, with a sample of raw bending strain data collected at 4 Hz. Two sensors are attached to each tree, on perpendicular sides of the trunk and bending strain is calculated by combining data from both. (B) Example for a single tree of the relationship between hourly maximum bending and wind speed. This relationship was modelled for each tree and the slopes of the models compared to give a relative risk of wind mortality for each tree.

load cell, whose resistance changes as it bends. We were therefore able to measure the bending as a change in voltage. We calibrated the sensor against a commercially available sensor (LCM PD-13 Linear displacement transducer) to convert the voltage signal to bending strain (S2).

Using small wood screws, we attached two *BioMech* sensors to each tree in line with the trunk axis (see Figure 2). The two sensors were attached on perpendicular sides of the trunk, to capture all axes of bending. The compass directions of the sensors differed among trees because each tree had different stem shapes and textures and the sensors need to be attached to a relatively flat surface. We situated the sensors at approximately

1 m above ground unless the tree had buttresses, in which case we attached the sensors above the buttress using a ladder. We measured the bending strains on the trunk of the tree at 4 Hz for over 4 months between April and July 2022, a total of over 3 billion measurements. Each sensor used a single $\frac{1}{2}$ AA size battery during this period and the main cause of sensor failure was humidity, rather than power issues. Our sampling was designed around clusters of trees, to enable wireless communication between sensors. These bending strain data are publicly available (Jackson, Bittencourt, and Coomes 2023).

The signals from the sensors drift over time due to temperature variation and tree growth (Jackson et al. 2021). This signal

drift results in a slowly varying offset which is not related to the tree's response to wind. We therefore removed this offset using a high-pass Butterworth filter, which removed signals which vary on time-scales slower than 10 min (Duperat, Gardiner, and Ruel 2020).

We combined the data from the pair of sensors attached to each tree to find the resultant bending strain using Pythagoras' theorem (square root of the sum of squares, S_2). This resultant strain does not distinguish between tension (positive strain) and compression (negative strain), but instead represents the absolute magnitude of the bending strain at any given time and in any direction. We divided these bending strain data by the species-specific breaking strain (Table S1), giving us a measure of how close the tree is to snapping at any point in time (Figure 2B). The resulting time series data have very high resolution (4 Hz) but are not directly comparable between trees because of (a) the spatial variability of wind gusts (b) data gaps due to transmission errors (we only used data where over 70% of the data were available for each hour and tree) and (c) noise which leads to large strains being recorded at low wind speeds. We therefore summarised the 4 Hz time series data following (Hale et al. 2012; Jackson et al. 2019).

We selected the maximum value for each hour for each tree (Figure 2A) and combined it with local hourly maximum wind speed data from the Lutz tower (Paton 2020). We modelled the relationship between tree bending and wind speed squared (Gardiner et al. 2008) using robust linear regression to avoid outliers at low wind speeds influencing the results. Each point in the regression was weighted by the gust speed, so that the rare high wind speed data influenced the fit more (per data point) than the very common low wind speed data (S3). Finally, we used these models to predict the wind mortality risk at the highest gust speed during our study period (11 m/s), giving a single value per tree. Our absolute wind mortality risk estimates (1%–7%) are valid for the 4-month period of our study. This represents a very short period in comparison to tree lifetimes and covers only a limited range of the wind speeds possible at this site. We therefore standardised all the trees by the weakest tree in the data set, giving a relative risk of wind-induced mortality per tree. This is sufficient for our current analysis and makes the wind mortality risk variable more readily understandable. These wind mortality risk estimates focus on mortality due to trunk snapping; we assume that the risk of uprooting is similar (Gardiner 2021).

2.3 | Quantifying Wind Exposure for Each Tree

We used a single measure of wind speed for all the trees in our study. Specifically, we used the hourly maximum wind speed measured at 48 m above the ground from the Lutz tower, which is located on average 1 km from the trees monitored on the Fairchild peninsula and 2.5 km away from the trees monitored on the west of the island. The wind speed and direction were measured every 10 s using an RM Young 05103 wind sensor, with the means and maxima being stored every 15 min. The wind climate is strongly directional, with 98% of the strong winds (over 7 m/s) since 2001 coming from $\pm 30^\circ$ of north. During the study period this figure was 92% (S6). Part of this directionality may be because the Lutz tower is in a valley and is sheltered from the West. We therefore additionally analysed the wind data from the

AVA tower, which is located on the plateau in the centre of the island, and found the dominant wind was north-westerly (S6).

To account for the different local wind environment experienced by each tree we defined a wind exposure index as the extent to which a tree overtops the surrounding canopy surface, which implicitly includes the variation due to topography. The area of surrounding canopy surface was defined in two ways: (1) using a circular area around the focal tree and (2) only considering the canopy surface in a triangular area to the north (i.e., upwind) of the focal tree (Figure 1C). The radius of the circle and the height of the triangle were both 50 m.

We mapped the location of each tree in the field on a portable tablet with recent (July 2022) high-resolution (20 cm) aerial images of the canopy pre-loaded. Eight trees could not be mapped in the field, but our sampling design meant that they were always close to other trees whose data were logged by the same data logger. We therefore calculated the wind exposure for these trees using their field measured height and the average surrounding canopy surface height of the nearby trees. Since the LiDAR canopy height data was collected in 2023, while the tree monitoring occurred in 2022, we manually checked and found that none of the focal trees had substantially changed in height in the intervening period.

2.4 | Statistical Analysis

We used our estimates of wind mortality risk based on field data to address our research questions. To address Q1, we tested how relative wind mortality risk varies with tree height, diameter and slenderness (tree height/diameter) for each species using univariate linear regressions. The wind mortality risk and slenderness were both log-normally distributed, so we log-transformed them before performing any analysis. Based on these results we chose to use slenderness instead of tree height in the following analysis. To address Q2 and Q3, we ran the following linear model, based on our mechanical understanding of the system:

$$\log(\text{wind mortality risk}) \sim \text{wood density group} \\ + \log(\text{slenderness}) + \text{wind exposure}$$

The continuous variables were centred and scaled prior to analysis. Our sampling design included only five species, two high wood density and three low wood density. The species were therefore grouped into a high wood density (*Dipteryx* and *Handroanthus*) and a low wood density (*Jacaranda*, *Anacardium* and *Virola*) groups. The wood density group was then included in the model as a factor, to give a clear measure of the difference in wind mortality risk due to wood density (Q2). We tested both a northerly wind exposure and overall wind exposure, as described in Section 2.3. We also tested for covariation between our predictor variables (slenderness and wind exposure) by calculating variable inflation factors. Finally, to test whether the trends in wind mortality risk differed between low and high wood density species, we modelled each wood density group separately using the following reduced model.

$$\log(\text{wind mortality risk}) \sim \log(\text{slenderness}) + \text{wind exposure}$$

3 | Results

3.1 | Tree Size and Wind Mortality Risk

We found no consistent relationship between relative wind mortality risk and tree height (Q1). Wind mortality risk increased with tree height for *Virola*, but decreased with tree height for *Anacardium* and *Dipteryx* (Figure 3A). Trunk diameter was a better predictor of wind mortality risk than tree height, with either negative or non-significant trends for all species (Figure 3B). However, the best predictor of wind mortality risk was tree slenderness (Figure 3C), the ratio of tree height to diameter. Wind mortality risk increased with tree slenderness for all species, although this trend was not significant for *Jacaranda* or *Handroanthus*. This result supports our expectation that slenderness drives wind mortality risk and we therefore use slenderness in our models.

We sampled trees over a range of sizes and found slight differences in the height diameter allometries between species (Figure 3D). *Anacardium* stands out as having particularly large trunk diameters for a given height. These large trunk diameters were associated with a lower wind mortality risk than the other low wood density species (Figure 3B). We note that the *Jacaranda* trees in our sample had smaller trunk

diameters (Figure 3A) and therefore higher slenderness than the other species.

3.2 | Wood Density and Wind Mortality Risk

Our estimates of relative wind mortality risk also varied by species, with the high wood density species (*Dipteryx* and *Handroanthus*) having substantially lower risk than the low wood density species (Q2). The high and low wood density species did not differ substantially in their height-diameter allometries and were sampled over a similar range of heights and diameters (Figure 3D). We can therefore group these species into high wood density and low wood density classes for the following modelling analysis.

Grouping trees by wood density class (Figure 4) confirmed that low wood density trees had substantially greater risk of wind mortality than high wood density trees (Q2). For example, a low wood density tree had a 4.3 times higher wind mortality risk than a high wood density tree, given the same slenderness (50) and exposure (10m above canopy). As expected, we also found an increase in wind mortality risk with tree slenderness (Figure 4A), but the effect of wood density was larger than that of slenderness and wind exposure (Table 1).

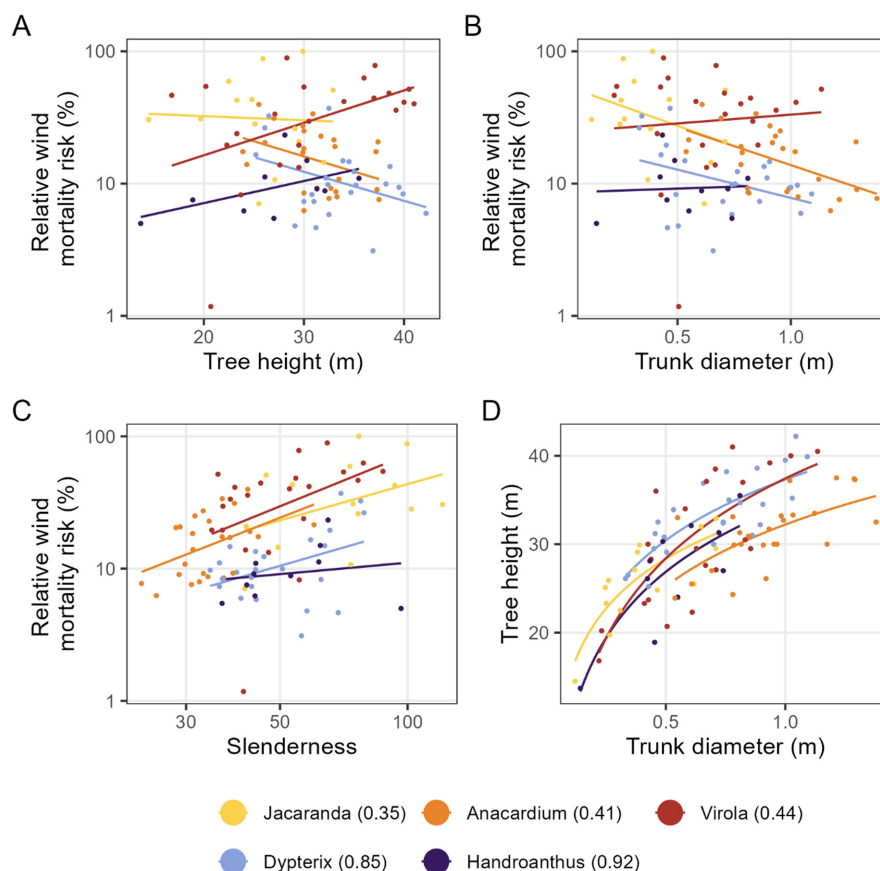


FIGURE 3 | The relative wind mortality risk (% , log scale) against (A) tree height, (B) trunk diameter and (C) tree slenderness (log scale), together with the tree height-diameter allometry (D). The fit lines in panels (A–C) are linear models for each species separately, not used for analysis but only to indicate the trend. A version of this figure with fitted parameters and fit statistics is given in the supplementary materials (S4). The numbers in parentheses next to the species names give wood specific gravity values from (Chudnoff 1984).

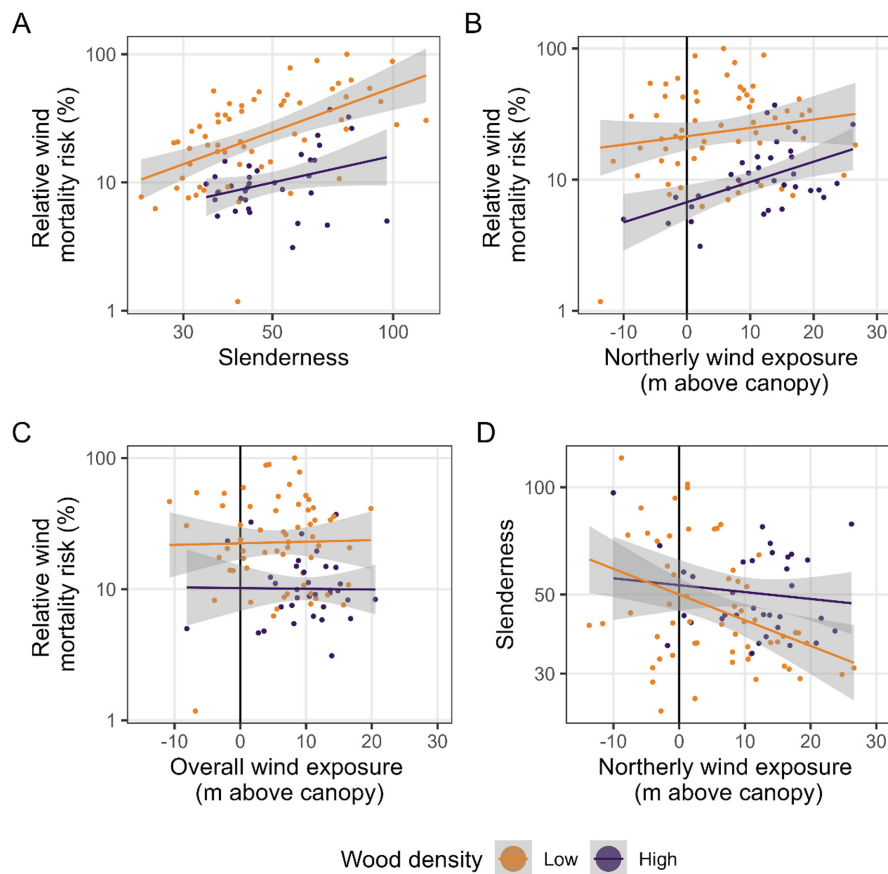


FIGURE 4 | Variation in relative wind mortality risk (%; log scale) with (A) tree slenderness, (B) northerly wind exposure and (C) overall wind exposure; note log scales for wind mortality risk and slenderness. Panel (D) shows the covariation between tree slenderness and northerly wind exposure. The trees have been grouped into low wood density (Jacaranda, Virola and Anacardium) and high wood density (Dipteryx and Handroanthus) classes. Model fit statistics are given in Table 1.

TABLE 1 | Results of the multiple linear regression models for relative tree mortality risk. The continuous variables were scaled before fitting the model.

	Combined model		Low wood density		High wood density	
	Est.	95% CI	Est.	95% CI	Est.	95% CI
Model terms						
Slenderness	25	(19, 31)	28	(20, 36)	15	(5, 26)
Wind exposure (northerly)	20	(13, 26)	20	(12, 29)	19	(9, 29)
Low wood density ^a	62	(49, 76)	—	—	—	—
Model summary						
Number of trees	95		61		34	
Adjusted R^2	0.56		0.46		0.37	
RMSE	28		30		22	

^aLow wood density was included as a factor and the value represents the increase in wind mortality risk for a tree with low wood density, compared to the same tree with high wood density. The final row shows the root mean squared error for each model.

3.3 | Wind Exposure and Acclimation

We found that wind mortality risk increased with northerly wind exposure (Figure 4B). However, the effect of wind exposure was smaller than that of either wood density or tree slenderness,

despite the fact that we specifically sampled over a wide range of wind exposures across a steep peninsula (Figure 1A). This increase was no longer evident if we used a circular area of canopy around the focal tree to define wind exposure (Figure 4C). This suggests that the trees have partially acclimated to their wind

environment, particularly to the prevailing northerly winds (Q3). We note that both tree slenderness and wind exposure depend on tree height and were therefore correlated, particularly for the low wood density trees (Figure 4D). However, variable inflation factors were all under 1.5, demonstrating that this slight covariation between predictors was unlikely to bias our models.

We subdivided our data into high wood density and low wood density species and ran reduced models for each group. We found that wind mortality risk increased faster with slenderness and wind exposure for the low wood density species (Table 1). Combined with the overall greater wind mortality risk of low wood density species, this suggests a lower degree of acclimation to their local wind environment, consistent with their acquisitive life-history strategy.

4 | Discussion

Tropical forests are unique in their high diversity of species and life-history strategies (Cooper et al. 2024). They also have complex multi-layered canopy structure, which create an especially turbulent wind environment (de Langre 2008). In this study we used novel sensors to measure how trees respond to this wind environment. Surprisingly, we found that wind mortality risk was only weakly positively related to local wind exposure, suggesting that the trees were well acclimated to their wind environment. However, we found that wind mortality risk was substantially higher for species with low wood density. This implies that the local wind environment influences forest structure and that wind safety is a key component of tree life-history strategy.

4.1 | Wind Mortality Risk Increases With Tree Slenderness, Not Tree Height

Tree height was weakly related to the wind mortality risk, and the relationship was positive for some species and negative for others (Q1). Slenderness, or the ratio of tree height to diameter, was a better predictor of wind mortality risk than tree height. The importance of slenderness is exemplified by *Anacardium*, which had a unique distinct height-diameter allometry in this study (Figure 1C). At a height of 37.5 m the trunk diameter of *Anacardium* was approximately 1.4 m, while the *Dipteryx* and *Virola* trunk diameters were approximately 1.1 m. This meant that *Anacardium* had a low wind mortality risk because of its low slenderness, despite the fact that it is a low wood density species.

The relationship between wind mortality risk and tree size is potentially complicated by two other factors. Firstly, wood material properties may change as the tree grows (de Bittencourt et al. 2022). We were unable to measure material properties for each individual tree, so we used species averages, therefore, it is possible that the increased wind exposure of tall trees is partially balanced by an unmeasured increase in the maximum strain the wood can withstand before snapping. However, we expect any such effect to be modest, considering that differences in wood density between species are greater than those within species for tropical trees (Chave et al. 2009). The second factor

is the tree roots. Our sensors measured the risk of the trunk snapping, but we could not quantify the risk of uprooting. We implicitly assume that trees balance their allocation such that the risk of uprooting is similar to the risk of snapping (Esquivel-Muelbert et al. 2020) and that this ratio remains relatively constant as the tree grows.

4.2 | Life-History Strategy and Wind Mortality Risk

We found that high wood density species were at much lower risk of snapping in the wind than low wood density species for a given tree slenderness or wind exposure (Q2). This provides empirical evidence in a tropical forest for the hypothesis that wind safety is an integral part of the wood economics spectrum (Chave et al. 2009). This is supported by a Puerto Rican hurricane damage study, which found high wood density species were more likely to survive than low wood density species (Uriarte, Thompson, and Zimmerman 2019), although low wood density species generally have a post-disturbance recruitment advantage (Uriarte et al. 2012). We therefore argue that the effects of wind should be considered alongside other environmental stressors such as drought as a key driver of forest structure and mortality.

While low wood density species generally have lower breaking strains, this doesn't make high wind mortality risk inevitable. Low wood density species can grow larger diameter trunks at lower construction costs, thus reducing their wind mortality risk (Larjavaara and Muller-Landau 2012; Larjavaara and Muller-Landau 2010), exemplified by *Anacardium* in this study. Our finding of higher wind mortality risk for low wood density species therefore suggests correlated selection on multiple traits associated with fast versus slow life histories (Reich 2014).

The severity of extreme weather events, including wind storms, is expected to increase with climate change (IPCC 2021). If trees do not fully acclimate to these novel wind environments in time, our study suggests that the mortality rates of low wood density species would increase faster than those of high wood density species. However, high wood density species typically have longer life cycles and slower growth rates (Chave et al. 2009; Díaz et al. 2016). We therefore postulate that these high wood density species may be slower to acclimate to new wind environments and may be the worst affected in the long run (i.e., on a decadal time scale).

4.3 | Does Wind Constrain Tropical Forest Structure?

We found that wind exposed trees only had a slightly greater wind mortality risk than sheltered trees (Q3, Table 1). We expected a much stronger increase in the wind mortality risk with wind exposure, because exposed trees experience a much greater wind load (Gardiner et al. 2008). Additionally, our sampling design maximised the variation in wind exposure by sampling trees across the steep local topography (Figure 1A). Nevertheless, we found that the variation in wind exposure had a much smaller effect on wind mortality risk than species wood density.

The most likely explanation for this weak effect of wind exposure is that the trees have acclimated to their local wind environment by changing their wood traits or increasing their diameter growth rates and therefore their slenderness (Bonnesoeur et al. 2016). This acclimation to local wind conditions is likely to impose trade-offs with some other growth priority, such as the addition of new leaves or vertical growth (Malhi et al. 2018). This would imply that wind exposure, and a tree's capacity to acclimate to this, may impose a strong selective pressure on trees. Furthermore, whole forest structure is likely to be altered by local wind acclimation and adaptation given the potential risk we observe it to pose to these trees. This is supported by a growing body of observational evidence showing that tree size and shape vary with wind environment. Wind speed was the strongest predictor of maximum tree height across the Brazilian Amazon (de Lima et al. 2023; Gorgens et al. 2021) and of crown size across the tropics (Banin et al. 2012). In addition, higher wind exposure was associated with lower tree heights across hilly terrain in New Zealand (Coomes et al. 2018) and Puerto Rico (Ankori-Karlinsky et al. 2024). These studies all suggested that the observed changes in tree size and shape may act to equalise wind mortality risk across a range of wind environments. The current study provides the first field data on wind mortality risk, confirming that it remained relatively constant across a range of wind exposures. Future work will extend this to multiple sites, to test whether the same result holds across different wind regimes.

Author Contributions

Toby D. Jackson: conceptualisation, funding acquisition, methodology, hardware design, fieldwork, data curation, formal analysis and writing—original draft. **Paulo Bittencourt:** conceptualisation, methodology, hardware design. **Jakob Poffley:** methodology, fieldwork. **Juliet Anderson:** methodology, fieldwork. **Helene C. Muller-Landau:** conceptualisation, methodology, logistics and support. **Pablo A. R. Ramos:** methodology, fieldwork, logistics and support. **Lucy Rowland:** conceptualisation, methodology. **David Coomes:** conceptualisation, funding acquisition and methodology. All authors contributed to the final draft.

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Data Availability Statement

All data used in this study are openly available online.

- Bending strain data are available here: <https://doi.org/10.5285/f03806fa-3596-4119-90c5-70254f39cfc0>
- Local wind speed data used are available here: https://smithsonian.figshare.com/articles/dataset/Barro_Colorado_Island_Lutz_tower_48m_Wind_Speed/10042427 (DOI: 10.25573/data.10042427.v24)

- LiDAR data used to calculate canopy surface height and wind exposure are available here: https://smithsonian.figshare.com/articles/dataset/Digital_Surface_Models_Whole_Island_2018-2023/24021381 (DOI: 10.25573/data.24021381.v2)
- Summary data, and R code used to process the data, create the figures and run the models are permanently available on github https://github.com/TobyDJackson/WindAndTrees_BarroColoradoIsland and archived on Zenodo: <https://zenodo.org/doi/10.5281/zenodo.12772776>

Peer Review

The peer review history for this article is available at <https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/ele.14527>.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.