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Impacts of anthropogenic climate change on tropical montane forests: an appraisal of the evidence

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ABSTRACT

In spite of their small global area and restricted distributions, tropical montane forests (TMFs) are biodiversity hotspots and important ecosystem services providers, but are also highly vulnerable to climate change. To protect and preserve these ecosystems better, it is crucial to inform the design and implementation of conservation policies with the best available scientific evidence, and to identify knowledge gaps and future research needs. We conducted a systematic review and an appraisal of evidence quality to assess the impacts of climate change on TMFs. We identified several skews and shortcomings. Experimental study designs with controls and long-term (≥10 years) data sets provide the most reliable evidence, but were rare and gave an incomplete understanding of climate change impacts on TMFs. Most studies were based on predictive modelling approaches, short-term (<10 years) and cross-sectional study designs. Although these methods provide moderate to circumstantial evidence, they can advance our understanding on climate change effects. Current evidence suggests that increasing temperatures and rising cloud levels have caused distributional shifts (mainly upslope) of montane biota, leading to alterations in biodiversity and ecological functions. Neotropical TMFs were the best studied, thus the knowledge derived there can serve as a proxy for climate change responses in under-studied regions elsewhere. Most studies focused on vascular plants, birds, amphibians and insects, with other taxonomic groups poorly represented. Most ecological studies were conducted at species or community levels, with a marked paucity of genetic studies, limiting understanding of the adaptive capacity of TMF biota. We thus highlight the long-term need to widen the methodological, thematic and geographical scope of studies on TMFs under climate change to address these uncertainties. In the short term, however, in-depth research in well-studied regions and advances in computer modelling approaches offer the most reliable sources of information for expeditious conservation action for these threatened forests.

Key words: biodiversity, cloud forests, conservation, ecological levels, ecosystem functions, evidence quality, global warming, research rigour, systematic review, tropical mountains.

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I. INTRODUCTION

Tropical montane forests (TMFs) are typically an evergreen ecosystem constrained to a narrow altitudinal belt, with an uneven canopy layer frequently enveloped by orographic clouds (Hamilton, 1995; Loope & Giambelluca, 1998; Still, Foster & Schneider, 1999; Foster, 2001; Richter, 2008). These forests often harbour high abundance and diversity of epiphytes (Loope & Giambelluca, 1998; Foster, 2001; Collin, 2001). TMFs are thus commonly referred to as cloud forests, mist forests or mossy forests, as well as numerous names in other languages, especially in Latin America (Brown & Kappelle, 2001) where most studies of this ecosystem have been conducted (Laurance *et al.*, 2011; Soh *et al.*, 2019).

Unlike other vegetation types defined by their taxonomic affiliation (e.g. coniferous forest, oak forest, etc.) or their phenological structure (e.g. deciduous forest, xerophilous shrubland, etc.), TMFs are characterised by the intersection of an atmospheric phenomenon (fog incidence) and a topographic feature (mountain slopes). Such restrictive features highlight the potential vulnerability of TMFs in the face of climate change (Hamilton, 1995), but also make impacts difficult to isolate from these ecosystems' intrinsic climatic variability (Vuille *et al.*, 2003). In this study, we focus on *anthropogenic* climate change, as defined by the United Nations Framework Convention on Climate Change (UNFCCC) in its Article 1 (Sands, 1992): a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.

There is abundant evidence that mountainous regions tend to warm up faster than their surrounding lowland areas and thus amplify the effects of increasing temperatures on upland plant communities in the long term (Aiba & Kitayama, 2002; Karmalkar, Bradley & Diaz, 2008; Loarie *et al.*, 2009; Ohmura, 2012; Torres, González & Comarazamy, 2008; Williams *et ali*, 2018; but see Pepin *et al.*, 2022). Rising altitude of cloud formation, and decreased water availability have been observed in response to higher mean annual air temperatures in tropical mountainous regions over recent decades (e.g. Crausbay & Hotchkiss, 2010; Murugan *et al.*, 2009; Sperling, Washington & Whittaker, 2004; but see Cuervo-Robayo *et al.*, 2020). Even if average annual changes in precipitation are small, marked seasonal shifts in water regime could severely impact upper montane communities (Hiltner *et al.*, 2016) that already live near their physiological limits (e.g. Catenazzi, Lehr & Vredenburg, 2014; Crausbay *et al.*, 2014; Muñoz *et al.*, 2016) and with little space to expand their ranges (the 'escalator to extinction'; Freeman *et al.*, 2021, p. 1706). These combined pressures could make them more likely to be outcompeted by climate-driven upwardly migrating species from nearby lowland areas (Sukumar, Suresh & Ramesh, 1995; Loope & Giambelluca, 1998; Oliveira *et al.*, 2014).

Despite recent advances in our understanding of the impacts of ongoing anthropogenic climate change on TMFs, concrete empirical evidence (i.e. compelling proof of climate change-driven impacts occurring in real time) remains scarce, partly because such assessments require long-term data that are difficult to collect and analyse (Wauchope *et al.*, 2021). For instance, it has been observed that plant communities can shift their distributions, but these movements lag behind the velocity of climate change (Feeley *et al.*, 2011; Corlett & Westcott, 2013; Sáenz-Romero *et al.*, 2016). Therefore, key ecosystems like TMFs help advance our knowledge of climate-driven distributional change because the microclimatic variability and island-like distribution of mountainous biomes not only results in high levels of endemism, but also high extinction vulnerability (Freeman *et al.*, 2018), making them natural laboratories for climate change (Silveira *et al.*, 2019; Tito, Vasconcelos & Feeley, 2020).

Numerous literature reviews on TMF research have been conducted, focusing on various aspects, including environmental determinants (Oliveira *et al.*, 2014; Fahey, Sherman & Tanner, 2016), ecosystem functions (Dalling *et al.*, 2016), ecosystem services (Buytaert, Cuesta-Camacho & Tobón, 2011), habitat degradation (Soh *et al.*, 2019),

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conservation (Peh *et al.*, 2011) and restoration strategies (Christmann & Menor, 2021), specific geographical regions (Rosas Rangel *et al.*, 2019; Sáenz-Romero *et al.*, 2020*a*; Tovar *et al.*, 2022) or taxonomic groups (Gotsch, Nadkarni & Amici, 2016; He, He & Hyvönen, 2016), and use of remote sensing technologies (Altarez, Apan & Maraseni, 2022). Our study goes beyond a systematic review on the effects of climate change on TMFs by critically evaluating the quality of the available evidence. We applied a replicable evidence-appraisal methodology to synthesise the current knowledge of the impacts of climate change on TMFs, with a focus on the published studies yielding the strongest evidence. This will serve as a guide to identify knowledge gaps and inform future research on this highly threatened biome.

Specifically, our research questions are: (*i*) what are the general thematic and methodological trends in the published studies investigating the impacts of climate change on TMFs? (*ii*) What are the implications of those trends in terms of our understanding and application of the current knowledge? (*iii*) How reliable is the literature in terms of the quality of the evidence it provides? (*iv*) What are the general forecasts for TMFs globally based on the most reliable evidence and the direction of future research?

II. METHODS

(1) Systematic review

We carried out a literature search on the effects of climate change on TMFs following a standard systematic review protocol (PRISMA-P; Shamseer *et al.*, 2015). The search terms were based on the most common names of TMFs and terms associated with long-term changes in the climate. The final search terms used were '(trop* monta* forest* OR cloud forest* OR trop* high* elevation* forest* OR trop* mid* elevation* forest* OR trop* mount* forest*) AND (climat* chang* OR glob* warm* OR temperature ris* OR clima* vari*).'

We conducted the literature search in July 2022 using four academic databases (*Web of Science*, *Scopus*, *ScienceDirect* and *Google Scholar*) and the *Google* search engine for the period 1994–2021. Relevant studies published during 2022 were omitted from the statistical analysis but are included in the discussion. The search string was run choosing the 'all fields' option if available, hits were sorted alphabetically, and relevant publications – i.e. studies that explicitly reported observed or projected effects of anthropogenic climate change on TMFs (or any component thereof) – were chosen based on title and abstract. Duplicated records were removed, and studies that mentioned climate change only as a potential future threat but did not investigate its effects on TMFs were excluded. Likewise, studies that described diversity patterns along elevational gradients but did not link them to environmental factors to allow inferences of potential future shifts were also discarded (Fig. 1). For *Google* searches, only the first 100 hits were reviewed to ensure that no relevant studies had been missed. A search in Spanish was conducted in the *Redalyc* database (www.redalyc.org), which did not yield any relevant studies, however, publications in Spanish and French listed under an English title, and thus captured by the search string, were retained. Since we aimed to rank the quality of the available scientific evidence, only peer-reviewed primary research articles were retained (see Section II.2). However, we checked reviews for 'snowballing' purposes (i.e. pursuing references of references; see Greenhalgh & Peacock, 2005). We excluded book chapters, reports and other grey literature. Palaeoclimatic and palaeoecological studies were excluded because our focus was on current anthropogenic climate change only.

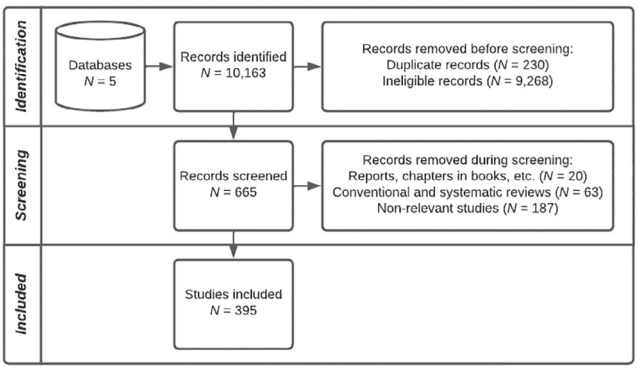

Fig. 1. Systematic search protocol. The final count includes all relevant studies from 1994 to 2021.

We extracted from individual studies information on study region, country, methodology, study duration, publication date, ecological level, taxonomic group, research topic, as well as measures of climate change and their observed effects in TMFs. We considered patterns of changing climate (rising temperature and increased or reduced precipitation) as binary variables (i.e. whether these measures were reported or tested in the study or not), and the observed impacts as categorical variables: occurrence of extreme events [strong El Niño Southern Oscillation (ENSO), cyclones, fires, frost, landslides], species' distributional changes [habitat losses (range contractions or fragmentations), and upslope or downslope shifts], impacts on biodiversity (increased vulnerability, population decline, extinctions, reduced genetic diversity, invasion of neighbouring communities and lowland biotic attrition), and other local-scale effects (alterations to carbon and other nutrient fluxes and stocks, soil functions, and phenological/physiological patterns).

To elucidate general trends in TMF research related to climate change, we investigated if studies were skewed towards a particular geographical region, taxonomic group, ecological level, or research topic; and if there were any associations between these parameters. We also investigated if studies reporting or testing an impact on TMFs tend to look at a particular measure of climate change or taxonomic group in their research. Only categories represented by at least 10 studies were analysed using chi-squared tests to avoid

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inferring spurious associations. These associations should be interpreted with caution because they are based solely on what individual studies reported (observations or historic records) or tested (experimentally or through modelling). Statistical tests were carried out in R 4.1.1, using *ggplot2* v.3.3.5 (Wickham, 2011) and *corrplot* v.090 (Wei *et al.*, 2017) packages.

(2) Evaluation of evidence quality

The evidence assessment tool devised by Mupepele *et al.* (2016) is designed to rank the quality of evidence provided by individual reviews and studies based primarily on their study designs. Studies that are poorly conducted (e.g. unclear research questions, inadequate sample sizes, lack of controls, etc.) are downgraded in the evidence hierarchy. The discrete categories of evidence quality and assessment criteria of the evidence assessment tool were specifically designed for conservation studies, but can be adapted for other fields of research. Our evidence assessment was an adaptation of Mupepele *et al.* (2016). We removed the 'review' (systematic and conventional) category, ranked highest by Mupepele *et al.* (2016), as its inclusion would result in double-counting of studies (i.e. studies captured by our search string are likely to occur in other reviews; Fig. 2). In addition, we carried out a methodological appraisal of each study. Studies with flaws and biases identified in terms of data collection and analyses or that employed outdated methodologies (mainly applicable to modelling studies) were downgraded to a lower level in the evidence hierarchy. Studies that combined multiple methodological approaches were classified according to their highest level in the evidence hierarchy [e.g. a study with both *ex-situ* experiments and modelling would be ranked as Level of Evidence 1b (LoE1b); Fig. 2, Table 1].

To define the hierarchical LoEs, we considered the following features: use of references and controls, execution of the study in the field (i.e. *in-situ*), long-term collection of data, high regularity of survey, and corroboration of findings derived from models with empirical observations (Table 1). Experimental study designs with a control carried out in the field provide very strong evidence (LoE1a). Experiments conducted *ex situ* yield only strong evidence (LoE1b) because artificial environments introduce potential biases to the study (Tito *et al.*, 2020). Observational studies spanning a minimum of 10 years with observations at regular intervals (weekly, monthly, etc.) also provide strong evidence by accounting for the long-term nature of climate patterns (Bruijnzeel, 2004; Chapman *et al.*, 2018), and are included in LoE1b. We prioritised the highest-ranked study design in studies that had employed both an *ex-situ* experiment and a modelling approach and therefore assigned these to LoE1b. None of the studies captured by our search string had conducted both field experiments and modelling.

LoE2 comprises short (<10 years) longitudinal and all cross-sectional observational studies, as well as the bulk of studies that relied on computer-based simulations (hereafter 'modelling'), i.e. projections of future climate conditions and especially ecological niche models, which include species distributions, life zones and relative abundance projections. Non-modelling studies are subdivided into <10-year long longitudinal studies (LoE2a, moderate evidence), sequential cross-sectional studies, i.e. resurveys (LoE2b, inconclusive evidence), and all other cross-sectional studies (LoE2c, circumstantial evidence), including comparative surveys (between different sites) and along altitudinal or latitudinal gradients (space-for-time substitution approach).

Given the requirement for long-term data in climate change research and the urgency to implement well-informed policies to preserve ecosystems from anthropogenic

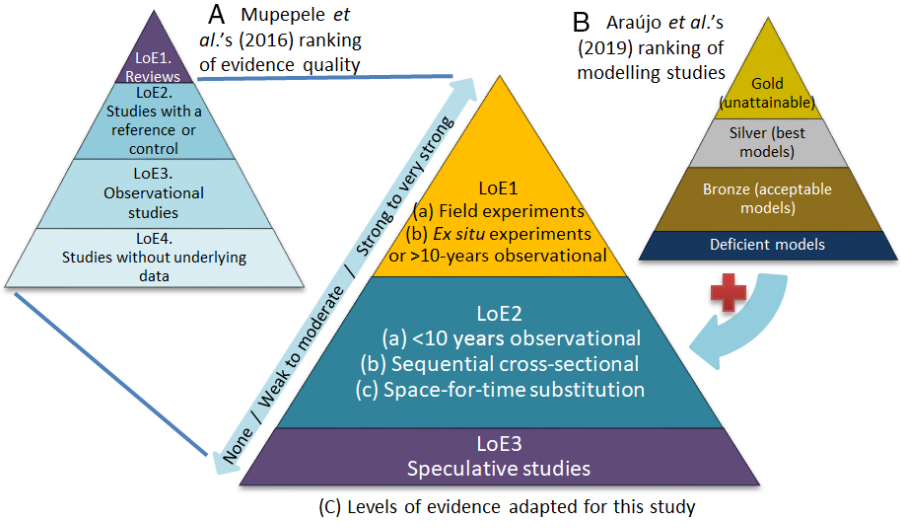

Fig. 2. Schematic representation of the adapted classification of studies according to (A) Level of Evidence (LoE) from Mupepele *et al.* (2016) and (B) assessment of modelling studies from Araujo *et al.* (2019). (C) The combined evidence assessment used in this review. See Table 1 for detailed explanation of levels.

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Table 1. Classification of studies according to Level of Evidence adapted from Mupepele *et al.* (2016). Modelling studies included in LoE2a–c correspond roughly to the silver, bronze and deficient levels proposed by Araújo *et al.* (2019), since their gold standard is unattainable for tropical montane forest (TMF) studies in relation to climate change.

Level of Evidence (LoE)		Main study design	Explanation
* Reviews are not included in this classification.			
1. Very strong to strong evidence of climate change effects	1a	Field experiments	Experimental studies that had a controlled design and were carried out in the field provide the strongest and most direct evidence.
	1b	*Ex situ* experiments OR time-series studies (≥10 years of regular – yearly, monthly, etc. – observations)	Long-term data sets provide strong evidence. Experiments carried out in artificial conditions may introduce uncertainty. Studies that employed both an *ex situ* experiment and a modelling approach belong to this level.
2. Moderate, inconclusive and circumstantial evidence of climate change effects, including observational and modelling studies	2a	Time-series studies (<10 years of regular – yearly, monthly, etc. – observations) OR modelling studies verified with empirical evidence	Short-term data sets provide evidence of changes taking place over time, but they may not be long enough to attribute observed changes confidently to shifting climatic patterns. Similarly, models that have been corroborated with field observations provide moderate evidence of changes that might occur in the future (comparable to the silver standard in Araújo *et al.*, 2019).
	2b	Sequential cross-sectional studies OR modelling studies not verified by empirical evidence	Cross-sectional studies that provide two or more snapshots of a system but lack regular/continuous data (resurveys), can inform on changes in a system. However, they do not allow an adequate analysis of the environmental influence on the observed changes. Similarly, models that have not been verified with field observations provide inconclusive evidence of the effects of climate change (comparable to the bronze standard in Araújo *et al.*, 2019).
	2c	Cross-sectional and comparative surveys, space-for-time substitution approaches OR non-forecasting modelling studies	Descriptive studies of conditions at a certain moment provide circumstantial evidence of environmental determinants of observed patterns. These include the use of spatial comparisons as a surrogate for temporal data, i.e. comparative surveys (e.g. temperate *versus* tropical sites) or altitudinal/latitudinal gradients as proxies for changes over time (space-for-time substitution). Modelling studies making inferences about future changes even though they are not designed to make forecasts or predictions are included in this level (comparable to the deficient category in Araújo *et al.*, 2019).
3. Studies without underlying data (no evidence)	3	Speculative studies OR data-deficient modelling-based inferences	Experts' educated guesses of expected future changes, usually based on past observed changes in analogous systems, are not considered as evidence. Modelling studies based on knowledge from other systems are also included in this level.

threats, modelling is widely used to forecast outcomes both in the near and distant future. Our scoring of evidence strength for modelling studies (LoE2a–c and LoE3) was based on the model's function and whether their conclusions were validated by field observations, and corresponds loosely to the silver, bronze and deficient standards for models proposed by Araújo *et al.* (2019) (Table 1, Fig. 2). In principle, modelling approaches using ideal data and next-generation tools that are still under development (the 'aspirational' gold standard) is unattainable for predictive climate change

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studies and is therefore not considered in our evidence quality scale. The silver standard corresponds to best modelling practices, i.e. a combination of the best-available data and tools to account for or quantify bias and uncertainty (LoE2a). The bronze standard implies limited acceptable practices that allow inferring implications from their results (LoE2b,c). Lastly, the deficient category corresponds to insufficiently robust data or modelling practices (LoE3), and this level also comprises all speculative studies, i.e., not supported by empirical data. These include expert opinions and speculations based on knowledge of other regions or ecosystem types.

III. RESULTS

(1) Distribution of studies

Our initial search string retrieved 10,163 studies. After successive elimination stages (Fig. 1), the final data set included 395 studies (see online Supporting Information, Table S1 for full list), published between 1994 and 2021 (Fig. 1). The number of publications increased from less than 10 annually before 2006 to an average of 30 from 2013 onwards, potentially reflecting an increased interest in TMFs.

Inconsistent definitions of TMFs, ambiguous latitudinal limits and different mapping methods have resulted in estimates of their global distribution and extent that vary by as much as an order of magnitude. However, an estimate of ~2M km^2 globally (Mulligan, 2010; Los *et al.*, 2019) has been reported relatively consistently, and is compatible with other recent regional estimates (e.g. ~401,300 km^2 TMF cover in the Neotropics; Helmer *et al.*, 2019). Around 75 nations are thought to have some TMF cover, however, there is no consensus regarding many countries such as Bhutan, East Timor, Eritrea, Eswatini, Lesotho, Nepal, Oman, Somalia, South Africa, South Sudan and Sudan (Fig. 3), and some authors count subnational territories separately, e.g. New Caledonia, Tahiti and La Réunion Island (see Karger *et al.*, 2021; Mulligan, 2010).

Of the 395 reviewed studies, 66.8% (264) were carried out in the Neotropics. South America had the highest number of studies (117, 29.6%), followed by North America (Mexico) with 67 (17.0%) and Central America with 54 (13.7%). Only 26 studies (6.6%) focused on the Caribbean (Figs 3 and 4A). Elsewhere, we found 71 (18.0%) studies in total for Asia; and there were 33 (8.4%) studies in Africa, 20 (5.1%) in Oceania (Australia, Papua New Guinea, and Melanesian islands), and 31 (7.8%) in other oceanic regions (Hawaii and Canary Islands). Relatively few studies examined TMFs in relation to climate change at a global scale (15, 3.8%; Fig. 4A).

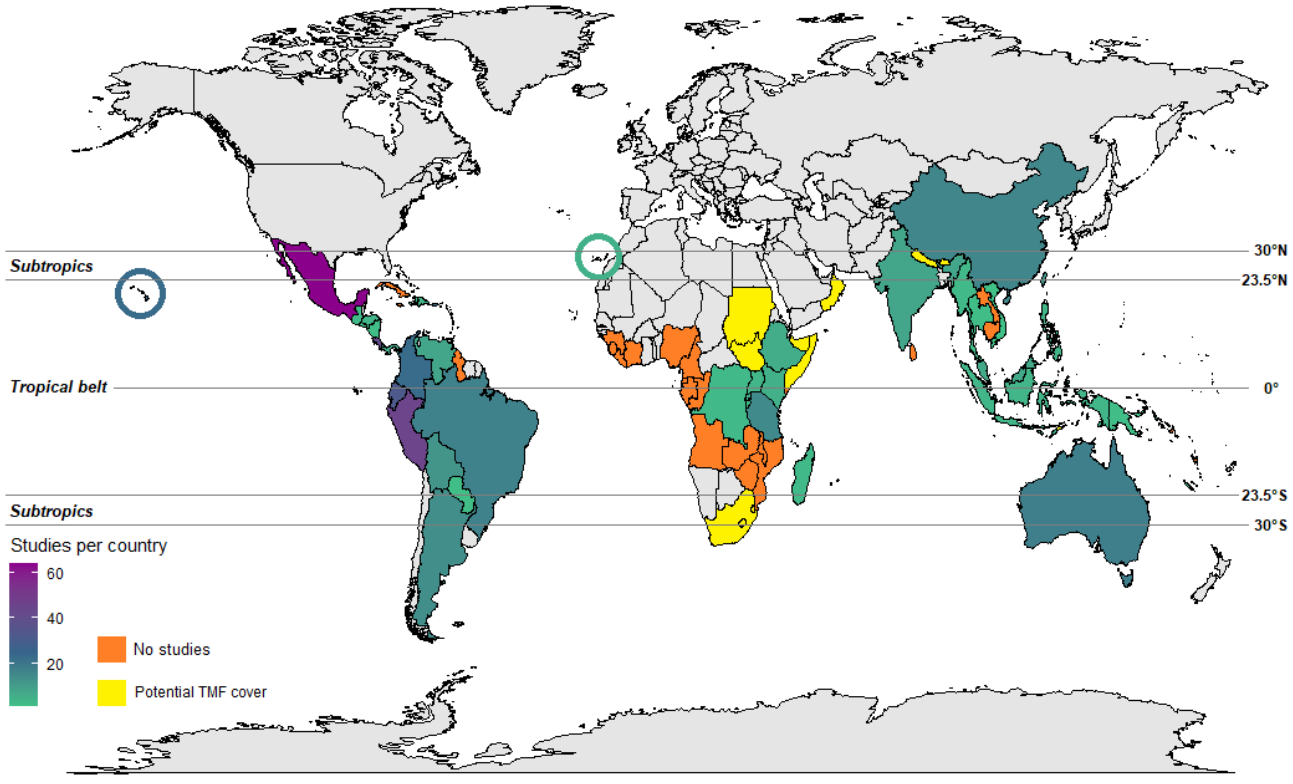

Fig. 3. Geographical distribution of retrieved studies by country or territory. The number of studies is indicated by the colour scale shown on the bottom left. Orange indicates countries with tropical montane forest (TMF) cover for which no relevant studies were found. Yellow indicates countries with contested TMF cover (see Karger *et al.*, 2021; Los *et al.*, 2019; Mulligan, 2010).

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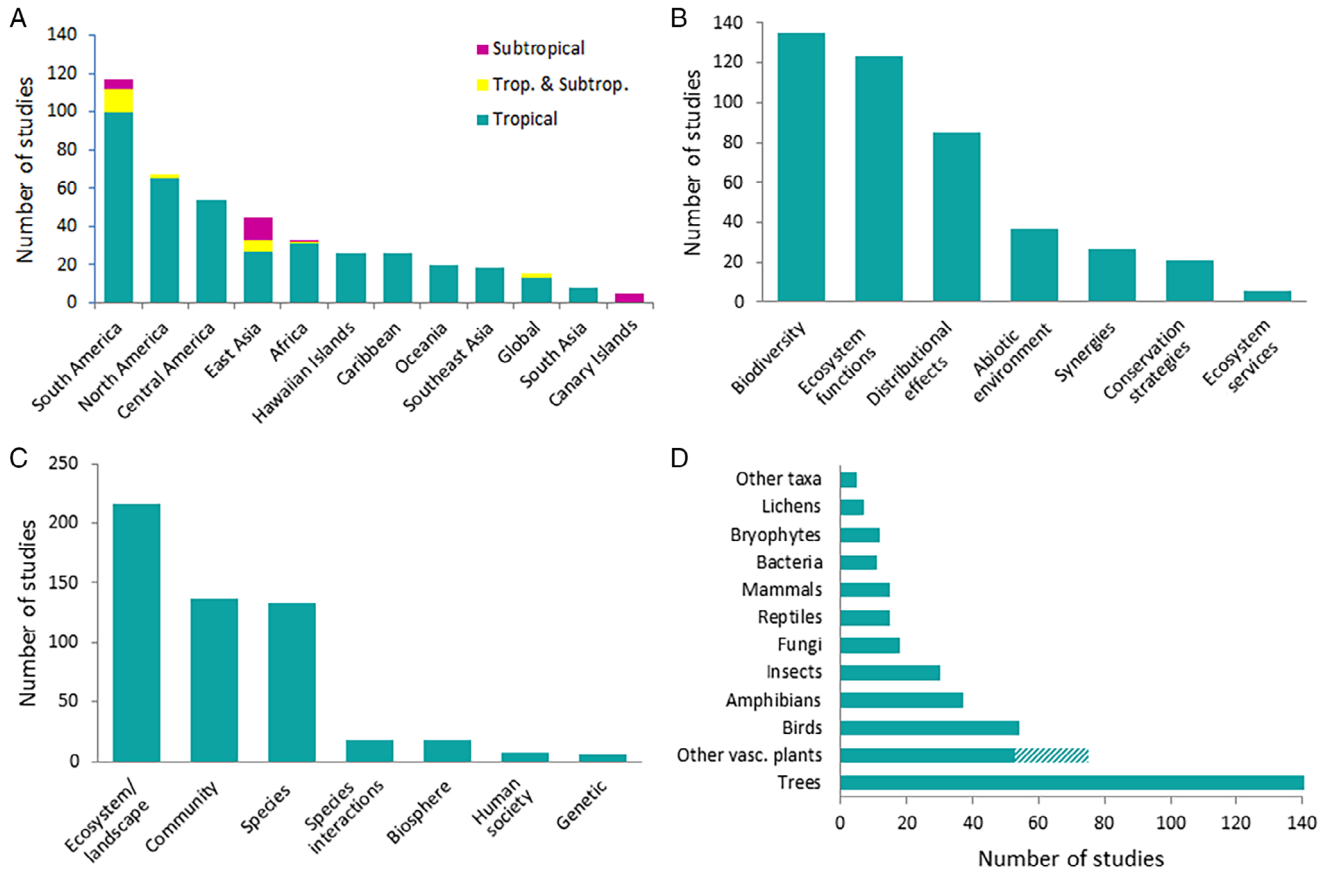

Fig. 4. Number of studies published from 1994 to 2021 on the effects of climate change on tropical and subtropical montane forests for different (A) geographic regions, (B) research topic, (C) ecological levels, and (D) taxonomic groups. In A, Oceania comprises Australia, Papua New Guinea and other islands of the South Pacific; the Hawaiian Islands are shown separately. In D, the striped portion of the 'other vascular plants' group corresponds to epiphytes.

The vast majority of studies took place in tropical regions (0° to 23.5° N and S), whereas exclusively subtropical (23.5° to 30° N and S; *sensu* Corlett, 2013) studies were only those conducted in the Canary Islands (Fig. 4A). Some studies included tropical–subtropical overlapping regions, mainly in Taiwan, Argentina and Brazil.

We found studies conducted in 32 countries and six subnational territories (Fig. 3). The most studied TMFs were those in the Neotropics, namely Mexico (64 studies, 16.2%), Peru (45, 11.4%), Costa Rica (42, 10.6%), Ecuador (32, 8.1%), Colombia (23, 5.8%), Brazil (17, 4.3%), Argentina (14, 3.5%) and Bolivia (12, 3.0%). In other regions, only Australia (18, 4.6%), Tanzania (15, 3.8%) and Taiwan (12, 3.0%) stood out. Well-represented subnational territories were the Hawaiian Islands (24, 6.1%) and Puerto Rico (20, 5.1%). We found fewer than 10 studies each for other countries and territories. Countries with potential areas of TMF (Mulligan, 2010; Karger *et al.*, 2021), for which we did not find any relevant studies include Angola, Cambodia, Cameroon, Comoros, Cuba, Equatorial Guinea, Gabon, Guinea, Guyana, Ivory Coast, Jamaica, Laos, Liberia, Malawi, Mauritius, Mozambique, Myanmar, Nigeria, Republic of the Congo, Sierra Leone, São Tomé and Príncipe, Saint Kitts and Nevis, Saint Vincent and the Grenadines, Solomon Islands, Sri Lanka, Vanuatu, Zambia and Zimbabwe.

Concerning the impacts of climate change on TMF components (Fig. 4B), most studies examined the effects on biodiversity (135, 34.2%), ecosystem functions (123, 31.1%) and distributional effects (85, 21.5%). Abiotic environment, synergies with other drivers of change and conservation strategies were the focus of 37 (9.4%), 27 (6.8%) and 21 (5.3%) studies, respectively, and despite the recognition of TMFs as important provider of ecosystem services, these were the focus of only six (1.5%) studies. Research effort at different ecological levels was also noticeably imbalanced (Fig. 4C). Most studies focused on the ecosystem or landscape (216, 54.7%), community (137, 34.7%) and species (132, 33.4%) levels. Considerably fewer studies investigated species interactions and biosphere (18, 4.6% each), human societal (7, 1.8%) and genetic (6, 1.5%) levels.

Taxonomically, vascular plants were the most researched taxonomic group (Fig. 4D), with trees alone considered in 141 (35.7%) studies, followed by other vascular plants (75, 19.0%), of which 22 (5.6%) studies corresponded to

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epiphytes. The next best studied taxonomic groups were birds (54, 13.7%), amphibians (37, 9.4%), insects (30, 7.6%), fungi (18, 4.6%), mammals (15, 3.8%), reptiles (15, 3.8%), bryophytes (12, 3.0%) and bacteria (11, 2.8%), while other groups were the focus of less than 10 studies each.

(2) Trends in the literature

We found that research from certain regions tended to focus on a particular taxonomic group ($\chi^2 = 129.77$, df = 81, $P < 0.001$). Research efforts in North America (i.e. Mexico) were skewed towards trees; in Oceania (mainly in the Wet Tropics Bioregion, northeastern Australia) were skewed towards insects; and in Central America (mainly in Costa Rica and Panama) towards both bryophytes and fungi. Conversely, studies on trees were scarce in Oceania, with only one study from Papua New Guinea (Venter *et al.*, 2017).

Some research topics were associated with certain geographic regions ($\chi^2 = 104.25$, df = 45, $P < 0.001$). For example, studies in the Caribbean tended to focus on the effects of changing abiotic conditions, such as changes in fog immersion, air temperature and streamflow. We also found an association between research topics and taxonomic groups ($\chi^2 = 268.83$, df = 45, $P < 0.001$). This was mainly driven by studies on ecosystem functions whose focus was on trees and bacteria. Tree studies focused on large-scale processes such as primary productivity, carbon sequestration and distributional shifts, whereas bacteria studies mainly examined soil functions, such as nutrient cycling and decomposition. There was also a dearth of diversity (e.g. abundances and community composition) studies on trees, compared to other taxa, such as birds and insects.

We did not find evidence that studies reporting or testing climate change impacts tend to use a particular measure of climate change or consider a particular taxonomic group in their research (i.e. no association between focus on climate change measures and on taxonomic groups). Studies reporting habitat losses (range contractions or fragmentations) focused more frequently on mammals ($\chi^2 = 41.07$, df = 10, $P < 0.001$), and were also more likely to report biodiversity losses in terms of abundances, species richness or species turnover, and extinctions ($\chi^2 = 10.32$, df = 4, $P = 0.035$).

(3) Assessment of the evidence on the impacts of climate change in TMFs

We found 30 (7.6%) field experimental studies (Fig. 5A), i.e. providing a 'very strong' LoE (LoE1a). They reflected the general geographical trend described in Section III.1, with five studies from Mexico, although four of these were conducted by one research team (García-Hernández *et al.*, 2019; Toledo-Aceves, García-Hernández & Paz, 2019; García-Hernández & Toledo-Aceves, 2020; Toledo-Aceves & del-Val, 2021). Four LoE1a studies were from Peru, followed by three each from China, Costa Rica and Hawaii, two each from Puerto Rico, Taiwan and Tanzania, and one study for Colombia, Ecuador, India, Panama, the Philippines and Rwanda. The scarcity of field experimental studies could be due to the relative inaccessibility of tropical montane regions, often in poorly connected rural areas of low-income countries, which makes field experiments impractical and costly in the absence of well-established research groups. By contrast, strong evidence (LoE1b; *ex-situ* experiments and long-term data sets), was found in 94 studies (23.8%). Around 13% of these studies (12, 3% of total) included the use of modelling methods. Studies that scored as moderate evidence (LoE2a) accounted for 58 studies (14.7%), including mainly <10 year data sets and a small contribution of modelling studies (6, 1% of total) that supported their forecasts with field observations. A third of the reviewed studies provided inconclusive evidence (LoE2b; 132 studies). The reliance of climate change studies on modelling methods was evident: modelling studies accounted for 81.8% (108, 27.3% of total) of studies in this level. The remaining studies in LoE2b were non-longitudinal observational resurveys that provided two or more snapshots suggesting temporal changes but did not allow identification of trends. Studies yielding circumstantial evidence (LoE2c) were common (73, 18.5%), mostly consisting of cross-sectional observational studies, and a small contribution from modelling approaches (11, 2.8% of total). Finally, speculative studies (LoE3a) were the least frequent (8, 2.0%).

Modelling methods were used by 144 (36.5%) studies in total. Climatic envelope models [mainly species distribution models (SDMs), as well as projections of species' population decline, extirpation or extinction under climate change] comprised over two thirds (102, 70.8%) of these; 20 (13.8%) were future climate projections (mainly estimations of future temperature and precipitation regimes), and the remainder (22, 15.3%) were a diverse array of computer-based simulations of changes in biomass, evapotranspiration, albedo, erosion, water runoff, etc. From 1994 to 2005, we found 14 studies that employed modelling methods, with no more than three studies annually, and zero modelling studies for some years, including 2005. Of these, only two were SDMs (Williams, Bolitho & Fox, 2003; Miles, Grainger & Phillips, 2004). From 2006 onwards, the use of modelling methods increased to an average of seven studies per year until 2018, and over 10 per year after 2019. Of the 130 modelling studies retrieved after 2006, 96 (73.8%) were SDMs. This trend coincides with the development of the modelling algorithm Maximum Entropy (MaxEnt; Elith *et al.*, 2006), which was employed by 58.5% of SDM studies, either on its own or in combination with other algorithms [e.g. Random Forests, Genetic Algorithm for Rule-Set Production (GARP), etc.].

An association between the LoE strength and research topics ($\chi^2 = 116.11$, df = 20, $P < 0.001$; Fig. 5B) revealed some methodological trends. This association partly was an artefact of the ranking of most modelling studies in LoE2b (i.e. distributional shifts as a main research topic was strongly associated with LoE2b). However, the association persisted after removing distributional studies ($\chi^2 = 68.45$, df = 16, $P < 0.001$) because studies on biodiversity also relied more

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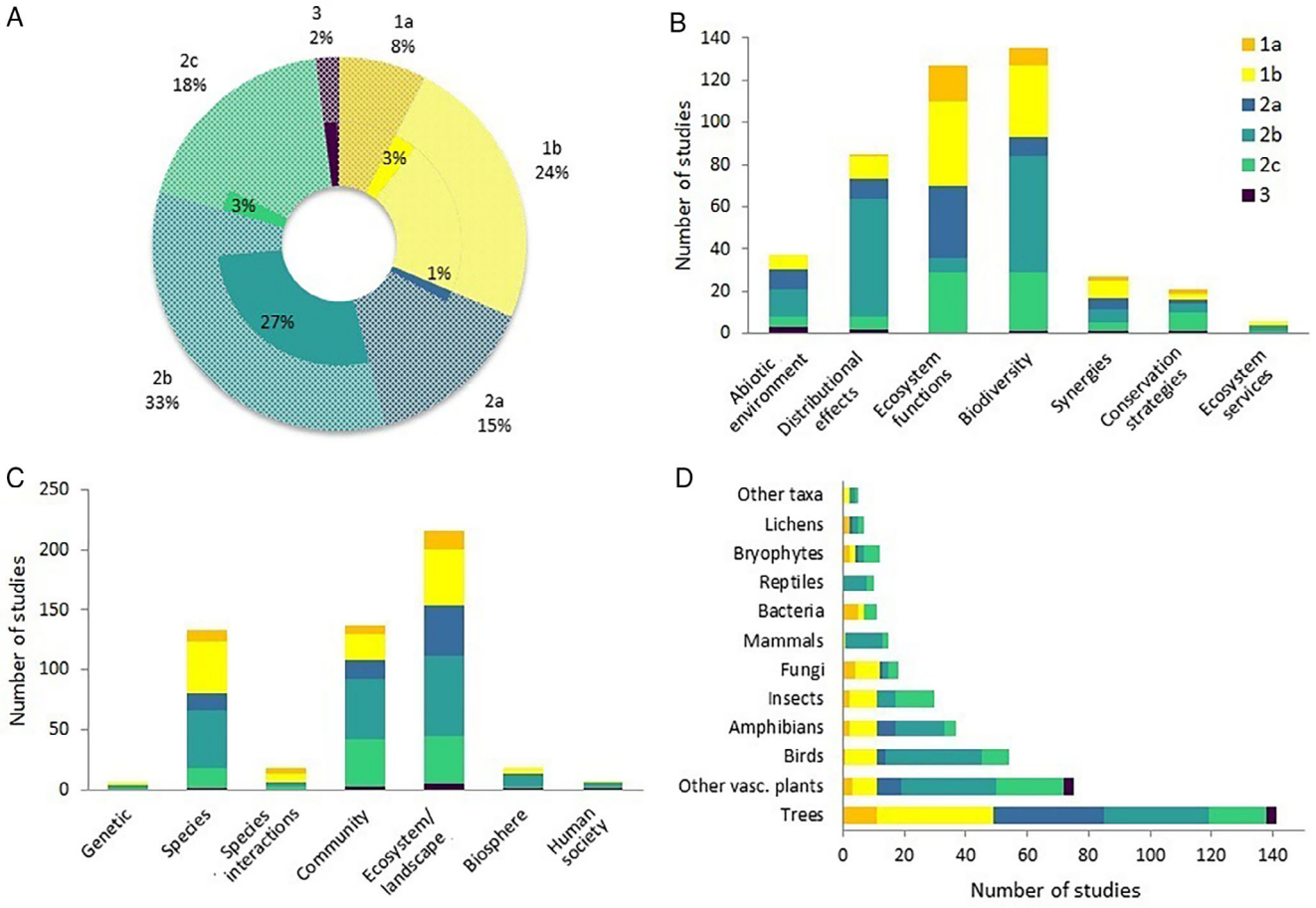

Fig. 5. Distribution of reviewed studies according to levels of evidence (LoE) category (see Table 1 and Fig. 2 for definitions of LoE categories). (A) Percentage of studies by LoE. Solid-coloured portions indicate the frequency of modelling studies within each level. (B–D) LoE of reviewed studies by (B) research topic, (C) ecological level, and (D) taxonomic group. In D, vascular epiphytes are included in the 'other vasc. plants' category.

on LoE2b approaches that yield inconclusive evidence (modelling and resurveys). Conversely, studies on ecosystem functions contained the most study designs providing strong evidence (LoE1b, experiments and long-term dendrochronological records).

Considering only the studies at species, community, and ecosystem or landscape levels (i.e. ecological levels with >100 studies each; Fig. 5C), we found an association of these studies with certain LoE strength ($\chi^2 = 23.44$, df = 10, $P = 0.009$). Whilst provision of inconclusive evidence (LoE2b) was most frequent in studies at these three ecological levels, the species and ecosystem or landscape levels also included a non-negligible proportion of studies yielding strong evidence (LoE1b). For the species level, these corresponded mainly to *ex-situ* experiments (e.g. thermal and drought tolerance experiments). For the ecosystem or landscape level, these were based on long-term data sets.

Regarding taxonomic groups, trees and other vascular plants, birds, amphibians, and insects were the only taxa represented in more than 20 studies each (Fig. 5D). By retaining only these groups and grouping together the remaining taxa, we found that studies of some taxonomic groups were associated with certain LoE strength ($\chi^2 = 79.49$, df = 20, $P < 0.001$). Studies of trees commonly provided evidence ranging from strong (LoE1b) to inconclusive (LoE2b), whereas studies of birds were associated more often with inconclusive evidence (LoE2b, modelling studies) and those of insects more with circumstantial evidence (LoE2c, comparative cross-sectional surveys). Very strong evidence (LoE1a) was provided most often in studies of other taxa (i.e. fungi, mammals, bacteria, reptiles, bryophytes, lichens, and others), driven by the use of field transplant experiments in studies of fungi, bryophytes, lichens, and bacterial (soil) communities.

(4) Evidence-based synthesis of impacts of climate change on TMFs

Ranking the published studies according to LoE strength allows us to outline better the current state of knowledge on the present or expected future impacts of climate change on TMFs. In this section, we summarise the findings on climate

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change impacts on the abiotic environment, biodiversity and ecosystem functions of TMFs, focusing primarily on the studies ranked highest in our evidence hierarchy in each case.

(a) *Changes in atmospheric conditions*

None of the published studies on atmospheric conditions employed field experiments (i.e. no LoE1a studies). Albeit scarce (7, 1.8%), evidence based on long-term studies (≥10-year observations; LoE1b) suggested that atmospheric changes in TMFs were a local or regional effect, rather than a global trend. A study analysing 100 years of meteorological data in Mexico showed that the subtropical (Nearctic) northern mountainous regions have experienced more consistent increments of both atmospheric temperature and precipitation since 1970 than the (Neo)tropical southern mountainous areas (Cuervo-Robayo *et al.*, 2020). Elsewhere, significant reductions in precipitation have been reported over recent decades (e.g. the Indian Western Ghats region; Murugan *et al.*, 2009). However, a decrease in rainfall does not necessarily affect the capacity of TMFs to intercept water from the atmosphere (e.g. La Hispaniola; Comarazamy *et al.*, 2015). TMFs in Puerto Rico had a higher likelihood of fog immersion during the dry periods of the year compared to the rainy season (Van Beusekom, González & Scholl, 2017). In addition, over 40 years of observations in Puerto Rico revealed no significant change of cloud base levels in the mountains (Miller *et al.*, 2018). Therefore, these data suggest that water availability within TMFs may not be adversely affected by reductions in precipitation.

Climatic trends can be confounded by large-scale factors such as topography (Aiba & Kitayama, 2002; Van Beusekom, González & Rivera, 2015; but see Loarie *et al.*, 2009) and global atmospheric patterns, including the ENSO cycle (Crausbay *et al.*, 2014), as well as by regional-scale phenomena like cyclones and fires. There is evidence of a feedback mechanism between defoliation caused by strong hurricanes and rising cloud levels (Scholl, Bassiouni & Torres-Sánchez, 2021), and accelerated thermophilisation (i.e. intrusion of lowland species adapted to warmer climates into cooler communities; Duque, Stevenson & Feeley, 2015; Fadrique *et al.*, 2018) of montane forests in the Caribbean region (Tanner *et al.*, 2022). Increased fire incidence linked to dryer atmospheric conditions could facilitate the expansion of fire-resistant species (Grau & Veblen, 2000), for instance, serotinous pine trees (Rodríguez-Trejo & Fulé, 2003; Climent *et al.*, 2004). In some regions (e.g. Mexico), however, fire incidence has declined over recent decades because of human management, which could negatively affect the regeneration of fire-adapted arboreal species (Yocom & Fulé, 2012; Cerano-Paredes *et al.*, 2021).

(b) *General decline of TMFs*

Most models (LoE2b) predict substantial losses of TMF area and biodiversity in the coming decades. Mexico is projected to suffer important reductions in TMF area, population declines and even extinctions by the end of the century, either due directly to climate change or in combination with other drivers of change, notably land-use change (e.g. Correa Ayram *et al.*, 2017; Golicher *et al.*, 2008; Ponce-Reyes *et al.*, 2017, 2013). Similar outcomes have been forecast for other montane regions, including Costa Rica (Colwell *et al.*, 2008), the tropical Andes (Ledo, Montes & Condes, 2009; Tejedor-Garavito *et al.*, 2015; Godoy-Bürki, 2016), the 'campos rupestres' (Bitencourt *et al.*, 2016) and the Atlantic forest biomes in Brazil (Castro *et al.*, 2020), the Neotropical realm as a whole (Helmer *et al.*, 2019), the Western Ghats region in India (Chakraborty *et al.*, 2013), China's *Abies* forests (Liao *et al.*, 2020), Myanmar's natural protected areas (Nwe, Zomer & Corlett, 2020), and the Australian Wet Tropics (Costion *et al.*, 2015).

(c) *Distributional effects on flora*

Atmospheric variables play a key role in shaping the distributions of species and whole communities, thus shifts in species' ranges are one of the expected consequences of climate change. The presence of clear boundaries between forests and other vegetation types (treelines) is primarily defined by temperature, precipitation and fog incidence, and has been confirmed in various tropical montane regions, including the Cordillera Central in the Dominican Republic (Martin, Sherman & Fahey, 2007; Martin & Fahey, 2014), the Afromontane forests in Ethiopia (Schmitt *et al.*, 2013), and in Hawaii (Crausbay & Hotchkiss, 2010). Upslope displacements of treelines have been observed over periods of 10 years or more (LoE1b) in Mexico (Jiménez-García *et al.*, 2021), protected areas in the tropical Andes (Lutz, Powell & Silman, 2013), Taiwan (Greenwood *et al.*, 2014), Hawaii (Koide *et al.*, 2017) and Mount Kilimanjaro (Shugart *et al.*, 2001), as well as changes in community composition that reflect upslope migrations of lowland plant species in Costa Rica (Feeley *et al.*, 2013).

Yet, many species' responses to spatial changes in temperature and precipitation may not be occurring at a sufficiently fast pace to keep up with the rate of climate change (Feeley *et al.*, 2013, 2011; Lutz *et al.*, 2013; but see Lu *et al.*, 2020). An analysis on avian seed dispersal in the Peruvian Andes concluded that several long-distance dispersal events would be necessary for the treeline to keep up with warming rates (Nowak *et al.*, 2022). And even if that dispersal occurs, experimental studies have found that species-specific thermal and drought tolerances might influence seedling recruitment rates at higher altitudes (Esperón-Rodríguez & Barradas, 2014; Rehm & Feeley, 2016; Fadrique *et al.*, 2018), potentially stymieing treeline expansion. However, an analysis of historic data of Taiwanese montane trees showed dissimilar responses at both intra- and interspecific levels; species already adapted to higher elevations moved upslope at higher rates, but these responses varied among life stages (O'Sullivan *et al.*, 2021).

The main bulk of evidence of distributional changes comes from forecasting modelling studies (LoE2b), which

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overwhelmingly project range contractions, population declines, local extinctions or a combination of these in TMF tree communities (e.g. John *et al.*, 2020; Neto dos Santos, Silva & Higuchi, 2020; Rojas Briceño *et al.*, 2020) and herbaceous plants (Setyawan *et al.*, 2020). These predicted range contractions are partially explained by the topography of mountains themselves because as species migrate upwards, the available area decreases. However, upward area reduction does not happen monotonically in over half of the world's mountainous regions (Elsen & Tingley, 2015), and the influence of topography is complex, in some cases potentially leading to horizontal rather than vertical displacements (Lippok *et al.*, 2014).

Several studies have looked at the potential limiting factors for treelines to track new climatically suitable areas. These factors include frost (Rehm & Feeley, 2015; Joshi, Ratnam & Sankaran, 2020; Rehm, Yelenik & D'Antonio, 2021), hydraulic stress (Song *et al.*, 2016*b*), fruit or seed production (Chapman *et al.*, 2018), seed dispersal (Hillyer & Silman, 2010; Rehm & Feeley, 2013; Nowak *et al.*, 2022), germination rates (Centre *et al.*, 2016), and even the absence of nurse plants (Soto-Correa *et al.*, 2013). By contrast, a field transplant experiment carried out in the Peruvian Andes concluded that soil was not a limiting factor for the establishment of trees at higher elevations (Tito, Vasconcelos & Feeley, 2021). It has been suggested that plants that have evolved in nutrient-poor soils might be 'pre-adapted' to cope with other environmental stressors (Whitman *et al.*, 2021). Thus, intra- and interspecific differential migration rates, in combination with other processes such as higher mortality of cold-resistant species and intrusion of lowland species into montane areas (e.g. de Gasper *et al.*, 2021), may lead to the formation of new communities adapted to warmer regimes (Wright, Muller-Landau & Schipper, 2009), i.e. thermophilisation (Duque *et al.*, 2015; Fadrique *et al.*, 2018).

While experimental studies to test responses of tree species to climate change rarely went beyond seed dispersal and seedling establishment, another defining component of the TMF flora, epiphytes, has been researched more often through experimental manipulations (LoE1a and LoE1b). Field transplant experiments to different elevations to simulate changing climatic regimes on bryophytes (Nadkarni & Solano, 2002; Song, Liu & Nadkarni, 2012; Wagner, Zotz & Bader, 2014) and ferns (Hsu, Oostermeijer & Wolf, 2014) consistently found slower rates of growth and leaf production, and higher mortality, even if some species or individuals displayed some plasticity. Similar results were obtained from *ex-situ* experiments with both bryophytes and vascular epiphytes (Zotz *et al.*, 2010; Gotsch *et al.*, 2015). Epiphytes' reliance on different water sources seems to be linked to their taxonomic affiliation; Liu *et al.* (2021) found that in a Chinese subtropical montane forest, bryophytes and ferns obtained water both from humus and fog, whereas lichens and seed plants relied almost exclusively on fog. Although significant tolerance to desiccation (Bader *et al.*, 2013) and temperature rise (up to an average of 3 °C) has been observed for some epiphytic species (Müller, Albach & Zotz, 2017), their ability to track new climatically suitable areas was not experimentally tested.

(*d*) *Effects on fauna*

Birds were the best-studied taxonomic group after all vascular plants (Fig. 4D). There was some empirical evidence (LoE1a and LoE1b) for the effects of climate change on avian species, such as recorded cases of upslope migrations in Honduras (Neate-Clegg *et al.*, 2018), the tropical Andes (Forero-Medina *et al.*, 2011*b*; Hermes *et al.*, 2018*a*; Hayes, Lecourt & del Castillo, 2018; Freeman *et al.*, 2018), Tanzania (Neate-Clegg *et al.*, 2021*b*) and New Guinea (Freeman, 2016). Elevational shifts have also been reported for moth assemblages on Mount Kinabalu, Malaysia (Chen *et al.*, 2009), and bats in Costa Rica (LaVal, 2004). However, these responses might be species specific (Anderson *et al.*, 2013) and not all species can successfully expand their ranges (Campos-Cerqueira & Aide, 2017; Neate-Clegg *et al.*, 2020). Even if elevational shifts do occur, they may result in intense competition for space and resources near mountaintops, triggering aggressive behaviours (Jankowski, Robinson & Levey, 2010), or leading to higher morbidity (Freed & Cann, 2013) and mortality rates (Shiao *et al.*, 2020).

Modelling studies (LoE2b) outline similar trends, overwhelmingly predicting range contractions, population declines, local extinctions or a combination of these in TMF birds (Colyn *et al.*, 2020), mammals (Ramírez-Bautista *et al.*, 2020; Raman *et al.*, 2020*a*,*b*), amphibians (Cruz-Elizalde *et al.*, 2020; Cordier *et al.*, 2020) and scorpions (de Araujo-Lira *et al.*, 2020). However, the influence of climate change on upslope migrations could be challenging to distinguish from that of land-use change (see Jacob *et al.*, 2015*a*,*b*).

The prospect for ectotherms is a matter of much concern. Thermal tolerance experiments (LoE1b) conducted with amphibians (Rueda-Solano *et al.*, 2016; von May *et al.*, 2017; González-del-Pliego *et al.*, 2020), reptiles (Muñoz *et al.*, 2016; Piantoni, Navas & Ibargüengoytía, 2016; Strangas *et al.*, 2019; but see Tao *et al.*, 2021) and insects (e.g. Montejo-Kovacevich *et al.*, 2020; Polato *et al.*, 2018; Shah *et al.*, 2017*b*) showed that tropical montane species are more susceptible to changes in temperature regimes relative to their lowland or temperate counterparts. However, some level of adaptive capacity was observed in some frog (von May *et al.*, 2017) and ant (Nowrouzi *et al.*, 2018) species, and in some cases, upslope migrations might be favoured by a relief from cold stress at higher elevations (Muñoz *et al.*, 2022). Many tropical montane amphibians have also been severely impacted by the compounding effect of pathogens (e.g. Anchukaitis & Evans, 2010; Catenazzi *et al.*, 2014, 2010; Neely *et al.*, 2020), with long-term studies confirming substantial population declines and even extinctions in recent decades (e.g. Barker & Ríos-Franceschi, 2015; Campos-Cerqueira & Aide, 2017; Pounds, Fogden & Campbell, 1999). Amphibian microhabitats can offer some buffering from impacts of climate change,

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especially for arboreal species (Scheffers *et al.*, 2013*a*,*b*, 2014), yet the overall expected outcome is loss of amphibian diversity at a global scale. Assemblages are projected to become much more homogenous due to selective extinctions of specialists (Menéndez-Guerrero, Green & Davies, 2020) and the intrusion of invasive lowland generalists (Rödder, 2009).

Empirical evidence showing effects of climate change on other major animal taxa, such as mammals, reptiles and most invertebrates, is too limited to identify any clear patterns. For instance, a resurvey of tropical montane ants in Costa Rica concluded that over a decade, the community became less diverse, with upland areas becoming more similar to lowland ones (Warne *et al.*, 2020) – suggesting that thermophilisation of communities is not limited to flora – however, this finding was promptly contested (Klimes *et al.*, 2021).

(*e*) *Effects on ecosystem functions*

Ecosystem functions are commonly studied through experimental manipulation in the field (LoE1a) or laboratory (LoE1b). Multiple soil transplant and litter decomposition experiments have found that increasing temperatures, altered water status or both can change decomposition rates and have a negative influence on the capacity of TMF soils to retain organic matter, potentially turning the systems into carbon emitters (e.g. Becker & Kuzyakov, 2018; Looby & Treseder, 2018; Nottingham *et al.*, 2019*b*, 2016). Higher temperatures also make nutrients more readily available, with potential cascading effects on vegetation and other soil properties (Dantas de Paula *et al.*, 2021). Some studies, however, have reached opposite conclusions or found no clear relationship between temperature or hydric regime and soil properties (e.g. He *et al.*, 2010; Scowcroft, Turner & Vitousek, 2000). Such equivocal conclusions could be due to the heterogeneity and localised nature of soil properties.

Montane trees are also expected to experience thermal and hydraulic stress under climate change. This may lead to increased respiration and reduced growth rates that translate into diminished carbon sequestration (e.g. Esperón-Rodríguez & Barradas, 2015*b*; Feeley *et al.*, 2020; Gutiérrez-García & Ricker, 2019). This vulnerability is partly due to the reliance of TMF plant communities on atmospheric water and the shielding effect of fog from direct solar radiation; both climatic factors at present attenuate vapour pressure deficit, to which TMF species are particularly responsive (e.g. Correa-Díaz *et al.*, 2020; Gotsch *et al.*, 2014*a*,*b*; Rodríguez-Ramírez *et al.*, 2020). These climatic factors also influence the growth rates of TMF trees (Keyimu *et al.*, 2020; Li *et al.*, 2020; Niessner *et al.*, 2020; Quadri, Silva & Zavaleta, 2021; Ricker, Gutiérrez-García & Daly, 2007; Rodríguez-Ramírez, Luna-Vega & Rozas, 2018; but see Camarero *et al.*, 2021), seed production (Rodríguez-Ramírez, Terrazas & Luna-Vega, 2019; Pau *et al.*, 2020), establishment (Chirino *et al.*, 2017; Toledo-Aceves *et al.*, 2019), and even plant–herbivore interactions (Bendix *et al.*, 2021; Toledo-Aceves & del-Val, 2021). The generalised persistent stress caused by climate change could explain high tree mortality events at a global scale (Allen *et al.*, 2010). It could also be linked to a browning trend observed in pantropical forests since the mid-1990s (Krishnaswamy, John & Joseph, 2014), or the contrasting greening trend during the past 20 years in central Mexico (Correa-Díaz, Romero-Sánchez & Villanueva-Díaz, 2021). Such large-scale vegetation changes can further boost rising temperatures by altering the forests' albedo effect (Doughty *et al.*, 2018) and render plant communities more susceptible to droughts.

IV. DISCUSSION

This review of the literature on impacts of climate change on TMFs shows that: (*i*) the rates of climate change are generally intensified rather than attenuated by elevation, making montane communities more susceptible to their effects; (*ii*) tropical montane communities might be able to respond by shifting their distributions primarily upslope, but (*iii*) not all species seem able to shift their distributions and the factors preventing them from tracking or establishing in new climatically suitable areas are unknown or not well understood; (*iv*) even if montane species are able to track suitable conditions fast enough, they risk running out of physical space; (*v*) the impacts of climate change on genetic diversity and species interactions within tropical montane ecosystems remain largely unknown; and (*vi*) the loss of biodiversity and functions of TMFs could result in the loss of valuable ecosystem services for human populations living close to tropical montane regions, with repercussions at a broader scale.

Additionally, this study revealed some significant knowledge gaps in several aspects (i.e. methodological approaches, geographical and taxonomic skews, and research topics) that need to be addressed, but also shows that there are some areas of opportunity, either expanding on the available knowledge, or by employing methodologies and data sources that have not been properly explored.

(1) Methodological gaps and opportunities

The nature of climate change as a global and long-term phenomenon limits our ability to produce in the short term abundant empirical evidence of its effects in real time on particular ecosystem types or any of their functions and biotic components. Instead, our assessment of evidence strength showed that there has been greater reliance on study designs that yield moderate, inconclusive and circumstantial evidence. Given that conventional study designs that yield strong evidence tend to be time-consuming, effort-intensive and costly in remote mountainous regions, a practical strategy is to accumulate independent lines of moderate, inconclusive or circumstantial, yet coherent evidence that build up the same narrative. Thus, greater effort is needed to reconcile contradicting findings across different study sites and spatiotemporal scales, as well as attempts to disentangle the synergistic influences of multiple environmental factors on

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the diversity and functions of TMFs. Albeit likely geographically biassed and difficult to interpret, long-term data sets are becoming increasingly abundant and accessible (Wauchope *et al.*, 2021).

Additionally, environmental gradients along mountain slopes make TMFs ideal locations to conduct field manipulation experiments (e.g. transplant experiments along temperature gradients). Field transplant experiments are recognised as a powerful tool capable of yielding robust evidence by replicating complex projected environmental conditions more accurately than laboratory trials (Nooten & Andrew, 2016; Silveira *et al.*, 2019; Tito *et al.*, 2020). These types of experiments are useful to inform assisted migration programmes (e.g. Castellanos-Acuña, Lindig-Cisneros & Sáenz-Romero, 2015; Sáenz-Romero *et al.*, 2020*b*), changes in ecological networks (e.g. Maunsell *et al.*, 2015), adaptation to urbanisation (e.g. Martin *et al.*, 2021), among others. Alternative methods to produce strong evidence in the short term include analysis of historical remote sensing data (e.g. aerial photography and satellite imagery to detect changes in ecosystem boundaries and canopy spectral changes over time), as well as 'natural' long-term records (e.g. dendrochronological studies; Rodríguez-Ramírez *et al.*, 2022).

Even though our review focuses exclusively on anthropogenic climate change, the potential value of palaeoclimatic and palaeoecological studies cannot be disregarded. In principle, studies of Quaternary-time and deep-time face similar challenges as long-term future-modelling studies, namely: 'the impossibility of distinguishing between true and false' (Biondi, 2014, p. 1), and their findings should be interpreted cautiously. For instance, Fitzpatrick *et al.* (2018) projected that by 2090 (i.e. seven decades), climates in North America will have shifted by as much as they did during the past 13,000 years. Hence, it seems unreasonable to expect that species will be able to replicate in just a few decades past migrations spanning millennia. Conversely, a few decades might simply be too little time to detect distributional changes, especially for long-living, slow-growing organisms such as trees than can live for centuries. In fact, a common criticism of ecological niche modelling approaches is their underlying assumption that present distributions reflect the whole set of conditions in which a species can persist (Feeley & Silman, 2010*a*; Sax, Early & Bellemare, 2013), which is not necessarily true and needs to be accounted for. Some studies warn that relying exclusively on 'realised distributions' as input for predictive distributional studies could overly restrict potential future suitable habitats and overestimate risks of extinction and extirpation (Veloz *et al.*, 2012; Sax *et al.*, 2013). However, we argue that given the current rate of anthropogenic climate change, it is preferable to avoid overly optimistic assumptions that may lead to inaction, especially for montane ecosystems globally. Moreover, sets of good practices have been suggested to improve the accuracy of palaeoecological reconstructions (e.g. Nogués-Bravo, 2009) and a combination of short-term ecological studies with long-term palaeoecological evidence can help us to understand the impacts of climate change better (Lamentowicz, Słowińska & Słowiński, 2016). These research strategies would help resolve conflicting lines of evidence to enable rapid preventive and adaptive responses to climate change impacts on TMFs.

(2) Geographical and taxonomic gaps and opportunities

Studies have been heavily concentrated in the Mesoamerican and Andean regions, both part of the Neotropical biogeographic realm. The fragmented evidence from other world regions suggests that other tropical montane regions may share similar climate change-induced impacts, albeit with some degree of local variation. Research efforts should be refocused on understudied regions to find out if there are any major discrepancies among them. Nonetheless, a few intensively researched areas, such as TMFs in Mexico, Costa Rica and Peru – representative of subtropical, mid-latitude tropical and nigh-equatorial TMFs, respectively – can be considered suitable proxies for environmental management while local studies elsewhere are in progress.

Most research on TMFs focuses on only a few taxa, yet these ecosystems are considered hotspots of biodiversity, much of which remains undescribed. For example, a recent survey of rove beetles (Staphylinidae), one of the largest families of organisms in the world, along an elevational gradient in Honduras found that they reached peak diversity precisely in the highly vulnerable TMF altitudinal belt (Dolson *et al.*, 2021). Such lack of knowledge on biotic components of TMFs obscures our understanding of their ecological networks, ecosystem functions, and the magnitude of potential losses if cascading extinctions occur. Fortunately, surveys of soil, understorey and canopy biota can be carried out relatively quickly and are less costly and effort intensive than long-term monitoring or manipulative study designs. Additionally, knowledge biases towards charismatic taxa can be exploited to set up 'umbrella species' conservation schemes.

(3) Thematic gaps and opportunities

Many studies support the notion that climate change will result in physiological pressures and distributional shifts of tropical montane communities, but assumptions of general climate-driven range shifts should be avoided (Rubenstein *et al.*, 2020). Empirical evidence also shows that climatic conditions can impede the effective establishment of tree communities (Rehm & Feeley, 2013; Song *et al.*, 2016*b*; Joshi *et al.*, 2020) and likely other components of tropical montane biota. In fact, species' ability to persist or migrate is influenced by their interactions with other ecosystem components, both biotic and abiotic (Jankowski *et al.*, 2010; Ramirez-Villegas *et al.*, 2014; Quiroga, Premoli & Kitzberger, 2018; Joshi *et al.*, 2020), but few studies have looked at ecological networks in TMFs (Benning *et al.*, 2002; Jankowski *et al.*, 2010; Hillyer & Silman, 2010; Ornelas, Licona-Vera & Ortiz-Rodriguez, 2018; Tito *et al.*, 2021). Improving our understanding of these

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interactions would help improve the accuracy of forecasts both in terms of distributional responses and potential future assemblages. Although field studies are needed to elucidate how tropical montane networks respond to climate change and other disturbances, existing databases can be used to construct and conduct robust analyses on ecological networks (e.g. de Almeida & Mikich, 2018; Fricke & Svenning, 2020), and project their responses under climate change scenarios.

More concerning is the paucity of studies at the genetic level in TMF research in relation to climate change, which has been previously acknowledged (Pauls *et al.*, 2013). For example, tropical tree populations are experiencing genetic bottlenecks following intense disturbance events, but tropical montane regions are understudied (Pautasso, 2009). For mountainous regions, this might be crucial because micro-evolutionary processes operate differently within a population along an elevational gradient, i.e. the leading edge, the central population and the rear edge (Kremer, Potts & Delzon, 2014). Sudden disturbance-induced migrations may lead to decreased phenotypic variability, further jeopardising the plasticity and ability of trees both to reach and to establish populations in new areas (Pertoldi, Bijlsma & Loeschcke, 2007). Also, highly variable conditions may not result in an adaptive response because selection processes are multi-directional and the existing genetic variation in a population might be insufficient to generate the genotypic combinations required for it to persist under new environmental conditions (Alfaro *et al.*, 2014). As the most conspicuous biotic component of forests, declines of trees could trigger negative cascading effects (Bawa & Dayanandan, 1998; Nagel *et al.*, 2019). Thus, the genetic status of trees is a factor that ought to be taken into account for assisted migration programmes (Alfaro *et al.*, 2014), and all these considerations are equally valid for other taxa. Unlike other knowledge gaps, the scarcity of studies at the genetic level is difficult to overcome though indirect and remote methods, however, the increasing accessibility and affordability of sequencing methods should facilitate extensive genetic surveys of tropical montane populations in the short term.

V. RECENT WORK

There have been recent developments since our systematic review was carried out. For example, Rico *et al.* (2023) reported that the genetic health of a tropical montane tree species in Mexico is threatened by human activity and climate change. Research on treeline expansion has also shown that dry conditions in the boundary between TMF and *páramo* in the Venezuelan Andes support a seedling bank, but with slow growth (Ramírez *et al.*, 2022); and some species may need treatment, such as scarification, to increase germination rates (Liyanage *et al.*, 2022). Thus, understanding the genetic adaptations and environmental influence of seeds and seedlings is crucial for conservation efforts. However, long-term monitoring is also necessary as some abiotic effects, such as soil properties, may not be noticeable for years (Martínez-Ramos *et al.*, 2022). Lastly, new knowledge of diversity patterns and spatial partitioning in various regions (Berrios, Coronado & Marsico, 2022; Morton *et al.*, 2022) emphasise the importance of traditional biodiversity surveys in TMFs, especially in understudied regions.

VI. CONCLUSIONS

(1) We highlight the long-term need to widen the methodological, thematic, taxonomic and geographical scope of studies on TMFs under climate change. In the short term, however, the accumulation of moderate to circumstantial evidence constitutes the most accessible and reliable tool to address uncertainties and gaps in current knowledge. As such, in-depth research in well-studied regions, use of alternative data sources (remote sensing and 'natural' long-term records), palaeoecological supporting evidence and advances and refinements of forecasting modelling techniques offer the most reliable and immediate sources of information for expeditious conservation action for these threatened forests.

(2) Natural variability within TMF regions represents a challenge for the generalisation of the findings of individual studies, but it simultaneously represents an exceptional opportunity to generate high-quality evidence of the impacts of climate change for both tropical montane species and lowland species. Environmental gradients along mountain slopes have been identified as natural laboratories, where field manipulation experiments (e.g. field transplant experiments, rain exclusion experiments, etc.) can be conducted in the short term to simulate complex projected environmental conditions with greater accuracy than can be achieved *ex situ*.

(3) We highlight the importance of modelling approaches in TMF research and encourage further refinement and development of these methods. To enhance their effectiveness, novel, more robust forecasting algorithms should be developed to account for uncertainties and sampling biases. Additionally, incorporating ecological information, such as species dispersal limitations, biotic interactions, and analyses of ecological networks, can make commonly used modelling approaches more informative. Optimising these approaches with more ecological information is crucial for the success of conservation strategies, such as the design of protected areas that consider future suitable habitats for whole biotic communities, and minimising losses of biodiversity and ecosystem functions.

(4) Despite the undeniable importance of trees in forests, the responses of other taxonomic groups to climate change should not be overlooked, as intraspecific interactions could prove decisive for the success of conservation measures. Similarly, the impacts of climate change at the genetic level remain largely unknown and the loss of genetic diversity can threaten the long-term viability of TMF populations.

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(5) We urge scientists to conduct similar evidence quality assessments in their respective fields. Experts in each area of research should critically ponder what study designs and data sources yield the most robust body of evidence and take them into consideration when carrying out reviews and planning future research.

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VIII. REFERENCES

References marked with asterisk (*) have been cited within the supporting information.

Aiba, S.-I. & Kitayama, K. (2002). Effects of the 1997–98 El Niño drought on rain forests of mount Kinabalu, Borneo. *Journal of Tropical Ecology* **18**, 215–230.

*Ainsworth, A. & Drake, D. R. (2020). Classifying Hawaiian plant species along a habitat generalist-specialist continuum: implications for species conservation under climate change. *PLoS One* **15**, e0228573.

Alfaro, R. I., Fady, B., Vendramin, G. G., Dawson, I. K., Fleming, R. A., Sáenz-Romero, C., Lindig-Cisneros, R. A., Murdock, T., Vinceti, B., Navarro, C. M., Skrøppa, T., Baldinelli, G., El-Kassaby, Y. A. & Loo, J. (2014). The role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change. *Forest Ecology and Management* **333**, 76–87.

*Alfonso-Corrado, C., Naranjo-Luna, F., Clark-Tapia, R., Campos, J., Rojas-Soto, O., Luna-Krauletz, M., Bodenhorn, B., Gorgonio-Ramírez, M. & Pacheco-Cruz, N. (2017). Effects of environmental changes on the occurrence of *Oreomunnea mexicana* (Juglandaceae) in a biodiversity hotspot cloud forest. *Forests* **8**, 261.

Allen, C. D., Macalady, A. K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Kitzberger, T., Rigling, A., Breshears, D. D., Hogg, E. H., Gonzalez, P., Fensham, R., Zhang, Z., Castro, J., Demidova, N., *et al.* (2010). A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *Forest Ecology and Management* **259**, 660–684.

*Altamirano-León, S., Ramírez-Martínez, J. C., Díaz-Porras, D. F., Balam-Narváez, R., Luna-Vega, I. & Contreras-Medina, R. (2022). Climate change and impact on distribution of tree species in the cloud forest of Oaxaca. *Revista Chapingo Serie Ciencias Forestales* **28**, 271–287.

Altarez, R. D. D., Apan, A. & Maraseni, T. (2022). Spaceborne satellite remote sensing of tropical montane forests: a review of applications and future trends. *Geocarto International* **37**, 1–29.

*Alvarado-Barrientos, M. S., Holwerda, F., Asbjornsen, H., Dawson, T. E. & Bruijnzeel, L. A. (2014). Suppression of transpiration due to cloud immersion in a seasonally dry Mexican weeping pine plantation. *Agricultural and Forest Meteorology* **186**, 12–25.

*Alvarado-Barrientos, M. S., Holwerda, F., Geissert, D. R., Muñoz-Villers, L. E., Gotsch, S. G., Asbjornsen, H. & Dawson, T. E. (2015). Nighttime transpiration in a seasonally dry tropical montane cloud forest environment. *Trees* **29**, 259–274.

*Amici, A. A., Nadkarni, N. M., Williams, C. B. & Gotsch, S. G. (2020). Differences in epiphyte biomass and community composition along landscape and within-crown spatial scales. *Biotropica* **52**, 46–58.

Anchukaitis, K. J. & Evans, M. N. (2010). Tropical cloud forest climate variability and the demise of the Monteverde golden toad. *Proceedings of the National Academy of Sciences* **107**, 5036–5040.

*Anderson, A. S., Reside, A. E., VanDerWal, J. J., Shoo, L. P., Pearson, R. G. & Williams, S. E. (2012). Immigrants and refugees: the importance of dispersal in mediating biotic attrition under climate change. *Global Change Biology* **18**, 2126–2134.

Anderson, A. S., Storlie, C. J., Shoo, L. P., Pearson, R. G. & Williams, S. E. (2013). Current analogues of future climate indicate the likely response of a sensitive montane tropical avifauna to a warming world. *PLoS One* **8**, e69393.

Araújo, M. B., Anderson, R. P., Márcia Barbosa, A., Beale, C. M., Dormann, C. F., Early, R., Garcia, R. A., Guisan, A., Maiorano, L., Naimi, B., O'Hara, R. B., Zimmermann, N. E. & Rahbek, C. (2019). Standards for distribution models in biodiversity assessments. *Science Advances* **5**, eaat4858.

*Arias-Aguilar, A., Chacón-Madrigal, E., LaVal, R. & Rodríguez-Herrera, B. (2020). Diversity and activity patterns of aerial insectivorous bats along an altitudinal gradient in a tropical forest in Costa Rica. *Hystrix* **31**, 58.

*Arzac, A., Llambí, L. D., Dulhoste, R., Olano, J. M. & Chacón-Moreno, E. (2019). Modelling the effect of temperature changes on plant life-form distribution across a treeline ecotone in the tropical Andes. *Plant Ecology & Diversity* **12**, 619–631.

*Ashton, L. A., Kitching, R. L., Maunsell, S. C., Bito, D. & Putland, D. A. (2011). Macrolepidopteran assemblages along an altitudinal gradient in subtropical rainforest – exploring indicators of climate change. *Memoirs of the Queensland Museum* **55**(2), 375–389.

*Bach, K., Kessler, M. & Gradstein, S. R. (2007). A simulation approach to determine statistical significance of species turnover peaks in a species-rich tropical cloud forest: a simulation approach to determine statistical significance of species turnover peaks. *Diversity and Distributions* **13**, 863–870.

Bader, M. Y., Reich, T., Wagner, S., González González, A. S. & Zotz, G. (2013). Differences in desiccation tolerance do not explain altitudinal distribution patterns of tropical bryophytes. *Journal of Bryology* **35**, 47–56.

Barker, B. S. & Ríos-Franceschi, A. (2015). Population declines of mountain coqui (*Eleutherodactylus portoricensis*) in the Cordillera Central of Puerto Rico. **22**.

*Barnes, P. W., Ryel, R. J. & Flint, S. D. (2017). UV screening in native and non-native plant species in the tropical alpine: implications for climate change-driven migration of species to higher elevations. *Frontiers in Plant Science* **8**, 1451.

*Batumike, R., Bulonvu, F., Imani, G., Akonkwa, D., Gahigi, A., Klein, J. A., Marchant, R. & Cuni-Sanchez, A. (2022). Climate change and hunter-gatherers in montane eastern DR Congo. *Climate and Development* **14**, 431–442.

*Baumbach, L., Warren, D. L., Yousefpour, R. & Hanewinkel, M. (2021). Climate change may induce connectivity loss and mountaintop extinction in Central American forests. *Communications Biology* **4**, 869.

Bawa, K. S. & Dayanandan, S. (1998). Global climate change and tropical Forest genetic resources. In *Potential Impacts of Climate Change on Tropical Forest Ecosystems* (ed. A. Markham), pp. 333–345. Springer, Netherlands, Dordrecht.

*Bax, V., Castro-Nunez, A. & Francesconi, W. (2021). Assessment of potential climate change impacts on montane forests in the Peruvian Andes: implications for conservation prioritization. *Forests* **12**, 375.

*Becker, J., Pabst, H., Mnyonga, J. & Kuzyakov, Y. (2015). Annual litterfall dynamics and nutrient deposition depending on elevation and land use at Mt. Kilimanjaro. *Biogeosciences* **12**, 5635–5646.

Becker, J. N. & Kuzyakov, Y. (2018). Teatime on Mount Kilimanjaro: assessing climate and land-use effects on litter decomposition and stabilization using the Tea Bag Index. *Land Degradation & Development* **29**, 2321–2329.

*Bender, I. M. A., Kissling, W. D., Böhning-Gaese, K., Hensen, I., Kühn, I., Nowak, L., Töpfer, T., Wiegand, T., Dehling, D. M. & Schleuning, M. (2019). Projected impacts of climate change on functional diversity of frugivorous birds along a tropical elevational gradient. *Scientific Reports* **9**, 17708.

Bendix, J., Aguire, N., Beck, E., Bräuning, A., Brandl, R., Breuer, L., Böhning-Gaese, K., de Paula, M. D., Hickler, T., Homeier, J., Inclan, D., Leuschner, C., Neuschulz, E. L., Schleuning, M., Suarez, J. P., *et al.* (2021). A research framework for projecting ecosystem change in highly diverse tropical mountain ecosystems. *Oecologia* **195**, 589–600.

Benning, T. L., LaPointe, D., Atkinson, C. T. & Vitousek, P. M. (2002). Interactions of climate change with biological invasions and land use in the Hawaiian Islands: modeling the fate of endemic birds using a geographic information system. *Proceedings of the National Academy of Sciences* **99**, 14246–14249.

Berrios, H. K., Coronado, I. & Marsico, T. D. (2022). High species richness and turnover of vascular epiphytes is associated with water availability along the elevation gradient of Volcán Maderas, Nicaragua. *Ecology and Evolution* **12**, e9501.

*Berriozabal-Islas, C., Rodrigues, J. F. M., Ramírez-Bautista, A., Becerra-López, J. L. & Nieto-Montes de Oca, A. (2018). Effect of climate change in lizards of the genus *Xenosaurus* (Xenosauridae) based on projected changes in climatic suitability and climatic niche conservatism. *Ecology and Evolution* **8**, 6860–6871.

*Berry, Z. C., Gotsch, S. G., Holwerda, F., Muñoz-Villers, L. E. & Asbjornsen, H. (2016). Slope position influences vegetation-atmosphere interactions in a tropical montane cloud forest. *Agricultural and Forest Meteorology* **221**, 207–218.

*Bertoncello, R., Yamamoto, K., Meireles, L. D. & Shepherd, G. J. (2011). A phytogeographic analysis of cloud forests and other forest subtypes amidst the Atlantic forests in south and Southeast Brazil. *Biodiversity and Conservation* **20**, 3413–3433.

Biondi, F. (2014). Paleoecology grand challenge. *Frontiers in Ecology and Evolution* **2**, 50.

Bitencourt, C., Rapini, A., Santos Damascena, L. & De Marco Junior, P. (2016). The worrying future of the endemic flora of a tropical mountain range

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under climate change. *Flora-Morphology, Distribution, Functional Ecology of Plants* **218**, 1–10.

*Blundo, C., Malizia, L. R., Blake, J. G. & Brown, A. D. (2012). Tree species distribution in Andean forests: influence of regional and local factors. *Journal of Tropical Ecology* **28**, 83–95.

*Bogawski, P., Damen, T., Nowak, M. M., Pędziwiatr, K., Wilkin, P., Mwachala, G., Pierzchalska, J. & Wiland-Szymańska, J. (2019). Current and future potential distributions of three *Dracaena* Vand. ex L. species under two contrasting climate change scenarios in Africa. *Ecology and Evolution* **9**, 6833–6848.

*Borchert, R., Robertson, K., Schwartz, M. D. & Williams-Linera, G. (2005). Phenology of temperate trees in tropical climates. *International Journal of Biometeorology* **50**, 57–65.

*Bothwell, L. D., Selmants, P. C., Giardina, C. P. & Litton, C. M. (2014). Leaf litter decomposition rates increase with rising mean annual temperature in Hawaiian tropical montane wet forests. *PeerJ* **2**, e685.

*Bouskill, N. J., Lim, H. C., Borglin, S., Salve, R., Wood, T. E., Silver, W. L. & Brodie, E. L. (2013). Pre-exposure to drought increases the resistance of tropical forest soil bacterial communities to extended drought. *The ISME Journal* **7**, 384–394.

Brown, A. D. & Kappelle, M. (2001). Introducción a los bosques nublados del Neotrópico: Una síntesis regional. *Bosques nublados del neotrópico*, 25–40.

Bruijnzeel, L. A. (2004). Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems & Environment* **104**, 185–228.

Buytaert, W., Cuesta-Camacho, F. & Tobón, C. (2011). Potential impacts of climate change on the environmental services of humid tropical alpine regions: climate change and environmental services. *Global Ecology and Biogeography* **20**, 19–33.

*Caballero-Villalobos, L., Fajardo-Gutiérrez, F., Calbi, M. & Silva-Arias, G. A. (2021). Climate change can drive a significant loss of suitable habitat for *Polylepis quadrijuga*, a treeline species in the sky islands of the northern Andes. *Frontiers in Ecology and Evolution* **9**, 661550.

Camarero, J. J., Gazol, A., Sánchez-Salguero, R., Fajardo, A., McIntire, E. J. B., Gutiérrez, E., Batllori, E., Boudreau, S., Carrer, M., Diez, J., Dufour-Tremblay, G., Gaire, N. P., Hofgaard, A., Jomelli, V., Kirdyanov, A. V., *et al.* (2021). Global fading of the temperature–growth coupling at alpine and polar treelines. *Global Change Biology* **27**, 1879–1889.

*Campos, A. (2014). Trends in soil respiration on the eastern slope of the Cofre de Perote Volcano (Mexico): environmental contributions. *Catena* **114**, 59–66.

Campos-Cerqueira, M. & Aide, T. M. (2017). Lowland extirpation of anuran populations on a tropical mountain. *PeerJ* **5**, e4059.

*Campos-Cerqueira, M. & Aide, T. M. (2021). Impacts of a drought and hurricane on tropical bird and frog distributions. *Ecosphere* **12**, e03352.

*Campos-Cerqueira, M., Arendt, W. J., Wunderle, J. M. & Aide, T. M. (2017). Have bird distributions shifted along an elevational gradient on a tropical mountain? *Ecology and Evolution* **7**, 9914–9924.

*Cárdenas, R. E. (2016). Fine-scale climatic variation drives altitudinal niche partitioning of tabanid flies in a tropical montane cloud forest, Ecuadorian Chocó. *Insect Conservation and Diversity* **9**, 87–96.

Castellanos-Acuña, D., Lindig-Cisneros, R. & Sáenz-Romero, C. (2015). Altitudinal assisted migration of Mexican pines as an adaptation to climate change. *Ecosphere* **6**, 1–16.

Castro, M. B., Barbosa, A. C. M. C., Pompeu, P. V., Eisenlohr, P. V., de Assis Pereira, G., Apgaua, D. M. G., Pires-Oliveira, J. C., Barbosa, J. P. R. A. D., Fontes, M. A. L., dos Santos, R. M. & Tng, D. Y. P. (2020). Will the emblematic southern conifer *Araucaria angustifolia* survive to climate change in Brazil? *Biodiversity and Conservation* **29**, 591–607.

Catenazzi, A., Lehr, E., Rodriguez, L. O. & Vredenburg, V. T. (2010). *Batrachochytrium dendrobatidis* and the collapse of anuran species richness and abundance in the Upper Manu National Park, Southeastern Peru: frog declines in the Tropical Andes. *Conservation Biology* **25**, 382–391.

Catenazzi, A., Lehr, E. & Vredenburg, V. T. (2014). Thermal physiology, disease, and amphibian declines on the eastern slopes of the Andes: frog declines in the Tropical Andes. *Conservation Biology* **28**, 509–517.

*Ceballos, S. J., Blundo, C., Malizia, A., Osinaga Acosta, O. & Carilla, J. (2021). Dynamics of tree mortality in subtropical montane forests of Northwestern Argentina. *Forest Ecology and Management* **497**, 119528.

Center, A., Etterson, J. R., Deacon, N. J. & Cavender-Bares, J. (2016). Seed production timing influences seedling fitness in the tropical live oak *Quercus oleoides* of Costa Rican dry forests. *American Journal of Botany* **103**, 1407–1419.

Cerano-Paredes, J., Iniguez, J. M., Villanueva-Díaz, J., Vázquez-Selem, L., Cervantes-Martínez, R., Esquivel-Arriaga, G., Franco-Ramos, O. & Rodríguez-Trejo, D. A. (2021). Effects of climate on historical fire regimes (1451–2013) in *Pinus hartwegii* forests of Cofre de Perote National Park, Veracruz, Mexico. *Dendrochronologia* **65**, 125784.

Chakraborty, A., Joshi, P. K., Ghosh, A. & Areendran, G. (2013). Assessing biome boundary shifts under climate change scenarios in India. *Ecological Indicators* **34**, 536–547.

*Chang, S.-C., Tseng, K.-H., Hsia, Y.-J., Wang, C.-P. & Wu, J.-T. (2008). Soil respiration in a subtropical montane cloud forest in Taiwan. *Agricultural and Forest Meteorology* **148**, 788–798.

Chapman, C. A., Valenta, K., Bonnell, T. R., Brown, K. A. & Chapman, L. J. (2018). Solar radiation and ENSO predict fruiting phenology patterns in a 15-year record from Kibale National Park, Uganda. *Biotropica* **50**, 384–395.

*Chen, D., Yu, M., González, G., Zou, X. & Gao, Q. (2017). Climate impacts on soil carbon processes along an elevation gradient in the tropical Luquillo Experimental Forest. *Forests* **8**, 90.

*Chen, I.-C., Hill, J. K., Shiu, H.-J., Holloway, J. D., Benedick, S., Chey, V. K., Barlow, H. S. & Thomas, C. D. (2011). Asymmetric boundary shifts of tropical montane Lepidoptera over four decades of climate warming: asymmetric boundary shifts of tropical Lepidoptera. *Global Ecology and Biogeography* **20**, 34–45.

Chen, I.-C., Shiu, H.-J., Benedick, S., Holloway, J. D., Chey, V. K., Barlow, H. S., Hill, J. K. & Thomas, C. D. (2009). Elevation increases in moth assemblages over 42 years on a tropical mountain. *Proceedings of the National Academy of Sciences* **106**, 1479–1483.

Chirino, E., Ruiz-Yanetti, S., Vilagrosa, A., Mera, X., Espinoza, M. & Lozano, P. (2017). Morpho-functional traits and plant response to drought conditions in seedlings of six native species of Ecuadorian ecosystems. *Flora* **233**, 58–67.

Christmann, T. & Menor, I. O. (2021). A synthesis and future research directions for tropical mountain ecosystem restoration. *Scientific Reports* **11**, 23948.

*Chu, H.-S., Chang, S.-C., Klemm, O., Lai, C.-W., Lin, Y.-Z., Wu, C.-C., Lin, J.-Y., Jiang, J.-Y., Chen, J., Gottgens, J. F. & Hsia, Y.-J. (2014). Does canopy wetness matter? Evapotranspiration from a subtropical montane cloud forest in Taiwan: canopy wetness and evapotranspiration of a Taiwan montane cloud forest. *Hydrological Processes* **28**, 1190–1214.

Climent, J., Tapias, R., Pardos, J. A. & Gil, L. (2004). Fire adaptations in the Canary Islands pine (*Pinus canariensis*). *Plant Ecology* **171**, 185–196.

*Colares, C., Roza, A. S., Mermudes, J. R. M., Silveira, L. F. L., Khattar, G., Mayhew, P. J., Monteiro, R. F., Nunes, M. F. S. Q. C. & Macedo, M. V. (2021). Elevational specialization and the monitoring of the effects of climate change in insects: beetles in a Brazilian rainforest mountain. *Ecological Indicators* **120**, 106888.

Collin, P. (2001). L'adaptation au milieu chez les plantes vasculaires. *L'Année Biologique* **40**, 21–42.

Colwell, R. K., Brehm, G., Cardelus, C. L., Gilman, A. C. & Longino, J. T. (2008). Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. *Science* **322**, 258–261.

Colyn, R. B., Ehlers Smith, D. A., Ehlers Smith, Y. C., Smit-Robinson, H. & Downs, C. T. (2020). Predicted distributions of avian specialists: a framework for conservation of endangered forests under future climates. *Diversity and Distributions* **26**, 652–667.

*Comarazamy, D. E. & González, J. E. (2011). Regional long-term climate change (1950–2000) in the midtropical Atlantic and its impacts on the hydrological cycle of Puerto Rico: regional and local climate changes. *Journal of Geophysical Research: Atmospheres* **116**, 1–18.

Comarazamy, D. E., González, J. E., Moshary, F. & Piasecki, M. (2015). On the hydrometeorological changes of a tropical water basin in the Caribbean and its sensitivity to midterm changes in regional climate. *Journal of Hydrometeorology* **16**, 997–1013.

Cordier, J. M., Lescano, J. N., Ríos, N. E., Leynaud, G. C. & Nori, J. (2020). Climate change threatens micro-endemic amphibians of an important South American high-altitude center of endemism. *Amphibia-Reptilia* **41**, 233–243.

Corlett, R. T. (2013). Where are the Subtropics? *Biotropica* **45**, 273–275.

Corlett, R. T. & Westcott, D. A. (2013). Will plant movements keep up with climate change? *Trends in Ecology & Evolution* **28**, 482–488.

Correa Ayram, C. A., Mendoza, M. E., Etter, A. & Pérez Salicrup, D. R. (2017). Potential distribution of mountain cloud forest in Michoacán, Mexico: prioritization for conservation in the context of landscape connectivity. *Environmental Management* **60**, 86–103.

Correa-Díaz, A., Romero-Sánchez, M. E. & Villanueva-Díaz, J. (2021). The greening effect characterized by the normalized difference vegetation index was not coupled with phenological trends and tree growth rates in eight protected mountains of Central Mexico. *Forest Ecology and Management* **496**, 119402.

Correa-Díaz, A., Silva, L. C. R., Horwath, W. R., Gómez-Guerrero, A., Vargas-Hernández, J., Villanueva-Díaz, J., Suárez-Espinoza, J. & Velázquez-Martínez, A. (2020). From trees to ecosystems: spatiotemporal scaling of climatic impacts on montane landscapes using dendrochronological, isotopic, and remotely sensed data. *Global Biogeochemical Cycles* **34**, e2019GB006325.

Costion, C. M., Simpson, L., Pert, P. L., Carlsen, M. M., John Kress, W. & Crayn, D. (2015). Will tropical mountaintop plant species survive climate change? Identifying key knowledge gaps using species distribution modelling in Australia. *Biological Conservation* **191**, 322–330.

1469185x, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/brv.12950 by University Of Southampton, Wiley Online Library on [09/05/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

*Crain, B. J. & Tremblay, R. L. (2017). Hot and bothered: changes in microclimate alter chlorophyll fluorescence measures and increase stress levels in tropical epiphytic orchids. *International Journal of Plant Sciences* **178**, 503–511.

Crausbay, S. D., Frazier, A. G., Giambelluca, T. W., Longman, R. J. & Hotchkiss, S. C. (2014). Moisture status during a strong El Niño explains a tropical montane cloud forest's upper limit. *Oecologia* **175**, 273–284.

Crausbay, S. D. & Hotchkiss, S. C. (2010). Strong relationships between vegetation and two perpendicular climate gradients high on a tropical mountain in Hawai'i: vegetation gradients on a tropical mountain. *Journal of Biogeography* **37**, 1160–1174.

Cruz-Elizalde, R., Magno-Benítez, I., Berriozabal-Islas, C., Ortíz-Pulido, R., Ramírez-Bautista, A. & Hernández-Austria, R. (2020). Climatic niche, natural history, and conservation status of the Porthole Treefrog, *Charadrahyla taeniopus* (Günther, 1901) (Anura: Hylidae) in Mexico. *Amphibian & Reptile Conservation* **14**, 12.

Cuervo-Robayo, A. P., Ureta, C., Gómez-Albores, M. A., Meneses-Mosquera, A. K., Téllez-Valdés, O. & Martínez-Meyer, E. (2020). One hundred years of climate change in Mexico. *PLoS One* **15**, e0209808.

*Cuesta, F., Tovar, C., Llambí, L. D., Gosling, W. D., Halloy, S., Carilla, J., Muriel, P., Meneses, R. I., Beck, S., Ulloa Ulloa, C., Yager, K., Aguirre, N., Viñas, P., Jácome, J., Suárez-Duque, D., *et al.* (2020). Thermal niche traits of high alpine plant species and communities across the tropical Andes and their vulnerability to global warming. *Journal of Biogeography* **47**, 408–420.

*Cuni-Sanchez, A., Omeny, P., Pfeifer, M., Olaka, L., Mamo, M. B., Marchant, R. & Burgess, N. D. (2019). Climate change and pastoralists: perceptions and adaptation in montane Kenya. *Climate and Development* **11**, 513–524.

*Cusack, D. F., Torn, M. S., McDowell, W. H. & Silver, W. L. (2010). The response of heterotrophic activity and carbon cycling to nitrogen additions and warming in two tropical soils. *Global Change Biology* **16**(9), 2555–2572.

Dalling, J. W., Heineman, K., González, G. & Ostertag, R. (2016). Geographic, environmental and biotic sources of variation in the nutrient relations of tropical montane forests. *Journal of Tropical Ecology* **32**, 368–383.

*Dangles, O., Carpio, C., Barragan, A. R., Zeddam, J.-L. & Silvain, J.-F. (2008). Temperature as a key driver of ecological sorting among invasive pest species in the tropical Andes. *Ecological Applications* **18**, 1795–1809.

Dantas de Paula, M., Forrest, M., Langan, L., Bendix, J., Homeier, J., Velescu, A., Wilcke, W. & Hickler, T. (2021). Nutrient cycling drives plant community trait assembly and ecosystem functioning in a tropical mountain biodiversity hotspot. *New Phytologist* **232**, 551–566.

de Almeida, A. & Mikich, S. B. (2018). Combining plant-frugivore networks for describing the structure of neotropical communities. *Oikos* **127**, 184–197.

de Araujo-Lira, A. F., Badillo-Montaño, R., Lira-Noriega, A. & de Albuquerque, C. M. R. (2020). Potential distribution patterns of scorpions in North-Eastern Brazil under scenarios of future climate change: scorpion distribution on climate change. *Austral Ecology* **45**, 215–228.

de Gasper, A. L., de Grittz, G. S., Russi, C. H., Schwartz, C. E. & Rodrigues, A. V. (2021). Expected impacts of climate change on tree ferns distribution and diversity patterns in subtropical Atlantic Forest. *Perspectives in Ecology and Conservation* **19**, 369–378.

*de la Cruz-Amo, L., Bañares-de-Dios, G., Cala, V., Granzow-de la Cerda, Í., Espinosa, C. I., Ledo, A., Salinas, N., Macía, M. J. & Cayuela, L. (2020). Trade-offs among aboveground, belowground, and soil organic carbon stocks along altitudinal gradients in Andean tropical montane forests. *Frontiers in Plant Science* **11**, 106.

*del Castillo, R. F., Argueta, S. T. & Sáenz-Romero, C. (2009). *Pinus chiapensis*, a keystone species: genetics, ecology, and conservation. *Forest Ecology and Management* **257**, 2201–2208.

*Delsinne, T., Arias-Penna, T. & Leponce, M. (2013). Effect of rainfall exclusion on ant assemblages in montane rainforests of Ecuador. *Basic and Applied Ecology* **14**, 357–365.

*Dialynas, Y. G. & Bras, R. L. (2019). Hydro-geomorphic behavior of contrasting tropical landscapes and critical zone response to changing climate: hydro-geomorphic response of contrasting tropical landscapes. *Earth Surface Processes and Landforms* **44**, 641–654.

Dolson, S. J., Loewen, E., Jones, K., Jacobs, S. R., Solis, A., Hallwachs, W., Brunke, A. J., Janzen, D. H. & Smith, M. A. (2021). Diversity and phylogenetic community structure across elevation during climate change in a family of hyperdiverse neotropical beetles (Staphylinidae). *Ecography* **44**, 740–752.

Doughty, C. E., Santos-Andrade, P. E., Shenkin, A., Goldsmith, G. R., Bentley, L. P., Blonder, B., Díaz, S., Salinas, N., Enquist, B. J., Martin, R. E., Asner, G. P. & Malhi, Y. (2018). Tropical forest leaves may darken in response to climate change. *Nature Ecology & Evolution* **2**, 1918–1924.

*Dulle, H. I., Ferger, S. W., Cordeiro, N. J., Howell, K. M., Schleuning, M., Böhning-Gaese, K. & Hof, C. (2016). Changes in abundances of forest understorey birds on Africa's highest mountain suggest subtle effects of climate change. *Diversity and Distributions* **22**, 288–299.

Duque, A., Stevenson, P. R. & Feeley, K. J. (2015). Thermophilization of adult and juvenile tree communities in the northern tropical Andes. *Proceedings of the National Academy of Sciences* **112**, 10744–10749.

*Dusenge, M. E., Wittemann, M., Mujawamariya, M., Ntawuhiganayo, E. B., Zibera, E., Ntirugulirwa, B., Way, D. A., Nsabimana, D., Uddling, J. & Wallin, G. (2021). Limited thermal acclimation of photosynthesis in tropical montane tree species. *Global Change Biology* **27**, 4860–4878.

*Eaton, W. D., Roed, M., Chassot, O. & Barry, D. (2012). Differences in soil moisture, nutrients and the microbial community between forests on the upper Pacific and Caribbean slopes at Monteverde, Cordillera de Tilaran: implications for responses to climate change. *Tropical Ecology* **53**(2), 235–240.

*Eguiguren-Velepucha, P. A., Chamba, J. A. M., Aguirre Mendoza, N. A., Ojeda-Luna, T. L., Samaniego-Rojas, N. S., Furniss, M. J., Howe, C. & Aguirre Mendoza, Z. H. (2016). Tropical ecosystems vulnerability to climate change in southern Ecuador. *Tropical Conservation Science* **9**, 1940082916668007.

Elith, J., Graham, C. H., Anderson, R. P., Dudík, M., Ferrier, S., Guisan, A., Hijmans, R. J., Huettmann, F. R., Leathwick, J., Lehmann, A., Li, J., Lohmann, L. G., Loiselle, B., Manion, G., Moritz, C., *et al.* (2006). Novel methods improve prediction of species' distributions from occurrence data. *Ecography* **29**, 129–151.

*Eller, C. B., Lima, A. L. & Oliveira, R. S. (2016). Cloud forest trees with higher foliar water uptake capacity and anisohydric behavior are more vulnerable to drought and climate change. *New Phytologist* **211**, 489–501.

Elsen, P. R. & Tingley, M. W. (2015). Global mountain topography and the fate of montane species under climate change. *Nature Climate Change* **5**, 772–776.

*Enquist, B. J. & Enquist, C. A. F. (2011). Long-term change within a Neotropical forest: assessing differential functional and floristic responses to disturbance and drought: differential functional responses to climate change in a tropical forest. *Global Change Biology* **17**, 1408–1424.

*Enquist, C. A. F. (2002). Predicted regional impacts of climate change on the geographical distribution and diversity of tropical forests in Costa Rica. *Journal of Biogeography* **29**, 519–534.

Esperón-Rodríguez, M. & Barradas, V. (2014). Potential vulnerability to climate change of four tree species from the central mountain region of Veracruz, Mexico. *Climate Research* **60**, 163–174.

*Esperón-Rodríguez, M. & Barradas, V. L. (2015*a*). Comparing environmental vulnerability in the montane cloud forest of eastern Mexico: a vulnerability index. *Ecological Indicators* **52**, 300–310.

Esperón-Rodríguez, M. & Barradas, V. L. (2015*b*). Ecophysiological vulnerability to climate change: water stress responses in four tree species from the central mountain region of Veracruz, Mexico. *Regional Environmental Change* **15**, 93–108.

*Esperón-Rodríguez, M., Beaumont, L. J., Lenoir, J., Baumgartner, J. B., McGowan, J., Correa-Metrio, A. & Camac, J. S. (2019). Climate change threatens the most biodiverse regions of Mexico. *Biological Conservation* **240**, 108215.

*Estrada-Contreras, I., Equihua, M., Castillo-Campos, G. & Rojas-Soto, O. (2015). Climate change and effects on vegetation in Veracruz, Mexico: an approach using ecological niche modelling. *Acta Botanica Mexicana* **73**, 73–93.

Fadrique, B., Báez, S., Duque, Á., Malizia, A., Blundo, C., Carilla, J., Osinaga-Acosta, O., Malizia, L., Silman, M., Farfán-Ríos, W., Malhi, Y., Young, K. R., Cuesta, C., Homeier, J. F., Peralvo, M., *et al.* (2018). Widespread but heterogeneous responses of Andean forests to climate change. *Nature* **564**, 207–212.

Fahey, T. J., Sherman, R. E. & Tanner, E. V. J. (2016). Tropical montane cloud forest: environmental drivers of vegetation structure and ecosystem function. *Journal of Tropical Ecology* **32**, 355–367.

Feeley, K., Martinez-Villa, J., Perez, T., Silva Duque, A., Triviño Gonzalez, D. & Duque, A. (2020). The thermal tolerances, distributions, and performances of tropical montane tree species. *Frontiers in Forests and Global Change* **3**, 25.

Feeley, K. J., Hurtado, J., Saatchi, S., Silman, M. R. & Clark, D. B. (2013). Compositional shifts in Costa Rican forests due to climate-driven species migrations. *Global Change Biology* **19**(11), 3472–3480.

Feeley, K. J. & Silman, M. R. (2010*a*). Biotic attrition from tropical forests correcting for truncated temperature niches: species loss accounting for truncated niches. *Global Change Biology* **16**, 1830–1836.

*Feeley, K. J. & Silman, M. R. (2010*b*). Land-use and climate change effects on population size and extinction risk of Andean plants: predicted range shifts in Andean plants. *Global Change Biology* **16**, 3215–3222.

*Feeley, K. J. & Silman, M. R. (2010*c*). Modelling the responses of Andean and Amazonian plant species to climate change: the effects of georeferencing errors and the importance of data filtering. *Journal of Biogeography* **37**, 733–740.

Feeley, K. J., Silman, M. R., Bush, M. B., Farfan, W., Cabrera, K. G., Malhi, Y., Meir, P., Revilla, N. S., Quisiyupanqui, M. N. R. & Saatchi, S. (2011). Upslope migration of Andean trees: Andean trees migrate upslope. *Journal of Biogeography* **38**, 783–791.

1469185x, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/brv.12950 by University Of Southampton, Wiley Online Library on [09/05/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Fitzpatrick, M. C., Blois, J. L., Williams, J. W., Nieto-Lugilde, D., Maguire, K. C. & Lorenz, D. J. (2018). How will climate novelty influence ecological forecasts? Using the quaternary to assess future reliability. *Global Change Biology* **24**, 3575–3586.

*Forero-Medina, G., Joppa, L. & Pimm, S. L. (2011*a*). Constraints to species' elevational range shifts as climate changes: constraints to elevational range shifts. *Conservation Biology* **25**, 163–171.

Forero-Medina, G., Terborgh, J., Socolar, S. J. & Pimm, S. L. (2011*b*). Elevational ranges of birds on a tropical montane gradient lag behind warming temperatures. *PLoS One* **6**, e28535.

Foster, P. (2001). The potential negative impacts of global climate change on tropical montane cloud forests. *Earth-Science Reviews* **55**, 73–106.

*Franklin, J., Majure, L. C., Encarnación, Y., Clase, T., Almonte-Espinosa, H., Landestoy, M., Kratter, A. W., Oswald, J. A., Soltis, D. E., Terrill, R. S. & Steadman, D. W. (2019). Changing ecological communities along an elevation gradient in seasonally dry tropical forest on Hispaniola (Sierra Martín García, Dominican Republic). *Biotropica* **51**, 802–816.

Freed, L. A. & Cann, R. L. (2013). Vector movement underlies avian malaria at upper elevation in Hawaii: implications for transmission of human malaria. *Parasitology Research* **112**, 3887–3895.

Freeman, B. G. (2016). Thermal tolerances to cold do not predict upper elevational limits in New Guinean montane birds. *Diversity and Distributions* **22**, 309–317.

*Freeman, B. G. & Class Freeman, A. M. (2014). Rapid upslope shifts in new Guinean birds illustrate strong distributional responses of tropical montane species to global warming. *Proceedings of the National Academy of Sciences* **111**, 4490–4494.

Freeman, B. G., Scholer, M. N., Ruiz-Gutierrez, V. & Fitzpatrick, J. W. (2018). Climate change causes upslope shifts and mountaintop extirpations in a tropical bird community. *Proceedings of the National Academy of Sciences* **115**, 11982–11987.

Freeman, B. G., Song, Y., Feeley, K. J. & Zhu, K. (2021). Montane species track rising temperatures better in the tropics than in the temperate zone. *Ecology Letters* **24**, 1697–1708.

Fricke, E. C. & Svenning, J.-C. (2020). Accelerating homogenization of the global plant–frugivore meta-network. *Nature* **585**, 74–78.

García-Hernández, M. d. l. Á. & Toledo-Aceves, T. (2020). Is there potential in elevational assisted migration for the endangered *Magnolia vovidesii*? *Journal for Nature Conservation* **53**, 125782.

García-Hernández, M. d. l. Á., Toledo-Aceves, T., López-Barrera, F., Sosa, V. J. & Paz, H. (2019). Effects of environmental filters on early establishment of cloud forest trees along elevation gradients: implications for assisted migration. *Forest Ecology and Management* **432**, 427–435.

*Garcia-Robledo, C., Charlotten-Silva, M., Cruz, C. & Kuprewicz, E. K. (2018). Low quality diet and challenging temperatures affect vital rates, but not thermal tolerance in a tropical insect expanding its diet to an exotic plant. *Journal of Thermal Biology* **77**, 7–13.

*Gasner, M. R., Jankowski, J. E., Ciecka, A. L., Kyle, K. O. & Rabenold, K. N. (2010). Projecting the local impacts of climate change on a central American montane avian community. *Biological Conservation* **143**, 1250–1258.

*Gavrutenko, M., Gerstner, B. E., Kass, J. M., Goodman, S. M. & Anderson, R. P. (2021). Temporal matching of occurrence localities and forest cover data helps improve range estimates and predict climate change vulnerabilities. *Global Ecology and Conservation* **27**, e01569.

*Geml, J., Pastor, N., Fernandez, L., Pacheco, S., Semenova, T. A., Becerra, A. G., Wicaksono, C. Y. & Nouhra, E. R. (2014). Large-scale fungal diversity assessment in the Andean Yungas forests reveals strong community turnover among forest types along an altitudinal gradient. *Molecular Ecology* **23**, 2452–2472.

*Gerold, G., Schawe, M. & Bach, K. (2008). Hydrometeorologic, Pedologic and vegetation patterns along an elevational transect in the montane forest of the Bolivian Yungas. *Die Erde* **139**, 28.

*Giamminola, E. M. (2020). Will global change modify the distribution of the *Anadenanthera colubrina* (Fabales: Fabaceae) plant, a key species in dry tropical forest? *Revista de Biología Tropical* **68**, 517–527.

*Giardina, C. P., Litton, C. M., Crow, S. E. & Asner, G. P. (2014). Warming-related increases in soil CO_2 efflux are explained by increased below-ground carbon flux. *Nature Climate Change* **4**, 822–827.

*Girardin, C. A. J., Farfan-Rios, W., Garcia, K., Feeley, K. J., Jørgensen, P. M., Murakami, A. A., Cayola Pérez, L., Seidel, R., Paniagua, N., Fuentes Claros, A. F., Maldonado, C., Silman, M., Salinas, N., Reynel, C., Neill, D. A., *et al.* (2014). Spatial patterns of above-ground structure, biomass and composition in a network of six Andean elevation transects. *Plant Ecology & Diversity* **7**, 161–171.

Godoy-Bürki, A. C. (2016). Efectos del cambio climático sobre especies de plantas vasculares del sur de los Andes Centrales: un estudio en el noroeste de Argentina (NOA). *Ecología Austral* **26**, 83–94.

*Goldsmith, G. R., Matzke, N. J. & Dawson, T. E. (2013). The incidence and implications of clouds for cloud forest plant water relations. *Ecology Letters* **16**, 307–314.

Golicher, D. J., Cayuela, L., Alkemade, J. R. M., González-Espinosa, M. & Ramírez-Marcial, N. (2008). Applying climatically associated species pools to the modelling of compositional change in tropical montane forests. *Global Ecology and Biogeography* **17**, 262–273.

*Golicher, D. J., Cayuela, L. & Newton, A. C. (2012). Effects of climate change on the potential species richness of Mesoamerican forests: effects of climate change on potential species richness. *Biotropica* **44**, 284–293.

*Gómez-Pineda, E., Sáenz-Romero, C., Ortega-Rodríguez, J. M., Blanco-García, A., Madrigal-Sánchez, X., Lindig-Cisneros, R., Lopez-Toledo, L., Pedraza-Santos, M. E. & Rehfeldt, G. E. (2020). Suitable climatic habitat changes for Mexican conifers along altitudinal gradients under climatic change scenarios. *Ecological Applications* **30**, e02041.

*Gontijo, A. S. B., Garcia, C. S., Righi, A. F. & Galdino, C. A. B. (2018). To warm on the rocks, to cool in the wind: thermal relations of a small-sized lizard from a mountain environment. *Journal of Thermal Biology* **76**, 52–57.

González-del-Pliego, P., Scheffers, B. R., Freckleton, R. P., Basham, E. W., Araújo, M. B., Acosta-Galvis, A. R., Medina Uribe, C. A., Haugaasen, T. & Edwards, D. P. (2020). Thermal tolerance and the importance of microhabitats for Andean frogs in the context of land use and climate change. *Journal of Animal Ecology* **89**, 2451–2460.

*González-Fernández, A., Manjarrez, J., García-Vázquez, U., D'Addario, M. & Sunny, A. (2018). Present and future ecological niche modeling of garter snake species from the trans-Mexican Volcanic Belt. *PeerJ* **6**, e4618.

Gotsch, S. G., Asbjornsen, H., Holwerda, F., Goldsmith, G. R., Weintraub, A. E. & Dawson, T. E. (2014*a*). Foggy days and dry nights determine crown-level water balance in a seasonal tropical montane cloud forest: foliar uptake and night-time transpiration determine crown-level water balance. *Plant, Cell & Environment* **37**, 261–272.

Gotsch, S. G., Crausbay, S. D., Giambelluca, T. W., Weintraub, A. E., Longman, R. J., Asbjornsen, H., Hotchkiss, S. C. & Dawson, T. E. (2014*b*). Water relations and microclimate around the upper limit of a cloud forest in Maui, Hawai'i. *Tree Physiology* **34**, 766–777.

*Gotsch, S. G., Davidson, K., Murray, J. G., Duarte, V. J. & Draguljić, D. (2017). Vapor pressure deficit predicts epiphyte abundance across an elevational gradient in a tropical montane region. *American Journal of Botany* **104**, 1790–1801.

*Gotsch, S. G., Dawson, T. E. & Draguljić, D. (2018). Variation in the resilience of cloud forest vascular epiphytes to severe drought. *New Phytologist* **219**, 900–913.

Gotsch, S. G., Nadkarni, N. & Amici, A. (2016). The functional roles of epiphytes and arboreal soils in tropical montane cloud forests. *Journal of Tropical Ecology* **32**, 455–468.

Gotsch, S. G., Nadkarni, N., Darby, A., Glunk, A., Dix, M., Davidson, K. & Dawson, T. E. (2015). Life in the treetops: ecophysiological strategies of canopy epiphytes in a tropical montane cloud forest. *Ecological Monographs* **85**, 393–412.

Grau, H. R. & Veblen, T. T. (2000). Rainfall variability, fire and vegetation dynamics in neotropical montane ecosystems in North-Western Argentina. *Journal of Biogeography* **27**, 1107–1121.

*Gray, L. K., Clarke, C., Wint, G. R. W. & Moran, J. A. (2017). Potential effects of climate change on members of the Palaeotropical pitcher plant family Nepenthaceae. *PLoS One* **12**, e0183132.

Greenhalgh, T. & Peacock, R. (2005). Effectiveness and efficiency of search methods in systematic reviews of complex evidence: audit of primary sources. *BMJ* **331**, 1064–1065.

Greenwood, S., Chen, J.-C., Chen, C.-T. & Jump, A. S. (2014). Strong topographic sheltering effects lead to spatially complex treeline advance and increased forest density in a subtropical mountain region. *Global Change Biology* **20**, 3756–3766.

*Gu, R.-Y., Lo, M.-H., Liao, C.-Y., Jang, Y.-S., Juang, J.-Y., Huang, C.-Y., Chang, S.-C., Hsieh, C.-I., Chen, Y.-Y., Chu, H. & Chang, K.-Y. (2021). Early peak of latent heat fluxes regulates diurnal temperature range in montane cloud forests. *Journal of Hydrometeorology* **22**(9), 2475–2487.

*Guillaumet, A., Kuntz, W. A., Samuel, M. D. & Paxton, E. H. (2017). Altitudinal migration and the future of an iconic Hawaiian honeycreeper in response to climate change and management. *Ecological Monographs* **87**, 410–428.

*Güizado-Rodríguez, M. A., Ballesteros-Barrera, C., Casas-Andreu, G., Barradas-Miranda, V. L., Téllez-Valdés, O. & Salgado-Ugarte, I. H. (2012). The impact of global warming on the range distribution of different climatic groups of *Aspidoscelis costata costata*. *Zoological Science* **29**, 834–843.

*Gurdak, D. J., Aragao, L. E. O. C., Rozas-Dávila, A., Huasco, W. H., Cabrera, K. G., Doughty, C. E., Farfan-Rios, W., Silva-Espejo, J. E., Metcalfe, D. B., Silman, M. R. & Malhi, Y. (2014). Assessing above-ground woody debris dynamics along a gradient of elevation in Amazonian cloud forests in Peru: balancing above-ground inputs and respiration outputs. *Plant Ecology & Diversity* **7**, 143–160.

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Gutiérrez-García, G. & Ricker, M. (2019). Influencia del clima en el crecimiento radial en cuatro especies de coníferas en la sierra de San Antonio Peña Nevada (Nuevo León, México). *Revista Mexicana de Biodiversidad* **90**, e902676.

*Gütlein, A., Gerschlauer, F., Kikoti, I. & Kiese, R. (2018). Impacts of climate and land use on N_2O and CH_4 fluxes from tropical ecosystems in the Mt. Kilimanjaro region. Tanzania. *Global Change Biology* **24**, 1239–1255.

Hamilton, L. S. (1995). Mountain cloud forest conservation and research: a synopsis. *Mountain Research and Development* **15**, 259.

*Harris, J. B. C., Dwi Putra, D., Gregory, S. D., Brook, B. W., Prawiradilaga, D. M., Sodhi, N. S., Wei, D. & Fordham, D. A. (2014). Rapid deforestation threatens mid-elevational endemic birds but climate change is most important at higher elevations. *Diversity and Distributions* **20**, 773–785.

Hayes, F. E., Lecourt, P. & del Castillo, H. (2018). Rapid southward and upward range expansion of a tropical songbird, the Thrush-like Wren (*Campylorhynchus turdinus*), in South America: a consequence of habitat or climate change? *Revista Brasileira de Ornitologia* **26**, 57–64.

He, X., He, K. S. & Hyvönen, J. (2016). Will bryophytes survive in a warming world? *Perspectives in Plant Ecology, Evolution and Systematics* **19**, 49–60.

He, X., Lin, Y., Han, G., Guo, P. & Tian, X. (2010). The effect of temperature on decomposition of leaf litter from two tropical forests by a microcosm experiment. *European Journal of Soil Biology* **46**, 200–207.

*He, X., Zhang, P., Lin, Y., Li, A., Tian, X. & Zhang, Q.-H. (2009). Responses of litter decomposition to temperature along a chronosequence of tropical montane rainforest in a microcosm experiment. *Ecological Research* **24**, 781–789.

Helmer, E. H., Gerson, E. A., Baggett, L. S., Bird, B. J., Ruzycki, T. S. & Voggesser, S. M. (2019). Neotropical cloud forests and páramo to contract and dry from declines in cloud immersion and frost. *PLoS One* **14**, e0213155.

*Hemp, A. (2005). Climate change-driven forest fires marginalize the impact of ice cap wasting on Kilimanjaro. *Global Change Biology* **11**, 1013–1023.

*Hemp, A. (2009). Climate change and its impact on the forests of Kilimanjaro. *African Journal of Ecology* **47**, 3–10.

*Henareh Khalyani, A., Gould, W. A., Falkowski, M. J., Muscarella, R., Uriarte, M. & Yousef, F. (2019). Climate change increases potential plant species richness on Puerto Rican uplands. *Climatic Change* **156**, 15–30.

Hermes, C., Keller, K., Nicholas, R. E., Segelbacher, G. & Schaefer, H. M. (2018*a*). Projected impacts of climate change on habitat availability for an endangered parakeet. *PLoS One* **13**, e0191773.

*Hermes, C., Segelbacher, G. & Schaefer, H. M. (2018*b*). A framework for prioritizing areas for conservation in tropical montane cloud forests. *Écoscience* **25**, 97–108.

*Hernández Gordillo, A. L., Vilchez Mendoza, S., Ngo Bieng, M. A., Delgado, D. & Finegan, B. (2021). Altitude and community traits explain rain forest stand dynamics over a 2370-m altitudinal gradient in Costa Rica. *Ecosphere* **12**, e03867.

*Hernández-Calderón, E., González-Rodríguez, A., Méndez-Alonzo, R., Vega-Peña, E. & Oyama, K. (2013). Contrasting leaf phenology in two white oaks, *Quercus magnoliifolia* and *Quercus resinosa*, along an altitudinal gradient in Mexico. *Canadian Journal of Forest Research* **43**, 208–213.

Hillyer, R. & Silman, M. R. (2010). Changes in species interactions across a 2.5 km elevation gradient: effects on plant migration in response to climate change: species interactions and plant migration. *Global Change Biology* **16**, 3205–3214.

Hiltner, U., Bräuning, A., Gebrekirstos, A., Huth, A. & Fischer, R. (2016). Impacts of precipitation variability on the dynamics of a dry tropical montane forest. *Ecological Modelling* **320**, 92–101.

*Horwath, A. B., Royles, J., Tito, R., Gudiño, J. A., Salazar Allen, N., Farfan-Rios, W., Rapp, J. M., Silman, M. R., Malhi, Y., Swamy, V., Latorre Farfan, J. P. & Griffiths, H. (2019). Bryophyte stable isotope composition, diversity and biomass define tropical montane cloud forest extent. *Proceedings of the Royal Society B: Biological Sciences* **286**, 20182284.

Hsu, R. C.-C., Oostermeijer, J. G. B. & Wolf, J. H. D. (2014). Adaptation of a widespread epiphytic fern to simulated climate change conditions. *Plant Ecology* **215**, 889–897.

*Hsu, R. C.-C., Tamis, W. L. M., Raes, N., de Snoo, G. R., Wolf, J. H. D., Oostermeijer, G. & Lin, S.-H. (2012). Simulating climate change impacts on forests and associated vascular epiphytes in a subtropical Island of East Asia: climate change impacts on forests and epiphytes. *Diversity and Distributions* **18**, 334–347.

*Iturralde-Pólit, P., Dangles, O., Burneo, S. F. & Meynard, C. N. (2017). The effects of climate change on a mega-diverse country: predicted shifts in mammalian species richness and turnover in continental Ecuador. *Biotropica* **49**, 821–831.

*Iwashita, D. K., Litton, C. M. & Giardina, C. P. (2013). Coarse woody debris carbon storage across a mean annual temperature gradient in tropical montane wet forest. *Forest Ecology and Management* **291**, 336–343.

Jacob, M., Annys, S., Frankl, A., De Ridder, M., Beeckman, H., Guyassa, E. & Nyssen, J. (2015*a*). Tree line dynamics in the tropical African highlands-identifying drivers and dynamics. *Journal of Vegetation Science* **26**, 9–20.

Jacob, M., Frankl, A., Beeckman, H., Mesfin, G., Hendrickx, M., Guyassa, E. & Nyssen, J. (2015*b*). North Ethiopian Afro-alpine tree line dynamics and forest-cover change since the early 20th century. *Land Degradation & Development* **26**, 654–664.

*Jankowski, J. E., Ciecka, A. L., Meyer, N. Y. & Rabenold, K. N. (2009). Beta diversity along environmental gradients: implications of habitat specialization in tropical montane landscapes. *Journal of Animal Ecology* **78**, 315–327.

*Jankowski, J. E., Merkord, C. L., Rios, W. F., Cabrera, K. G., Revilla, N. S. & Silman, M. R. (2013). The relationship of tropical bird communities to tree species composition and vegetation structure along an Andean elevational gradient. *Journal of Biogeography* **40**, 950–962.

*Jankowski, J. E. & Rabenold, K. N. (2007). Endemism and local rarity in birds of neotropical montane rainforest. *Biological Conservation* **138**, 453–463.

Jankowski, J. E., Robinson, S. K. & Levey, D. J. (2010). Squeezed at the top: interspecific aggression may constrain elevational ranges in tropical birds. *Ecology* **91**, 1877–1884.

*Jasso-Flores, I., Galicia, L., Chávez-Vergara, B., Merino, A., Tapia-Torres, Y. & García-Oliva, F. (2020). Soil organic matter dynamics and microbial metabolism along an altitudinal gradient in Highland tropical forests. *Science of the Total Environment* **741**, 140143.

Jiménez-García, D., Li, X., Lira-Noriega, A. & Peterson, A. T. (2021). Upward shifts in elevational limits of forest and grassland for Mexican volcanoes over three decades. *Biotropica* **53**, 798–807.

*Jiménez-García, D. & Peterson, A. T. (2019). Climate change impact on endangered cloud forest tree species in Mexico. *Revista Mexicana de Biodiversidad* **90**, 1–14.

*Jiménez-López, D. A., Martínez-Camilo, R., Martínez-Meléndez, N. & Kessler, M. (2020). Diversity of epiphyte ferns along an elevational gradient in El Triunfo biosphere reserve, southern Mexico. *Plant Ecology and Evolution* **153**, 12–21.

*Jiménez-Rodríguez, C. D., Calvo-Alvarado, J. C. & Jackson, J. K. (2015). Performance of two hydrological models in predicting daily flow under a climate change scenario for mountainous catchments in northwestern Costa Rica. *Mountain Research and Development* **35**, 240–253.

*Jin, N. Y., Go, R., Nulit, R., Eng, K. H., Ching, T. M., Nordin, F. A., Nuruddin, A. A. & Sook, L. N. (2012). *Orchids of Cloud Forest in Genting Highlands*, p. 23. Pahang, Malaysia.

*Johansson, M. U., Frisk, C. A., Nemomissa, S. & Hylander, K. (2018). Disturbance from traditional fire management in subalpine heathlands increases Afro-alpine plant resilience to climate change. *Global Change Biology* **24**, 2952–2964.

John, E., Bunting, P., Hardy, A., Roberts, O., Giliba, R. & Silayo, D. S. (2020). Modelling the impact of climate change on Tanzanian forests. *Diversity and Distributions* **26**, 1663–1686.

*Jones, R. W., O'brien, C. W., Ruiz-Montoya, L. & Gómez-Gómez, B. (2008). Insect diversity of tropical montane forests: diversity and spatial distribution of weevils (Coleoptera: Curculionidae) inhabiting leaf litter in southern Mexico. *Annals of the Entomological Society of America* **101**, 128–139.

Joshi, A. A., Ratnam, J. & Sankaran, M. (2020). Frost maintains forests and grasslands as alternate states in a montane tropical forest–grassland mosaic; but alien tree invasion and warming can disrupt this balance. *Journal of Ecology* **108**, 122–132.

Karger, D. N., Kessler, M., Lehnert, M. & Jetz, W. (2021). Limited protection and ongoing loss of tropical cloud forest biodiversity and ecosystems worldwide. *Nature Ecology & Evolution* **5**, 854–862.

Karmalkar, A. V., Bradley, R. S. & Diaz, H. F. (2008). Climate change scenario for Costa Rican montane forests. *Geophysical Research Letters* **35**, L11702.

Keyimu, M., Li, Z., Zhang, G., Fan, Z., Wang, X. & Fu, B. (2020). Tree ring–based minimum temperature reconstruction in the central Hengduan Mountains, China. *Theoretical and Applied Climatology* **141**, 359–370.

*Klauke, N., Schaefer, H. M., Bauer, M. & Segelbacher, G. (2016). Limited dispersal and significant fine-scale genetic structure in a tropical montane parrot species. *PLoS One* **11**, e0169165.

Klimes, P., Bishop, T. R., Fayle, T. M. & Xing, S. (2021). Reported climate change impacts on cloud forest ants are driven by sampling bias: a critical evaluation of Warne et al. (2020). *Biotropica* **53**, 982–986.

*Klorvuttimontara, S., McClean, C. J. & Hill, J. K. (2011). Evaluating the effectiveness of protected areas for conserving tropical forest butterflies of Thailand. *Biological Conservation* **144**, 2534–2540.

Koide, D., Yoshida, K., Daehler, C. C. & Mueller-Dombois, D. (2017). An upward elevation shift of native and non-native vascular plants over 40 years on the Island of Hawai'i. *Journal of Vegetation Science* **28**, 939–950.

Kremer, A., Potts, B. M. & Delzon, S. (2014). Genetic divergence in forest trees: understanding the consequences of climate change. *Functional Ecology* **28**, 22–36.

*Kreyling, J., Wana, D. & Beierkuhnlein, C. (2010). Potential consequences of climate warming for tropical plant species in high mountains of Southern Ethiopia: consequences of warming in Southern Ethiopia. *Diversity and Distributions* **16**, 593–605.

1469185x, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/brv.12950 by University Of Southampton, Wiley Online Library on [09/05/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Krishnaswamy, J., John, R. & Joseph, S. (2014). Consistent response of vegetation dynamics to recent climate change in tropical mountain regions. *Global Change Biology* **20**, 203–215.

*Krömer, T., Acebey, A., Kluge, J. & Kessler, M. (2013). Effects of altitude and climate in determining elevational plant species richness patterns: a case study from Los Tuxtlas, Mexico. *Flora-Morphology, Distribution, Functional Ecology of Plants* **208**, 197–210.

*Kuo, C.-C., Su, Y., Liu, H.-Y. & Lin, C.-T. (2021). Assessment of climate change effects on alpine summit vegetation in the transition of tropical to subtropical humid climate. *Plant Ecology* **222**, 933–951.

*La Marca, E., Lips, K. R., Lotters, S., Puschendorf, R., Ibanez, R., Rueda-Almonacid, J. V., Schulte, R., Marty, C., Castro, F., Manzanilla-Puppo, J., Garcia-Perez, J. E., Bolanos, F., Chaves, G., Pounds, J. A., Toral, E., *et al.* (2005). Catastrophic population declines and extinctions in Neotropical harlequin frogs (Bufonidae: Atelopus). *Biotropica* **37**, 190–201.

*La Sorte, F. A., Butchart, S. H. M., Jetz, W. & Böhning-Gaese, K. (2014). Range-wide latitudinal and elevational temperature gradients for the world's terrestrial birds: implications under global climate change. *PLoS One* **9**, e98361.

Lamentowicz, M., Słowińska, S. & Słowiński, M. (2016). Combining short-term manipulative experiments with long-term palaeoecological investigations at high resolution to assess the response of *Sphagnum* peatlands to drought, fire and warming. *Mires and Peat* **18**, 1–17.

*Larsen, T. H. (2012). Upslope range shifts of Andean dung beetles in response to deforestation: compounding and confounding effects of microclimatic change: dung beetles shift upslope with land-use. *Biotropica* **44**, 82–89.

*Latta, S. C., Tinoco, B. A. & Graham, C. H. (2011). Patterns and magnitude of temporal change in avian communities in the Ecuadorian Andes. *The Condor* **113**, 24–40.

Laurance, W. F., Carolina Useche, D., Shoo, L. P., Herzog, S. K., Kessler, M., Escobar, F., Brehm, G., Axmacher, J. C., Chen, I.-C., Gámez, L. A., Hietz, P., Fiedler, K., Pyrcz, T., Wolf, J., Merkord, C. L., *et al.* (2011). Global warming, elevational ranges and the vulnerability of tropical biota. *Biological Conservation* **144**, 548–557.

LaVal, R. K. (2004). Impact of global warming and locally changing climate on tropical cloud forest bats. *Journal of Mammalogy* **85**, 237–244.

*Lawton, R. O., Nair, U. S., Pielke, R. A. & Welch, R. M. (2001). Climatic impact of tropical lowland deforestation on nearby montane cloud forests. *Science* **294**, 584–587.

Ledo, A., Montes, F. & Condes, S. (2009). Species dynamics in a montane cloud forest: identifying factors involved in changes in tree diversity and functional characteristics. *Forest Ecology and Management* **258**, S75–S84.

*Li, J., Hilbert, D. W., Parker, T. & Williams, S. (2009). How do species respond to climate change along an elevation gradient? A case study of the grey-headed robin (*Heteromyias albispecularis*). *Global Change Biology* **15**, 255–267.

Li, Y., Xu, Y., Li, Y., Wu, T., Zhou, G., Liu, S., Meng, Y., Wang, J., Ling, L. & Liu, J. (2020). Warming effects on morphological and physiological performances of four subtropical montane tree species. *Annals of Forest Science* **77**, 2.

Liao, Z., Zhang, L., Nobis, M. P., Wu, X., Pan, K., Wang, K., Dakhil, M. A., Du, M., Xiong, Q., Pandey, B. & Tian, X. (2020). Climate change jointly with migration ability affect future range shifts of dominant fir species in Southwest China. *Diversity and Distributions* **26**, 352–367.

Lippok, D., Beck, S. G., Renison, D., Hensen, I., Apaza, A. E. & Schleuning, M. (2014). Topography and edge effects are more important than elevation as drivers of vegetation patterns in a neotropical montane forest. *Journal of Vegetation Science* **25**, 724–733.

*Lips, K. R. (1998). Decline of a tropical montane amphibian fauna. *Conservation Biology* **12**, 106–117.

*Liptzin, D., Silver, W. L. & Detto, M. (2011). Temporal dynamics in soil oxygen and greenhouse gases in two humid tropical forests. *Ecosystems* **14**, 171–182.

*Litton, C. M., Giardina, C. P., Albano, J. K., Long, M. S. & Asner, G. P. (2011). The magnitude and variability of soil-surface CO_2 efflux increase with mean annual temperature in Hawaiian tropical montane wet forests. *Soil Biology and Biochemistry* **43**, 2315–2323.

*Litton, C. M., Giardina, C. P., Freeman, K. R., Selmants, P. C. & Sparks, J. P. (2020). Impact of mean annual temperature on nutrient availability in a tropical montane wet forest. *Frontiers in Plant Science* **11**, 784.

Liu, L.-L., Yang, B., Lu, H.-Z., Wu, Y., Meng, X.-J., Zhang, Y.-J. & Song, L. (2021). Dry-season fog water utilization by epiphytes in a subtropical montane cloud forest of Southwest China. *Water* **13**, 3237.

Liyanage, G. S., Offord, C. A., Crayn, D. M., Guja, L. K., Worboys, S. & Sommerville, K. D. (2022). Understanding seed dormancy and germination aids conservation of rainforest species from tropical montane cloud forest: a case study confirming morphophysiological dormancy in the genus. *Australian Journal of Botany* **70**, 399–408.

*Lloret, F. & González-Mancebo, J. M. (2011). Altitudinal distribution patterns of bryophytes in the Canary Islands and vulnerability to climate change. *Flora-Morphology, Distribution, Functional Ecology of Plants* **206**, 769–781.

Loarie, S. R., Duffy, P. B., Hamilton, H., Asner, G. P., Field, C. B. & Ackerly, D. D. (2009). The velocity of climate change. *Nature* **462**, 1052–1055.

*Looby, C. I., Maltz, M. R. & Treseder, K. K. (2016). Belowground responses to elevation in a changing cloud forest. *Ecology and Evolution* **6**, 1996–2009.

*Looby, C. I. & Treseder, K. K. (2018). Shifts in soil fungi and extracellular enzyme activity with simulated climate change in a tropical montane cloud forest. *Soil Biology and Biochemistry* **117**, 87–96.

Loope, L. L. & Giambelluca, T. W. (1998). Vulnerability of Island tropical montane cloud forests to climate change, with special reference to east Maui, Hawaii. In *Potential Impacts of Climate Change on Tropical Forest Ecosystems* (ed. A. Markham), pp. 363–377. Springer, Netherlands, Dordrecht.

*López-Arce, L., Ureta, C., Granados-Sánchez, D., Rodríguez-Esparza, L. & Monterroso-Rivas, A. (2019). Identifying cloud forest conservation areas in Mexico from the potential distribution of 19 representative species. *Heliyon* **5**, e01423.

*Los, S. O., Street-Perrott, F. A., Loader, N. J. & Froyd, C. A. (2021). Detection of signals linked to climate change, land-cover change and climate oscillators in tropical montane cloud forests. *Remote Sensing of Environment* **260**, 112431.

Los, S. O., Street-Perrott, F. A., Loader, N. J., Froyd, C. A., Cuní-Sanchez, A. & Marchant, R. A. (2019). Sensitivity of a tropical montane cloud forest to climate change, present, past and future: Mt. Marsabit, N. Kenya. *Quaternary Science Reviews* **218**, 34–48.

Lu, X., Liang, E., Wang, Y., Babst, F. & Camarero, J. J. (2020). Mountain treelines climb slowly despite rapid climate warming. *Global Ecology and Biogeography* **30**, 305–315.

Lutz, D. A., Powell, R. L. & Silman, M. R. (2013). Four decades of Andean timberline migration and implications for biodiversity loss with climate change. *PLoS One* **8**, e74496.

*Lyu, M., Giardina, C. P. & Litton, C. M. (2021). Interannual variation in rainfall modulates temperature sensitivity of carbon allocation and flux in a tropical montane wet forest. *Global Change Biology* **27**, 3824–3836.

*Macedo, M. V., Monteiro, R. F., Flinte, V., Almeida-Neto, M., Khattar, G., da Silveira, L. F. L., Araújo, C. d. O., Araújo, R. d. O., Colares, C., Gomes, C. V. S., Mendes, C. B., Santos, E. F. & Mayhew, P. J. (2018). Insect elevational specialization in a tropical biodiversity hotspot. *Insect Conservation and Diversity* **11**, 240–254.

Martin, P. H. & Fahey, T. J. (2014). Mesoclimatic patterns shape the striking vegetation mosaic in the cordillera central, Dominican Republic. *Arctic, Antarctic, and Alpine Research* **46**, 755–765.

Martin, P. H., Sherman, R. E. & Fahey, T. J. (2007). Tropical montane forest ecotones: climate gradients, natural disturbance, and vegetation zonation in the cordillera central, Dominican Republic. *Journal of Biogeography* **34**, 1792–1806.

Martin, R. A., Chick, L. D., Garvin, M. L. & Diamond, S. E. (2021). In a nutshell, a reciprocal transplant experiment reveals local adaptation and fitness trade-offs in response to urban evolution in an acorn-dwelling ant. *Evolution* **75**, 876–887.

Martínez-Ramos, M., González-Espinosa, M., Ramírez-Marcial, N., Negrete-Yankelevich, S. & Mena, R. H. (2022). Mid-and long-term ecological changes after enrichment planting with native tree species in Mexican tropical mountain forests. *Restoration Ecology*e13847.

*Maul, K., Wei, Y.-M., Nebel, M., Luebert, F., Ho, B.-C., Quandt, D. & Kessler, M. (2020). Different predictors shape the diversity patterns of epiphytic and non-epiphytic liverworts in montane forests of Uganda. *Frontiers in Plant Science* **11**, 765.

Maunsell, S. C., Kitching, R. L., Burwell, C. J. & Morris, R. J. (2015). Changes in host-parasitoid food web structure with elevation. *Journal of Animal Ecology* **84**, 353–363.

Menéndez-Guerrero, P. A., Green, D. M. & Davies, T. J. (2020). Climate change and the future restructuring of Neotropical anuran biodiversity. *Ecography* **43**, 222–235.

*Metcalfe, D. B. & Ahlstrand, J. C. M. (2019). Effects of moisture dynamics on bryophyte carbon fluxes in a tropical cloud forest. *New Phytologist* **222**, 1766–1777.

Miles, L., Grainger, A. & Phillips, O. (2004). The impact of global climate change on tropical forest biodiversity in Amazonia. *Global Ecology and Biogeography* **13**, 553–565.

Miller, P., Mote, T., Ramseyer, C., Van Beusekom, A., Scholl, M. & González, G. (2018). A 42 year inference of cloud base height trends in the Luquillo Mountains of northeastern Puerto Rico. *Climate Research* **76**, 87–94.

*Molina-Venegas, R., Fischer, M. & Hemp, A. (2020). Plant evolutionary assembly along elevational belts at Mt. Kilimanjaro: using phylogenetics to assess biodiversity threats under climate change. *Environmental and Experimental Botany* **170**, 103853.

Montejo-Kovacevich, G., Martin, S. H., Meier, J. I., Bacquet, C. N., Monllor, M., Jiggins, C. D. & Nadeau, N. J. (2020). Microclimate buffering and thermal tolerance across elevations in a tropical butterfly. *Journal of Experimental Biology* **223**, jeb220426.

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*Monterroso-Rivas, A. I., Gómez-Díaz, J. D. & Tinoco-Rueda, J. A. (2013). Bosque mesófilo de montaña y escenarios de cambio climático: Una evaluación en Hidalgo, México. *Revista Chapingo Serie Ciencias Forestales y del Ambiente* **19**, 29–43.

*Monterroso-Rivas, A. I., Ramírez-García, A. G. & Gómez-Díaz, J. D. (2016). Cambio en la disponibilidad hídrica futura en un bosque mesófilo de montaña de México. **41**, 9.

*Morales, M. S., Villalba, R., Grau, H. R. & Paolini, L. (2004). Rainfall-controlled tree growth in high-elevation subtropical treelines. *Ecology* **85**, 3080–3089.

Morton, E. R., Robinson, S. K., Mulindahabi, F., Masozera, M., Singh, A. & Oli, M. K. (2022). Spatiotemporal patterns in an Afrotropical montane forest bird community. *Global Ecology and Conservation* **40**, e02333.

*Mujawamariya, M., Manishimwe, A., Ntirugulirwa, B., Zibera, E., Ganszky, D., Ntawuhiganayo Bahati, E., Nyirambangutse, B., Nsabimana, D., Wallin, G. & Uddling, J. (2018). Climate sensitivity of tropical trees along an elevation gradient in Rwanda. *Forests* **9**, 647.

Müller, L.-L. B., Albach, D. C. & Zotz, G. (2017). 'Are 3 °C too much?': Thermal niche breadth in Bromeliaceae and global warming. *Journal of Ecology* **105**, 507–516.

Mulligan, M. (2010). Modeling the tropics-wide extent and distribution of cloud forest and cloud forest loss, with implications for conservation priority. In *Tropical Montane Cloud Forests: Science for Conservation and Management* (Volume **740**), pp. 16–38. Cambridge University Press, Cambridge, UK.

Muñoz, M. M., Feeley, K. J., Martin, P. H. & Farallo, V. R. (2022). The multidimensional (and contrasting) effects of environmental warming on a group of montane tropical lizards. *Functional Ecology* **36**, 419–431.

Muñoz, M. M., Langham, G. M., Brandley, M. C., Rosauer, D. F., Williams, S. E. & Moritz, C. (2016). Basking behavior predicts the evolution of heat tolerance in Australian rainforest lizards: physiological evolution in Australian skinks. *Evolution* **70**, 2537–2549.

Mupepele, A.-C., Walsh, J. C., Sutherland, W. J. & Dormann, C. F. (2016). An evidence assessment tool for ecosystem services and conservation studies. *Ecological Applications* **26**, 1295–1301.

Murugan, M., Shetty, P. K., Anandhi, A., Ravi, R., Alappan, S., Vasudevan, M. & Gopalan, S. (2009). Rainfall changes over tropical montane cloud forests of southern Western Ghats, India. *Current Science* **97**, 1755–1760.

Nadkarni, N. M. & Solano, R. (2002). Potential effects of climate change on canopy communities in a tropical cloud forest: an experimental approach. *Oecologia* **131**, 580–586.

Nagel, T. A., Iacopetti, G., Javornik, J., Rozman, A., De Frenne, P., Selvi, F. & Verheyen, K. (2019). Cascading effects of canopy mortality drive long-term changes in understorey diversity in temperate old-growth forests of Europe. *Journal of Vegetation Science* **30**, 905–916.

*Navas, C. A., Carvajalino-Fernández, J. M., Saboyá-Acosta, L. P., Rueda-Solano, L. A. & Carvajalino-Fernández, M. A. (2013). The body temperature of active amphibians along a tropical elevation gradient: patterns of mean and variance and inference from environmental data. *Functional Ecology* **27**, 1145–1154.

Neate-Clegg, M. H. C., Jones, S. E. I., Burdekin, O., Jocque, M. & Şekercioğlu, Ç. H. (2018). Elevational changes in the avian community of a Mesoamerican cloud forest park. *Biotropica* **50**, 805–815.

Neate-Clegg, M. H. C., O'Brien, T. G., Mulindahabi, F. & Şekercioğlu, Ç. H. (2020). A disconnect between upslope shifts and climate change in an Afrotropical bird community. *Conservation Science and Practice* **2**, e291.

*Neate-Clegg, M. H. C., Stanley, T. R., Şekercioğlu, Ç. H. & Newmark, W. D. (2021*a*). Temperature-associated decreases in demographic rates of Afrotropical bird species over 30 years. *Global Change Biology* **27**, 2254–2268.

Neate-Clegg, M. H. C., Stuart, S. N., Mtui, D., Şekercioğlu, Ç. H. & Newmark, W. D. (2021*b*). Afrotropical montane birds experience upslope shifts and range contractions along a fragmented elevational gradient in response to global warming. *PLoS One* **16**, e0248712.

Neely, W. J., Greenspan, S. E., Ribeiro, L. P., Carvalho, T., Martins, R. A., Rodriguez, D., Rohr, J. R., Haddad, C. F. B., Toledo, L. F. & Becker, C. G. (2020). Synergistic effects of warming and disease linked to high mortality in cool-adapted terrestrial frogs. *Biological Conservation* **245**, 108521.

Neto dos Santos, G., Silva, A. C. d. & Higuchi, P. (2020). Impact fo climate change on the geographical distribution of a cloud forest indicator tree species. *Revista Árvore* **44**, e4432.

Niessner, A., Küppers, M., Graham, J., Valenzuela, L., Güney, A., Remmele, S. & Zimmermann, R. (2020). Climate and seasonal rainfall anomalies along an elevational gradient in the El Sira Mountains, Peru, and their impacts on tree radial growth. *Journal of Forestry Research* **31**, 1521–1538.

Nogués-Bravo, D. (2009). Predicting the past distribution of species climatic niches. *Global Ecology and Biogeography* **18**, 521–531.

Nooten, S. S. & Andrew, N. R. (2016). Transplant experiments – a powerful method to study climate change impacts. In *Global Climate Change and Terrestrial Invertebrates* (eds S. N. Johnson and T. H. Jones), pp. 46–67. John Wiley & Sons, Ltd, Chichester, UK.

*Notter, B., MacMillan, L., Viviroli, D., Weingartner, R. & Liniger, H.-P. (2007). Impacts of environmental change on water resources in the Mt. Kenya region. *Journal of Hydrology* **343**, 266–278.

*Nottingham, A. T., Bååth, E., Reischke, S., Salinas, N. & Meir, P. (2019*a*). Adaptation of soil microbial growth to temperature: using a tropical elevation gradient to predict future changes. *Global Change Biology* **25**, 827–838.

Nottingham, A. T., Turner, B. L., Whitaker, J., Ostle, N., Bardgett, R. D., McNamara, N. P., Salinas, N. & Meir, P. (2016). Temperature sensitivity of soil enzymes along an elevation gradient in the Peruvian Andes. *Biogeochemistry* **127**, 217–230.

Nottingham, A. T., Whitaker, J., Ostle, N. J., Bardgett, R. D., McNamara, N. P., Fierer, N., Salinas, N., Ccahuana, A. J. Q., Turner, B. L. & Meir, P. (2019*b*). Microbial responses to warming enhance soil carbon loss following translocation across a tropical forest elevation gradient. *Ecology Letters* **22**, 1889–1899.

Nowak, L., Schleuning, M., Bender, I. M. A., Böhning-Gaese, K., Dehling, D. M., Fritz, S. A., Kissling, W. D., Mueller, T., Neuschulz, E. L., Pigot, A. L., Sorensen, M. C. & Donoso, I. (2022). Avian seed dispersal may be insufficient for plants to track future temperature change on tropical mountains. *Global Ecology and Biogeography* **31**, 848–860.

Nowrouzi, S., Andersen, A. N., Bishop, T. R. & Robson, S. K. A. (2018). Is thermal limitation the primary driver of elevational distributions? Not for montane rainforest ants in the Australian wet tropics. *Oecologia* **188**, 333–342.

*Nowrouzi, S., Andersen, A. N., Macfadyen, S., Staunton, K. M., VanDerWal, J. & Robson, S. K. A. (2016). Ant diversity and distribution along elevation gradients in the Australian wet tropics: the importance of seasonal moisture stability. *PLoS One* **11**, e0153420.

Nwe, T., Zomer, R. J. & Corlett, R. T. (2020). Projected impacts of climate change on the protected areas of Myanmar. *Climate* **8**, 99.

*Odell, E. H., Ashton, L. A. & Kitching, R. L. (2016). Elevation and moths in a central eastern Queensland rainforest: moth assemblages in a central QLD forest. *Austral Ecology* **41**, 133–144.

*O'Donnell, S. & Kumar, A. (2006). Microclimatic factors associated with elevational changes in army ant density in tropical montane forest. *Ecological Entomology* **31**, 491–498.

Ohmura, A. (2012). Enhanced temperature variability in high-altitude climate change. *Theoretical and Applied Climatology* **110**, 499–508.

Oliveira, R. S., Eller, C. B., Bittencourt, P. R. L. & Mulligan, M. (2014). The hydroclimatic and ecophysiological basis of cloud forest distributions under current and projected climates. *Annals of Botany* **113**, 909–920.

Ornelas, J. F., Licona-Vera, Y. & Ortiz-Rodriguez, A. E. (2018). Contrasting responses of generalized/specialized mistletoe-host interactions under climate change. *Écoscience* **25**, 223–234.

*Ortega-Andrade, H. M., Prieto-Torres, D. A., Gómez-Lora, I. & Lizcano, D. J. (2015). Ecological and geographical analysis of the distribution of the mountain tapir (*Tapirus pinchaque*) in Ecuador: importance of protected areas in future scenarios of global warming. *PLoS One* **10**, e0121137.

*O'Sullivan, K. S. W., Ruiz-Benito, P., Chen, J. & Jump, A. S. (2021). Onward but not always upward: individualistic elevational shifts of tree species in subtropical montane forests. *Ecography* **44**, 112–123.

Pau, S., Cordell, S., Ostertag, R., Inman, F. & Sack, L. (2020). Climatic sensitivity of species' vegetative and reproductive phenology in a Hawaiian montane wet forest. *Biotropica* **52**, 825–835.

Pauls, S. U., Nowak, C., Bálint, M. & Pfenninger, M. (2013). The impact of global climate change on genetic diversity within populations and species. *Molecular Ecology* **22**, 925–946.

Pautasso, M. (2009). Geographical genetics and the conservation of forest trees. *Perspectives in Plant Ecology, Evolution and Systematics* **11**, 157–189.

Peh, K. S.-H., Soh, M. C. K., Sodhi, N. S., Laurance, W. F., Ong, D. J. & Clements, R. (2011). Up in the clouds: is sustainable use of tropical montane cloud forests possible in Malaysia? *Bioscience* **61**, 27–38.

Pepin, N. C., Arnone, E., Gobiet, A., Haslinger, K., Kotlarski, S., Notarnicola, C., Palazzi, E., Seibert, P., Serafin, S., Schöner, W., Terzago, S., Thornton, J. M., Vuille, M. & Adler, C. (2022). Climate changes and their elevational patterns in the mountains of the world. *Reviews of Geophysics* **60**, e2020RG000730.

Pertoldi, C., Bijlsma, R. & Loeschcke, V. (2007). Conservation genetics in a globally changing environment: present problems, paradoxes and future challenges. *Biodiversity and Conservation* **16**, 4147–4163.

*Phillips, O. L. (1996). Long-term environmental change in tropical forests: increasing tree turnover. *Environmental Conservation* **23**, 235–248.

Piantoni, C., Navas, C. A. & Ibargüengoytía, N. R. (2016). Vulnerability to climate warming of four genera of New World iguanians based on their thermal ecology. *Animal Conservation* **19**, 391–400.

*Platts, P. J., Gereau, R. E., Burgess, N. D. & Marchant, R. (2013). Spatial heterogeneity of climate change in an Afromontane Centre of endemism. *Ecography* **36**, 518–530.

1469185x, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/brv.12950 by University Of Southampton, Wiley Online Library on [09/05/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Polato, N. R., Gill, B. A., Shah, A. A., Gray, M. M., Casner, K. L., Barthelet, A., Messer, P. W., Simmons, M. P., Guayasamin, J. M., Encalada, A. C., Kondratieff, B. C., Flecker, A. S., Thomas, S. A., Ghalambor, C. K., Poff, N. L., *et al.* (2018). Narrow thermal tolerance and low dispersal drive higher speciation in tropical mountains. *Proceedings of the National Academy of Sciences* **115**, 12471–12476.

Ponce-Reyes, R., Nicholson, E., Baxter, P. W. J., Fuller, R. A. & Possingham, H. (2013). Extinction risk in cloud forest fragments under climate change and habitat loss. *Diversity and Distributions* **19**, 518–529.

Ponce-Reyes, R., Plumptre, A. J., Segan, D., Ayebare, S., Fuller, R. A., Possingham, H. P. & Watson, J. E. M. (2017). Forecasting ecosystem responses to climate change across Africa's Albertine rift. *Biological Conservation* **209**, 464–472.

*Ponce-Reyes, R., Reynoso-Rosales, V.-H., Watson, J. E. M., VanDerWal, J., Fuller, R. A., Pressey, R. L. & Possingham, H. P. (2012). Vulnerability of cloud forest reserves in Mexico to climate change. *Nature Climate Change* **2**, 448–452.

*Ponette-González, A. G., Weathers, K. C. & Curran, L. M. (2010). Water inputs across a tropical montane landscape in Veracruz, Mexico: synergistic effects of land cover, rain and fog seasonality, and interannual precipitation variability. *Global Change Biology* **16**, 946–963.

*Pounds, J. A., Bustamante, M. R., Coloma, L. A., Consuegra, J. A., Fogden, M. P. L., Foster, P. N., La Marca, E., Masters, K. L., Merino-Viteri, A., Puschendorf, R., Ron, S. R., Sánchez-Azofeifa, G. A., Still, C. J. & Young, B. E. (2006). Widespread amphibian extinctions from epidemic disease driven by global warming. *Nature* **439**, 161–167.

*Pounds, J. A. & Crump, M. L. (1994). Amphibian declines and climate disturbance: the case of the golden toad and the harlequin frog. *Conservation Biology* **8**, 72–85.

Pounds, J. A., Fogden, M. P. L. & Campbell, J. H. (1999). Biological response to climate change on a tropical mountain. *Nature* **398**, 611–615.

*Pouteau, R. & Birnbaum, P. (2016). Island biodiversity hotspots are getting hotter: vulnerability of tree species to climate change in New Caledonia. *Biological Conservation* **201**, 111–119.

*Pouteau, R., Meyer, J.-Y., Blanchard, P., Nitta, J. H., Terorotua, M. & Taputuarai, R. (2016). Fern species richness and abundance are indicators of climate change on high-elevation islands: evidence from an elevational gradient on Tahiti (French Polynesia). *Climatic Change* **138**, 143–156.

*Puschendorf, R., Carnaval, A. C., VanDerWal, J., Zumbado-Ulate, H., Chaves, G., Bolaños, F. & Alford, R. A. (2009). Distribution models for the amphibian chytrid *Batrachochytrium dendrobatidis* in Costa Rica: proposing climatic refuges as a conservation tool. *Diversity and Distributions* **15**, 401–408.

Quadri, P., Silva, L. C. R. & Zavaleta, E. S. (2021). Climate-induced reversal of tree growth patterns at a tropical treeline. *Science. Advances* **7**, eabb7572.

Quiroga, M. P., Premoli, A. C. & Kitzberger, T. (2018). Niche squeeze induced by climate change of the cold-tolerant subtropical montane *Podocarpus parlatorei*. *Royal Society Open Science* **5**, 180513.

Raman, S., Shameer, T. T., Charles, B. & Sanil, R. (2020*a*). Habitat suitability model of endangered *Latidens salimalii* and the probable consequences of global warming. *Tropical Ecology* **61**, 570–582.

Raman, S., Shameer, T. T., Sanil, R., Usha, P. & Kumar, S. (2020*b*). Protrusive influence of climate change on the ecological niche of endemic brown mongoose (*Herpestes fuscus fuscus*): a MaxEnt approach from Western Ghats, India. *Modeling Earth Systems and Environment* **6**, 1795–1806.

*Rambal, S., Cavender-Bares, J., Sparks, K. L. & Sparks, J. P. (2020). Consequences of drought severity for tropical live oak (*Quercus oleoides*) in Mesoamerica. *Ecological Applications* **30**, e02135.

Ramírez, L. A., Llambí, L. D., Azocar, C. J., Fernandez, M., Torres, J. E. & Bader, M. Y. (2022). Patterns in climate and seedling establishment at a dry tropical treeline. *Plant Ecology* **223**, 1047–1068.

*Ramírez-Amezcua, Y., Steinmann, V. W., Ruiz-Sanchez, E. & Rojas-Soto, O. R. (2016). Mexican alpine plants in the face of global warming: potential extinction within a specialized assemblage of narrow endemics. *Biodiversity and Conservation* **25**, 865–885.

Ramírez-Bautista, A., Thorne, J. H., Schwartz, M. W. & Williams, J. N. (2020). Trait-based climate vulnerability of native rodents in southwestern Mexico. *Ecology and Evolution* **10**, 5864–5876.

Ramirez-Villegas, J., Cuesta, F., Devenish, C., Peralvo, M., Jarvis, A. & Arnillas, C. A. (2014). Using species distributions models for designing conservation strategies of Tropical Andean biodiversity under climate change. *Journal for Nature Conservation* **22**, 391–404.

*Rapp, J. M., Silman, M. R., Clark, J. S., Girardin, C. A. J., Galiano, D. & Tito, R. (2012). Intra- and interspecific tree growth across a long altitudinal gradient in the Peruvian Andes. *Ecology* **93**, 2061–2072.

*Ravindranath, N. & Sukumar, R. (1998). Climate change and tropical forests in India. In *Potential Impacts of Climate Change on Tropical Forest Ecosystems*, pp. 423–441. Springer, Netherlands.

*Raxworthy, C. J., Pearson, R. G., Rabibisoa, N., Rakotondrazafy, A. M., Ramanamanjato, J.-B., Raselimanana, A. P., Wu, S., Nussbaum, R. A. & Stone, D. A. (2008). Extinction vulnerability of tropical montane endemism from warming and upslope displacement: a preliminary appraisal for the highest massif in Madagascar. *Global Change Biology* **14**, 1703–1720.

*Regalado, C. M. & Ritter, A. (2021). Fog mitigates the consequences of a profligate water use strategy in a Macaronesian cloud forest tree species. *Journal of Hydrology* **593**, 125871.

Rehm, E. M. & Feeley, K. J. (2013). Forest patches and the upward migration of timberline in the southern Peruvian Andes. *Forest Ecology and Management* **305**, 204–211.

Rehm, E. M. & Feeley, K. J. (2015). Freezing temperatures as a limit to forest recruitment above tropical Andean treelines. *Ecology* **96**, 1856–1865.

Rehm, E. M. & Feeley, K. J. (2016). Seedling transplants reveal species-specific responses of high-elevation tropical treeline trees to climate change. *Oecologia* **181**, 1233–1242.

Rehm, E. M., Yelenik, S. & D'Antonio, C. (2021). Freezing temperatures restrict woody plant recruitment and restoration efforts in abandoned montane pastures. *Global Ecology and Conservation* **26**, e01462.

*Reyes-Chávez, J., Quail, M., Tarvin, S., Kessler, M. & Batke, S. P. (2021). Nowhere to escape – diversity and community composition of ferns and lycophytes on the highest mountain in Honduras. *Journal of Tropical Ecology* **37**, 72–81.

*Richards, J. H. (2021). Assessing the strength of climate and land-use influences on montane epiphyte communities. *Conservation Biology* **35**, 1496–1506.

Richter, M. (2008). Tropical mountain forests-distribution and general features. In *The Tropical Montane Forest. Patterns and Processes in a Biodiversity Hotspot*, pp. 7–24. Göttingen Centre for Biodiversity and Ecology, Universitätsverlag Göttingen, Göttingen.

Ricker, M., Gutiérrez-García, G. & Daly, D. C. (2007). Modeling long-term tree growth curves in response to warming climate: test cases from a subtropical mountain forest and a tropical rainforest in Mexico. *Canadian Journal of Forest Research* **37**, 977–989.

Rico, Y., Zurita-Solís, M. A., León-Tapia, M. Á. & Miguel-Peñaloza, A. (2023). High genetic diversity but spatially restricted genetic connectivity in a tropical montane cloud forest tree (*Magnolia schiedeana*). *Tree Genetics & Genomes* **19**, 1.

*Ritter, A., Regalado, C. M. & Aschan, G. (2009). Fog reduces transpiration in tree species of the Canarian relict heath-laurel cloud forest (Garajonay National Park, Spain). *Tree Physiology* **29**, 517–528.

*Ritter, A., Regalado, C. M. & Guerra, J. C. (2019). The impact of climate change on water fluxes in a Macaronesian cloud forest. *Hydrological Processes* **33**, 2828–2846.

*Robertson, A. L., Malhi, Y., Farfan-Amezquita, F., Aragao, L. E. O. C., Silva Espejo, J. E. & Robertson, M. A. (2010). Stem respiration in tropical forests along an elevation gradient in the Amazon and Andes: stem respiration across Amazon-Andes transect. *Global Change Biology* **16**, 3193–3204.

Rödder, D. (2009). 'Sleepless in Hawaii' – does anthropogenic climate change enhance ecological and socioeconomic impacts of the alien invasive *Eleutherodactylus coqui* Thomas 1966 (Anura: Eleutherodactylidae)? *North-Western Journal of Zoology* **5**, 16–25.

*Rodríguez-Quiel, E. E., Mendieta-Leiva, G. & Bader, M. Y. (2019). Elevational patterns of bryophyte and lichen biomass differ among substrates in the tropical montane forest of Baru volcano, Panama. *Journal of Bryology* **41**, 95–106.

Rodríguez-Ramírez, E. C., Ferrero, M. E., Acevedo-Vega, I., Crispin-DelaCruz, D. B., Ticse-Otarola, G. & Requena-Rojas, E. J. (2022). Plastic adjustments in xylem vessel traits to drought events in three Cedrela species from Peruvian tropical Andean forests. *Scientific Reports* **12**, 21112.

Rodríguez-Ramírez, E. C., Luna-Vega, I. & Rozas, V. (2018). Tree-ring research of Mexican beech (*Fagus grandifolia* Subsp. *Mexicana*) a relict tree endemic to eastern Mexico. *Tree-Ring Research* **74**, 94–107.

Rodríguez-Ramírez, E. C., Terrazas, T. & Luna-Vega, I. (2019). The influence of climate on the masting behavior of Mexican beech: growth rings and xylem anatomy. *Trees* **33**, 23–35.

Rodríguez-Ramírez, E. C., Vázquez-García, J. A., García-González, I., Alcántara-Ayala, O. & Luna-Vega, I. (2020). Drought effects on the plasticity in vessel traits of two endemic *Magnolia* species in the tropical montane cloud forests of eastern Mexico. *Journal of Plant Ecology* **13**, 331–340.

Rodríguez-Trejo, D. A. & Fulé, P. Z. (2003). Fire ecology of Mexican pines and a fire management proposal. *International Journal of Wildland Fire* **12**, 23.

Rojas Briceño, N. B., Cotrina Sánchez, D. A., Barboza Castillo, E., Barrena Gurbillón, M. Á., Sarmiento, F. O., Sotomayor, D. A., Oliva, M. & Salas López, R. (2020). Current and future distribution of five timber forest species in Amazonas, Northeast Peru: contributions towards a restoration strategy. *Diversity* **12**, 305.

*Rojas-Soto, O. R., Sosa, V. & Ornelas, J. F. (2012). Forecasting cloud forest in eastern and southern Mexico: conservation insights under future climate change scenarios. *Biodiversity and Conservation* **21**, 2671–2690.

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*Román-Cuesta, R. M., Salinas, N., Asbjornsen, H., Oliveras, I., Huaman, V., Gutiérrez, Y., Puelles, L., Kala, J., Yabar, D., Rojas, M., Astete, R., Jordán, D. Y., Silman, M., Mosandl, R., Weber, M., *et al.* (2011). Implications of fires on carbon budgets in Andean cloud montane forest: the importance of peat soils and tree resprouting. *Forest Ecology and Management* **261**, 1987–1997.

Rosas Rangel, D. M., Mendoza, M. E., Gómez-Tagle, A. & Tobón Marín, C. (2019). Avances y desafios en el conocimiento de los bosques mesófilos de montaña de México. *Madera y Bosques* **25**, 1–19.

*Rosselli, L., Stiles, F. G. & Camargo, P. A. (2017). Changes in the avifauna in a high Andean cloud forest in Colombia over a 24-year period. *Journal of Field Ornithology* **88**, 211–228.

*Round, P. D. & Gale, G. A. (2008). Changes in the status of *Lophura* pheasants in Khao Yai National Park, Thailand: a response to warming climate?: Lophura pheasants in Khao Yai. *Biotropica* **40**, 225–230.

Rubenstein, M. A., Weiskopf, S. R., Carter, S. L., Eaton, M. J., Johnson, C., Lynch, A. J., Miller, B. W., Morelli, T. L., Rodriguez, M. A., Terando, A. & Thompson, L. M. (2020). Do empirical observations support commonly-held climate change range shift hypotheses? A systematic review protocol. *Environmental Evidence* **9**, 10.

*Rueda-Solano, L. A., Navas, C. A., Carvajalino-Fernández, J. M. & Amézquita, A. (2016). Thermal ecology of montane *Atelopus* (Anura: Bufonidae): a study of intrageneric diversity. *Journal of Thermal Biology* **58**, 91–98.

*Ruiz-Benito, P., Madrigal-González, J., Young, S., Mercatoris, P., Cavin, L., Huang, T.-J., Chen, J.-C. & Jump, A. S. (2015). Climatic stress during stand development alters the sign and magnitude of age-related growth responses in a subtropical mountain pine. *PLoS One* **10**, e0126581.

Sáenz-Romero, C., Lindig-Cisneros, R. A., Joyce, D. G., Beaulieu, J., St Clair, J. B. & Jaquish, B. C. (2016). Assisted migration of forest populations for adapting trees to climate change. *Revista Chapingo serie ciencias forestales y del ambiente* **22**, 303–323 Universidad Autónoma Chapingo, Coordinación de Revistas Institucionales.

Sáenz-Romero, C., Mendoza-Maya, E., Gómez-Pineda, E., Blanco-García, A., Endara-Agramont, A. R., Lindig-Cisneros, R., López-Upton, J., Trejo-Ramírez, O., Wehenkel, C., Cibrián-Tovar, D., Flores-López, C., Plascencia-González, A. & Vargas-Hernández, J. J. (2020*a*). Recent evidence of Mexican temperate forest decline and the need for ex situ conservation, assisted migration, and translocation of species ensembles as adaptive management to face projected climatic change impacts in a megadiverse country. *Canadian Journal of Forest Research* **50**, 843–854.

Sáenz-Romero, C., O'Neill, G., Aitken, S. N. & Lindig-Cisneros, R. (2020*b*). Assisted migration field tests in Canada and Mexico: lessons, limitations, and challenges. *Forests* **12**, 9.

*Salinas, N., Malhi, Y., Meir, P., Silman, M., Roman Cuesta, R., Huaman, J., Salinas, D., Huaman, V., Gibaja, A., Mamani, M. & Farfan, F. (2011). The sensitivity of tropical leaf litter decomposition to temperature: results from a large-scale leaf translocation experiment along an elevation gradient in Peruvian forests. *New Phytologist* **189**, 967–977.

Sands, P. (1992). The United Nations framework convention on climate change. In *Review of European, Comparative & International Environmental Law* **1**, 270–277.

*Santillán, V., Quitián, M., Tinoco, B. A., Zárate, E., Schleuning, M., Böhning-Gaese, K. & Neuschulz, E. L. (2020). Direct and indirect effects of elevation, climate and vegetation structure on bird communities on a tropical mountain. *Acta Oecologica* **102**, 103500.

*Sarmiento, F. O. & Kooperman, G. J. (2019). A socio-hydrological perspective on recent and future precipitation changes over tropical montane cloud forests in the Andes. *Frontiers in Earth Science* **7**, 324.

Sax, D. F., Early, R. & Bellemare, J. (2013). Niche syndromes, species extinction risks, and management under climate change. *Trends in Ecology & Evolution* **28**, 517–523.

Scheffers, B. R., Brunner, R. M., Ramirez, S. D., Shoo, L. P., Diesmos, A. & Williams, S. E. (2013*a*). Thermal buffering of microhabitats is a critical factor mediating warming vulnerability of frogs in the Philippine biodiversity hotspot. *Biotropica* **45**, 628–635.

Scheffers, B. R., Edwards, D. P., Diesmos, A., Williams, S. E. & Evans, T. A. (2014). Microhabitats reduce animal's exposure to climate extremes. *Global Change Biology* **20**, 495–503.

Scheffers, B. R., Phillips, B. L., Laurance, W. F., Sodhi, N. S., Diesmos, A. & Williams, S. E. (2013*b*). Increasing arboreality with altitude: a novel biogeographic dimension. *Proceedings of the Royal Society B: Biological Sciences* **280**, 20131581.

*Scheffers, B. R. & Williams, S. E. (2018). Tropical mountain passes are out of reach – but not for arboreal species. *Frontiers in Ecology and the Environment* **16**, 101–108.

Schmitt, C. B., Senbeta, F., Woldemariam, T., Rudner, M. & Denich, M. (2013). Importance of regional climates for plant species distribution patterns in moist Afromontane forest. *Journal of Vegetation Science* **24**, 553–568.

Scholl, M. A., Bassiouni, M. & Torres-Sánchez, A. J. (2021). Drought stress and hurricane defoliation influence mountain clouds and moisture recycling in a tropical forest. *Proceedings of the National Academy of Sciences* **118**, e2021646118.

*Schuur, E. A. G. (2001). The effect of water on decomposition dynamics in Mesic to wet Hawaiian montane forests. *Ecosystems* **4**, 259–273.

Scowcroft, P. G., Turner, D. R. & Vitousek, P. M. (2000). Decomposition of *Metrosideros polymorpha* leaf litter along elevational gradients in Hawaii. *Global Change Biology* **6**, 73–85.

*Şekercioğlu, C. H., Schneider, S. H., Fay, J. P. & Loarie, S. R. (2008). Climate change, elevational range shifts, and bird extinctions. *Conservation Biology* **22**, 140–150.

*Selmants, P. C., Adair, K. L., Litton, C. M., Giardina, C. P. & Schwartz, E. (2016). Increases in mean annual temperature do not alter soil bacterial community structure in tropical montane wet forests. *Ecosphere* **7**, e01296.

*Selmants, P. C., Litton, C. M., Giardina, C. P. & Asner, G. P. (2014). Ecosystem carbon storage does not vary with mean annual temperature in Hawaiian tropical montane wet forests. *Global Change Biology* **20**, 2927–2937.

Setyawan, A. D., Supriatna, J., Nisyawati, N., Nursamsi, I., Sutarno, S., Sugiyarto, S., Sunarto, S., Pradan, P., Budiharta, S., Pitoyo, A., Suhardono, S., Setyono, P. & Indrawan, M. (2020). Anticipated climate changes reveal shifting in habitat suitability of high-altitude selaginellas in Java, Indonesia. *Biodiversitas Journal of Biological Diversity* **21**, 5482–5497.

*Shah, A. A., Funk, W. C. & Ghalambor, C. K. (2017*a*). Thermal acclimation ability varies in temperate and tropical aquatic insects from different elevations. *Integrative and Comparative Biology* **57**, 977–987.

Shah, A. A., Gill, B. A., Encalada, A. C., Flecker, A. S., Funk, W. C., Guayasamin, J. M., Kondratieff, B. C., Poff, N. L., Thomas, S. A., Zamudio, K. R. & Ghalambor, C. K. (2017*b*). Climate variability predicts thermal limits of aquatic insects across elevation and latitude. *Functional Ecology* **31**, 2118–2127.

Shamseer, L., Moher, D., Clarke, M., Ghersi, D., Liberati, A., Petticrew, M., Shekelle, P., Stewart, L. A. & the PRISMA-P Group (2015). Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015: elaboration and explanation. *BMJ* **349**, g7647.

*Sheldon, K. S., Yang, S. & Tewksbury, J. J. (2011). Climate change and community disassembly: impacts of warming on tropical and temperate montane community structure: climate change and community disassembly. *Ecology Letters* **14**, 1191–1200.

*Shi, J. P. & Zhu, H. (2009). Tree species composition and diversity of tropical mountain cloud forest in the Yunnan, southwestern China. *Ecological Research* **24**, 83–92.

*Shiao, M.-T., Chuang, M.-C., Yuan, H.-W. & Wang, Y. (2015). Effects of weather variation on the timing and success of breeding in two cavity-nesting species in a subtropical montane forest in Taiwan. *The Auk* **132**, 671–684.

Shiao, M.-T., Chuang, M.-C., Yuan, H.-W. & Wang, Y. (2020). Seasonal rainfall in subtropical montane cloud forests drives demographic fluctuations in a Green-backed tit population. *The Condor* **122**, duaa043.

*Shoo, L. P., Storlie, C., Vanderwal, J., Little, J. & Williams, S. E. (2011). Targeted protection and restoration to conserve tropical biodiversity in a warming world: conservation of climate change refugia. *Global Change Biology* **17**, 186–193.

*Shoo, L. P., Storlie, C., Williams, Y. M. & Williams, S. E. (2010). Potential for mountaintop boulder fields to buffer species against extreme heat stress under climate change. *International Journal of Biometeorology* **54**, 475–478.

Shugart, H. H., French, N. H. F., Kasischke, E. S., Slawski, J. J., Dull, C. W., Shuchman, R. A. & Mwangi, J. (2001). Detection of vegetation change using reconnaissance imagery. *Global Change Biology* **7**, 247–252.

*Sierra-Morales, P., Rojas-Soto, O., Ríos-Muñoz, C. A., Ochoa-Ochoa, L. M., Flores-Rodríguez, P. & Almazán-Núñez, R. C. (2021). Climate change projections suggest severe decreases in the geographic ranges of bird species restricted to Mexican humid mountain forests. *Global Ecology and Conservation* **30**, e01794.

*Silva, V. D.e., Beirao, M. V. & Cardoso, D. C. (2020). Thermal tolerance of fruit-feeding butterflies (Lepidoptera: Nymphalidae) in contrasting mountaintop environments. *Insects* **11**, 278.

Silveira, F. A. O., Barbosa, M., Beiroz, W., Callisto, M., Macedo, D. R., Morellato, L. P. C., Neves, F. S., Nunes, Y. R. F., Solar, R. R. & Fernandes, G. W. (2019). Tropical mountains as natural laboratories to study global changes: a long-term ecological research project in a megadiverse biodiversity hotspot. *Perspectives in Plant Ecology, Evolution and Systematics* **38**, 64–73.

*Singh, M., Badcock-Scruton, J. & Collins, C. M. (2021). What will remain? Predicting the representation in protected areas of suitable habitat for endangered tropical avifauna in Borneo under a combined climate- and land-use change scenario. *Sustainability* **13**, 2792.

Soh, M. C. K., Mitchell, N. J., Ridley, A. R., Butler, C. W., Puan, C. L. & Peh, K. S.-H. (2019). Impacts of habitat degradation on tropical montane biodiversity and ecosystem services: a systematic map for identifying future research priorities. *Frontiers in Forests and Global Change* **2**, 83.

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Song, L., Liu, W.-Y. & Nadkarni, N. M. (2012). Response of non-vascular epiphytes to simulated climate change in a montane moist evergreen broad-leaved forest in Southwest China. *Biological Conservation* **152**, 127–135.

*Song, X., Li, J., Zhang, W., Tang, Y., Sun, Z. & Cao, M. (2016*a*). Variant responses of tree seedling to seasonal drought stress along an elevational transect in tropical montane forests. *Scientific Reports* **6**, 36438.

Song, X., Nakamura, A., Sun, Z., Tang, Y. & Cao, M. (2016*b*). Elevational distribution of adult trees and seedlings in a tropical montane transect, Southwest China. *Mountain Research and Development* **36**, 342.

*Song, Y.-G., Petitpierre, B., Deng, M., Wu, J.-P. & Kozlowski, G. (2019). Predicting climate change impacts on the threatened *Quercus arbutifolia* in montane cloud forests in southern China and Vietnam: conservation implications. *Forest Ecology and Management* **444**, 269–279.

Soto-Correa, J. C., Sáenz-Romero, C., Lindig-Cisneros, R. & de la Barrera, E. (2013). The neotropical shrub *Lupinus elegans*, from temperate forests, may not adapt to climate change. *Plant Biology* **15**, 607–610.

Sperling, F. N., Washington, R. & Whittaker, R. J. (2004). Future climate change of the subtropical North Atlantic: implications for the cloud forests of Tenerife. *Climatic Change* **65**, 103–123.

*Sreekumar, E. R. & Nameer, P. O. (2021). Impact of climate change on two high-altitude restricted and endemic flycatchers of the Western Ghats, India. *Current Science* **121**, 1335.

*Staunton, K. M., Nakamura, A., Burwell, C. J., Robson, S. K. A. & Williams, S. E. (2016). Elevational distribution of flightless ground beetles in the tropical rainforests of North-Eastern Australia. *PLoS One* **11**, e0155826.

Still, C. J., Foster, P. N. & Schneider, S. H. (1999). Simulating the effects of climate change on tropical montane cloud forests. *Nature* **398**, 608–610.

Strangas, M. L., Navas, C. A., Rodrigues, M. T. & Carnaval, A. C. (2019). Thermophysiology, microclimates, and species distributions of lizards in the mountains of the Brazilian Atlantic Forest. *Ecography* **42**, 354–364.

*Strauch, A. M., Giardina, C. P., MacKenzie, R. A., Heider, C., Giambelluca, T. W., Salminen, E. & Bruland, G. L. (2017). Modeled effects of climate change and plant invasion on watershed function across a steep tropical rainfall gradient. *Ecosystems* **20**, 583–600.

Sukumar, R., Suresh, H. S. & Ramesh, R. (1995). Climate change and its impact on tropical montane ecosystems in southern India. *Journal of Biogeography* **22**, 533.

*Sun, H., Wu, Y., Zhou, J., Bing, H. & Zhu, H. (2020). Climate influences the alpine soil bacterial communities by regulating the vegetation and the soil properties along an altitudinal gradient in SW China. *Catena* **195**, 104727.

*Tagliari, M. M., Vieilledent, G., Alves, J., Silveira, T. C. L. & Peroni, N. (2021). Relict populations of *Araucaria angustifolia* will be isolated, poorly protected, and unconnected under climate and land-use change in Brazil. *Biodiversity and Conservation* **30**, 3665–3684.

Tanner, E. V. J., Bellingham, P. J., Healey, J. R. & Feeley, K. J. (2022). Hurricane disturbance accelerated the thermophilization of a Jamaican montane forest. *Ecography* **2022**, e06100.

Tao, S., Cheng, K., Li, X., Han, X., Wang, J., Zheng, R. & Sun, B. (2021). The thermal biology of *Takydromus kuehnei* indicates tropical lizards from high elevation have not been severely threatened by climate change. *Frontiers in Ecology and Evolution* **9**, 767102.

Tejedor-Garavito, N., Newton, A. C., Golicher, D. & Oldfield, S. (2015). The relative impact of climate change on the extinction risk of tree species in the montane tropical Andes. *PLoS One* **10**, e0131388.

*Téllez-Valdés, O., Dávila-Aranda, P. & Lira-Saade, R. (2006). The effects of climate change on the long-term conservation of *Fagus grandifolia var. mexicana*, an important species of the cloud forest in eastern Mexico. *Biodiversity and Conservation* **15**, 1095–1107.

*Thang, T. H. & Thu, A. M. (2021). Microsite preferences and determinants for recruitment of keystone tree species in a tropical montane forest of Myanmar. *Journal of Sustainable Forestry* **40**, 846–861.

*Thang, T. H., Thu, A. M. & Chen, J. (2020). Tree species of tropical and temperate lineages in a tropical Asian montane forest show different range dynamics in response to climate change. *Global Ecology and Conservation* **22**, e00973.

Tito, R., Vasconcelos, H. L. & Feeley, K. J. (2020). Mountain ecosystems as natural laboratories for climate change experiments. *Frontiers in Forests and Global Change* **3**, 38.

Tito, R., Vasconcelos, H. L. & Feeley, K. J. (2021). Multi-population seedling and soil transplants show possible responses of a common tropical montane tree species (*Weinmannia bangii*) to climate change. *Journal of Ecology* **109**, 62–73.

Toledo-Aceves, T. & del-Val, E. (2021). Do plant-herbivore interactions persist in assisted migration plantings? *Restoration Ecology* **29**, e13318.

Toledo-Aceves, T., García-Hernández, M. d. l. Á. & Paz, H. (2019). Leaf functional traits predict cloud forest tree seedling survival along an elevation gradient. *Annals of Forest Science* **76**, 111.

*Toledo-Aceves, T., Meave, J. A., González-Espinosa, M. & Ramírez-Marcial, N. (2011). Tropical montane cloud forests: current threats and opportunities for their conservation and sustainable management in Mexico. *Journal of Environmental Management* **92**, 974–981.

Torres, I., González, J. E. & Comarazamy, D. E. (2008). Impacts of a changing climate and low land use on a tropical montane cloud Forest. In *Environmental Problems in Coastal Regions VII*, pp. 59–70. WIT Press, The New Forest, UK.

*Tovar, C., Arnillas, C. A., Cuesta, F. & Buytaert, W. (2013). Diverging responses of tropical Andean biomes under future climate conditions. *PLoS One* **8**, e63634.

Tovar, C., Carril, A. F., Gutiérrez, A. G., Ahrends, A., Fita, L., Zaninelli, P., Flombaum, P., Abarzúa, A. M., Alarcón, D., Aschero, V., Báez, S., Barros, A., Carilla, J., Ferrero, M. E., Flantua, S. G. A., *et al.* (2022). Understanding climate change impacts on biome and plant distributions in the Andes: challenges and opportunities. *Journal of Biogeography* **49**, 1420–1442.

*Townsend, P. A. & Masters, K. L. (2015). Lattice-work corridors for climate change: a conceptual framework for biodiversity conservation and social-ecological resilience in a tropical elevational gradient. *Ecology and Society* **20**, art1.

*Tsai, C.-F., Lee, Y.-F., Chen, Y.-H., Chen, W.-M. & Kuo, Y.-M. (2015). Species turnover in tropical montane forest avifauna links to climatic correlates. *Global Ecology and Conservation* **3**, 541–552.

*Urrutia, R. & Vuille, M. (2009). Climate change projections for the tropical Andes using a regional climate model: temperature and precipitation simulations for the end of the 21st century. *Journal of Geophysical Research* **114**, D02108.

*Valtonen, A., Molleman, F., Chapman, C. A., Carey, J. R., Ayres, M. P. & Roininen, H. (2013). Tropical phenology: bi-annual rhythms and interannual variation in an Afrotropical butterfly assemblage. *Ecosphere* **4**, art36.

Van Beusekom, A. E., González, G. & Rivera, M. M. (2015). Short-term precipitation and temperature trends along an elevation gradient in northeastern Puerto Rico. *Earth Interactions* **19**, 1–33.

Van Beusekom, A. E., González, G. & Scholl, M. A. (2017). Analyzing cloud base at local and regional scales to understand tropical montane cloud forest vulnerability to climate change. *Atmospheric Chemistry and Physics* **17**, 7245–7259.

*Vásquez-Morales, S. G., Téllez-Valdés, O., Pineda-López, M. d. R., Sánchez-Velásquez, L. R., Flores-Estevez, N. & Viveros-Viveros, H. (2014). Effect of climate change on the distribution of *Magnolia schiedeana*: a threatened species. *Botanical Sciences* **92**, 575–585.

*Velásquez Restrepo, J. O., Maniguaje, N. L. & Duque, Á. J. (2012). Diversidad y dinámica de un bosque subandino de altitud en la región norte de los Andes colombianos. *Revista de Biología Tropical* **60**, 943–952.

*Velásquez-Tibatá, J., Salaman, P. & Graham, C. H. (2013). Effects of climate change on species distribution, community structure, and conservation of birds in protected areas in Colombia. *Regional Environmental Change* **13**, 235–248.

*Velo-Antón, G., Parra, J. L., Parra-Olea, G. & Zamudio, K. R. (2013). Tracking climate change in a dispersal-limited species: reduced spatial and genetic connectivity in a montane salamander. *Molecular Ecology* **22**, 3261–3278.

Veloz, S. D., Williams, J. W., Blois, J. L., He, F., Otto-Bliesner, B. & Liu, Z. (2012). No-analog climates and shifting realized niches during the late quaternary: implications for 21st-century predictions by species distribution models. *Global Change Biology* **18**, 1698–1713.

Venter, M., Dwyer, J., Dieleman, W., Ramachandra, A., Gillieson, D., Laurance, S., Cernusak, L. A., Beehler, B., Jensen, R. & Bird, M. I. (2017). Optimal climate for large trees at high elevations drives patterns of biomass in remote forests of Papua New Guinea. *Global Change Biology* **23**, 4873–4883.

*Vieira, S. A., Alves, L. F., Duarte-Neto, P. J., Martins, S. C., Veiga, L. G., Scaranello, M. A., Picollo, M. C., Camargo, P. B., do Carmo, J. B., Neto, E. S., Santos, F. A. M., Joly, C. A. & Martinelli, L. A. (2011). Stocks of carbon and nitrogen and partitioning between above- and belowground pools in the Brazilian coastal Atlantic Forest elevation range: carbon and nitrogen stocks in Atlantic Forest. *Ecology and Evolution* **1**, 421–434.

*Villa, P. M., Pérez-Sánchez, A. J., Nava, F., Acevedo, A. & Cadenas, D. A. (2019). Local-scale seasonality shapes anuran community abundance in a cloud forest of the tropical Andes. *Zoological Studies* **58**, e17.

*Villers-Ruíz, L. & Trejo-Vázquez, I. (1998). Climate change on Mexican forests and natural protected areas. *Global Environmental Change* **8**, 141–157.

*Vollstädt, M. G. R., Albrecht, J., Böhning-Gaese, K., Hemp, A., Howell, K. M., Kettering, L., Neu, A., Neuschulz, E. L., Quitián, M., Santillán, V. E., Töpfer, T., Schleuning, M. & Fritz, S. A. (2020). Direct and plant-mediated effects of climate on bird diversity in tropical mountains. *Ecology and Evolution* **10**, 14196–14208.

von May, R., Catenazzi, A., Corl, A., Santa-Cruz, R., Carnaval, A. C. & Moritz, C. (2017). Divergence of thermal physiological traits in terrestrial breeding frogs along a tropical elevational gradient. *Ecology and Evolution* **7**, 3257–3267.

Vuille, M., Bradley, R. S., Werner, M. & Keimig, F. (2003). 20th century climate change in the tropical Andes: observations and model results. In *Climate Variability and Change in High Elevation Regions: Past, Present & Future* (ed. H. F. Diaz), pp. 75–99. Springer, Netherlands, Dordrecht.

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Wagner, S., Zotz, G. & Bader, M. Y. (2014). The temperature acclimation potential of tropical bryophytes. *Plant Biology* **16**, 117–124.
*Wallace, J. & McJannet, D. (2013). How might Australian rainforest cloud interception respond to climate change? *Journal of Hydrology* **481**, 85–95.
*Wang, H., Cornell, J. D., Hall, C. A. S. & Marley, D. P. (2002). Spatial and seasonal dynamics of surface soil carbon in the Luquillo experimental Forest, Puerto Rico. *Ecological Modelling* **147**, 105–122.
*Wang, H., Hall, C. A. S., Scatena, F. N., Fetcher, N. & Wu, W. (2003). Modeling the spatial and temporal variability in climate and primary productivity across the Luquillo Mountains, Puerto Rico. *Forest Ecology and Management* **179**, 69–94.
Warne, C. P. K., Hallwachs, W., Janzen, D. H. & Smith, M. A. (2020). Functional and genetic diversity changes through time in a cloud forest ant assemblage. *Biotropica* **52**, 1084–1091.
Wauchope, H. S., Amano, T., Geldmann, J., Johnston, A., Simmons, B. I., Sutherland, W. J. & Jones, J. P. G. (2021). Evaluating impact using time-series data. *Trends in Ecology & Evolution* **36**, 196–205.
Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y. & Zemla, J. (2017). Package 'corrplot'. *Stat* **56**, e24.
*Weintraub, S. R., Cole, R. J., Schmitt, C. G. & All, J. D. (2016). Climatic controls on the isotopic composition and availability of soil nitrogen across mountainous tropical forest. *Ecosphere* **7**, e01412.
*Whitaker, J., Ostle, N., Nottingham, A. T., Ccahuana, A., Salinas, N., Bardgett, R. D., Meir, P. & McNamara, N. P. (2014). Microbial community composition explains soil respiration responses to changing carbon inputs along an Andes-to-Amazon elevation gradient. *Journal of Ecology* **102**, 1058–1071.
Whitman, M., Beaman, R. S., Repin, R., Kitayama, K., Aiba, S. & Russo, S. E. (2021). Edaphic specialization and vegetation zones define elevational range-sizes for Mt Kinabalu regional flora. *Ecography* **44**, 1698–1709.
*Wicaksono, C. Y., Aguirre-Gutierrez, J., Nouhra, E., Pastor, N., Raes, N., Pacheco, S. & Geml, J. (2017). Contracting montane cloud forests: a case study of the Andean alder (*Alnus acuminata*) and associated fungi in the Yungas. *Biotropica* **49**, 141–152.
Wickham, H. (2011). ggplot2. *Wiley Interdisciplinary Reviews: Computational Statistics* **3**, 180–185.
*Wilcke, W., Leimer, S., Peters, T., Emck, P., Rollenbeck, R., Trachte, K., Valarezo, C. & Bendix, J. (2013). The nitrogen cycle of tropical montane forest in Ecuador turns inorganic under environmental change. *Global Biogeochemical Cycles* **27**, 1194–1204.
*Wilcke, W., Velescu, A., Leimer, S., Blotevogel, S., Alvarez, P. & Valarezo, C. (2020). Total organic carbon concentrations in ecosystem solutions of a remote tropical montane forest respond to global environmental change. *Global Change Biology* **26**, 6989–7005.
*Williams, C. B., Murray, J. G., Glunk, A., Dawson, T. E., Nadkarni, N. M. & Gotsch, S. G. (2020). Vascular epiphytes show low physiological resistance and high recovery capacity to episodic, short-term drought in Monteverde, Costa Rica. *Functional Ecology* **34**, 1537–1550.
Williams, J. N., Rivera, R., Choe, H., Schwartz, M. W. & Thorne, J. H. (2018). Climate risk on two vegetation axes—tropical wet-to-dry and temperate arid-to-moist forests. *Journal of Biogeography* **45**, 2361–2374.
Williams, S. E., Bolitho, E. E. & Fox, S. (2003). Climate change in Australian tropical rainforests: an impending environmental catastrophe. *Proceedings of the Royal Society of London. Series B: Biological Sciences* **270**, 1887–1892.
*Willig, M. R., Presley, S. J. & Cullerton, E. I. (2021). A canonical metacommunity structure over 3 decades: ecologically consistent but spatially dynamic patterns in a hurricane-prone montane forest. *Oecologia* **196**, 919–933.
*Wilson, R. D., Trueman, J. W. H., Williams, S. E. & Yeates, D. K. (2007). Altitudinally restricted communities of schizophoran flies in Queensland's wet tropics: vulnerability to climate change. *Biodiversity and Conservation* **16**, 3163–3177.
*Woodhams, D. C., Alford, R. A., Briggs, C. J., Johnson, M. & Rollins-Smith, L. A. (2008). Life-history trade-offs influence disease in changing climates: strategies of an amphibian pathogen. *Ecology* **89**, 1627–1639.
Wright, S. J., Muller-Landau, H. C. & Schipper, J. (2009). The future of tropical species on a warmer planet. *Conservation Biology* **23**, 1418–1426.
Yocom, L. L. & Fulé, P. Z. (2012). Human and climate influences on frequent fire in a high-elevation tropical forest. *Journal of Applied Ecology* **49**, 1356–1364.
*Young, K. R. & Lipton, J. K. (2006). Adaptive governance and climate change in the tropical highlands of western South America. *Climatic Change* **78**, 63–102.
*Young, K. R., Ponette-González, A. G., Polk, M. H. & Lipton, J. K. (2017). Snowlines and treelines in the tropical Andes. *Annals of the American Association of Geographers* **107**, 429–440.
*Yuste, J. C., Hereş, A.-M., Ojeda, G., Paz, A., Pizano, C., García-Angulo, D. & Lasso, E. (2017). Soil heterotrophic CO_2 emissions from tropical high-elevation ecosystems (Páramos) and their sensitivity to temperature and moisture fluctuations. *Soil Biology and Biochemistry* **110**, 8–11.
*Zach, A., Horna, V., Leuschner, C. & Zimmermann, R. (2010). Patterns of wood carbon dioxide efflux across a 2,000-m elevation transect in an Andean moist forest. *Oecologia* **162**, 127–137.
*Zamora-Vilchis, I., Williams, S. E. & Johnson, C. N. (2012). Environmental temperature affects prevalence of blood parasites of birds on an elevation gradient: implications for disease in a warming climate. *PLoS One* **7**, e39208.
*Zhang, H., Henderson-Sellers, A. & McGuffie, K. (1996). Impacts of tropical deforestation. Part I: process analysis of local climatic change. *Journal of Climate* **9**, 1497–1517.
*Zhang, M., Yu, G.-R., Zhang, L.-M., Sun, X.-M., Wen, X.-F., Han, S.-J. & Yan, J.-H. (2010). Impact of cloudiness on net ecosystem exchange of carbon dioxide in different types of forest ecosystems in China. *Biogeosciences* **7**, 711–722.
*Zhou, Z., Jiang, L., Du, E., Hu, H., Li, Y., Chen, D. & Fang, J. (2013). Temperature and substrate availability regulate soil respiration in the tropical mountain rainforests, Hainan Island, China. *Journal of Plant Ecology* **6**, 325–334.
*Zhou, Z., Ouyang, Y., Qiu, Z., Zhou, G., Lin, M. & Li, Y. (2017). Evidence of climate change impact on stream low flow from the tropical mountain rainforest watershed in Hainan Island, China. *Journal of Water and Climate Change* **8**, 293–302.
*Zimmermann, M., Meir, P., Bird, M. I., Malhi, Y. & Ccahuana, A. J. Q. (2010). Temporal variation and climate dependence of soil respiration and its components along a 3000 m altitudinal tropical forest gradient. *Global Biogeochemical Cycles* **24**, GB4012.
Zotz, G., Bogusch, W., Hietz, P. & Ketteler, N. (2010). Growth of epiphytic bromeliads in a changing world: the effects of CO_2, water and nutrient supply. *Acta Oecologica* **36**, 659–665.
*Zuleta, D., Benavides, A. M., López-Rios, V. & Duque, A. (2016). Local and regional determinants of vascular epiphyte mortality in the Andean mountains of Colombia. *Journal of Ecology* **104**, 841–849.

IX. SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Table S1. Details of 395 studies published between 1994 and 2021 included in the assessment of evidence strength for impacts of anthropogenic climate change on tropical montane forests.

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