# Biogeographical patterns of species richness, range size and phylogenetic diversity of ferns along elevational-latitudinal gradients in the tropics and its transition zone

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“An overwhelming body of evidence supports the conclusion that every organism alive today and all those who have ever lived are members of a shared heritage that extends back to the origin of life 3.8 billion years ago”. This sentence is an invitation to reflect about our non-independence as a living beins. We are part of something bigger!

"Eine überwältigende Anzahl von Beweisen stützt die Schlussfolgerung, dass jeder heute lebende Organismus und alle, die jemals gelebt haben, Mitglieder eines gemeinsamen Erbes sind, das bis zum Ursprung des Lebens vor 3,8 Milliarden Jahren zurückreicht." Dieser Satz ist eine Einladung, über unsere Nichtunabhängigkeit als Lebende Wesen zu reflektieren. Wir sind Teil von etwas Größerem!

# PREFACE

All doors were opened to start this travel, beginning for the many magical pristine forest of Ecuador, Sierra de Juárez Oaxaca and los Tuxtlas in Veracruz, some of the most biodiverse zones in the planet, were I had the honor to put my feet, contemplate their beauty and perfection and work in their mystical forest. It was a dream into reality!

The collaboration with the German counterpart started at the beginning of my academic career and I never imagine that this will be continued to bring this research that summarizes the efforts of many researchers that worked hardly in the overwhelming and incredible biodiverse tropics.

This international research was part of collaboration between multiple researchers and institutions mainly from Mexico, Guatemala, Ecuador, Germany and Switzerland, that included and extensive labor related to the distribution of ferns and lycophytes from the Equator to the north limit of the tropics in Mexico analyzing three fundamental aspects of the plant distribution: the local ecological plot-based assessment, the biogeographical and phylogenetic aspects, giving light on the key factors of plant distribution and diversity at different levels along elevational-latitudinal gradients using ferns as a model group.

I did this work with deeply respect and admiration to the Nature, with whom the human kind should be reconnected. If we could recognize and have always in mind that all life forms in this existence are connected, new forms of thinking and actions of mutual respect between the beings with whom we cohabit the earth will bring a different reality in this period of planetary crisis. This simply statement recognizing the connection of all beings in the *praxis* is very powerful and transformative.

# Biogeographical patterns of species richness, range size and phylogenetic diversity of ferns along elevational-latitudinal gradients in the tropics and its transition zone

# Biogeografische Muster des Artenreichtums, der Verbreitungsgröße und der phylogenetischen Vielfalt von Farnen entlang von Höhen-Breitengradienten in den Tropen und ihrer Übergangszone

**Summary**-Although elevational-latitudinal patterns of plant and animal diversity have been studied for centuries, factors driving the observed patterns are still controversially discussed. Tropical mountains offer an excellent natural experiment to unravel these drivers of biogeographical patterns and the integration of multiple elevational gradients along an extended latitudinal gradient is an outstanding opportunity to decipher underlying mechanism of large-scale patterns of species richness. In this research the data obtained from Mexico were unified with elevational transects in America spanning 0° to 23°N degrees of latitude, mostly between sea level and mountain tops (200-4000 m a.s.l.). Hereby, the latitudinal gradient covered by this investigation runs from most studied tropics through the transition zone of sub-tropical regions in order to integrate increasingly seasonal and dry climates, which are known to limit the diversity of ferns as humidity-dependent organisms.

How the fern and lycophytes (hereafter ferns) richness and species range size patterns change along elevational-latitudinal gradients is poorly explored, as well as the phylogenetic relationships within species assemblages. The objective of this research was to describe such patterns and understand the broad scale distribution of other important components of biodiversity as the phylogenetic diversity and associated metrics, using a standardized methodology that allows the comparison of elevational transects. In order to assess these patterns, I first intensively sampled an elevational gradient in the Sierra de Juárez, Oaxaca, Mexico, known as the “ferns hunter paradise”, a hotspot of biodiversity in a hyperhumid tropical region. Following the uniform sampling protocol of the working group around Michael Kessler (Zurich) and Jürgen Kluge (Marburg), I sampled at each elevation four to eight plots of 20 x 20 m ($400m^2$) and analyzed changes in fern assemblages along this elevational gradient. The plots were established in natural zonal forest, avoiding special structural features and disturbed areas whenever possible. In each plot, DNA samples were taken and all fern species and their abundances were recorded for terrestrials and epiphytes. The results are presented in a series of chapters starting from the analyses of the gradient in Mexico, followed by the central work of this research, where richness and range size patterns of eight elevational transects in Mexico were analyzed together with climatic correlates, and the assessment of the historical component (phylogenetics) of 11 elevational gradients understanding the processes that governs the species richness. In the following the central questions and results of the three studies will be briefly described.

In Chapter 2 we analyzed in detail one of the most diverse elevational transect in Mexico with 15 elevational steps in Sierra de Juárez Oaxaca, a hotspot of biodiversity, comparing the

richness patterns with central and South America. In 121 plots we found 195 fern species, with the highest species numbers recorded at mid-elevations (1,100–2,200 m) and lower richness at both gradient extremes. This hump-shaped pattern was mainly driven by epiphytes, which contributed about 40% to the total species richness. This species group had wider elevational ranges than terrestrial species, which contributed 38% to the total richness (20 % were recorded within both life forms), and were more or less constant at low to mid elevations about 2,500 m, followed by a gradual decline. Overall, richness per plot was low compared to other elevational gradients within the tropics closer to the Equator. This decline of species richness towards the subtropics and temperate regions appears to be rather abrupt within Central America, but additional data are needed to close the remaining gap of knowledge between Costa Rica and Mexico. This work has been published 2018 in the American Fern Journal (Hernández-Rojas *et al.* 2018).

In the central work of this research (Chapter 3), we assessed the richness and range size patterns of ferns and lycophytes along seven elevational gradients (with in total 658 plots) at different latitudes and searched for predictors of range size from a set of environmental factors. We calculated the latitudinal range using the northern and southern limits of each species and averaged the latitudinal range of all species within assemblages weighted by their abundances. We related climatic factors and the changes with latitude and elevation with range size using linear mixed-effects models. Species richness per plot increased with elevation up to about 1,500-2,000 m, with strong differences in overall species richness between transects and a reduction with increasing latitude. The mean weighted range size of species within assemblages declined with elevation, and increased with latitude. However, we also found marked differences between the Atlantic and Pacific slopes of Mexico, as well as low range size in humid regions. The best models described about 76%–80% of the variability in range size and included the seasonality of both temperature and precipitation, and annual cloud cover. As a conclusion, latitudinal and elevational patterns of range size in fern assemblages are driven by an interplay of factors favoring wide-ranging species (higher latitudes with increasing temperature seasonality and dryer habitat conditions) and those favoring species with restricted ranges (higher elevations with more humid habitat conditions), with additional variation introduced by the specific conditions of individual mountain ranges. Climatically stable, humid habitats apparently provide favorable conditions for small-ranged fern species, and should accordingly be given high priority in regional conservation planning. This work was published 2020 in the Journal of Biogeography (Hernández-Rojas *et al.* 2020).

Finally, phylogenetic approaches should be seen as an integral component of studies of the causal basis of community structure, which permits the understanding of how communities have evolved through time, and a deeper understanding of biogeographical processes. This historical aspect is included as the final part of this research (Chapter 4) that was aimed to unfold the complex changes in the phylogenetic structure along elevation (200-4000 m.a.s.l.) and latitude (0°-23° N). We compiled a comprehensive data set including eleven elevational transects (more than 900 spp. and 868 plots), closing the gap of information observed in Chapter 2. At this point I should highlight the relevance of this research as a product of the work of many researchers that I have the honor to synthesize to get a complete view of biogeographic and phylogenetic patterns. One of the major tasks before analyzing the data was to compile the phylogenetic information of the more than 900 species, of which only 70 % were already present in the most recent dissolved phylogenetic tree, and the remaining 30 % species had to be added on the basis of putative closest relatives due to exhaustive examination of morphological characteristics and expert knowledge. Our results showed that latitude and elevation per se are weak explanatory variables for phylogenetic diversity, but incorporating climatic variables clearly enhance the explanatory power of the models. We used different phylogenetic measures in order to capture different aspects of evolutionary history of this plant group and were thus able to understand, how species groups have evolved to currently form the observed gradients in Central America. Overall, the phylogenetic diversity decreased with increased latitude and elevation, as could be observed by increasingly clustering of closely related species. Additionally, it is worthwhile to look at taxonomic group of ferns separately for the main lifeforms, as they are not only ecologically different, but also not congruent in their evolutionary history. Epiphytic phylogenetic diversity had a positive relationship with humidity, while the phylogenetic diversity of terrestrial was determined by temperature. The general pattern of phylogenetic diversity is mainly driven for the suppression of the old, basal tropical, terrestrial lineages rather than by recent evolutionary history and better explained by climatic variables. This work was submitted to *frontiers of biogeography*. In continuation of this work and as an outlook to further studies, I am heading for to continue the research in tropical areas, where the deforestation and disturbance, respectively, and general human activities play a central role, which are impacting tremendously the legacy of millions of years of evolution. In the context of the species richness patterns, it is necessary to fill the gaps of knowledge present in America. In this regard, I will intend to incorporate historical factors that enables a deeper understanding of biogeographical processes.

**Zusammenfassung-**Die Erforschung von Diversität entlang von Höhen- und latitudinalen Gradienten ist schon lang ein zentrales biogeographisches Thema, trotzdem werden Faktoren, die die beobachteten Muster bestimmen, immer noch kontrovers diskutiert. Tropische Gebirge bieten dabei ein ausgezeichnetes natürliches Experiment, um die Ursachen biogeografischer Muster zu entschlüsseln. In diesem Zusammenhang bot sich die hervorragende Gelegenheit, im Rahmen dieser Dissertation Artverteilungsmuster einer großen und einheitlichen Pflanzengruppe, der Farne, an mehreren Höhengradienten entlang eines ausgedehnten latitudinalen Gradienten zu untersuchen, um den zugrunde liegenden Mechanismus großräumiger Muster des Artenreichtums zu entschlüsseln. Bei dieser Untersuchung wurden die in Mexiko gewonnenen Daten mit entsprechenden Daten aus anderen Regionen in Amerika zusammengefasst, die sich latitudinal vom Äquator bis 23° nördlicher Breite, und in der Höhe zwischen dem Meeresspiegel und den jeweiligen Berggipfeln (200 m - 4000 m) erstrecken. Dabei reicht der von dieser Untersuchung abgedeckte latitudinale Gradient von den Tropen in Ecuador bis in die Übergangszone zu subtropischen Regionen in Zentral-Mexiko, um zunehmend saisonale und trockene Klimazonen einzubeziehen, von denen vermutet werden kann, dass die letzteren Klimate die Diversität von Farnen als feuchtigkeitsabhängige Organismen einschränken können.

Wie sich der Reichtum von echten Farnen und Bärlappgewächsen (im Folgenden einheitlich als ‚Farne' bezeichnet) und die Arealgrößen sowie die phylogenetischen Beziehungen innerhalb von Artengemeinschaften entlang von Höhen- und latitudinalen Gradienten ändern, sind nur unzureichend untersucht. Das Ziel dieses Forschungsprojektes war es, die gefundenen Muster zu beschreiben sowie die Muster phylogenetischen Vielfalt unter Verwendung einer standardisierten Methodik zu verstehen und in einem räumlichen und historischen Kontext einzuordnen. In einem ersten Schritt habe ich zunächst intensiv einen Höhengradienten in der Sierra de Juárez, Oaxaca, Mexiko, untersucht, der als „Fern Hunter's Paradise" bekannt ist, einem Hotspot der Artenvielfalt in einer hyperhumiden tropischen Region. Unter Verwendung eines etablierten, einheitlichen Aufnahmeprotokolls der Arbeitsgruppe um Michael Kessler (Universität Zürich) habe ich in jeder Höhestufe von 100 m bis 200 m vier bis acht Parzellen von 400 m² (insgesamt 121) beprobt und Änderungen der Farnzusammensetzung entlang dieses Höhengradienten analysiert. Die Parzellen wurden in natürlichen zonalen Wäldern angelegt, wobei nach Möglichkeit besondere geomorphologische Situationen (tiefe Bacheinschnitte,

Berggrate) und gestörte Gebiete (Erdrutsche) vermieden wurden. In jeder Parzelle wurden von allen gefundenen Farnarten DNA-Proben entnommen sowie ihre Häufigkeit insgesamt und getrennt nach Lebensform (terrestrisch, epiphytisch) getrennt aufgezeichnet. Die Ergebnisse werden hier in einer Reihe von Kapiteln vorgestellt, beginnend mit den Analysen des untersuchten Gradienten in Oaxaca, Mexiko, gefolgt der Analyse der Diversitäts- und Arealgrößenmuster dieses und sieben weiterer Höhengradienten in Mexiko, die von anderen Projekten der Arbeitsgruppe um Michael Kessler erhoben wurden. Des Weiteren werden an insgesamt elf Höhengradienten (die erwähnten acht in Mexiko sowie drei weitere südlich bis Ecuador) Zusammenhänge der erhobenen Diversitätsmuster mit Klimafaktoren bewertet und die phylogenetischen Zusammensetzungen der Farngemeinschaften als evolutionär-historische Komponente untersucht. Im Folgenden werden Inhalt und zentrale Ergebnisse dieser drei Studien vorgestellt.

In Kapitel 2 haben wir einen der vielfältigsten Höhengradienten in Mexiko mit 15 Höhenstufen in der Sierra de Juárez, Oaxaca, einem Hotspot der biologischen Vielfalt, detailliert analysiert und die Diversitätsmuster mit denen aus Mittel- und Südamerika verglichen. In 121 Untersuchungsflächen fanden wir insgesamt 195 Farnarten, wobei die höchsten Artenzahlen in mittleren Höhenlagen (1100 m - 2200 m) und ein geringerer Reichtum an beiden Gradientenenden verzeichnet wurden. Dieses buckelförmige Muster wurde hauptsächlich von den Epiphyten gebildet, die etwa 40 % zum gesamten Artenreichtum beitrugen. Diese Artengruppe hatte größere Höhenausdehnungen als die terrestrischen Arten. Letztere trugen 38 % zur Gesamtartezahl bei (20 % wurden in beiden Lebensformen erfasst) und waren in niedrigen bis mittleren Höhen von etwa 2500 m mehr oder weniger konstant, gefolgt von einem allmählichen Rückgang bis in hohe Gebirgslagen. Insgesamt war der Artenreichtum pro Untersuchungsfläche im Vergleich zu anderen Höhengradienten in den Tropen näher am Äquator gering. Dieser Rückgang des Artenreichtums nordwärts in Richtung Subtropen und gemäßigte Regionen erschien in Mittelamerika ziemlich abrupt, es sind jedoch zusätzliche Daten erforderlich, um die verbleibende Wissenslücke zwischen Costa Rica und Mexiko zu schließen. Diese Arbeit wurde 2018 im *American Fern Journal* veröffentlicht (Hernández-Rojas *et al.* 2018).

In der zentralen Arbeit dieses Forschungsvorhabens (Kapitel 3) haben wir Diversität und Arealgrößen von Farngemeinschaften entlang von sieben Höhengradienten (mit insgesamt 658 Parzellen) in verschiedenen latitudinalen Breiten untersucht und nach Prädiktoren aus einer

Reihe von Umweltfaktoren gesucht. Wir haben die latitudinale Ausdehnung unter Verwendung der nördlichen und südlichen Arealgrenzen für jede Art ermittelt und darauf aufbauend die mittlere latitudinale Ausdehnung der Farngemeinschaften, gewichtet nach den Häufigkeiten der Arten innerhalb der Gemeinschaften, berechnet. Mit Hilfe von linearen gemischten Modellen haben wir diese Größen zu Höhen- und latitudinalen Gradienten sowie zu relevanten Klimafaktoren in Beziehung gesetzt. Die Diversität pro Untersuchungsfläche nahm mit der Meereshöhe bis 1500 bis 2000 m zu, wobei sich die Diversität zwischen den Transekten stark unterschied und mit zunehmendem Breitengrad abnahm. Die mittlere gewichtete Arealgröße von Arten innerhalb von Farngemeinschaften nahm mit der Meereshöhe ab und mit dem Breitengrad zu. Wir fanden jedoch auch deutliche Unterschiede zwischen der atlantischen und pazifischen Seite der mittelamerikanischen Landbrücke Mexikos. Die besten Modelle beschrieben etwa 76 % bis 80 % der Variabilität der mittleren Arealgröße und beinhalteten die Klimavariablen Temperatur-Saisonalität und Niederschlag sowie die jährliche Wolkenbedeckung. Zusammenfassend lässt sich sagen, dass Arealgrößen von Farngemeinschaften durch ein Zusammenspiel der Faktoren bestimmt werden, wobei Artgemeinschaften mit großen Arealen in höhere Breiten mit zunehmender Temperatur-Saisonalität und trockeneren Lebensraumbedingungen, und solche mit eingeschränkten Arealen in höheren Gebirgen günstigen feuchten Lebensraumbedingungen zu finden sind. Klimastabile, feuchte Lebensräume bieten offenbar günstige Bedingungen für Farnarten mit geringer Verbreitung (Endemiten) und sollten daher in der regionalen Naturschutzplanung eine hohe Priorität erhalten. Diese Arbeit wurde 2020 in im *Journal of Biogeography* veröffentlicht (Hernández-Rojas *et al.* 2020).

Zusätzlich sollen phylogenetische Ansätze als integraler Bestandteil von Studien zur Artgemeinschaftbildung angesehen werden, die das Verständnis der Entwicklung der Gemeinschaften im Laufe der Zeit und ein tieferes Verständnis der biogeografischen Prozesse ermöglichen. Dieser historische Aspekt ist als abschließender Teil dieses Forschungsprojektes in Kapitel 4 enthalten, das darauf abzielte, die komplexen Veränderungen der phylogenetischen Struktur entlang von Höhengradienten (200 m - 4000 m) und des Breitengrads (0° - 23°N) zu untersuchen. Wir haben einen umfassenden Datensatz mit insgesamt elf Höhengradienten (mit mehr als 900 Arten auf 868 Untersuchungsflächen) zusammengestellt, um die in Kapitel 2 beobachtete Datenlücke zu schließen. An dieser Stelle möchte ich die Relevanz dieser Forschung als Produkt der Arbeit vieler Forscher hervorheben, die ich auswerten darf, um einen vollständigen Überblick über biogeografische und phylogenetische Muster zu erhalten. Eine der

Hauptaufgaben vor der Analyse der Daten bestand darin, die phylogenetischen Informationen der mehr als 900 Arten zusammenzustellen, von denen ‚nur' 70 % im phylogenetischen Baum vorhanden waren, und die verbleibenden 30 % der Arten mussten hier eingeordnet werden. Grundlage dieser langwierigen Einordnung war die engste Verwandtschaft zu mutmaßlichen Nachbararten, die basierend auf einer umfassenden Untersuchung der morphologischen Merkmale und mithilfe von Expertenwissen vorgenommen wurde. Unsere Ergebnisse zeigen, dass Breitengrad und Höhe für sich nur schwache erklärende Variablen für die phylogenetische Vielfalt sind, aber die Einbeziehung klimatischer Variablen die Erklärungskraft der Modelle deutlich verbessert. Wir haben verschiedene phylogenetische Maße angewendet, um verschiedene Aspekte der Evolutionsgeschichte dieser Pflanzengruppe zu erfassen, und konnten so versuchen zu verstehen, wie sich Artengruppen entwickelt haben, um die derzeit die beobachteten Gradienten in Mittelamerika zu bilden. Insgesamt nahm die phylogenetische Vielfalt mit zunehmendem Breitengrad und zunehmender Höhe ab, was durch eine zunehmende Häufung sehr nah verwandter Arten beobachtet werden konnte. Darüber hinaus lohnt es sich, die wichtigsten Lebensformen getrennt zu betrachten, da sie nicht nur ökologisch unterschiedlich, sondern auch in ihrer Evolutionsgeschichte nicht kongruent sind. Die phylogenetische Vielfalt der epiphytischen Lebensform wies einen positiven Zusammenhang zur Luftfeuchtigkeit auf, während die phylogenetische Vielfalt der terrestrischen Arten durch die Temperatur bestimmt wurde. Das allgemeine Muster der phylogenetischen Vielfalt beruht hauptsächlich auf dem Verschwinden der alten basalen tropischen terrestrischen Linien und nicht auf der jüngsten Evolutionsgeschichte und wird besser durch klimatische Variablen erklärt. Diese Arbeit wurde im *Frontiers of Biogeography* eingereicht. In Fortsetzung dieser Arbeit und als Ausblick auf weitere Studien werde ich die Forschung an Farngemeinschaften in tropischen Gebieten fortsetzen, in denen Entwaldung beziehungsweise Störung und die allgemeinen menschlichen Aktivitäten eine zentrale Rolle spielen, die das Erbe von Millionen von Jahren Evolution enorm reduzieren. Im Zusammenhang mit den Diversitätsmustern ist es zusätzlich wünschenswert, die Wissenslücken in America zu schließen. In diesem Zusammenhang beabsichtige ich auch, einen ganzheitlicheren Ansatz zu verfolgen, der historische Faktoren einbezieht, welche ein tieferes Verständnis der biogeografischen Prozesse ermöglichen.

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# CHAPTER 1

## General Introduction

# 1 General introduction

## 1.1 The gradients of species richness and range size: two classical hypotheses in biogeography

The study of elevational diversity gradients dates back to the foundation of biogeography, Humboldt, Darwin and Wallace provided the first modern detailed observation of how the natural world changes with elevation, nevertheless the origins of the biogeography (the geography of nature) must reach far back in the early history of our species (Lomolino 2001). Many hypotheses have been proposed to explain patterns in nature, especially the variation of species richness among regions and its distribution. Two of the very classical hypotheses in biogeography, that we tested here in an elevational and latitudinal context, are the latitudinal gradient of increasing species richness from the polar regions towards the tropics (Darwin 1859, von Humboldt [1828] 2004), for most major groups of terrestrial organisms, diversity is highest in the tropics (Gaston & Blackburn 2000), and the Rapoport's rule that assumes that tropical species tend have smaller ranges, allowing more species to coexist in tropical versus temperate regions (Stevens 1989).

Although elevational-latitudinal patterns of plant and animal diversity have been studied for centuries, factors driving the observed patterns are still controversially debated (e.g., Hillebrand 2004, Qian & Ricklefs 2011) and elevational gradients have increasingly gained attention within the research field of assessing the relative contribution of a plethora of proposed drivers of species richness patterns. Elevational gradients are differ from the latitudinal gradient in that they are more concise, have many more replications (Rahbek 2005, McCain 2009 a), and are nested in one biogeographic region having gone through similar geological and evolutionary history (Körner 2000), and partly allow for disentangling different ecological factors that vary in different ways along different elevational gradients (Lomolino 2001). Latitudinal and elevational gradients thus both represent large-scale biogeographical gradients along which biodiversity changes in clear, and often predictable ways. Due to the different spatial extents and specific ecological transitions of the two types of gradients, a combination of latitudinal and elevational gradients offers a unique opportunity to disentangle the relative roles of different drivers of range size and species richness patterns.

Originally the Rapoport's rule (RR) was conceived for latitudinal gradients, the idea that range sizes may be determined by climatic seasonality, was later extended to elevational gradients as well (Stevens 1992, "climatic–variability" hypothesis). While these patterns have been documented for a wide range of taxa in many regions (Addo-Bediako *et al.* 2000: insects; Ribas & Schoereder 2006: many groups; Morin & Lechowicz 2011: trees; Pintor *et al.* 2015: lizards; Tomašových *et al.* 2016: birds and marine bivalves), there are also a good number of studies, mainly along elevational gradients in animals but also in plants, that do not corroborate the rule or even reporting a reverse pattern or mixed results suggesting that it varies between taxa and continents (Rohde *et al.* 1993, Ruggiero 1994, Rohde & Heap 1996, Bhattarai & Veetas 2006, Pintor *et al.* 2015, Ribas & Schoereder 2006, Zhou 2019). Support for the rule is also scarce in the tropics (Rhode 1996, Blackburn & Gaston 1996). Even if a pattern of range size distribution accords to RR, there are a number of complications in understanding the underlying processes. Furthermore, the classical interpretation of RR focuses only on temperature seasonality, even though seasonal variations in humidity may be equally important for explaining the range size distributions (Gaston & Chown 1999, Pintor *et al.* 2015). Especially in the tropics, where there is little seasonal variation in temperatures, variations in precipitation patterns may play an important role.

Also, for a long time, ecologists did not incorporate historical biogeography in explaining large-scale richness patterns (with few exceptions such as Ricklefs & Schluter 1993, Webb *et al.* 2002), and gradients of richness were predominantly explained by variations in the physical environment. However, there is increasing evidence that local diversity is strongly connected to regional diversity, raising the question of the historical component of local diversity patterns (e.g., Wiens & Donoghue 2004, Ricklefs 2005, Roy & Goldberg 2007). Ecological gradients may also show phylogenetic patterns reflecting historical differences between regions as well as inherited traits of clades contributing to the plant diversity (Ricklefs 2005, Hawkins *et al.* 2005, 2006). For example, the tropics may harbour a higher diversity across many taxa than temperate regions because the taxa have originated there ("out of the tropics", Jablonski et al 2006) and had a greater extent in the historical past (Behrensmeyer *et al.* 1992, Kissling *et al.* 2012), thus most extant clades are originally tropical, leading to greater time and space availability for speciation. Moreover, a higher amount of energy in the tropics leads to shorter generation times and thus higher diversification rates ("speciation–extinction", Cardillo 1999). Turning towards outer-tropical regions, adaptations are necessary to disperse and persist in cold and climatically seasonal regions, and these have evolved only in some taxa ("niche conservatism", Wiens & Donoghue 2004; "habitat filtering", Harper 1977, Keddy 1992), representing clusters of closely related species that tend to be ecologically more similar and should therefore show higher competition (Darwin 1859, Cavender-Bares et al 2009, Cahill *et al*. 2008).

## 1.2 Ferns as a model group for biogeographical question

Ferns have lightweight, dust-like spores generally between 30 μm and 70 μm (Tryon & Lugardon 1991) that disperse easily by wind. It has been shown that fern spores can tolerate low temperatures and high UV light in the upper atmosphere (Gradstein & Van Zanten 2001) allowing the long-distance dispersal. This characteristic is due to the alternations of two generations: the sporophyte that is very conspicuous and the gametophyte, a very small independent plant (some millimeters) responsible for the sexual reproduction (Mehltreter 2010). They are independent of pollinators and seed vectors and have very few co-evolved herbivores and habitat preference that their distribution reflected climate and other features (Barrington 1993). Due to their spore dispersal, ferns are largely independent of biotic interactions and represent a suitable group to investigate biogeographical questions. They might serve as a model of how land plants have evolved and adapted to their environment (Kessler 2010).

Furthermore, ferns are the second-most diverse lineage of vascular plants on Earth with a rather complex evolutionary history and an estimated age of 431 ma (older than angiosperms), but also including more recent lineages with an approximately age of 40 ma to nearly 80 ma (Testo & Sundue 2016) that radiated at the same time with early angiosperms (Schneider *et al.* 2004).

## 1.3 Objectives and outline of the study

This research was a part of an international collaborative initiative planned mainly by Dr. Jürgen Kluge (Germany) and Dr. Michael Kessler group (Switzerland), who have an intensive research in elevational gradients worldwide, to fill the absence of plot-based data in the Neotropics, especially in Mexico. Originally, we had the intention to include information only from Mexico but the availability of data of the research group and the new computational available tools allowed the inclusion of many transect spanning from the Equator to the North of Mexico and the integration of data from Honduras provided for collaborators. I should highlight the relevance of this research as a product of the work of many researchers that I have the honor to synthesize to get a complete view of biogeographic and phylogenetic patterns, but I also contributed with new field information from Mexico.

My objective was to describe how the richness patterns and range size of species change along elevational gradients as well the phylogenetic relationships inside of the species assemblages using ferns as a model group and a standardized methodology that allows the comparison of elevational transects at different latitudes, utilizing plot-based data specifically in pristine forest from the Equator to the north of Mexico (Appendix F 10). This zone, from the tropics including the transition to the subtropics, offers a big potential to unravel drivers of species richness, phylogenetic and distributional patterns as an area of biotic overlap that combines both types of gradients. In order to assess these patterns for ferns and lycophytes, I analyzed changes in their assemblages along elevational gradients with a consistent, standardized methodology (plots of 20 x 20 m, Karger *et al.* 2014, Kessler & Bach 1999).

As a result, I obtained three central publications, in collaboration with the researches included in every chapter, two of which are already published (Chapters 2 and 3). In the first publication I analyzed in detailed one of the most diverse elevational transect with 15 elevational steps in Sierra de Juárez Oaxaca, a hotspot of biodiversity (Fig. 1.1, Appendix F 5 - F 9), comparing the richness patterns with central and South America. I found a hump-shaped pattern that was mainly driven by epiphytes, which contributed about 40% to the total species richness and had wider elevational ranges than terrestrial species, which contributed 38% to the total richness (20 % were recorded within both life forms), and were more or less constant at low to mid elevations about 2,500 m, followed by a gradual decline. Overall, richness per plot was low compared to other elevational gradients within the tropics closer to the Equator. This decline of species richness towards the subtropics and temperate regions appears to be rather abrupt within Central America, but additional data were needed to close the remaining gap of knowledge between Costa Rica and Mexico.

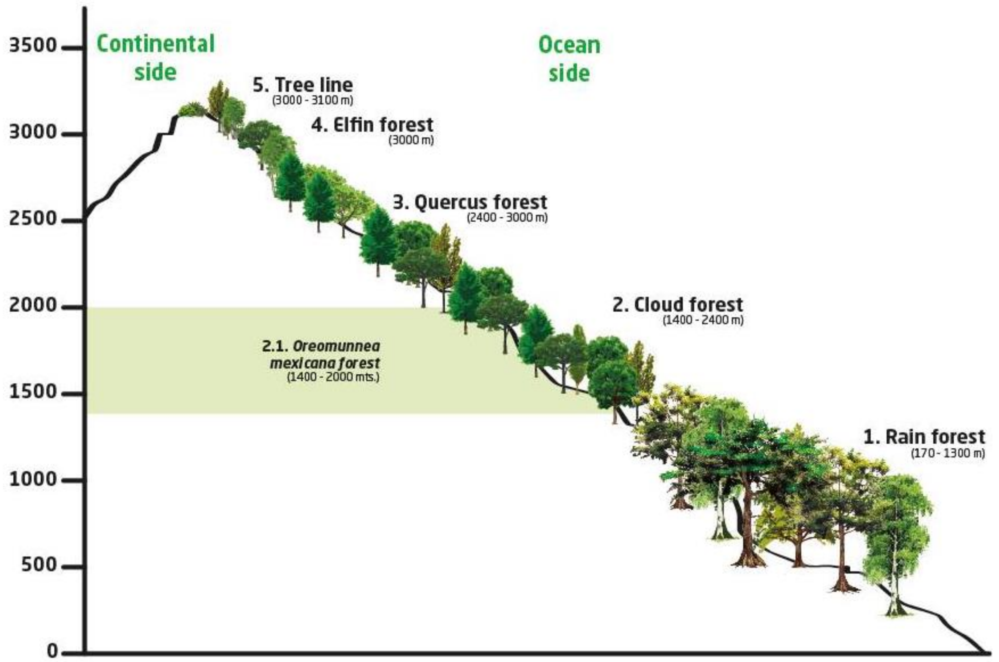

Fig. 1.1 Detail description of an individual transect located at sierra de Juárez Oaxaca, a hyper-humid region known as the Ferns Hunter’s paradise by Mickel (1965).

In the third chapter and central work of this research, Iassessed the richness and range size patterns of ferns and lycophytes along seven elevational gradients (658 plots) at different latitudes and searched for predictors of range size from a set of environmental factors. I found that species richness per plot increased with elevation up to about 1,500– 2,000 m, with strong differences in overall species richness between transects and a reduction with increasing latitude. The mean weighted range size of species within assemblages declined with elevation, and increased with latitude. Latitudinal and elevational patterns of range size in fern assemblages are driven by an interplay of factors favouring wide-ranging species (higher latitudes with increasing temperature seasonality; dryer habitat conditions) and those favouring species with restricted ranges (higher elevations; humid habitat conditions), with additional variation introduced by the specific conditions of individual mountain ranges.

Finally, phylogenetic approaches should be seen as an integral component of studies of the causal basis of community structure, which permits the understanding of how communities have evolved through time, and a deeper understanding of biogeographical processes (Losos1996). This historical aspect is included as the final part of this research (Chapter 4) that was aimed to unfold the complex changes in the phylogenetic structure along elevation (200-4000 m a.s.l.) and latitude (0°-23° N). I compiled a comprehensive data set including eleven elevational transects (more than 900 spp. and 868 plots), closing the gap of information observed in Chapter 2. The results showed that latitude and elevation per se are weak explanatory variables for phylogenetic diversity, but incorporating climatic variables clearly enhance the explanatory power of the models. Overall, the phylogenetic diversity decreased with increased latitude and elevation, increasingly clustering of closely related species. The general pattern of phylogenetic diversity was mainly driven for the suppression of the old, basal tropical, terrestrial lineages rather than by recent evolutionary history and better explained by climatic variables.

# CHAPTER 2

## Richness Patterns of Ferns along an Elevational Gradient in the Sierra de Juárez, Oaxaca, Mexico: a Comparison with Central and South America

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with Michael Kessler, Thorsten Krömer, César Carvajal-Hernández,
Anna Weigand and Jürgen Kluge

# Richness Patterns of Ferns along an Elevational Gradient in the Sierra de Juárez, Oaxaca, Mexico: a Comparison with Central and South America

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## Abstract

The transition zone from the tropics to the subtropics in Mexico is an outstanding and poorly explored area of biotic overlap, and as such very interesting to evaluate how species richness patterns change in the latitudinal context. In order to assess alpha diversity patterns of ferns in this zone, we analyzed changes in their assemblages along an elevational gradient from 300 m to 3,000 m in the Sierra de Juárez, Oaxaca, and compared the results with similar studies conducted in Central and South America. We report the most detailed plot-based elevational gradient study on ferns in the region and provide detailed data on species abundances and elevational ranges. In 121 plots of 20 x 20 m, we found 195 fern species, with the highest species numbers recorded at mid-elevations (1,100–2,200 m) and lower richness at both gradient extremes. This hump-shaped pattern was mainly driven by epiphytes, which contributed about 40% to the total species richness and had wider elevational ranges than terrestrial species, which contributed 38% to the total richness, and were more or less constant at low to mid elevations about 2,500 m, followed by a gradual decline. Overall, richness per plot was low compared to other elevational gradients within the tropics closer to the Equator. This decline of species richness towards the subtropics and temperate regions appears to be rather abrupt within Central America, but additional data are needed to close the remaining gap of knowledge between Costa Rica and Mexico.

KEYWORDS
Pteridophytes, alpha diversity, distribution, elevational range, Priority Terrestrial Region

# 2 RICHNESS PATTERNS OF FERNS ALONG AN ELEVATIONAL GRADIENT IN THE SIERRA DE JUÁREZ, OAXACA, MEXICO: A COMPARISON WITH CENTRAL AND SOUTH AMERICA

## 2.1 INTRODUCTION

Ferns and lycophytes (although different lineages, henceforth called ferns) globally comprise about 11,000 species, thus being the second most diverse group of vascular plants on Earth (Moran 1998, PPG I 2016). With more than 1,000 recorded species, they are well represented in Mexico, which has one of the best-documented fern floras in the world (Mickel & Smith 2004). The country is considered an epicenter for species radiations in some fern groups (principally groups specialized in seasonally dry habitats), and the states of Oaxaca, Chiapas, and Veracruz harbor the highest species numbers in the country (Krömer *et al.* 2015, Mickel & Beitel 1988, Mickel & Smith 2004). Because fern taxonomy is well studied and non-woody life forms contribute up to 58% of the vascular plant richness in tropical forests (Gentry & Dodson 1987, Linares-Palomino *et al.* 2009), ferns represent a valuable group for ecological and biogeographic studies.

In this regard, elevational gradients are an interesting natural experiment, because they include major environmental changes within short horizontal distances, while dispersal limitation is minimized. Ferns have been widely studied along tropical elevational gradients in recent years, and show consistent general richness pattern at local and regional scales, with highest richness commonly found at mid-elevations and decreasing diversity towards both high and low elevations (Parris *et al.* 1992, Kessler 2001a, Bhattarai *et al.* 2004, Kluge *et al.* 2006, Watkins *et al.* 2006, Karger *et al.* 2011, Kessler *et al.* 2011, Salazar *et al.* 2015,). With respect to major life-forms, this hump-shaped distributional trend in tropical mountains is commonly driven by epiphytes, which are extraordinarily rich in multi-structured tree crowns within the humid cloud condensation layer between 1,000–3,000 m (, Kessler 2000a, Kluge & Kessler 2005, Watkins *et al.* 2006, Krömer *et al.* 2013, Acebey *et al.* 2017). However, how elevational fern richness changes with latitude is less well explored, and two alternative hypotheses have been proposed. The first assumes that richness peaks along elevational gradients gradually shift towards lower elevations with increasing distance frothe Equator in parallel with decreasing temperatures. Thus, Kessler *et al.* (2011) showed that the maximum richness of ferns along elevational gradients in tropical wet environments is situated at around 15–17°C mean annual temperature, and this level should be found at lower elevations at higher latitudes. Alternatively, when comparing various fern transects from Bolivia to Mexico, Salazar *et al.* (2015) found that overall elevational richness is strikingly constant between Costa Rica and northern Bolivia. The major shift towards lower species richness was found at the transition from tropical to subtropical climates. However, this decline was not linked to a downward shift in the elevation of the richness peak, but rather reflected a general decline of species richness, as also found by Krömer *et al.* (2013), Acebey *et al.* (2017), and Carvajal-Hernández *et al.* (2017) in the regions of Los Tuxtlas and central Veracruz, in the southeast of Mexico. Apart from these publications, no other suitable transects have been studied thus far to allow a fine-scale assessment of the change of species richness patterns at the Mexican transition zone (MTZ, *sensu* Halffter & Morrone 2017) between tropical and subtropical climates.

In the present study, we attempt to close a gap in our knowledge about elevational species richness patterns of ferns starting with the analysis of an extensive elevational gradient in the Sierra de Juárez, Oaxaca, inside the MTZ by presenting plot-based species richness data together with an annotated species list with detailed information on abundance and life form assignments. Specifically, we ask the following questions:

How does local species richness of ferns change with elevation?

Is the elevational pattern of species richness and ranges different between both major life forms (terrestrials and epiphytes)?

Is the total and maximum species richness significantly lower in magnitude and elevation compared to other studies performed in Central and South America?

## 2.2 MATERIALS AND METHODS

### 2.2.1 Study area

The study area was located in southeastern Mexico in the Sierra de Juárez (also called Sierra Norte), Oaxaca, and the majority of the localities belong to the Chinantla region (Fig. 1, additional plot information in Appendix T2-1). The Sierra de Juárez has been declared a Priority Terrestrial Region due to its species and ecosystem richness (Arriaga *et al.* 2000), and thus is an important area for conservation. The eastern slope of the Sierra de Juárez hosts a very rich and one of the most distinctive floras in Mexico (Meave *et al.* 2017) and represents the northernmost location within the Neotropics, where a large and well-preserved elevational gradient of humid tropical forest still remains (Boyle 1996).

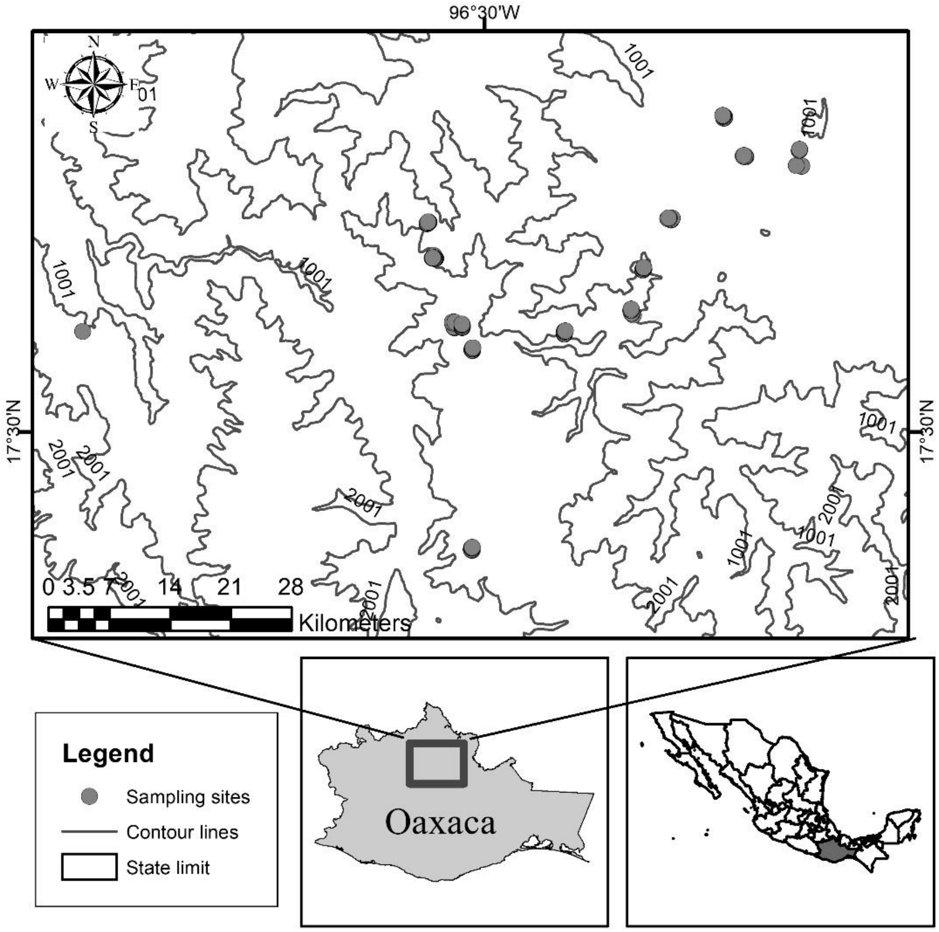

Fig. 2.1 Study area in the Sierra de Juárez, Oaxaca, Mexico, showing the locations of the sampling sites (dots).

There is an abrupt elevational increase in this area in less than 30 km from Valle Nacional (ca. 65 m) to the top of Humo Chico Mountain (ca. 3,200 m; Meave *et al.* 2006), called the–fern hunter‘s paradise by John Mickel (1965) during fieldwork to prepare the first treatment about ferns from Oaxaca (Mickel & Beitel 1988). Given the extensive deforestation elsewhere in Mexico (Rosete-Vergés *et al.* 2014), the presence of this gradient of humid montane forest in Oaxaca is remarkable (Rzedowski & Palacios-Chávez

1977).

Despite a generally good conservation status above 1,000 m, human activities are leaving an important footprint in the lower parts of the area (Meave *et al.* 2017). In addition, the Sierra is periodically impacted by strong winds from the Gulf coast (>80 km/h), which disturb the forest structure (Alfonso-Corrado *et al.* 2017). There are few general studies on vegetation along the whole gradient in the Sierra de Juárez (Boyle 1996; Meave *et al.* 2006, Rzedowski & Chávez 1977, Rincón-Gutierrez 2007). However, a recently published extensive floristic survey in the region reported 130 fern species along an elevational range from 250–3,020 m (Meave *et al.* 2017). Forest zonation begins in the lowlands with tropical rain forest from 300–1,000 m, followed by a transitional forest zone from 1,100–1,300 m, and cloud forest at 1,400–2,000 m (sometimes to 2,500 or more). Within the cloud forest belt, there are areas of forest dominated by *Oreomunnea mexicana*. Above 2,500 m there is *Quercus* forest and above 3,000 m elfin forest forms the treeline ecotone at around 3,100 m.

### 2.2.2 Climate

La Chinantla is considered a hyperhumid region in Mexico (Meave *et al.* 2006, Meave *et al.* 2017), but there are few climatic records for localities in the Sierra de Juárez. The climate at the lowest elevation is hot (>22°C) changing to a warm climate (18–22°C) higher up, and temperate at higher elevations (5–12 °C) (Meave *et al.* 2006). Mean annual precipitation is around 3,590 mm at the lower part of the gradient (Valle Nacional), 5,800 mm in the middle (La Esperanza), and 3,240 mm at the upper part at the locality of Humo Chico (Meave *et al.* 2006). Due to the scarcity of meteorological records in the study area, we extracted ecologically important temperature and precipitation data (Fig. 2) from the global climate dataset CHELSA (Karger *et al.* 2017).

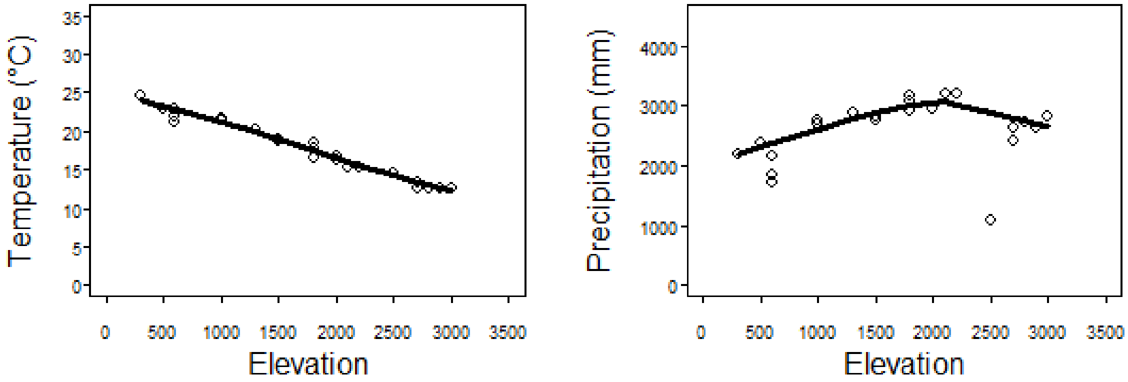

Fig. 2.2 Elevational trends of (a) mean annual temperature and (b) precipitation. Data derived from the CHELSA data set (Karger *et al.*, 2017) for each plot of the elevational transect in the Sierra de Juárez, Oaxaca, Mexico. Trend lines were set with locally weighted regressions (LOWESS).

### 2.2.3 Fern sampling

A total of 121 plots were inventoried at 15 sites along an elevational gradient between 300 m and 3,000 m at elevational intervals of 200–400 m (Appendix T 2-1). At each elevation, eight plots of 20 x 20 m were sampled with a consistent, standardized methodology (Karger *et al.* 2014, Kessler & Bach 1999). The plots were established in natural zonal forest, avoiding special structural features like canopy gaps, ridges, ravines, riparian areas, treefall gaps, landslides, and other disturbed areas whenever possible. In each plot, all fern species and their abundances were recorded for terrestrials (growing on soil, rocks, and dead wood) and epiphytes. In most cases, the abundance (i.e., number of individuals of a species) is easy to assess, exceptions are only small species with distant fronds on long creeping and interwoven rhizomes (e.g., Hymenophyllaceae). Because in these cases exact numbers of individuals can only be obtained by destructive sampling, we treated a species patch as one individual in order not to overestimate the abundance of these species. Epiphytes were sampled up to heights of eight m, with trimming poles and recorded using binoculars at greater heights, by climbing lower parts of trees, and by searching recently fallen trees and branches within and adjacent to the plots (Gradstein *et al.* 2003).

Samples of all fern species were collected and deposited in the University Herbarium, University of California (UC) in Berkeley, USA, herbarium XAL of the Instituto de Ecología, A. C. (Xalapa, Veracruz, Mexico) and herbarium MEXU of the Universidad Autónoma de México (Mexico City, Mexico). Collections were identified by the first author and Alan R. Smith (UC). Taxonomy primarily followed Mickel & Smith (2004) and the current classification for lycophytes and ferns established by the Pteridophyte Phylogeny Group (PPG I 2016) and Hassler (2018).

### 2.2.4 Data analysis

We assessed plot-based alpha-diversity for all species and separately for the two major lifeforms (terrestrials and epiphytes) and described their trends by locally weighted regressions (LOWESS). In order to assess whether the elevational ranges of terrestrials and epiphytes were different, we used a Wilcoxon signed-rank test. We considered a species as belonging to both life forms when more than 20% of the total number of individuals occurred in each life form. The frequencies of these three categories of life forms were compared with an analysis of variance (ANOVA) and a Tukey post-hoc test ($P < 0.001$). We compared species richness per plot of our gradient with other similar transects from Bolivia, Ecuador, Costa Rica, and Mexico based on Kessler (2000a, 2001a), Kluge & Kessler (2005), Krömer *et al.* (2013), Salazar *et al.* (2015), and Carvajal-Hernández *et al.* (2017). To test the differences in mean plot richness of all transects, we used an analysis of variance and a Tukey post-hoc test ($P < 0.001$). Because the general objective of this work and the general richness pattern was not altered, we included atypical data from the site at 2,500 m located on the other side of the mountain chain (leeward), which was excluded only in the comparison between transects. All data analyses were conducted in the statistical package R (R Core Team 2016).

## 2.3 RESULTS

In the 121 plots, we recorded 195 species of ferns and lycophytes belonging to 60 genera and 21 families, including two new records for Oaxaca State, Ctenitis salvinii and Phlegmariurus capillaris, as well as one species recently described as new to science (Ceradenia sacksii; Sundue 2017) (Table 2-1). The most species-rich genera were Elaphoglossum (20 species, Appendix F 2-1), Asplenium (18), and Pleopeltis and Hymenophyllum (12 each). The most species-rich families were Polypodiaceae (49), Dryopteridaceae (35) and Hymenophyllaceae (25).

Table 2-1**.** Species list of lycophytes and ferns recorded along the elevational gradient in the Sierra de Juárez, Oaxaca, Mexico. Data are presented with the minimum (**Min**) and maximum (**Max**) observed elevational distribution, frequency of the species (**F**; the number of plots in which the species was recorded), the mean number of individuals per plot (**N**), and substrate including the life form: t: terrestrial, he: hemiepiphytic, e: for epiphytes comprising the Johansson (1974) zonation in which th epiphytes occurred (from zone 1 to zone 5), dw: dead wood, and r: rocks. Species marked with n are new records for Oaxaca and with * were found outside or close to the investigated plots.

| **Lycophytes** | **Min** | **Max.** | **N** | **F** | **Life form** |
|---|---|---|---|---|---|
| **Lycopodiaceae** | | | | | |
| n*Phlegmariurus capillaris* (Sodiro) B. Øllg. | 2100 | 2100 | 1.00 | 1 | e4 |
| **Phlegmariurus cuernavacensis* (Underw. & F.E. Lloyd) B. Øllg. | 2800 | 2800 | 1.00 | 1 | e4 |
| *Phlegmariurus dichotomus* (Jacq.) W.H. Wagner | 500 | 500 | 1.00 | 2 | e4 |
| *Phlegmariurus linifolius* (L.) B. Øllg. | 1000 | 2200 | 1.67 | 6 | e1, e2, e3, e4 |
| *Phlegmariurus myrsinites* (Lam.) B. Øllg. | 2000 | 2100 | 1.33 | 3 | e2, e3 |
| *Phlegmariurus pringlei* (Underw. & F.E. Lloyd) B. Øllg. | 1500 | 2200 | 4.00 | 4 | e1, e2, e3, e4 |
| *Phlegmariurus taxifolius* (Sw.) Á. Löve & D. Löve | 600 | 2000 | 1.89 | 9 | (r), e2, e3, e4, e5 |
| *Phlegmariurus wilsonii* (Underw. & F.E. Lloyd) B. Øllg. | 1500 | 1500 | 1.00 | 1 | e3 |
| **Selaginellaceae** | | | | | |
| *Selaginella* aff. *subrugosa* Mickel & Beitel | 1800 | 1800 | 3.20 | 5 | t |
| *Selaginella flexuosa* Spring | 1000 | 2100 | 10.83 | 6 | t, dw |
| *Selaginella mosorongensis* Hieron. | 300 | 600 | 16.11 | 19 | t, dw, r |
| *Selaginella oaxacana* Spring (GCI) | 1300 | 1500 | 27.88 | 8 | t |
| *Selaginella subrugosa* Mickel & Beitel | 1300 | 1300 | 4.00 | 3 | t |
| *Selaginella* sp. | 600 | 600 | 7.50 | 2 | r |
| **Ferns** | | | | | |
| **Aspleniaceae** | | | | | |
| *Asplenium abscissum Willd.* | 500 | 600 | 13.67 | 3 | (t), r, e1, e2, e3, e4 |
| *Asplenium auriculatum Sw.* | 1500 | 1500 | 11.00 | 2 | dw, e1, e2, e3, e4 |
| *Asplenium cuspidatum* Lam. | 500 | 1800 | 41.63 | 8 | (t), dw, r, e1, e2, e3, e4 |
| *Asplenium fragrans* Sw. | 1500 | 2700 | 14.00 | 6 | dw, r, e1, e2, e3 |
| *Asplenium hallbergii* Mickel & Beitel | 2900 | 2900 | 94.00 | 2 | r, e1 |

| | | | | | |
|---|---|---|---|---|---|
| *Asplenium harpeodes* Kunze | 2100 | 2100 | 7.00 | 1 | e2 |
| *Asplenium miradorense* Liebm. | 150 | 2100 | 9.75 | 4 | t, dw, r, e1, e2 |
| *Asplenium monanthes* L. | 2500 | 2700 | 1.80 | 5 | t, r, e1 |
| *Asplenium polyphyllum* Bertol. | 2700 | 2700 | 2.00 | 1 | e2 |
| *Asplenium pteropus* Kaulf. | 1000 | 1000 | 2.00 | 1 | e2 |
| *Asplenium salicifolium* L. | 500 | 500 | 1.50 | 2 | e3 |
| *Asplenium radicans* L. | 1800 | 1800 | 1.00 | 2 | t, e1 |
| *Asplenium serratum* L. | 300 | 600 | 52.53 | 15 | (t), dw, r, e2, e3 |
| *Asplenium uniseriale* Raddi | 1300 | 1300 | 5.50 | 2 | t |
| *Asplenium* sp. (cf. A. uniseriale Raddi) | 2100 | 2100 | 1.00 | 1 | t |
| *Hymenasplenium riparium* (Liebm.) L. Regalado & Prada | 1000 | 1300 | 5.75 | 4 | t, e2, e3, e4 |
| **Athyriaceae** | | | | | |
| *Diplazium diplazioides* (Klotzsch & H.Karst.) Alston | 1000 | 2100 | 7.50 | 8 | t |
| *Diplazium franconis* Liebm. | 2100 | 2100 | 3.00 | 2 | t |
| *Diplazium lonchophyllum* Kunze | 600 | 600 | 3.00 | 3 | t |
| *Diplazium plantaginifolium* (L.) Urb. | 600 | 600 | 14.00 | 2 | t |
| *Diplazium striatum* (L.) C. Presl | 1000 | 1000 | 5.00 | 1 | t |
| *Diplazium ternatum* Liebm. | 1000 | 2100 | 12.10 | 20 | t, (e1) |
| **Blechnaceae** | | | | | |
| *Austroblechnum wardiae (*Mickel & Beitel) Gasper & V.A.O.Dittrich | 2100 | 2100 | 1.00 | 1 | t |
| *Lomaridium ensiforme* (Liebm.) Gasper & V.A.O.Dittrich | 1500 | 2200 | 4.63 | 8 | t, (e1), (e2) |
| *Lomaridium fragile* (Liebm.) Gasper & V.A.O. Dittrich | 1500 | 2000 | 2.75 | 4 | (t), e1, e2, e3 |
| *Parablechnum falciforme* (Liebm.) Gasper & Salino | 180 | 2200 | 5.00 | 8 | t, (e1) |
| **Cyatheaceae** | | | | | |
| *Cyathea aristata* Domin | 1500 | 1500 | 2.50 | 2 | t |
| *Cyathea divergens* Kunze | 1500 | 1500 | 4.00 | 1 | t |
| *Cyathea firma* (Bak.) Domin | 1500 | 1500 | 3.50 | 2 | t |
| *Cyathea fulva* (M. Martens & Galeotti) Fée | 1500 | 2200 | 3.12 | 26 | t, (e1) |
| *Cyathea liebmannii* Domin | 1000 | 1000 | 20.00 | 1 | t |
| *Cyathea myosuroides* (Liebm.) Domin | 1000 | 1000 | 9.00 | 1 | t, (e1), (e3) |
| *Cyathea salvinii* (Hook.) Domin | 1500 | 2000 | 8.25 | 4 | t |
| *Cyathea schiedeana* Domin | 1000 | 1500 | 14.00 | 17 | t |

| | | | | | |
|---|---|---|---|---|---|
| *Sphaeropteris horrida* (Liebm.) R.M. Tryon | 1000 | 1000 | 2.00 | 1 | t |
| *Cyathea* sp. | 2100 | 2100 | 3.00 | 1 | t |
| **Dennstaedtiaceae** | | | | | |
| *Histiopteris incisa* (Thunb.) J. Sm. | 2000 | 2000 | 2.00 | 1 | t |
| *Hypolepis nigrescens* Hook. | 1000 | 1000 | 2.00 | 1 | t |
| *Pteridium feei* (W. Schaffn. ex Fée) Faull | 2500 | 2900 | 15.67 | 12 | t |
| **Dicksoniaceae** | | | | | |
| *Lophosoria quadripinnata* (J.F. Gmel.) C.Chr. | 2100 | 2200 | 3.75 | 4 | t |
| **Dryopteridaceae** | | | | | |
| *Arachniodes denticulata* (Sw.) Ching | 1300 | 2200 | 32.94 | 36 | t, dw, r, (e1) |
| *Bolbitis portoricensis* (Spreng.) Hennipman | 500 | 500 | 18.00 | 1 | t |
| *Ctenitis* sp. (cf. *C. excelsa* (Desv.) Proctor) | 300 | 1300 | 3.86 | 7 | t, r |
| *Ctenitis hemsleyana* (Baker ex Hemsl.) Copel. | 2000 | 2200 | 9.00 | 6 | t, e1 |
| *Ctenitis melanosticta* (Kunze) Copel. | 500 | 500 | 7.60 | 5 | t, r |
| *Ctenitis nigrovenia* (Christ) Copel. | 300 | 300 | 6.00 | 4 | t |
| [n]*Ctenitis salvinii* (Baker) Stolze | 600 | 600 | 5.50 | 2 | t, r |
| *Dryopteris nubigena* Maxon & C.V. Morton | 2800 | 3000 | 5.25 | 4 | r, (e1) |
| *Dryopteris wallichiana* (Spreng.) Hyl. | 2700 | 3000 | 32.88 | 16 | t, r |
| *Elaphoglossum affine* (M.Martens & Galeotti) T. Moore | 2800 | 2900 | 27.80 | 5 | t, r, e1 |
| *Elaphoglossum alan-smithii* Mickel | 2100 | 2200 | 6.25 | 4 | e1, e2, e3, e4, e5 |
| *Elaphoglossum dissitifrons* Mickel | 2000 | 2900 | 11.71 | 17 | t, e1, e2, e3, e4, e5 |
| *Elaphoglossum glabellum* J.Sm. | 1000 | 1000 | 1.00 | 1 | e1 |
| *Elaphoglossum glaucum* T. Moore | 1800 | 3000 | 13.41 | 22 | t, r, e1, e2, e3, e4 |
| *Elaphoglossum* sp. (cf. *E. glaucum* T. Moore) | 2100 | 2200 | 23.00 | 2 | e1, e2, e3, e4 |
| *Elaphoglossum guatemalense* (Klotzsch) T. Moore | 1000 | 2000 | 7.43 | 21 | t, dw, e1, e2, e3, e4, e5 |
| *Elaphoglossum leonardii* Mickel | 2800 | 2800 | 34.00 | 2 | r |
| *Elaphoglossum lonchophyllum* (Fée) T. Moore | 1500 | 2100 | 10.33 | 3 | e1, e2, e3 |
| *Elaphoglossum muscosum* (Sw.) T. Moore | 1500 | 1500 | 1.00 | 1 | e2 |
| *Elaphoglossum paleaceum* (Hook. & Grev.) Sledge | 2100 | 2200 | 6.64 | 11 | e1, e2, e3, e4, e5 |
| *Elaphoglossum parduei* Mickel | 2000 | 2000 | 5.80 | 5 | e1, e2, e3 |
| *Elaphoglossum peltatum* (Sw.) Urb. | 1500 | 2200 | 18.25 | 24 | t, dw, rc, e1, e2, e3, e4, e5 |

| | | | | | |
|---|---|---|---|---|---|
| *Elaphoglossum petiolatum* (Sw.) Urb. | 2900 | 2900 | 1.00 | 2 | e1, e2, e3, e4 |
| *Elaphoglossum pringlei* (Davenp.) C.Chr. | 2500 | 2500 | 8.33 | 3 | t, dw, r |
| *Elaphoglossum sartorii* (Liebm.) Mickel | 600 | 2200 | 22.17 | 35 | t, dw, r, e1, e2, e3, e4 |
| *Elaphoglossum seminudum* Mickel | 2200 | 2200 | 80.25 | 4 | t, e1 |
| *Elaphoglossum squamipes* (Hook.) T. Moore | 2700 | 2900 | 4.00 | 3 | (t), dw, r, e1, e2 |
| *Elaphoglossum tenuifolium* (Liebm.) T. Moore | 2800 | 2900 | 7.80 | 5 | t, r |
| *Elaphoglossum vestitum* (Schltdl. & Cham.) Schott | 600 | 2100 | 17.57 | 37 | e1, e2, e3, e4, e5 |
| *Elaphoglossum* sp. | 1000 | 1000 | 2.00 | 1 | e2 |
| *Lastreopsis effusa* (Sw.) Tindale | 600 | 600 | 2.00 | 1 | t, r |
| *Megalastrum mexicanum* R.C. Moran & J. Prado | 600 | 600 | 13.25 | 4 | t |
| *Polystichum hartwegii* (Klotzsch) Hieron | 1800 | 2700 | 7.50 | 8 | t |
| *Polystichum mickelii* A.R. Sm. | 1300 | 1300 | 2.33 | 3 | t, r |
| *Stigmatopteris longicaudata* C. Chr. | 1500 | 1500 | 63.33 | 3 | t |
| **Gleicheniaceae** | | | | | |
| *Diplopterygium bancroftii* (Hook.) A.R. Sm. | 1800 | 1800 | 2.00 | 1 | t |
| **Hymenophyllaceae** | | | | | |
| *Abrodictyum rigidum* (Sw.) Ebihara & Dubuisson | 1000 | 1800 | 26.73 | 11 | t, r |
| *Didymoglossum hymenoides* (Hedw.) Copel. | 1300 | 1300 | 2.50 | 2 | e1, e2 |
| *Didymoglossum kraussii* (Hook. & Grev.) C. Presl | 300 | 500 | 3.33 | 9 | dw, e1, e3 |
| *Didymoglossum ovale* E. Fourn. | 500 | 500 | 3.00 | 1 | r, e1 |
| *Didymoglossum reptans* (Sw.) C. Presl | 1500 | 2100 | 10.00 | 12 | t, dw, r, e1, e2, e3 |
| *Hymenophyllum asplenioides* Sw. | 1500 | 2200 | 4.88 | 8 | (t), e1, e2 |
| * *Hymenophyllum brevistipes* Liebm. | 1200 | 1200 | 1.00 | 1 | e2 |
| *Hymenophyllum ectocarpon* Fée | 1800 | 3000 | 10.73 | 40 | t, dw, r, e1, e2, e3 |
| *Hymenophyllum fragile* (Hedw.) C.V. Morton | 2100 | 2200 | 7.88 | 8 | t, dw, r, e1, e2 |
| *Hymenophyllum fucoides* Sw. | 2100 | 2200 | 11.88 | 8 | t, e1, e2 |
| *Hymenophyllum hirsutum* (L.) Sw. | 1000 | 1500 | 3.33 | 3 | e1, e2, e3 |
| *Hymenophyllum lanatum* Fée | 1500 | 2200 | 2.15 | 13 | (t), e1, e2, e3 |
| *Hymenophyllum myriocarpum* Hook. | 2000 | 2900 | 18.95 | 20 | t, dw, e1, e2, e3, e4 |
| *Hymenophyllum polyanthos* (Sw.) Sw. | 1000 | 2000 | 3.75 | 16 | t, dw, r, e1, e2, e3 |
| *Hymenophyllum tegularis* (Desv.) Proctor & Lourteig | 2800 | 2800 | 4.00 | 1 | r |
| *Hymenophyllum trapezoidale* Liebm. | 1500 | 2200 | 9.21 | 14 | t, r, e1, e2, e3 |

| | | | | | |
|---|---|---|---|---|---|
| *Hymenophyllum tunbrigense* Sm. | 3000 | 3000 | 13.00 | 1 | t, dw, e1 |
| *Hymenophyllum undulatum* (Sw.) Sw. | 1500 | 1800 | 5.40 | 5 | e1, e2, e3 |
| *Polyphlebium capillaceum* (L.) Ebihara & Dubuisson | 1000 | 2100 | 2.80 | 5 | dw, e1, e2 |
| *Polyphlebium hymenophylloides* (Bosch) Ebihara & Dubuisson | 1800 | 2200 | 2.86 | 7 | t, dw, e1, e2 |
| *Polyphlebium pyxidiferum* (L.) Ebihara & Dubuisson | 500 | 1500 | 1.50 | 4 | r, e1, e2, e4 |
| *Trichomanes lucens* Sw. | 1800 | 2000 | 1.00 | 2 | t |
| *Trichomanes polypodioides* L. | 1000 | 1500 | 43.00 | 3 | t, e2 |
| *Trichomanes crispum* L. | 1300 | 1300 | 3.00 | 1 | e1 |
| *Vandenboschia collariata* (Bosch) Ebihara & K. Iwats. | 600 | 600 | 3.67 | 3 | r, e1 |
| *Vandenboschia radicans* (Sw.) Copel. | 1300 | 1500 | 6.20 | 5 | t, dw, r, e1, e2 |
| **Lindsaeaceae** | | | | | |
| *Lindsaea arcuata* Kunze | 1000 | 1500 | 4.08 | 13 | t |
| *Lindsaea lancea* Christ | 1000 | 1000 | 1.00 | 1 | t |
| **Lomariopsidaceae** | | | | | |
| *Lomariopsis mexicana* Holttum | 1300 | 1300 | 2.00 | 1 | t, he, (e1),( e2) |
| *Lomariopsis recurvata* Fée | 300 | 600 | 4.64 | 11 | t, he, (r), (e1), (e2), (e3) |
| **Lygodiaceae** | | | | | |
| *Lygodium heterodoxum* Kunze | 300 | 300 | 1.50 | 2 | t, he, (e1) |
| **Marattiaceae** | | | | | |
| *Danaea moritziana* C. Presl | 1000 | 1300 | 7.50 | 4 | t |
| *Marattia excavata* Underw. | 1500 | 1500 | 1.00 | 3 | t |
| *Marattia weinmanniifolia* Liebm. | 2100 | 2100 | 2.00 | 4 | t |
| **Plagiogyriaceae** | | | | | |
| *Plagiogyria pectinata* (Liebm.) Lellinger | 2800 | 3000 | 34.50 | 12 | t, (e2) |
| **Polypodiaceae** | | | | | |
| *Alansmia cultrata* (Willd.) Moguel & M. Kessler | 1800 | 2900 | 19.64 | 14 | r, e1, e2, e3 |
| *Campyloneurum xalapense* Fée | 600 | 1500 | 10.22 | 18 | t, dw, e1, e2, e3, e4, e5 |
| *Campyloneurum amphostenon* (Kunze ex Klotzsch) Fée | 2100 | 2900 | 2.75 | 4 | e2 |
| *Campyloneurum angustifolium* (Sw.) Fée | 300 | 1000 | 5.73 | 22 | t, e1, e2, e3, e4, e5 |
| *Ceradenia oidiophora* (Mickel & Beitel) A.R. Sm. | 2100 | 2100 | 2.00 | 2 | e1, e2 |
| $^{n}$*Ceradenia sacksii* Sundue | 2800 | 2800 | 20.00 | 2 | r |
| *Cochlidium linearifolium Maxon ex C. Chr.* | 1000 | 3000 | 37.11 | 37 | e1, e2, e3, e4, e5 |

| | | | | | |
|---|---|---|---|---|---|
| *Galactodenia delicatula (M. Martens & Galeotti) Sundue & Labiak* | 2000 | 3000 | 5.77 | 22 | e1, e2, e3, e4 |
| *Melpomene leptostoma* (Fée) A.R. Sm. & R.C. Moran | 1500 | 2200 | 7.25 | 24 | e1, e2, e3, e4, e5 |
| *Melpomene moniliformis* (Lag. ex Sw.) A.R. Sm. & R.C. Moran | 2800 | 2900 | 63.73 | 11 | t, dw, r, e1, e2, (e4) |
| *Melpomene pilosissima* (M. Martens & Galeotti) A.R.Sm. & R.C. Moran | 2800 | 2800 | 5.00 | 1 | e2 |
| *Melpomene xiphopteroides* (Liebm.) A.R. Sm. & R.C. Moran | 1000 | 2000 | 3.20 | 5 | e1, e2, e3, e5 |
| **Moranopteris basiattenuata* (Jenman) R.Y. Hirai & J. Prado | 2400 | 2400 | 1.00 | 1 | e1 |
| *Moranopteris trichomanoides* (Sw.) R.Y. Hirai & J. Prado | 1800 | 1800 | 2.00 | 1 | e2 |
| **Mycopteris semihirsuta* (Klotzsch) Sundue | 2400 | 2400 | 1.00 | 1 | e1 |
| *Niphidium crassifolium* (L.) Lellinger | 300 | 1300 | 3.47 | 17 | t, e1, e2, e3, e4 |
| *Pecluma longepinnulata* (E. Fourn.) F.C. Assis & Salino | 1300 | 2100 | 10.53 | 15 | t, dw, r, e1, e2, e3, e4 |
| *Pecluma atra (*A.M. Evans) M.G. Price | 300 | 300 | 4.33 | 3 | r, e2, e3 |
| *Pecluma consimilis* (Mett.) M.G. Price | 500 | 600 | 5.20 | 5 | t, dw, r, e1, e2, e3, e4 |
| *Pecluma dispersa* (A.M. Evans) M.G. Price | 500 | 500 | 2.00 | 1 | e1 |
| *Pecluma divaricata* (E. Fourn.) Mickel & Beitel | 500 | 500 | 7.00 | 2 | e2, e3 |
| *Pecluma hartwegiana* (Hook.) F.C. Assis & Salino | 2700 | 3000 | 78.24 | 25 | dw, r, e1, e2, e3, e4, e5 |
| *Pecluma rhachipterygia* (Liebm.) F.C. Assis & Salino | 600 | 1300 | 8.00 | 8 | t, rc, e1, e2 |
| *Pecluma sursumcurrens* (Copel.) M.G. Price | 500 | 500 | 1.00 | 1 | dw, e1, e2, e3, e4, e5 |
| *Phlebodium pseudoaureum* (Cav.) Lellinger | 300 | 2200 | 3.16 | 25 | t, e1, e2, e3, e4, e5 |
| *Pleopeltis alansmithii* (R.C. Moran) A.R. Sm. & Tejero | 2100 | 3000 | 33.25 | 32 | (t), dw, r, e1, e2, e3, e4, e5 |
| *Pleopeltis angusta* Humb. & Bonpl. ex Willd. | 600 | 1800 | 3.25 | 8 | e1, e2, e3, e4 |
| *Pleopeltis astrolepis* (Liebm.) E. Fourn. | 300 | 600 | 1.60 | 5 | e3, e4 |
| *Pleopeltis conzattii* (Weath.) R.M. Tryon & A.F. Tryon | 2500 | 2500 | 1.00 | 1 | t |
| *Pleopeltis crassinervata* T. Moore | 600 | 2200 | 7.18 | 17 | e1, e2, e3, e4, e5 |
| *Pleopeltis fallax* (Schltdl. & Cham.) Mickel & Beitel | 500 | 600 | 1.67 | 3 | t, dw, e1, e2, e3 |
| *Pleopeltis furfuracea* (Schltdl. & Cham.) A.R. Sm. & Tejero | 500 | 600 | 6.25 | 4 | t, e2, e3, e4 |
| *Pleopeltis madrensis* (J.Sm.) A.R. Sm. & Tejero | 2500 | 2500 | 4.00 | 2 | e1, e2, e3 |
| *Pleopeltis mexicana* (Fée) Mickel & Beitel | 1000 | 3000 | 34.68 | 34 | t, r, e1, e2, e3, e4, e5 |
| *Pleopeltis muenchii* (Christ) L.D. Gómez | 2700 | 3000 | 56.15 | 26 | t, dw, r, e1, e2, e3, e4, e5 |
| *Pleopeltis plebeia* (Schltdl. & Cham.) A.R. Sm. & Tejero | 1000 | 3000 | 18.06 | 32 | t, r, e1, e2, e3, e4, e5 |
| *Pleopeltis polypodioides* (L.) E.G. Andrews & Windham | 300 | 1500 | 8.00 | 14 | t, e1, e3, e4 |
| *Pleopeltis pyrrholepis* (Fée) A.R. Sm. & Tejero | 300 | 1000 | 5.10 | 10 | e1, e2, e3, e4, e5 |
| *Polypodium echinolepis* Fée | 1300 | 1500 | 5.18 | 11 | e1, e2, e3, e4, e5 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| *Polypodium martensii* Mett. | 2500 | 2900 | 34.86 | 21 | (t), e1, e2, e3, e4, e5 |
| *Polypodium plesiosorum* Kunze | 600 | 600 | 4.50 | 2 | e2, e4, e5 |
| *Polypodium pleurosorum* Kunze ex Mett. | 1800 | 2200 | 9.88 | 24 | t, e1, e2, e3, e4, e5 |
| *Polypodium puberulum* Schltdl. & Cham. | 2000 | 2200 | 5.69 | 16 | e1, e2, e3, e4, e5 |
| *Polypodium rhodopleuron* Kunze | 2100 | 2100 | 1.50 | 2 | t, e1, e2, e3, e4, e5 |
| *Polypodium subpetiolatum* Hook. | 2700 | 2700 | 4.00 | 2 | e1 |
| *Polypodium* sp. | 1000 | 1000 | 3.00 | 1 | e1 |
| *Serpocaulon falcaria* (Kunze) A.R. Sm. | 1500 | 2700 | 23.39 | 28 | t, r, e1, e2, e3, e4 |
| *Serpocaulon triseriale* (Sw.) A.R. Sm. | 300 | 1000 | 3.63 | 8 | t, dw, e1, e2, e3, e4, e5 |
| *Stenogrammitis delitescens* (Maxon) Labiak | 2200 | 2200 | 8.00 | 1 | e2 |
| *Stenogrammitis hellwigii* (Mickel & Beitel) Labiak | 2800 | 3000 | 21.13 | 15 | r, e1, e2 |
| *Stenogrammitis prionodes* (Mickel & Beitel) Labiak | 1500 | 2200 | 9.33 | 18 | e1, e2, e3, e4, e5 |
| *Terpsichore aspleniifolia* (L.) A. R. Sm. | 2400 | 2400 | 1 | 1 | r |
| **Pteridaceae** |  |  |  |  |  |
| *Adiantum poiretii* Wikstr. | 2500 | 2500 | 7.00 | 2 | t, e1 |
| *Adiantum pulverulentum* L. | 300 | 600 | 7.35 | 17 | t |
| *Adiantum tenerum* Sw. | 500 | 500 | 2.00 | 1 | t |
| *Adiantum trapeziforme* L. | 500 | 500 | 8.00 | 1 | t |
| *Ananthacorus angustifolius* (Sw.) Underw. & Maxon | 500 | 500 | 3.50 | 2 | e3 |
| *Antrophyum ensiforme* Hk.in Benth. | 1000 | 2100 | 6.36 | 11 | e1, e2, e3, e4 |
| *Gaga chaerophylla* (M. Martens & Galeotti) F. W. Li & Windham | 1800 | 1800 | 1.00 | 1 | t |
| *Jamesonia hirta* (Kunth) Christenh | 2000 | 2000 | 1.00 | 1 | t |
| *Polytaenium chlorosporum* (Mickel & Beitel) E.H.Crane | 500 | 1300 | 2.40 | 5 | e1 |
| *Polytaenium feei* (W. Schaffn. ex Fée) Maxon | 500 | 600 | 11.40 | 5 | (t), dw, r, e1, e2, e3 |
| *Pteris altissima* Poir. | 300 | 600 | 3.00 | 4 | t, dw |
| *Vittaria bradeorum* Rosenst. | 1500 | 2200 | 2.82 | 11 | dw, e1, e2 |
| *Vittaria flavicosta* Mickel & Beitel | 500 | 1000 | 2.89 | 9 | (t) e1, e2, e3, e4 |
| *Vittaria graminifolia* Kaulf. | 2100 | 3000 | 30.87 | 39 | (t) dw, r, e1, e2, e3, e4, e5 |
| **Saccolomataceae** |  |  |  |  |  |
| *Saccoloma inaequale* (Kunze) Mett. | 1000 | 100 | 12.71 | 21 | t |
| **Tectariaceae** |  |  |  |  |  |
| *Tectaria heracleifolia* (Willd.) Underw. | 300 | 600 | 50.63 | 19 | t, r |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| **Thelypteridaceae** |  |  |  |  |  |
| *Goniopteris biolleyi* (Christ) Pic. Serm. | 600 | 600 | 1.00 | 1 | t |
| *Goniopteris ghiesbreghtii* (Linden) J. Sm. | 600 | 600 | 6.00 | 2 | t |
| *Goniopteris hatchii* (A.R.Sm.) Á. Löve & D. Löve | 1500 | 1500 | 12.50 | 2 | t, dw |
| *Goniopteris imbricata* (Liebm.) Á. Löve & D. Löve | 500 | 500 | 3.67 | 6 | t |
| *Goniopteris liebmannii* (Maxon & C.V. Morton) Salino & T.E. Almeida | 300 | 500 | 7.14 | 7 | t |
| *Goniopteris obliterata* C. Presl | 300 | 300 | 5.67 | 3 | t |

Fern species richness followed a hump-shaped elevational pattern with highest species numbers per plot at mid-elevations between 1,500 and 2,100 m and a marked decline towards both low and high elevations (Fig. 2-3). The highest total species richness per elevational step was 57 species at 1,500–2,100 m and the lowest at 3,000 m with 15 species.

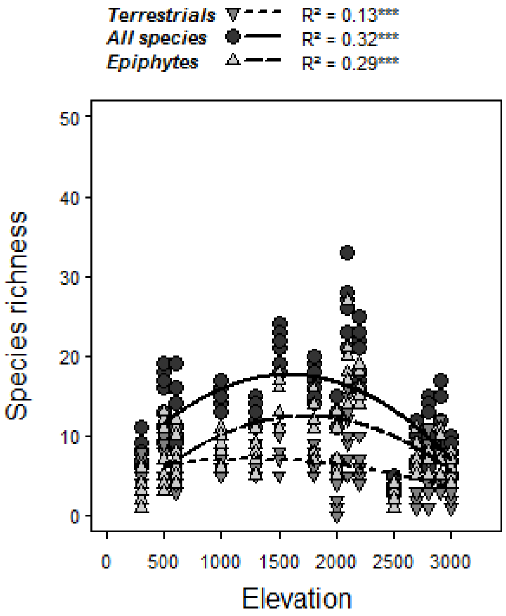

Fig. 2-3. Richness patterns of ferns (number of species per plot) along the elevational gradient in Sierra de Juárez, Oaxaca, Mexico. Values are given for all species (dots, continuous line), and separately for terrestrials (downwards-pointing triangles, short-dashed lines) and epiphytes (upwards-pointing triangles, long-dashed lines). Trend lines were set with locally weighted regressions (LOWESS).

Within the total of 195 species we found 141 growing as terrestrials and 129 as epiphytes, whereas 75 were strictly terrestrial and 77 strictly epiphytic, which means that 39 species were recorded within both life forms, excluding four hemiepiphytic species. Species with double notations (as terrestrials and epiphytes) mainly belonged to the families Dryopteridaceae, Polypodiaceae, and Hymenophyllaceae. Both major life forms followed different trends, with epiphytic richness per plot mostly about double of the terrestrials, and with a pronounced hump-shaped peak, whereas terrestrials were more or less constant up to 2,500 m and decreasing slightly at higher elevations (Fig. 2-3).

Epiphytic species on average had a wider elevational range and frequency than terrestrials (elevational range of epiphytes: 510.3 ± 580.8 m and terrestrials: 222.8 ± 351.9 m; Wilcoxon test, P<0.01, frequency of epiphytes: 9.61 ± 10.06, both: 10.35 ± 10.21 and terrestrials: 5.77 ± 6.85, ANOVA, F = 4.8, df = 2, P < 0.01).

All other transects from Bolivia, Ecuador, Costa Rica, and Mexico showed a hump-shaped richness pattern and similar maximum richness at mid-elevations (more or less at the same elevation). Only the transects located at the edges of the tropical realm, in Mexico and the southernmost transect, at Masicurí in Bolivia, presented lower richness values compared with Costa Rica, Ecuador, and the other transect in Bolivia (Fig. 2-4, ANOVA, *F*=20.27, *df* = 7, P < 0.001). However, the peak of maximum richness did not decrease with increasing latitude towards lower elevations.

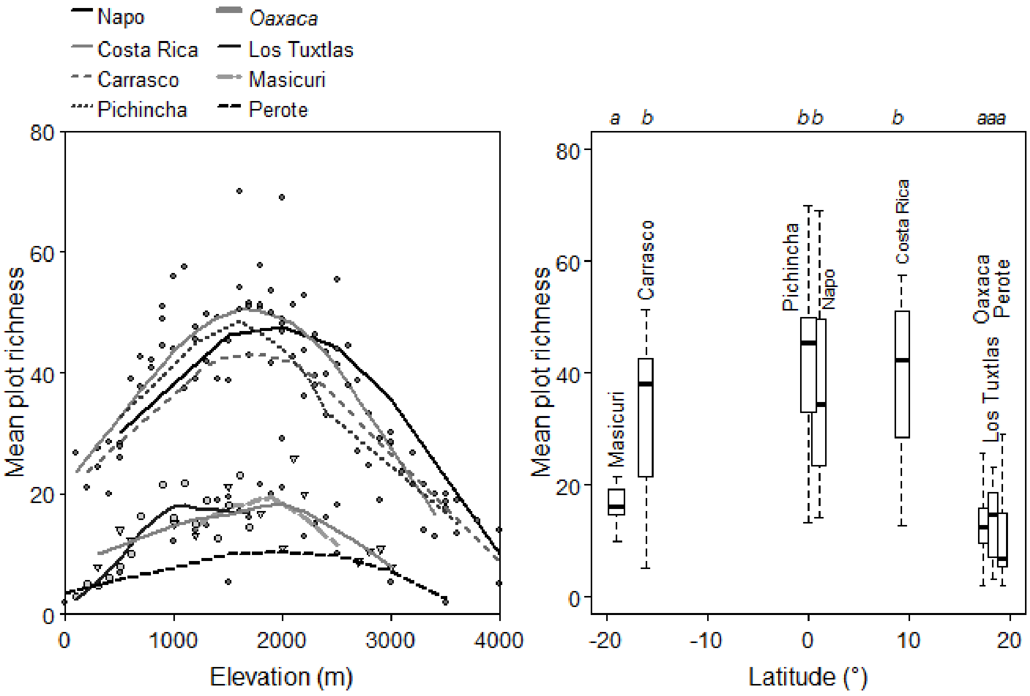

Fig.2-4 Left: Patterns of fern species richness along eight elevational transects in the Neotropics, following the latitudinal gradient from Bolivia (-19 and-16° S) via Ecuador (~0°) and Costa Rica (9° N) to Mexico: Los Tuxtlas (17° N) and Cofre de Perote (19° N), Veracruz and Sierra de Juárez, Oaxaca (18° N). Trendlines were set with locally weighted regressions (LOWESS). Right: Mean plot richness plotted against latitude. Letters above indicated significant different groups following analysis of variance (ANOVA), and Tukey post-hoc test (P< 0.001).

## 2.4 DISCUSSION

With this study, we report the most detailed plot-based study on fern species richness along a complete elevational gradient (300–3,000 m) in humid tropical forest in Mexico. In 121 plots we found 195 species mostly belonging to the families Polypodiaceae, Dryopteridaceae, and Hymenophyllaceae, coinciding with other transects in Mexico (Acebey *et al.* 2017, Carvajal-Hernández *et al.* 2017, Krömer *et al.* 2013), Central and South America (Kluge & Kessler 2005, Mehltreter 1995, Salazar *et al.* 2015). The species recorded in this study represent 29% of the total ferns of the state of Oaxaca in a surface of ca. 95,360 km$^2$ and 18% of Mexico (Mickel & Smith 2004), this in only 4.8 ha of sampling. This shows the importance of the Sierra de Juárez, as a national refuge for ferns, since in this sampling area occur more species than in larger areas as the Yucatan Peninsula (ca. 125,000 km$^2$; integrated for three complete states in Mexico) with only 65 species (Fernández Carnevali *et al.* 2012) or the state of Tabasco (ca. 24,731 km$^2$) with 169 species (Carvajal-Hernández *et al*. 2018).

The highest species numbers were recorded at mid-elevations at about 1,500–2,100 m. This hump-shaped pattern of fern richness is commonly found in tropical mountains and has been explained by climatic factors, especially temperature, precipitation, and fog frequency, e.g., from the Andes (Kessler 2001a, Krömer *et al.* 2005, Salazar *et al.* 2015), Central America (Watkins *et al.* 2006), Asia (Bhattarai *et al.* 2004, Grytnes & Beaman 2006), and Africa (Hemp 2002). However, while species richness counts, especially in the Neotropics, average 40–50 species in plots of the same size as in this study, we found a considerably lower number of fern species at mid-elevations (on average 25 species), which was comparable to nearby transects in Veracruz (, Krömer *et al.* 2013, Acebey *et al.* 2017, Carvajal-Hernández *et al.* 2017). Higher species richness is expected in riparian and ravine zones in the Sierra de Juárez, where ferns are more abundant due to humid conditions (Kessler 2010, Kluge & Kessler 2011a, Carvajal-Hernández & Krömer 2015). Because this study excluded these habitats, the total number of species is likely to be somewhat higher than found here.

In evaluating life forms, we observed that the elevational hump of species richness was mainly driven by epiphytes. Apart from the extremes at the upper and lower ends of the gradient, this life form had twice the number of species per plot as terrestrial taxa. This has also been reported before (Kessler 2001a, Kluge & Kessler 2005, Watkins *et al.* 2006, Krömer *et al.* 2013, Salazar *et al.* 2015, Acebey *et al.* 2017) and seems to be a consistent tropics-wide fern richness pattern. In our study, we additionally found that epiphytes had a wider elevational range and were more frequent compared to terrestrial species, as also found for ferns in Bolivia (Kessler 2002). Dispersal might play a role in the broader distribution of epiphytes, because spores released in the forest canopy are likely to disperse greater distances (Peck *et al.* 1990). Additionally, epiphytic and terrestrial niches operate at largely different scales: whereas terrestrial microhabitats change due to, e.g., soil nutrients, soil moisture, and topographic parameters over distances of several dozen meters (Jones *et al.* 2011, Cicuzza *et al.* 2013), epiphytic niche differentiation is driven by small-scale features due to tree crown architecture (Krömer *et al.* 2007). Hence, a study plot of 400 m² is likely to contain a wider range of epiphytic than terrestrial microhabitats with the consequence that this plot usually contains a higher number of epiphytes with a wider ecological variability.

Probably the most interesting result of our study is that, at least for neotropical ferns, there appears to be no gradual downward shift in species richness with increasing distance from the Equator, but a sudden reduction of species richness at the transitions from the tropics to the subtropics, as already reported by Salazar *et al.* (2015). The causes of this sudden reduction in fern richness are probably related to climatic conditions but may also include a historical and evolutionary signal related to the tropical origin of many major fern groups (Kessler *et al.* 2016). Although the regional fern diversity of humid montane forests in southeastern Mexico is high, we found that at the local scale it is lower compared with similar ecosystems in Costa Rica, Ecuador, and Bolivia. The confirmation of the Mexican Biogeographic Transition Zone (MTZ) for ferns suggests that this zone is likely a consequence of climatic factors. Colder temperatures and especially the occurrence of frost act as climatically limiting factors of fern distributions with increasing elevation (Bhattarai *et al.* 2004, Kluge *et al.* 2006) and may be limiting factors in the latitudinal distributions of ferns with increasing distance from the Equator. Moreover, the lack of appropriate data from the latitudinal range between Costa Rica and Mexico indicates that the change in species richness may also either be abrupt further south or even more gradual across Central America. Therefore, more research is needed inside of this transition zone and in Central America to have a complete overview of the latitudinal diversity patterns.

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# CHAPTER 3

## Latitudinal patterns of species richness and range size of ferns along elevational gradients at the transition from tropics to subtropics

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With: Jürgen Kluge, Thorsten Krömer, César Carvajal-Hernández, Libertad Silva, Georg Miehe, Marcus Lehnert, Anna Weigand and Michel Kessler

# LATITUDINAL PATTERNS OF SPECIES RICHNESS AND RANGE SIZE OF FERNS ALONG ELEVATIONAL GRADIENTS AT THE TRANSITION FROM TROPICS TO SUBTROPICS

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## Abstract

The objective of this research was to assess the range size patterns of ferns and lycophytes along elevational gradients at different latitudes in an ecographical transition zone (Mexico, from 15° to 23° N) and search for predictors of range size of ferns and lycophytes from a set of environmental factors. All terrestrial and epiphytic species were recorded in 658 plots of 400 $m^2$ along eight elevational gradients. To test if the range size within assemblages increases with elevation and latitude, we calculated the latitudinal range using the northern and southern limits of each species and averaged the latitudinal range of all species within assemblages weighted by their abundances. We related climatic factors and the changes with latitude and elevation with range size using linear mixed-effects models. Species richness per plot increased with elevation up to about 1500-2000 m, with strong differences in overall species richness between transects and a reduction with increasing latitude. The mean weighted range size of species within assemblages declined with elevation, and increased with latitude, as predicted by theory. However, we also found marked differences between the Atlantic and Pacific slopes of Mexico, as well as low range size in humid regions. The best models described about 76-80 % of the variability in range size and included the seasonality in both temperature and precipitation, and annual cloud cover. Latitudinal and elevational patterns of range size in fern assemblages are driven by an interplay of factors favouring wide-ranging species (higher latitudes with increasing temperature seasonality; dryer habitat conditions) and those favouring species with restricted ranges (higher elevations; humid habitat conditions), with additional variation introduced by the specific conditions of individual mountain ranges. Climatically stable, humid habitats apparently provide favourable conditions for small-ranged fern species, and should accordingly be given high priority in regional conservation planning.

## KEYWORDS

distribution, diversity, elevation, endemism, latitude, pteridophytes, Rapoport’s Rule

# 3 LATITUDINAL PATTERNS OF SPECIES RICHNESS AND RANGE SIZE OF FERNS ALONG ELEVATIONAL GRADIENTS AT THE TRANSITION FROM TROPICS TO SUBTROPICS

## 3.1 INTRODUCTION

One of the most striking patterns in nature is the enormous variation of range sizes of species, ranging from species which occur only in a few square meters to others that are found across the entire globe (Brown *et al.* 1996, Gaston 1998). This variation is not random, but shows distinct patterns related to environmental and geographical conditions as well as the evolutionary history and ecological requirements of the taxa (Smith 1993, Lomolino *et al.* 2006, Kreft *et al.* 2010). Accordingly, a number of ecogeographical rules have been developed to capture these relationships.

One of these rules is Rapoport's rule (RR), which proposes that the latitudinal range size of species is greater at higher latitudes, and that tropical species tend to have smaller ranges allowing more species to coexist in tropical versus temperate regions (Stevens 1989). Originally conceived for latitudinal gradients, the idea that range sizes may be determined by climatic seasonality was later extended to elevational gradients as well (Stevens 1992, climatic variability hypothesis). While these patterns have been documented for a wide range of taxa in many regions (Addo-Bediako *et al.* 2000: insects; Ribas & Schoereder 2006: many groups; Morin & Lechowicz 2011: trees; Pintor *et al.* 2015: lizards; Tomašových *et al.* 2016: birds and marine bivalves), there are also a good number of studies, mainly along elevational gradients in animals but also in plants, that do not corroborate the rule or even reporting a reverse pattern or mixed results suggesting that it varies between taxa and continents (Rohde *et al.* 1993, Ruggiero 1994, Rohde & Heap 1996, Bhattarai & Veetas 2006, Pintor *et al.* 2015, Ribas & Schoereder 2006, Zhou 2019). Support for the rule is also scarce in the tropics (Rhode 1996, Blackburn & Gaston 1996).

Even if a pattern of range size distribution accords to RR, there are a number of complications in understanding the underlying processes. The classic assumption is that temperature conditions are more seasonal at higher latitudes (Stevens 1989, 1992). When species adapt to these conditions, they widen their niche breadth (tolerance breadth; Stevens 1992, Slatyer *et al.* 2013) and thus attain wider geographical ranges. However, the spatial distribution of climatic conditions may vary with latitude or elevation, so that even if species have constant niche breadths, this will result in different range size patterns. Furthermore, the classical interpretation of RR focusses only on temperature seasonality, even though seasonal variations in humidity may be equally important for explaining the range size distributions (Gaston & Chown 1999, Pintor *et al.* 2015). Especially in the tropics, where there is little seasonal variation in temperatures, variations in precipitation patterns may play an important role. Finally, latitudinal and elevational climatic gradients, while sharing many similarities, also have crucial differences. For instance, elevational ranges (amplitudes) of species typically increase with elevation (Janzen 1967, Stevens 1989, 1992, Sklenář &Jørgensen 1999, Kessler 2001b, McCain 2009b), which would support RR. However, geographical range sizes (total area) on average decrease with an increase in elevation (Kessler 2000b, Kessler 2002, Kessler & Kluge 2008, Kessler 2010, Steinbauer *et al.* 2016). One explanation is that rugged mountainous terrain habitats with patchy distributions ('sky islands') support fragmented species populations that are more prone to speciation than species inhabiting extensive habitats without geographical barriers (Kruckeberg & Rabinovitz 1985, Kessler 2001b, Antonelli *et al.* 2009, McCormack *et al.* 2009). Besides, past climatic fluctuations determining the connectivity between sky islands may be an important driver of diversification by leading to successive cycles of population expansion and fragmentation ("flickering connectivity systems"; Flantua & Hooghiemstra 2018, Flantua *et al.* 2019). Clearly, understanding the spatial variation of species range sizes along latitudinal or elevational gradients requires more detailed understanding than suggested by the conceptually simply RR.

Thus, putting species range sizes into a broader context, range sizes are influenced by a wide range of geographical and evolutionary factors. For instance, species with restricted range sizes are often found in localized habitats, either geographically such as on oceanic islands, or environmentally, such as on specialized geological substrates (Carlquist 1974, Kruckeberg & Rabinovitz 1985, Major 1988, Kier *et al.* 2009). In addition, the geological and evolutionary history of a region also plays an important role in determining current species distributions (Brown *et al.* 1996, Lomolino *et al.* 2006). For example, Mexico is exceptionally rich in endemic species in numerous taxonomic groups, which is related to its high geological and environmental heterogeneity (Rzedowski 1962, Tryon 1972, Rzedowski 2006, Myers *et al.* 2000, Brummitt *et al.* 2016). In particular, dry forest and desert areas are characterized by high endemism and superendemism (high levels of neo- and paleo-endemics; Sosa & De Nova 2012, Sosa *et al.* 2018). Accordingly, the arid

Pacific side of the country is a center of endemism for many groups of plants and animals, presumably due to the long-term environmental stability of the region (Lott & Atkinson 2006, Rzedowski 2006). To a lesser degree, endemism has also been associated with humid forests, which in Mexico are distributed as habitat islands forming an intracontinental habitat archipelago (Llorente-Bousquets *et al.* 1992).

Determining the causes of the geographical distribution of range sizes is important in a conservational context, because a small range size is one of the main predictors of extinction risk of species (Purvis *et al.* 2000). In this sense, the current availability of large databases of species distributions and occurrence records offers outstanding opportunities to document and understand range size patterns and other large-scale patterns of biodiversity across geographic and environmental gradients. Nevertheless, many biases have been detected in large data banks, such as gaps in the available information, uncertainties in species identification/taxonomy and distributional information, errors in occurrence coordinates, and incomplete species richness for poorly explored regions (Meyer 2016, Meyer *et al.* 2016, Qian *et al.* 2018). Yet, the improvement of these data bases in the last years, and their careful and critical use, depending of the study objectives and region, make them an important tool in macroecology and biogeography.

Ferns and lycophytes (hereafter jointly referred as “ferns” for simplicity) are taxonomically well-studied and well-suited groups to investigate biogeographical questions because of their spore dispersal (wind-borne), which makes them largely independent from biotic dispersal agents (Barrington 1993), and thus links patterns of range sizes and endemism mainly to abiotic factors. Additionally, ferns are a moderately species-rich group, still manageable to handle when seeking to conduct a full census within a study area, but diverse enough to show a wide range of range size patterns and to allow for quantitative analyses. With more than 1,088 recorded species (J. D. Tejero-Díez, pers. com., 2019), they are well represented in Mexico, which has one of the best-documented fern floras in the world (Mickel & Smith 2004). Generally speaking, ferns are physiologically more limited by drought and low temperatures than angiosperms (Brodribb *et al.* 2009, Brodribb & McAdam 2011), so that their diversity declines more steeply towards arid and cold climatic conditions (Kreft *et al.* 2010). As a result, fern diversity peaks in tropical montane cloud forests and declines towards lower and higher elevations and higher latitudes (Kessler *et al.* 2011, Salazar *et al.* 2015, Khine *et al.* 2019).

Little is known about the distribution of range sizes in ferns. In Costa Rica, Bolivia, and Kenia (Kessler 2001b, Kluge & Kessler 2006, Zhou *et al.* 2019), fern ranges tend to decrease with elevation, but the latitudinal patterns and the relationship to climatic factors remain unexplored. Nevertheless, considering that fern diversity peaks in the most humid habitats, and that such very wet habitats have a localized and patchy distribution (Llorente-Bousquets *et al.* 1992, Killeen *et al.* 2007, Sanginés-Franco *et al.* 2015), it seems reasonable to expected that fern species adapted to such conditions have similarly localized and patchy ranges.

In this study we explored the patterns of latitudinal range size of ferns along eight elevational gradients located at different latitudes in the Mexican transition zone from the tropics (south of Mexico) to the subtropics (30 km south of the Tropic Cancer Line), which is considered a global biodiversity hotspot (Myers *et al.* 2000) and a center of fern endemism (Brummitt *et al.* 2016). We asked whether mean range sizes of fern assemblages vary with latitude and elevation, specifically hypothesizing that mean range sizes increase with latitude as Rapoport's rule proposes (H1) and decrease with elevation (H2). We further hypothesized that mean range sizes increase with increasing environmental stress factors such as low temperature, precipitation, and humidity, and high climatic seasonality (H3a). Conversely, we predict that mean range sizes decrease with increasing humidity due to the water-dependency of the study group, related to the geographical fragmentation of environmentally suitable areas for specialized ferns (H3b).

## 3.2 MATERIALS AND METHODS

### 3.2.1 Study area

The Mexican transition zone is the complex area where the Neotropical and Nearctic biotas overlap, and in a strict sense corresponds to the mountain highlands of Mexico, Guatemala, El Salvador and Nicaragua (Halffter & Morrone 2017). We here present data from eight elevational gradients at a range of 0 m to 3500 m elevation at 15-23° latitude N on both the Pacific and Atlantic (Gulf of Mexico) sides of Mexico (Fig. 3-1, Appendix T 3-3). Three transects have been considered in previous studies: Los Tuxtlas (prresence data) (Krömer *et al.* 2013, Acebey *et al.* 2017), Perote (Carvajal-Hernández & Krömer 2015, Carvajal-Hernández *et al.* 2017), and Oaxaca (Hernández-Rojas *et al.* 2018).

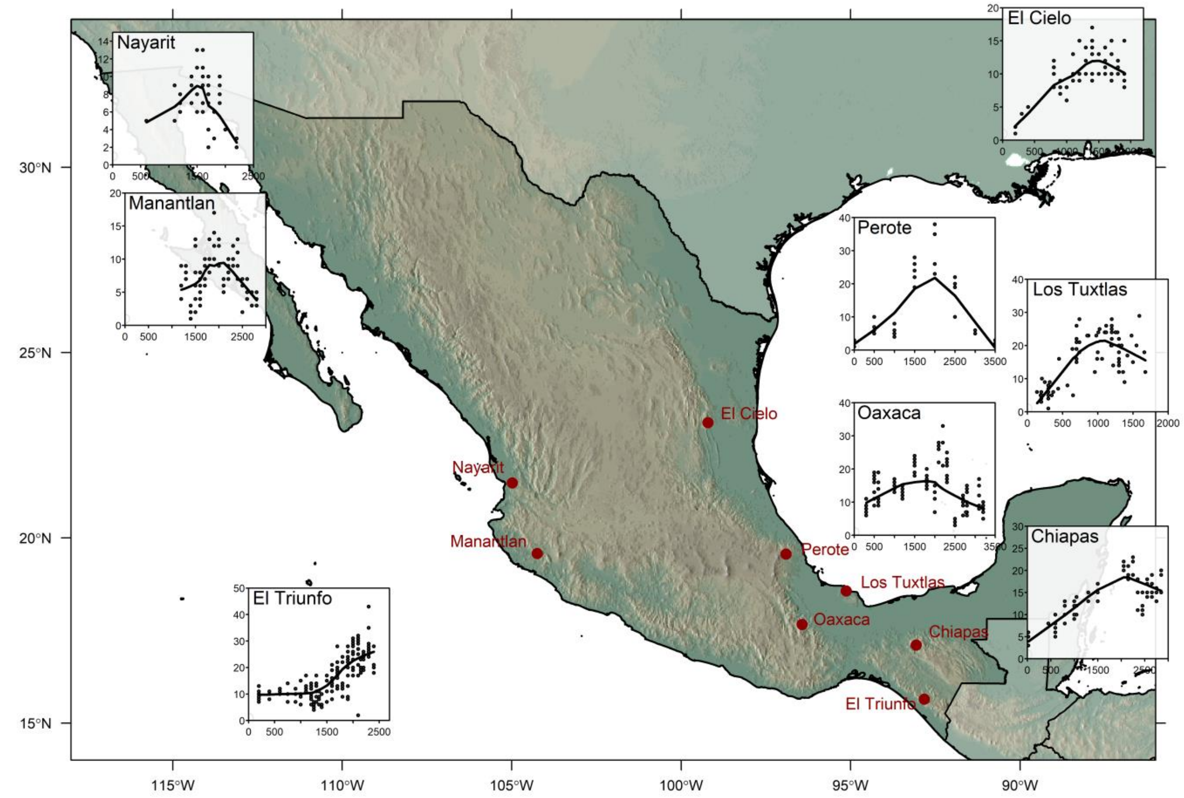

Fig. 3-1 Location of the eight study transects and their fern species richness patterns at the transition from tropics to the subtropics in Mexico between 15°-23° N. Points represent the mean latitude of all plots per site, indicated in every richness panel.

### 3.2.2 Fern sampling

On each gradient, we sampled the fern assemblages at regular elevational intervals of 100-300 m (every 500 m at Perote), depending on accessibility. At each elevation, depending on the suitability of the slope, 4-8 plots of 20 x 20 m (400 m$^2$) were sampled with a consistent, standardized methodology (Kessler & Bach 1999, Karger *et al.* 2014). The plots were established in natural zonal forest, avoiding special structural features like canopy gaps, ridges, ravines, riparian areas, tree fall gaps, landslides, and other disturbed areas whenever possible, which all change microenvironmental conditions and have special fern assemblages. In each plot, all fern species and their abundances were recorded for terrestrial (soil, rocks, and dead wood) and for epiphytic substrates. Species with long creeping rhizomes were counted as patches. Epiphytes were sampled up to heights of 8 m with trimming poles and recorded at greater heights by using binoculars, climbing lower parts of trees, and searching recently fallen trees and branches within and adjacent to the plots (Gradstein *et al.* 2003, Sarmento Cabral *et al.* 2015).

Samples of all fern species were collected and deposited in the University Herbarium, University of California (UC) in Berkeley, USA, herbarium XAL of the Instituto de Ecología, A. C. (Xalapa, Mexico), MEXU of the Universidad Autónoma de México (Mexico City, Mexico), CIB of the Instituto de Investigaciones Biológicas (Universidad Veracruzana, Xalapa, Mexico), HEM of the Universidad de Ciencias y Artes de Chiapas (Tuxtla Gutiérrez-García, Mexico) and UAMIZ of the Universidad Autónoma Metropolitana-Iztapalapa (Mexico City, Mexico). Collections were identified by A. R. Smith (UC), A. Hernández-Rojas, and C. Carvajal-Hernández. Taxonomy primarily followed Mickel & Smith (2004) and the current classification for ferns and lycophytes established by the Pteridophyte Phylogeny Group (PPG I 2016). Species names and authors were checked on the International Plant names Index (IPNI).

### 3.2.3 Explanatory variables

Ferns are closely dependent of climatic variables related to humidity because their sexual reproduction is linked to the presence of water (Page 2002) and because of their poor stomatal control (Kessler 2001a, Brodribb & McAdam 2011). Because water stress is not only determined by water input into a system (by precipitation or fog), but also by evapotranspiration which is related to high temperatures, we specifically included energy- and humidity-related variables as predictors of species distribution and their range size. Besides temperature and precipitation and their temporal variability, cloud cover is also a suitable predictor in this context because clouds reduce solar radiation and provide extra ‘occult’ precipitation (Bruijnzeel & Veeneklaas 1998, Hartmann 1993). Thus, we extracted the following climatic variables per plot from the global climate data base set CHELSA (Karger *et al.* 2017): Annual mean temperature and precipitation (Bio1, Bio12), as well as temperature and precipitation seasonality (Bio4, Bio15). From ‘EarthEnv’, we extracted annual cloud cover and its seasonality (CloudA, CloudS; Wilson & Jetz 2016). We checked for collinearity between the climatic variables using the Variance Inflation Factor (VIF; Naimi *et al.*, 2014). Variables with values >6 where not used in the same model (for example, Elevation and Annual Temperature), but all variables were included in different models of the same analysis. We also included the position in the country (Pacific and

Atlantic side) as a fixed factor, because the sides are known to have different biogeographic histories and habitat connectivity, leading to markedly different patterns of endemism for many groups of organisms (Rzedowski 2006).

### 3.2.4 Species ranges

We used the latitudinal range (range between the northern and southern range limits) of each species as a simple gradual measure of range size. To quantify the latitudinal ranges of the species, we used American species occurrences combined with our own records for a total of 173.110 species records. Data were obtained from the Biodiversity Information Facility (GBIF, www.gbif.org, accessed August-September 2018) databank using the ‘rgbif’ package in R (R Core Team 2019). Coordinates of fossil records and specimens from botanical gardens or herbaria were excluded. To detect errors and suspicious patterns (outliers) within the dataset, we mapped the coordinates and checked the latitudinal range of each species using ‘maptools’ (Bivand & Lewin-Koh 2019). Range sizes were checked against TROPICOS (Flora mesoamericana, Moran & Riba 1995), Catalogue of Life (Hassler 2018), Mickel & Smith (2004), Labiak & Prado (2007), Vasco *et al.* (2009), Larsen *et al.* (2010), Vasco (2011), Labiak (2011), Lehnert (2013), Smith & Tejero (2014), Lóriga *et al*. (2014), Arana *et al.* (2016), Barbosa-Silva *et al.* (2016),Villaseñor (2016), Kessler & Smith (2017), Ponce *et al.* (2017) and Smith *et al.* (2018), and suspicious and wrong observations were corrected (for example coordinates in the sea).With these latitudinal ranges, we calculated the mean range size of all species (excluding especies varieties and species identified only up to genus) in each individual plot as an index of range size within the assemblage (plot). To account for different species abundances within assemblages, we also calculated a 'weighted mean' including the number of individuals of the species, thus down-weighting rare species. The aim of this weighting was to reduce the influence of species that do not belong to the core communities at a site: Because of their spore dispersal, many fern species can occasionally or temporarily occur outside of their core ranges, and such sink populations can strongly impact species richness patterns (Kessler *et al.* 2011, 2014).

### 3.2.5 Statistical analysis

We used linear mixed effects models (LMMs) to control for the non-independence among data points in assessing changes in the species ranges with elevation, latitude, and in relation to climatic variables (fixed effects), because these models allow for spatial autocorrelation between neighbors (Crawley 2007), and Likelihood Ratio Tests (LRT) or 'deviance tests' to compare between a null model without the term of interest and the model including this term to determine if one is a better fit to the data than the other (Luke, 2017; Winter 2019). For the model including climatic variables or many fixed effects we used the mixed function in the package 'afex' that performs a full suite of likelihood ratio tests for all fixed effects in a model and constructs the correspondent comparison model providing p values for all fixed effects in a model (Singmann *et al.* 2016, Winter 2019). All variables used in the models were scaled. We also tested the random structure of our models using the restricted maximum likelihood (Winter 2019) choosing the different transects and groups of plots in the same elevation (Transect/Step) as random effects for the analysis of all transects together. The analysis by individual transects was performed using "Step" or group of plots in the same elevation as a random effect to avoid overfitting the model with a complex random structure. In order to evaluate the association between range size, latitude, elevation and the climatic variables, we calculated the Spearman correlations. Because climatic variables interact in complex ways in relation to latitude, elevation, and position in the country (Atlantic and Pacific sides of Mexico, "Side"), and because our data was not perfectly balanced with regard to these factors (e.g., different elevational spans of the transects), we additionally ran a model with these climatic variables against the residual of the model including latitude, elevation and side.

For model selection we used the dredge function in the R "MuMIn" package (Barton 2019). To decide whether such a simplified model was an enhancement to the previous model, we calculated the cAIC (conditional Akaike Information Criterion; Saefken *et al.* 2018), with a lower cAIC indicating a better model. The amount of variation explained by the fixed (marginal $R^2$) and random effects (conditional $R^2$) of each model was calculated using the 'MuMIn' package (Nakagawa & Schielzeth 2013, Barton 2019). Residuals of models were checked (see example in appendices). All analyses were performed with the statistical platform R (R Core Team 2019), using the packages 'usdm' (Naimi *et al.* 2014), ‘lme4’ (Bates *et al.* (2015), ‘afex’ (Singmann *et al.* 2016) ‘MuMIn’ (Barton 2019), ‘cAIC4’ (Saefken & Rueganer 2018), ‘vegan’ (Oksanen *et al.* 2019), and ‘ggeffects’ (Lüdecke 2018 to plot the models).

## 3.3 RESULTS

In total, in the 658 plots along the eight study transects, we recorded 410 fern species and 8 varieties, representing about 40 % of the Mexican fern flora (Mickel & Smith 2004, Villaseñor 2016, J. D. Tejero-Díez 2019, pers. com., Appendix T 3-2). Generally speaking, species richness per plot increased with elevation up to about 1500-2000 m, but with strong differences in overall species richness between transects and a reduction with latitude (Fig. 3-1 and 3-2). No fewer than 17.1 % of the species were recorded in only one plot, 26.2 % in 2-5 plots, 22.5 % in 6-15 plots, and only 34.0 % in 16 or more plots.

The most species-rich families were Polypodiaceae (97), Dryopteridaceae (76), Pteridaceae (44), and Hymenophyllaceae (31). Latitudinal range sizes of species ranged from 0.6° in *Goniopteris tuxtlensis,* a localized endemic, to 138.3° in the widespread species *Cystopteris fragilis*. Overall, mean latitudinal range size was 30.7°. The family Dryopteridaceae presented the smallest mean range sizes (19.3°± 17.7° SD, latitude), Polypodiaceae (24.7° ± 19.2°), and Pteridaceae intermediate ranges 38.5° ± 20.3°), and Hymenophyllaceae the largest ones (45.1° ± 15.0°).

Mean latitudinal range sizes of species in an assemblage increased with latitude (X2(1) = 7.71, p<0.01) on both the Atlantic and Pacific sides, and decreased with elevation on the Atlantic side (X2(1) = 9.56, p<0.01). Overall, Pacific and Atlantic sides differed, presenting smaller range sizes on the Atlantic side (X2(1) = 11.5, p<0.01, Fig. 3-3). Including a random intercept and random slope models (Range size~Elevation) allowed us to see different tendencies between transects (Appendix F 3-1).

The analysis of individual transects showed contrasting results with different climatic factors related to latitudinal range size along each transect (Table 3-1, Fig. 3-2). The same was true when separating the data by side and by elevational group. When separating sides, variables related to humidity were important for the Pacific side, whereas the seasonal variability in temperature and humidity were important on the Atlantic side.

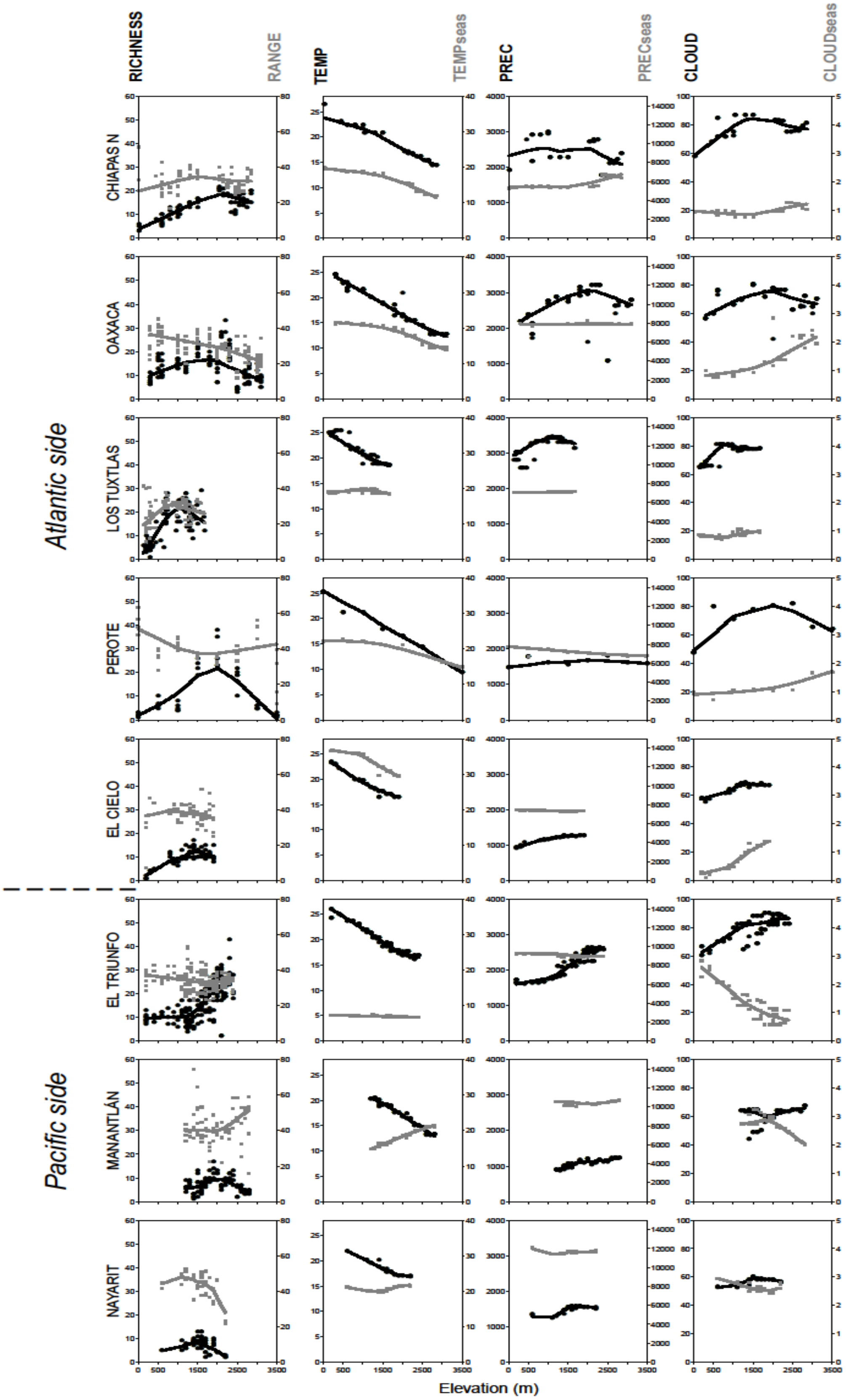

Fig. 3-2. Richness and range size patterns of ferns, and environmental factors along eight elevational transects in Mexico betwee 15°-23°N..

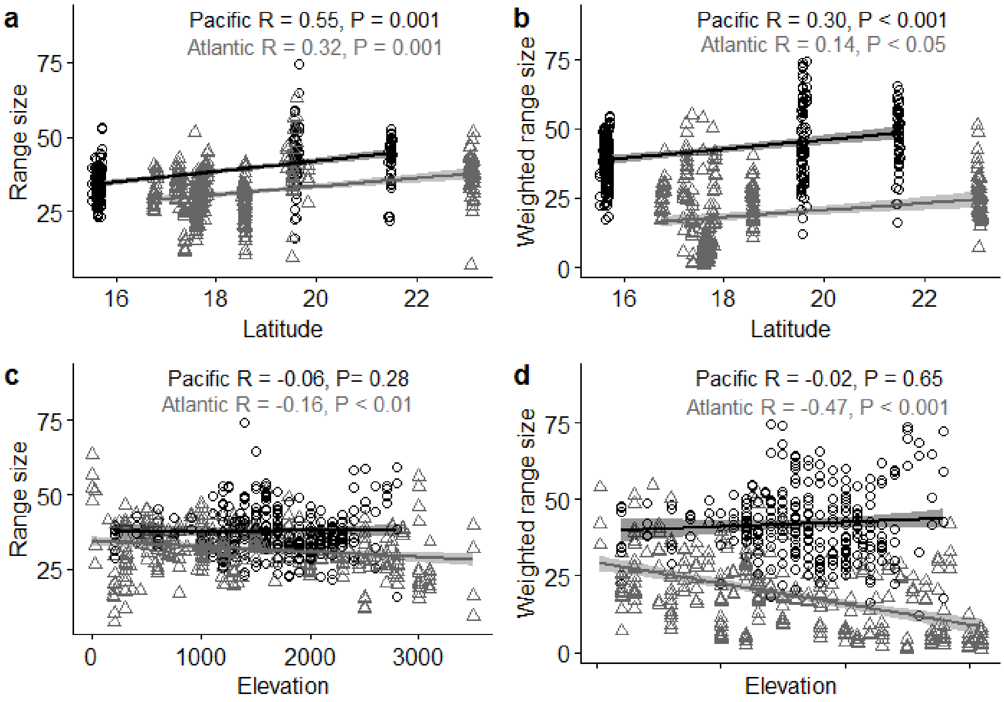

Fig. 3-3. Relationship between latitudinal range size of ferns, latitude, and elevation along eight elevational transects in Mexico between 15°-23° N (Spearman correlation). Pacific side, black circles; Atlantic side, gray triangles. For weighted range sizes, only the seven transects were included.

Incorporating all transects and separating elevational groups, we found that in the upper part of the mountains, temperature was crucial, in the lowlands, precipitation and at intermediate elevations, the seasonal variation of precipitation. Also, using these elevational groups but separated by sides, we found that on the Atlantic side, precipitation seasonality was important at all elevations, whereas on the Pacific side seasonality in both precipitation and temperature were important.

Table 3-2. Model selection table derived from the model including the residuals of range size (and weighted range size) explained by latitude, elevation and Side (Model les) using as random effect the transect. Full model: Residuals of model les ~ Bio1+Bio4+Bio12+Bio15+ CloudA+ CloudS. Bio1, Bio4: annual mean temperature and its seasonality, Bio12, Bio15: annual precipitation and its seasonality and CloudA, CloudS: annual cloud cover and its seasonality.

| **Model** | **Response variable** | **Fix effects** | **Df** | **AICc** | **Delta** | **Weight** |
|---|---|---|---|---|---|---|
| 1 | Residual of non-weighted range size | Bio15+Bio4+ CloudA | 7 | 4306.3 | 0.00 | 0.25 |
| 2 | | Bio15+Bio4+CloudA+ Bio12 | 8 | 4306.3 | 0.04 | 0.25 |
| 3 | Residual of weighted range size | CloudS+CloudA+Bio4+Bio1 | 8 | 4186.0 | 00.0 | 0.45 |
| 4 | | CloudA+CloudS+Bio4 | 7 | 4186.4 | 0.42 | 0.37 |

The use of all transects together allowed us to find general patterns and the explanatory power increased significantly in terms of the variance described by the fixed effects when combining all transects using side (Pacific and Atlantic) as fixed effect in the models (Table 3-1)

Integrating all environmental variables in a global model (full model) including all transects revealed that the most important terms were side, precipitation seasonality annual cloud cover, and temperature seasonality (Fig. 3-4 f, c and b), this model explained 62 % of the variability in range size but even more (70 %) when using weighted values (Table 3-1, Appendix T 3-1). With this division, high seasonality in temperature was related to larger range sizes on both sides, whereas high precipitation seasonality was related to small ranges on the Atlantic slope and large ranges on the Pacific slope. Annual cloud cover showed a negative relationship to range size on the Pacific side but not on the Atlantic side (Fig. 3-4c).

When the effect of latitude, elevation, and side of the country was controlled using the residuals of this model (Model les) against the climatic variables still some climatic variables remained important (Table 3-2), showing that they have and strong effect on range size, mainly the seasonality.

In general, small values of range size were found at intermediate values of precipitation seasonality, low temperature seasonality, and a high annual cloud cover. The humid Atlantic side presented a higher proportion of small range size species relative to the dry Pacific side (Fig. 3-4). All models were checked and no pattern was left in the residuals.

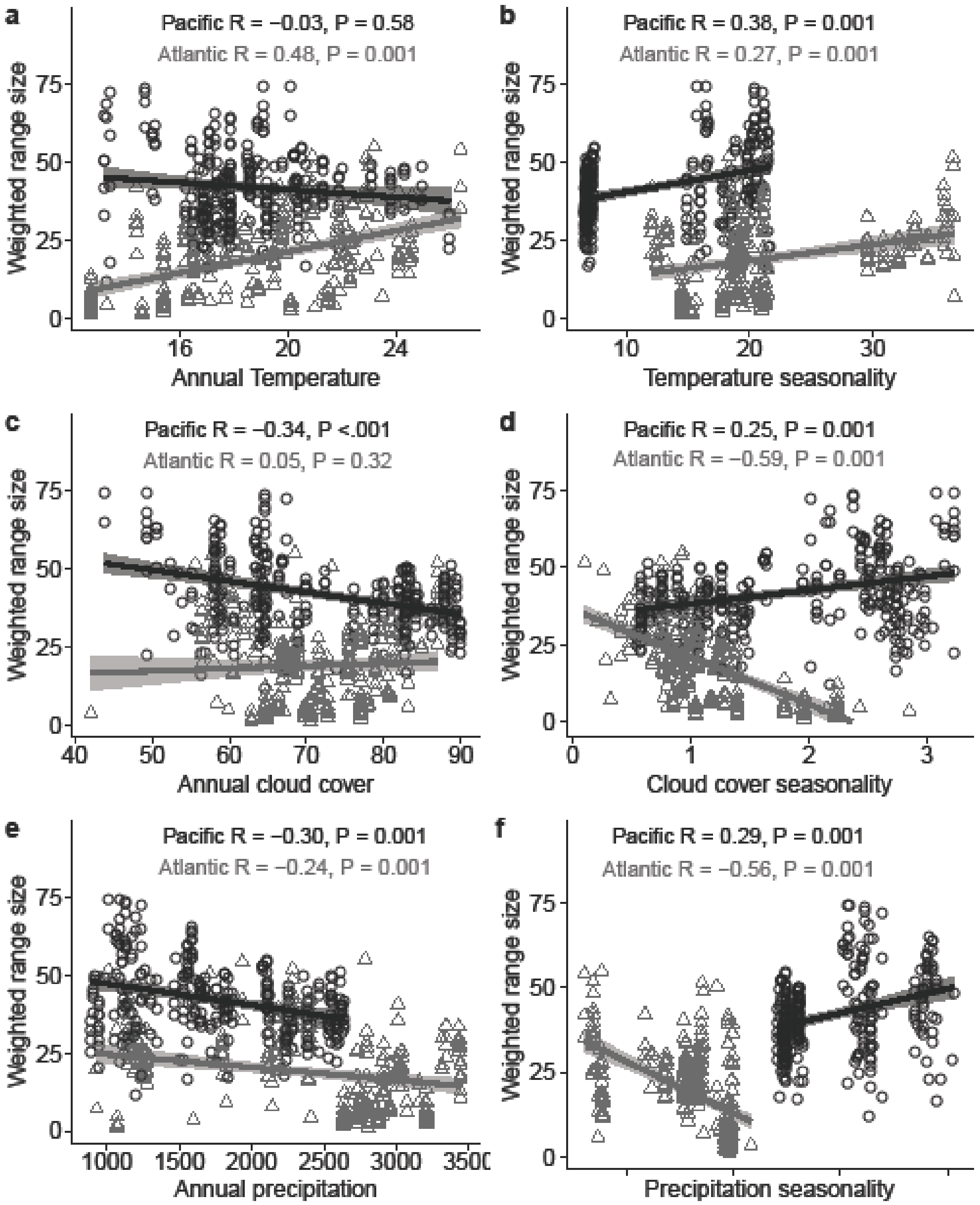

Fig. 3-4 Relationship between climatic variables and range size of ferns along eight elevational transects in Mexico between 15°-23° N (Spearman correlation). Pacific side, black circles; Atlantic side, gray triangles.

Table 3-1. Likelihood ratio test results with p values for all fix effects in the Linear mixed models (Coefficients), by transects, sides (A= Atlantic and P= Pacific), and elevational groups, using Step or group of plots in the same elevation as random factors. For all transects together the Transect / Step random factor structure was used. Similar values in the marginal ($R^2$m) and conditional $R^2$ ($R^2$c) indicates that a linear model is the adequate model with the same coefficients. P: Pacific side, A: Atlantic side, Bio1, Bio4: annual mean temperature and its seasonality, Bio12, Bio15: annual precipitation and its seasonality and CloudA, CloudS: annual cloud cover and its seasonality. Significance codes: *** P <0.001, * *P<0.01, *P<0.05

| **Transect** | **Side** | **Bio1** | **Bio4** | **Bio12** | **Bio15** | **CloudA** | **CloudS** | **$R^2$m** | **$R^2$c** |
|---|---|---|---|---|---|---|---|---|---|
| Triunfo (16.5) | | | 490.06*** | | 80.92*** | | -15.85*** | 0.21 | 0.34 |
| Manantlan (19.6) | | | | -113.45* | | -25.92*** | | 0.38 | 0.38 |
| Nayarit (21.4) | | 80.88*** | 187.77* | 156.06** | -219.29** | | | 0.41 | 0.59 |
| ChiapasN (17.1) | | | | -14.94** | | -13.03* | -73.85** | *0.55* | *0.55* |
| Oaxaca (17.5) | | 38.22*** | -95.07*** | | | 11.14* | | *0.64* | *0.83* |
| Tuxtlas a(18.5) | | | 72.28* | -22.82** | -462.44** | | | *0.34* | *0.34* |
| Tuxtlas b(18.5) | | | | | | 38.21* | 99.60* | *0.45* | *0.45* |
| Perote (19.4) | | 23.24* | | | | 46.97* | | *0.58* | *0.62* |
| Cielo (23.1) | | -82.21* | | -242.12* | | | -83.17** | *0.38* | *0.57* |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Pacific- all plots | | | | | -15.48* | -10.22*** | -12.99*** | 0.23 | 0.35 |
| Atlantic- all plots | | | -3.66* | -5.49*** | -7.06** | | -8.09** | 0.56 | 0.77 |

| **Atlantic per elevational groups** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0-700 | | | -33.51*** | -14.98*** | -7.08* | -12.84*** | -44.82*** | 0.40 | 0.40 |
| 701-1300 | | | 19.66** | 10.12* | -11.35** | 10.36* | | 0.76 | 0.82 |
| 1301-1800 | | | | | -23.48** | | -56.58* | 0.86 | 0.86 |
| 1801-1400 | | -17.88* | -9.15** | | -10.56** | -33.46** | -40.44** | 0.71 | 0.71 |
| 2401-3500 | | | 73.30* | | -52.53*** | | | 0.92 | 0.92 |

| **Pacific per elevational groups** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0-700 | | 138.13* | 920.32* | | 824.89* | -152.64** | -222.10** | 0.68 | 0.68 |
| 701-1300 | | | -188.60* | | -189.81* | | | 0.24 | 0.24 |
| 1301-1800 | | | | | | -15.60** | -18.95* | 0.30 | 0.34 |
| 1801-1400 | | 66.37*** | 179.57*** | 63.85*** | -119.05*** | | | 0.45 | 0.58 |
| 2401-3500 | | | | | | | | 0.46 | 0.46 |

| **By elevational groups (no division between Atlantic and Pacific)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0-700 | | | -11.09** | | -8.14*** | -9.68** | | 0.33 | 0.33 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 701-1300 | | | | -7.48** | | | | 0.58 | 0.85 |
| 1301-1800 | | | -9.46*** | | | -6.94* | | 0.46 | 0.68 |
| 1801-1400 | | | -8.69** | -6.87** | 5.90** | | | 0.50 | 0.71 |
| 2401-3500 | | 32.66** | 47.91** | | | | | 0.76 | 0.83 |
| **All transects (no division between Atlantic and Pacific)** | | | | -5.04** | -10.12* | -5.40*** | -5.7** | 0.23 | 0.93 |
| **All transects (Step as random effect)** | | | | | | | | | |
| | A- 49.55*** | | | -3.63* | -10.88** | -5.34*** | -5.53*** | 0.62 | 0.81 |
| **Best model** (climatic variables Random effect: Step ) | P- 47.95*** | | 5.62*** | | -10.85*** | -2.96*** | | 0.59 | 0.76 |

## 3.4 DISCUSSION

The main results of our study can be summarized in the following five points. First, overall latitudinal range size increased with increasing latitude. Second, range size decreased with elevation on the Atlantic slope but not on the Pacific slope. Third, range size decreased in areas with high humidity, low temperature seasonality, and intermediate precipitation seasonality, as well as constant cloud cover. Fourth, there was a strong difference in range size between the Pacific and Atlantic sides that was not captured by the climatic factors, with ranges on the Pacific side being much broader. Fifth, we found great variation between individual transects.

Our results confirm the first hypothesis, that on average, latitudinal species ranges become wider at higher latitudes, which is in accordance with Rapoport’s Rule (Stevens 1989). This pattern has been previously documented for algae (Santelices & Marquet 1998) and other plant (Stevens 1992) and animal groups (Stevens 1996: marine fishes; Fleishman *et al.* 1998: butterflies; Swaegers *et al.* 2014: dragonflies; Böhm *et al.* 2017: snakes) mainly in the northern hemisphere, and while not fundamentally novel, it is confirmative for ferns and reflects the representativeness of our data. Because temperature and precipitation seasonality showed a linear trend with latitude, we can exclude the possibility that this pattern was driven by a spatially unequal distribution of climatic seasonality, which would result in different range sizes despite equal climatic niche breadths (Gaston & Chown 1999, Tomašových *et al.* 2015). Rather, it seems likely that increasingly stressful and variable climatic conditions require broader climatic tolerances of the species, resulting in wider climatic niches and accordingly larger ranges (Janzen 1967, Stevens 1989).

In contrast, our second hypothesis that range sizes of ferns should decrease with elevation (Zhou *et al.* 2019), was supported only on the Atlantic (Gulf of Mexico and Caribbean) side of Mexico, whereas on the drier Pacific side we detected no elevational trend. A decrease of range size with elevation has also been found in ferns in Costa Rica (Kluge & Kessler 2006) and Bolivia (Kessler 2002), as well as in other plants and animals (e.g., Gifford & Kozak 2012, Steinbauer *et al.* 2016), and is likely linked to topographic complexity, leading to geographically fragmented species ranges which foster allopatric speciation (Kessler 2001b, Antonelli *et al.* 2009). This effect appears to be most pronounced in wet tropical climates (Kier *et al.* 2009) or areas of favourable ocean currents that create refugia for endemics (Harrison & Noss 2017), as found on the Atlantic slope. In addition, formation of endemic species might also be related to past climatic fluctuations that led to successive periods of habitat connectivity and disruption (Flantua & Hooghiemstra 2018), although this remains to be tested for the Mexican mountains.

The lack of this pattern on the Pacific side is puzzling, but may be related to its overall aridity, since we found that fern range sizes increase with increasing aridity (Fig. 3-4e, f). Interestingly, for drought-adapted plant groups such as *Bursera* (Rzedowski 2006), *Ipomoea* (Lott & Atkinson 2006), or many ferns that prefer arid conditions such as *Anemia* or cheilantoid ferns like *Argyrochosma*, *Gaga*, *Myriopteris*, and *Notholaena* (Mickel & Smith 2004), the Pacific slope of Mexico is a well-known center of endemism. The same is true for insect groups like bees that thrive in arid environments (Bye *et al.* 1993). It thus appears that in the case of ferns on the Pacific slope of Mexico, the expected elevational effect on species range sizes is overridden by stressful climatic factors.

In this regard, we found overall that latitudinal range sizes of ferns were smallest in areas of high precipitation and cloud cover. Ferns are well known to have highest diversity in wet habitats (Hemp 2001, Kluge & Kessler 2005, Hietz 2010, Kessler *et al.* 2011), presumably as a result of their less efficient control of stomatal transpiration as compared to angiosperms (Page 2002, Brodribb *et al.* 2009, Brodribb & McAdam 2011). Accordingly, it is reasonable to propose that wet habitats, which in Mexico are present mainly on the Atlantic side (e.g., 4000-7000 mm/a at Los Tuxtlas; Gutiérrez-García & Ricker 2011, or La Chinantla; Meave *et al.* 2017) and whose distribution decreases northwards, act as localized refuges for many fern species that depend on such conditions. Because of the localized distribution of the habitats, the species will accordingly have localized ranges. In contrast, species capable of surviving in dryer, more widespread habitats will have broader ranges. Species range sizes decreased in areas with less seasonality of both precipitation and cloud cover only on the Atlantic side. This may reflect the generally more favorable conditions for ferns on this side (Fig. 3-4).

In addition, we also found transect-specific patterns that are not captured by the general relationships discussed so far. This supports the idea that individual mountain ranges are unique depending on their geology, topographical profiles, and past climatic fluctuations, resulting in individual “mountain fingerprints” (Flantua & Hooghiemstra

2018). We refrain from discussing the individual transect patterns in more detail pending replicated sampling in the different mountain ranges to confirm the patterns, but point out that there appear to be range-specific patterns that merit future investigation.

Based on all of the above, we conclude that the distribution of range size of Mexican ferns is driven by an interplay of factors favouring wide-ranging species (higher latitudes with increasing temperature seasonality; dryer habitat conditions) and those favouring species with restricted ranges (higher elevations; more humid habitat conditions), with additional variation introduced by the specific conditions of the individual mountain ranges. The interactions of these factors are complex and are strikingly different between the Atlantic and Pacific slopes of Mexico, so that under certain conditions, specific relationships may be overshadowed by other relationships (Tejero-Díez *et al.* 2014). This shows that understanding the distribution of species range sizes should not be simplified too much and that understanding the distribution of range sizes must take into consideration a wide range of factors at various spatial scales. This is also relevant for conservation action, in which range-restricted or endemic species are frequently given priority due to their higher extinction risks (Purvis *et al.* 2000). Since climatic conditions are currently strongly changing, understanding the underlying causal relationships rather than only the current patterns of the distribution of range-restricted species is crucial to making informed predictions about the future of many plant species. Our study points to the overriding importance of climatically humid and stable habitat islands for fern conservation, while acknowledging regional variation.

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# CHAPTER 4

# Phylogenetic diversity of ferns reveals different patterns of niche conservatism and habitat filtering between epiphytic and terrestrial assemblages

Invitation to the special issue on elevation gradients for *Frontiers of Biogeography* (submitted)

with Kluge Jürgen, Noben Sarah, Reyes Chávez Johan, Krömer Thorsten,
Carvajal-Hernández César, Salazar Laura & Michael Kessler

# PHYLOGENETIC DIVERSITY OF FERNS REVEALS DIFFERENT PATTERNS OF NICHE CONSERVATISM AND HABITAT FILTERING BETWEEN EPIPHYTIC AND TERRESTRIAL ASSEMBLAGES

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## Abstract

Much attention has been directed to understanding species richness patterns, but adding phylogenetic diversity allows us to further analyze the evolutionary and historical processes determining current diversity patterns. We analyzed phylogenetic patterns of fern species assemblages in 868 study plots along a wide range of elevational (0-4000 m) and latitudinal (0°-23°N) gradients in the Neotropics to allow a deeper understanding of evolutionary processes underlying current patterns of diversity and community assembly. Overall, we found that phylogenetic diversity decreases with increasing latitude and elevation, but that these geographical factors per se are weak explanatory variables. Incorporating environmental variables strongly enhances the predictive model power, so that fern assemblages are phylogenetically more diverse under wet and warm to cool conditions at low latitudes and elevations. Further, whereas epiphytic fern assemblages are strongly influenced by climatic factors, this is not the case for terrestrial ones, suggesting that edaphic conditions and vegetation structure may have a stronger influence on the evolution and diversification of terrestrial ferns. In conclusion this suggests that the evolution of fern assemblages has been strongly influenced by phylogenetic niche conservatism and environmental filtering.

Key words: monilophytes, pteridophytes; phylogenetic patterns; biogeography, latitudinal, elevational gradient, tropics.

Running title: Phylogenetic diversity of ferns along gradients of latitude and elevation

# 4 PHYLOGENETIC DIVERSITY OF FERNS REVEALS DIFFERENT PATTERNS OF NICHE CONSERVATISM AND HABITAT FILTERING BETWEEN EPIPHYTIC AND TERRESTRIAL ASSEMBLAGES

## 4.1 INTRODUCTION

Biodiversity is distributed very unevenly in the globe and explaining geographical patterns of species richness remains one of biogeography's major challenges. An example of this uneveness is the latitudinal gradient of increasing species richness from the polar regions towards the tropics (a classical pattern in biogeography, von Humboldt [1828] 2004, Darwin 1859, Pianka 1966, Mittelbach *et al.* 2007, Brown 2014). Despite of over 200 years of research, the factors driving the observed patterns are still controversially discussed (e.g., Hillebrand 2004, Qian and Ricklefs 2011, Oliveira and Scheffers 2019). Recently considered, partly interlinked explanations for such large-scale richness patterns appear to involve mainly climatic variables (e.g., Hawkins *et al.* 2003, Currie *et al.* 2004, Weigand *et al.* 2019, Abotsi *et al.* 2020), and historical and evolutionary processes (e.g., Ricklefs 2004, Wiens and Donoghue 2004, Fine 2015). In recent decades, elevational gradients have increasingly gained attention for assessing the relative contribution of the plethora of proposed drivers of species richness patterns. For a long time, there was an unquestioned belief that elevational gradients simply mirror latitudinal gradients because both span a transition from warm to cold climatic conditions. However, Rahbek (1995) showed that this perception was the result of an overemphasis on a few studies showing such monotonic declines, and that across nearly all taxonomic groups the majority of studies find unimodal richness patterns with maximum richness at some intermediate point of the gradient, as confirmed by many studies since then (e.g., Grytnes and Beaman 2006, Grau *et al.* 2007, Kessler *et al.* 2011, Pandey *et al.* 2020). Elevational gradients further differ from the latitudinal gradient in that they are more concise (usually tens of km) and have many more replications (Rahbek 2005, McCain 2009), which allows for disentangling the effects of different ecological factors that vary in different ways along different elevational gradients (Lomolino 2001). Latitudinal and elevational gradients thus both represent large-scale biogeographical gradients along which biodiversity changes in clear and often predictable ways. Because of the different spatial extents and specific ecological transitions of the two types of gradients, a combination of latitudinal and elevational gradients offers a unique opportunity to disentangle the relative roles of different drivers of species richness patterns (Qian *et al.* 2020).

There is increasing evidence that local diversity is strongly connected to regional diversity, raising the question of the historical component of local diversity patterns (e.g., Wiens and Donoghue 2004, Ricklefs 2005, Roy and Goldberg 2007, Weigand *et al.* 2019). Biotic assemblages along ecological gradients may thus show phylogenetic patterns reflecting historical differences between regions as well as inherited traits of clades contributing to the assemblages (Ricklefs 2005, Hawkins *et al.* 2005, 2006). For example, the tropics may harbor higher diversity across many taxa than temperate regions because the taxa have originated there ("out of the tropics", Jablonski *et al.* 2006) and had a greater extent in the past (Behrensmeyer *et al.* 1992, Kissling *et al.* 2012), so that most extant clades are originally tropical, leading to greater time and space availability for speciation. Moreover, a higher amount of energy in the tropics leads to shorter generation times and thus higher diversification rates ("speciation–extinction", Cardillo 1999, Mittelbach *et al.* 2007). Turning towards outer-tropical regions, adaptations are necessary to disperse and persist in cold and climatically seasonal regions, and these have evolved only in some taxa ("niche conservatism", Wiens and Donoghue 2004; "habitat filtering", Harper 1977), that represent clusters of closely related species that tend to be ecologically more similar and should therefore show higher competition (Darwin 1859, Cavender-Bares *et al.* 2009).

As species assemblages may show non-random patterns of species co-occurrences (Webb *et al.* 2002), the degree of relatedness between co-occurring species in terms of phylogenetic similarity may shed light on prevailing ecological processes such as environmental filtering (Weiher and Keddy 1995, de Bello *et al.* 2006) and niche differentiation (Stubbs and Bastow Wilson 2004). The processes behind these assumptions state that either the probability of a species to persist in an assemblage may increase if it is distinct from other species in the assemblage ("overdispersion": more efficient exploitation of the available resources to reduce competitive interactions, see Diáz and Cabido 1997, Hooper *et al.* 2005), or that the environment sets limits on the occurrence of species unsuited to these ambient conditions and admit only species that are viable under the given environmental conditions (e.g. climate, disturbance regimes).

Ultimately, neither latitude nor elevation directly influence organisms. Rather, the actual drivers of the diversity patterns are ecological and historical factors that are associated with latitude and elevation (Körner 2007). For this reason, to truly understand how diversity patterns have developed, it is useful to not just analyze patterns against elevation and latitude, but also in relation to the covarying factors. The challenge here is identifying the crucial factors among the dozens of potential ecological drivers, whose influence is also likely to interact among each other and to differ in importance along different parts of the geographical gradients (Perrigo *et al.* 2020). Historical factors such as the timing of mountain uplift (Hoorn *et al.* 2013) are even more important to quantify. For this reason, a combination of geographical (latitude, elevation), ecological, and (if available) historical factors is optimal to understand the origin of diversity patterns.

In order to elucidate large-scale richness patterns, we investigated an evolutionarily well delimited plant group (ferns) within a region of high diversity along both latitudinal and elevational gradients. Ferns are the second-most diverse lineage of vascular plants on Earth with a rather complex evolutionary history and an estimated age of 431 ma, but also including more recent lineages with an approximately age of 40 ma to nearly 80 ma (Testo and Sundue 2016, Lehtonen *et al.* 2017). Due to their dispersal and reproduction via spores, ferns are largely independent of biotic interactions and represent a suitable group to investigate the phylogenetic aspect of biogeographical questions. By evaluating the relationship between climate and phylogenetic diversity on latitudinal and elevational gradients, our aim was to provide insight into the mechanisms driving assembly of species from regional pools into local assemblages (Qian *et al.* 2020). The Neotropics offer a unique opportunity for the analysis of gradients of biodiversity because they contain one of the greatest centers of fern species diversity (Tryon and Tryon 2012), numerous mountain ranges, and because the mountain ranges are largely arranged in a north to south fashion.

We gathered a dataset of 868 study plots and 922 fern species using a uniform sampling protocol, spanning the latitudinal gradient from the equator to 23°N, between sea level and mountain tops up to 4000 m. Thus, the latitudinal gradient covered by our study runs from the inner tropics through the transition zone of subtropical regions, which allowed us to integrate seasonal and dry climates, which are known to limit the diversity of ferns as humidity-dependent organisms (Page 2002, Brodribb and McAdam 2011), so that we expected them to react in terms of species assemblage patterns and their underlying phylogenetic diversity.

In previous studies, we have already shown that along our studied elevational gradients species richness (number of species per plot) of ferns show the characteristic hump-shaped pattern (Kessler *et al.* 2011, Salazar *et al.* 2015, Hernández-Rojas *et al.* 2020), and that overall richness of the gradients decreases from the equator northwards (Hernández-Rojas *et al.* 2018). In light of the phylogenetic hypotheses outlined above, for the present study we expected that the phylogenetic diversity of fern assemblages should decrease with increasing environmental stress. Within tropical humid mountain forests, where temperatures are moderate and humidity is consistently high, ferns do not experience physical but competitive limitations (Karger *et al.* 2014, Kessler *et al.* 2014), whereas towards low and high elevations (heat and frost) and towards high latitudes (increasing frost, drought, and seasonality), physical limitations for fern growth and reproduction emerge, not only changing richness, but also community composition and hence phylogenetic richness.

Specifically, we expected that

H1: Phylogenetic diversity decreases (i) latitudinally from south to north (i.e., tropics to subtropics) and (ii) elevationally towards extreme ends of the elevational gradient; and that

H2: these trends are closely related to the physical environment, especially amount and seasonality of precipitation.

## 4.2 MATERIALS AND METHODS

### 4.2.1 Study Area

We studied 11 elavational gradients between Ecuador (0°) and northern Mexico (23°N) (Fig. 4.1, Table 4.1). Elevational gradients extended from almost sea level to timberline (where present) and were selected in order to cover natural zonal forest with limited human disturbance patterns. With the exception of the transect in Honduras, the gradients have been described before, and further details may be found in previous publications: Costa Rica: Kluge and Kessler (2005); Ecuador: Salazar *et al.* (2015); Los Tuxtlas: Krömer *et al.* (2013), Hernández-Rojas *et al.* (2020); Perote: Carvajal-Hernández and Krömer (2015); Oaxaca: Hernández-Rojas *et al.* (2018); Triunfo, ChiapasN, Manantlan, Nayarit, and El Cielo: Hernández-Rojas *et al.* (2020).

Table4.1 Description of the study sites from the Equator to the limits of the tropics in Mexico

| **No.** | **Transect** | **Number of plots** | **Latitude (mean between plots)** | **Elevational range (m asl)** |
|---|---|---|---|---|
| 1 | Cielo* | 56 | 23.106 N, - 99.204 W | 200-2000 |
| 2 | Nayarit* | 47 | 21.483 N, - 104.979 W | 600-2200 |
| 3 | Manantlán* | 77 | 19.577 N, - 104.249W | 1200-2800 |
| 4 | Perote* | 38 | 19.558 N, - 96.903 W | 0-3500 |
| 5 | Tuxtlas* | 89 | 18.568 N, - 95.125 W | 100-1700 |
| 6 | Oaxaca* | 121 | 17.659 N, - 96.427 W | 300-3000 |
| 7 | ChiapasN* | 66 | 17.105 N, - 93.062 W | 100-2900 |
| 8 | Triunfo* | 163 | 15.643 N, - 92.822 W | 200-2400 |
| 9 | Honduras | 80 | 14.551 N, - 88.659 W | 1200-2800 |
| 10 | Costa Rica | 99 | 10.120 N, - 84.021 W | 100-3400 |
| 11 | Ecuador | 32 | -0.596 S, - 77.87 W | 500-4000 |

*Transecs located in Mexico.

### 4.2.2Vegetation sampling

On each gradient, we sampled the fern assemblages at regular elevational intervals of 100-300 m (every 500 m at Ecuador and Perote), depending on accessibility of zonal natural forest. At each elevation, up to 8 plots of 20 m x 20 m (400 m2) were sampled with a consistent, standardized methodology (Kessler and Bach 1999, Karger *et al.* 2014), avoiding special topographic and thus microclimatic changes like deep ravines and ridges. This size is small enough to keep environmental factors and forest structure more or less homogeneous within the plots and is the minimum area required for representative pteridophyte surveys in humid tropical forests (Kessler and Bach 1999). Within each plot, all terrestrial and epiphytic ferns were recorded. The following climbing, but ground-rooting species and genera were treated as terrestrials: *Lomaridium ensiforme*, Lomariopsis, Lygodium, *Mickelia lindigii,* and *M. bernouilii,* Odontosoria, Oleandra, Olfersia, Polybotrya, and Salpichlaena. Since we mostly did not climb the host trees, crown and high trunk epiphytes were recorded using binoculars and collecting poles, and by searching recently fallen trees and branches within the plot or adjacent locations (Gradstein *et al.* 2003).

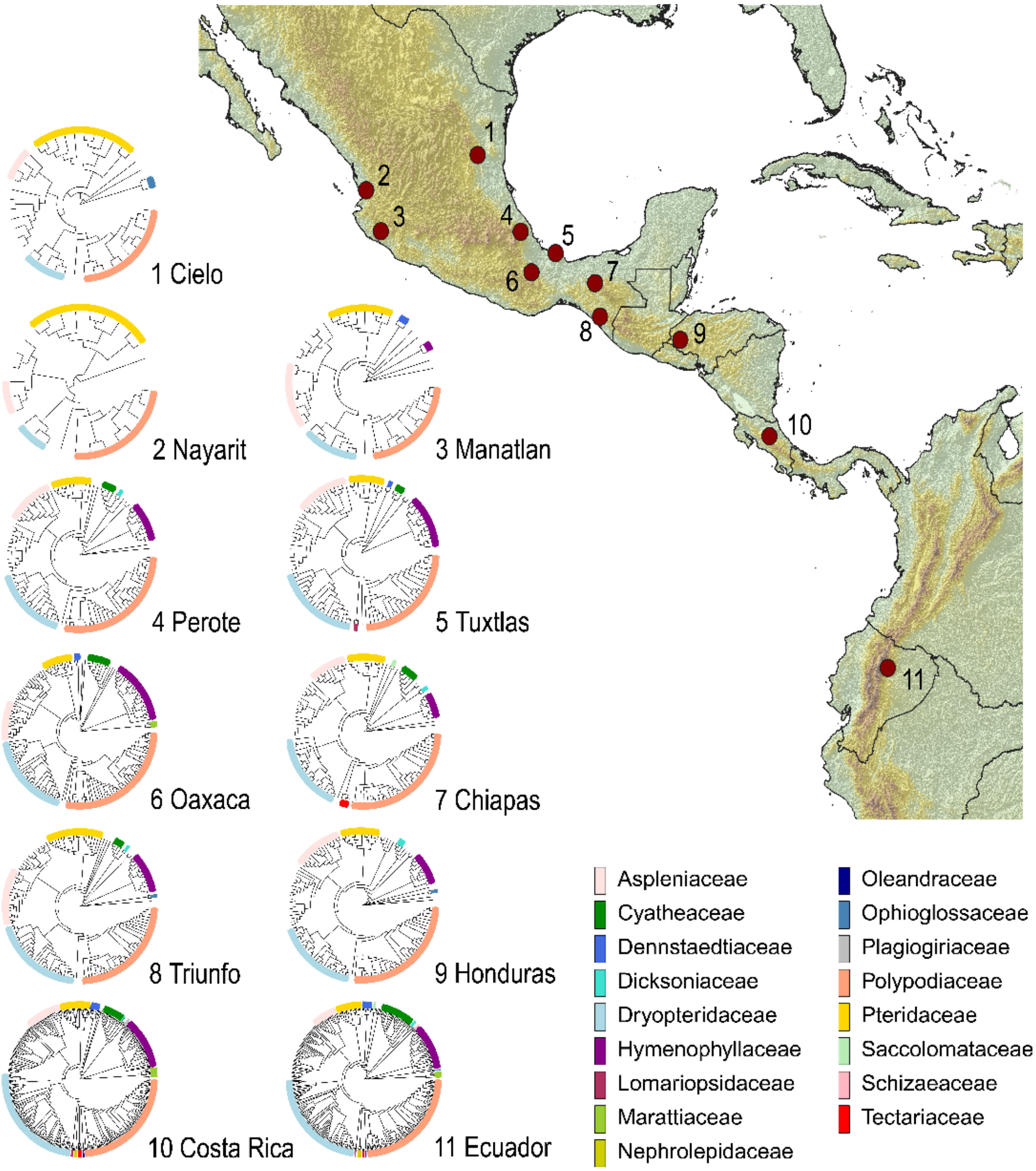

Fig. 4-1 Location of the 11 elevational transects including their phylogenetic tree showing the most important families.

### 4.2.3 Phylogenetic data

We measured the simple evolutionary relatedness within ecological communities or species assemblages using the most compressive available time calibrated phylogeny that includes the sequence data from six chloroplast region of 5057 tips of fern species (more than half of the extant ferns, Noben *et al.*, in press). We excluded lycophytes because they are sister to ferns plus seed plants and thus not closely related (PPG I 2016). Only taxa determined to the species level and some determined to genus (mainly for Ecuador, if they were the only species of the genus recorded) were included. Of the total of 922 species, 632 (68.5%) were represented in the phylogenetic tree (see Appendix T 4-1). For the 290 species (31.5%) not represented in the phylogeny, we searched for the putative closest relative in the phylogenetic tree (based on morphology), avoiding to use the 632 species that had already been selected.

We analyzed three different data sets separately: all species, terrestrials, and epiphytes, because both major fern life forms represent different ecological groups and thus react differently to environmental drivers in terms of richness and composition. We used presence-only data because a few plots had no abundance information, to avoid personal biases in abundance estimation, and because preliminary analyses showed that phylogenetic diversity patterns were similar using both presence-absence and abundance data. We used two different measures for calculating phylogenetic diversity of the assemblages: mean pairwise distance (MPD), which is an estimate of the average phylogenetic relatedness on basis of the branches between all possible pairs of taxa in a local community (plot assemblage) (Kembel 2010), and MNTD or mean nearest taxon distance, which is the mean distance separating each species in the community from it closest relative. MPD is generally thought to be more sensitive to tree-wide patterns of phylogenetic clustering and evenness, whereas MNTD is more sensitive to patterns of evenness and clustering closer to the tips of the phylogeny (Kembel 2010, Cadotte and Davis 2016). Since these metrics of phylogenetic diversity are not statistically independent of species richness, we used the standardized effect sizes (SES) of these metrics (sMPD and sMNTD), which compare empirical values against randomized null communities (Kembel *et al.* 2010) to standardize for unequal richness across samples (Faith 1992) (for constructing an appropriate Null model see next section). Positive SES values indicate phylogenetic overdispersion, or a greater phylogenetic distance among co-occurring species than expected by chance and thus high phylogenetic diversity. Negative SES values indicate phylogenetic clustering, or smaller phylogenetic distances among co-occurring species than expected by chance (Kembel *et al.* 2010). All phylogenetic metrics and null model estimation were obtained by using the R package picante (Kembel *et al.* 2010).

### 4.2.4 Null model selection

Selecting an appropriate null model is crucial and requires knowing the model assumptions and choosing the appropriate species pool (Gotelli and Graves, 1996, Gotelli, 2000, Webb *et al.* 2011). Because all transects belong to a coherent biogeographical region, we analyzed all transects together taking the whole species list as the basic species pool. We tested two procedures to gain 9999 randomly constructed assemblages using a fully constrained model that randomizes the community data matrix keeping richness and occurrence frequencies constant (constrained model: “trial swap algorithm”, Miklós and Podani 2004, which is a modification of the “independent swap algorithm”, Gotelli and Graves 1996, Gotelli 2000, but performs much faster using the same constraints). This model assumes that a species ability to colonize a plot is proportional to its frequency in the community matrix (Kembel and Hubbell 2006). We also used a model without any constraints in the randomization procedure, randomly shuffling the tips labels across the tips of the phylogeny (unconstrained model, “taxa labels”). Both models showed highly congruent results in the phylogenetic pattern differing only in the magnitude (Supplementary F 4-1), so that we here only show results for the null assemblages constructed with the trialswap algorithm.

### 4.2.5 Explanatory variables

As environmental variables, we included energy-related variables (temperature) and humidity-related variables, since the study group is closely dependent on climatic factors related to humidity because their sexual reproduction is linked to the presence of water (Page 2002) and because of their poor stomatal control (Kessler 2001a, Brodribb and McAdam 2011). Besides mean temperature and precipitation and their temporal variability and extreme values, we additionally included cloud cover as a variable because clouds reduce solar radiation and provide extra ‘occult’ precipitation (Bruijnzeel and Veeneklaas 1998). We extracted the following climatic variables per plot from the global climate data base set CHELSA (Karger *et al.* 2017): Annual mean temperature and precipitation (Bio1, Bio12), as well as temperature and precipitation seasonality (Bio4, Bio15), the seasonal extremes maximum temperature of the warmest and coldest month, and the precipitation of the wettest and driest month (Bio5, Bio6, Bio13 and Bio14). Annual cloud cover and its seasonality were extracted from the 'EarthEnv'-dataset (CA, CS, Wilson and Jetz 2016). We checked for correlations between these variables to control for multicollinearity in models and excluded variables from the dataset that were highly correlated to already included variables (Pearson's R>75). As a result, we used the following variables to construct the full model: mean annual temperature TEMP, temperature seasonality TEMPs, annual precipitation PREC, and mean annual cloud cover CA. Also, we ran models using latitude, elevation, and elevation to the square (Elevation + Elevation2) because of the mostly humped nature of fern elevational gradients (Kessler *et al.* 2011).

### 4.2.6 Statistics

Because spatially proximate plots often share many species and to account for differences in plot numbers between transects, for the analyses we combined the phylogenetic diversity values of all plots in steps of 500 m, and used these means for further analyses. Since our individual data points (plots) were not randomly distributed between the latitudinal and elevational limits, we used linear mixed effects models (LMMs) to control for the non-independence among data points in assessing changes in the phylogenetic variables with elevation, latitude, and in relation to climatic variables (fixed effects), because these models allow for spatial autocorrelation between neighbors (Crawley 2013). We used Likelihood Ratio Tests (LRT) or 'deviance tests' to compare between a null model without the term of interest and the model including this term to determine if one is a better fit to the data than the other (Luke 2017, Winter 2019). For the models including climatic variables or many fixed effects, we performed a full suite of likelihood ratio tests for all fixed effects in a model and constructed the correspondent comparison model providing p values for all fixed effects in a model (Singmann *et al.* 2020, Winter 2019). All variables used in the models were scaled (mean = 0 and SD = 1). To account for the non-independence of our data, the analyses were performed using the mean per elevational band every 500 m in elevation using the random structure “1|TRANSEC” indicating that the intercept is different for each transect, and “1” stands for the intercept here. In other words, there is going to be multiple responses per transect and these responses will depend on each transect baseline level. To decide whether such a simplified model was an enhancement to the previous model, we calculated the cAIC (conditional Akaike Information Criterion, Saefken and Ruegamer 2018), with a lower cAIC indicating a better model. Additionally, we calculated the amount of variation explained by the fixed (marginal R2) and random effects (conditional R2) of each model.

All analyses were performed with the statistical platform R (R Core Team 2020) using the packages ‘lme4’ (Bates *et al*. 2015), ‘afex’ (Singmann *et al.* 2020), ‘MuMIn’ (Barton 2019), ‘cAIC4’ (Saefken *et al.* 2018), ‘MuMIn’ (Nakagawa and Schielzeth 2013, Barton 2019), and ‘ggtree’ (Yu *et al.* 2017, Yu *et al.* 2018, Yu 2020) to construct the phylogentic trees showed here.

## 4.3 RESULTS

Along the latitudinal gradient, not only species richness decreased, but the species set was thinning out in a non-random manner (Fig. 4-1). Especially typical tropical fern groups like tree ferns (Cyatheaceae) and filmy ferns (Hymenophyllaceae), but also the families Gleicheniaceae, Lomariopsidaceae, Nephrolepidaceae, Marratiaceae, and Schizaceae faded out, whereas especially phylogenetically young families like Dryopteridaceae and Polypodiaceae kept their dominance within the species sets of the gradients (Fig. 4-1).

The core tropical gradients in Ecuador and Costa Rica showed overdispersion of sMPD almost throughout their elevational ranges, with decreasing values towards high elevation sites around tree line (clustering, Fig. 4-2). Towards higher latitudes, overdispersion was increasingly limited to mid-elevations and clustering dominating in the northernmost transects. In contrast, values of sMNTD rarely revealed overdispersion and showed unspecific patterns. Separation for major life forms showed that this overall pattern was strongly driven by epiphytic species, whereas terrestrial communities showed values shifted to more clustered communities.

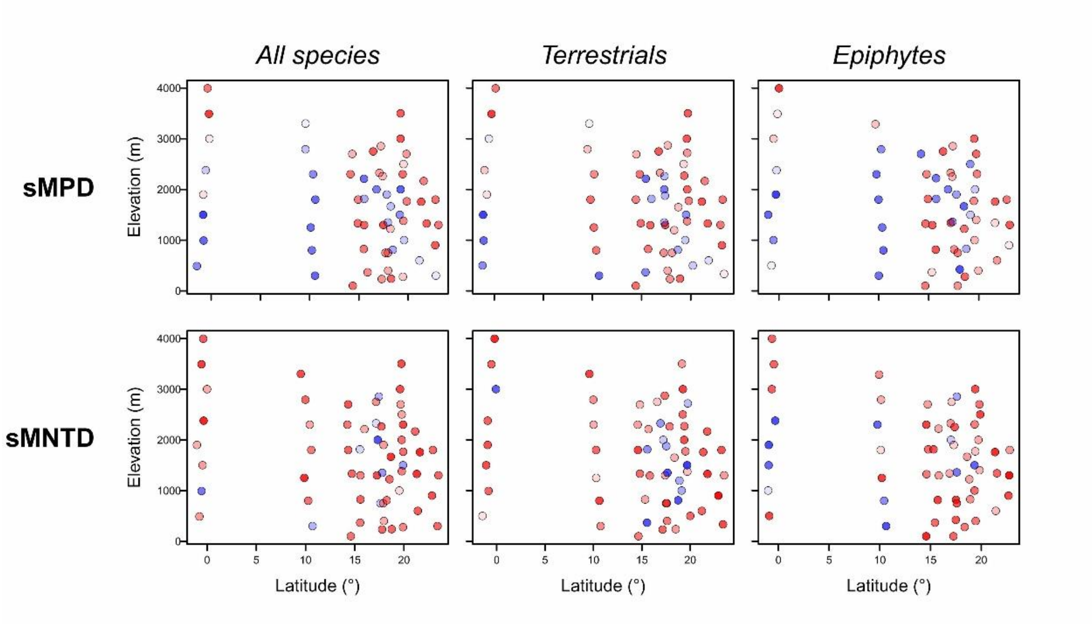

Fig. 4-2 Patterns of standardized effect sizes of the MPD (mean pairwise distance) and MNTD (mean nearest taxon distance) for all fern species, and for terrestrial and epiphytic ones separately against latitude and elevation. Values of sMPD and sMNTD are indicated by colors: red: negative values, blue: positive values; color intensity increases with difference from zero.

Model relations of sMPD and sMNTD values to spatial and climatic variables showed that when considering all species, latitude and elevation per se did not have a strong effect on the phylogenetic variables (Tab. 2). In terms of explained variance (marginal $R^2$), models of sMPD only including spatial variables (latitude, elevation) had $R^2$m values of 0.13-0.17, whereas when including climatic variables, values were much higher ($R^2$m = 0.43) and showed positive relationships. sMNTD showed no patterns, neither with latitude or elevation, nor with climatic factors. Terrestrial assemblages only showed weak latitudinal and elevational patterns of sMPD ($R^2$m = 0.09-0.13), but none in relation to climatic factors, whereas sMNTD showed no significant patterns at all. Finally, the patterns of epiphytic assemblages largely mirrored the overall patterns for sMPD, whereas for sMNTD, they showed additional, albeit weak relationships with latitude and elevation ($R^2$m = 0.13-0.20), as well as with climate ($R^2$m = 0.10).

Table 4-2. Results of the Likelihood ratio test by phylogenetic variable with p values for all fixed effects in the linear mixed models (coefficients), using the transects as random factor and the mean per elevational band on 500 m. Only the models with delta=0 are showed (function dredge). TEMP and TEMPs: annual mean temperature and its seasonality, PREC: annual precipitation and CA: annual cloud cover. *** *P* <0.001, ***P*<0.01, **P*<0.05.

| | | **ELEV** | **LAT** | **TEMP** | **PREC** | **TEMPs** | **CA** | **$R^2$m** | **$R^2$c** |
|---|---|---|---|---|---|---|---|---|---|
| ***All species*** | sMPD | -0.006** | | | | | | 0.17 | 0.50 |
| | | | -0.007* | | | | | 0.13 | 0.21 |
| | | | | 0.005* | 0.008* | | 0.006* | **0.43** | 0.47 |
| | sMNTD | | | 0.004* | | | | 0.00 | 0.07 |
| ***Terrestrials*** | sMPD | -0.002* | | | | | | 0.13 | 0.20 |
| | | | | 0.003* | | | | 0.09 | 0.12 |
| | sMNTD | - | - | - | - | - | - | - | - |
| ***Epiphytes*** | sMPD | -0.012*** | | | | | | 0.14 | 0.54 |
| | | | -0.014* | | | | | 0.16 | 0.31 |
| | | | | | 0.016*** | | 0.009* | **0.47** | 0.47 |
| | sMNTD | -0.007 *** | | | | | | 0.13 | 0.52 |
| | | | -0.010* | | | | | **0.20** | 0.29 |
| | | | | | 0.008* | | 0.007* | 0.10 | 0.15 |

## 4.4 Discussion

With these first phylogenetic analyses of a large dataset from a latitudinally wide range of elevational transects in the Neotropics, we are able to detect relatively low, but clear and significant phylogenetic trends of the taxonomic compositions of ferns and their environmental correlates. These relations do not only shed light on the environmental limits set to distributions and niches of this group of vascular plants, but more importantly on their evolutionary processes and abilities of its major life forms and taxonomic groups to originate and adapt to increasingly stressful environments, as mirrored by the latitudinal and elevational gradients.

An underlying consideration of our study is that neither of the two geographical gradient types, latitude and elevation, do explain anything per se. Rather, it is their climatic and spatial structure which are relevant. While this is well known, in principle (Körner 2007, Qian *et al.* 2020), many studies still treat latitude and elevation as direct explanatory factors. We here interpret them as geographical gradients along which patterns of phylogenetic diversity may be seen, but that are not directly driven by them. In the following, we therefore focus our interpretations more on the underlying ecological factors, also because these showed stronger relationships with the phylogenetic patterns.

The first clear pattern was that sMPD showed clear positive relationships with mean annual precipitation, temperature, and cloud cover, meaning that assemblages in hot, wet, and cloudy habitats tended to have higher relative phylogenetic diversity than those under cold, dry, and sunny conditions. Interestingly, this pattern was only seen for sMPD and not for sMNTD, indicating that it was driven by the presence or absence of deep phylogenetic lineages, rather than by more recent radiations within distinct lineages. Indeed, examinations of the distribution of individual families showed that this pattern is driven by phylogentically old families such as Cyatheaceae, Dicksoniaceae Dennstaedtiaceae, Hymenophyllaceae, Lomariopsidaceae, Marratiaceae, Nephrolepidaceae, Plagiogyriaceae, Saccolomataceae and Schizaceae (Fig. 4-1), which all showed a more or less sudden decline in diversity when reaching subtropical climates in Mexico (~15°N) and dry and cold habitats in general. In contrast, evolutionary younger families such as Dryopteridaceae and Polypodiaceae, gained dominance in colder and dryer habitats (Fig. 4-1).

Overall, this pattern suggests a strong effect of phylogenetic niche conservatism (Jablonski *et al.* 2006, Jansson *et al.* 2013), in which phylogenetically older fern lineages evolved under humid tropical conditions, which were globally prevalent over much of the time period of the original diversification of major fern lineages (Page 2002, Wiens and Donoghue 2004, Becker et al. 2016). The extant lineages from this original fern radiation clearly still favour such conditions, and their dropping out towards colder and dryer habitats thus has a strong effect on phylogenetic measures emphasizing deep phylogenetic splits such as MPD (Kembel 2010, Webb *et al.* 2011). The underlying climatic gradients in both directions tell the well-known story of diversity gradients in ferns, which are poorly adapted to withstand extreme temperatures and drought because of passive stomatal control (Barrington 1993, Brodribb *et al.* 2009, Brodribb and McAdam 2011). This pattern of decreasing phylogenetic diversity with increasing latitude and elevation and towards dry and cold habitats has been previously documented in ferns (Kluge and Kessler 2011a) and in other groups of organisms (e.g., trees: Qian and Ricklefs 2011; herbs: Masante *et al.* 2019; hummingbirds: Graham et al. 2009; microbes: Wang *et al.* 2012), and is one of the major explanations for high tropical species diversity in these groups. However, there appear to be differences between study groups and geographical regions that may deserve closer examination. For instance, among forest trees in eastern North America, Qian *et al.* (2020) found that phylogenetic patterns were clearer along elevational than latitudinal gradients, which is not the case in our study, and that tip-weighted phylogenetic measures (MNTD) showed clearer patterns than base-weighted measures (MPD), which is the opposite of what we found. It is too early to derive generalizations from such a contrast, but unsurprisingly it would appear that ferns and angiosperm trees show different patterns of phylogenetic community structure reflecting their different evolutionary histories.

Interestingly, we found that terrestrial and epiphytic fern assemblages showed very different phylogenetic diversity patterns. Whereas epiphytic assemblages largely mirrored the overall pattern, this was not the case for the terrestrial assemblages. We suspect that this may at least partly be driven by the fact that epiphytic ferns only occur in six major lineages: the evolutionarily old Hymenophyllaceae and Psilotaceae, and the younger Pteridaceae (in the vittarioid ferns), Aspleniaceae, Dryopteridaceae, and Polypodiaceae (Schneider *et al.* 2004, Schuettpelz and Pryer 2009, Noben *et al.* in press). Of these, the Psilotaceae and vittarioids are almost entirely tropical, the Hymenophyllaceae is mainly so, and the Aspleniaceae, Dryopteridaceae, and Polypodiaceae are well represented in temperate regions, although mainly with non-epiphytic species. Thus, it is not surprising that a very clear pattern emerges: the phylogenetically more basal lineages are tropical, and the phylogenetically younger lineages are widespread. As a result, the loss of many families, especially the Hymenophyllaceae, which is very abundant in wet tropical forests, towards arid and cold habitats results in a strong phylogenetic signal that presumably, drives the pattern of sMPD seen by us. Indeed, in the most arid and cold environments, only the family Polypodiaceae remains as epiphytes (Sylvester *et al.* 2014, Sundue *et al*. 2014). This – from a fern historical perspective – young family (90-30 my old, Schneider *et al.* 2004, Schuettpelz and Pryer 2009, Testo and Sundue 2016), has evolved numerous adaptations to both dry and cold conditions, including water storage, poikilohydry, and frost tolerance (Barrington 1993, Watkins *et al.* 2007, Sundue *et al.* 2014).

Among terrestrial ferns, in contrast, the pattern is much less clear. Essentially all fern families have terrestrial representatives, and many fern families are exclusively terrestrial. Thus, although some tropical fern families clearly avoid dry and cold habitats (e.g., Cyatheaceae, Lomariopsidaceae, Lygodiaceae, Marattiaceae, Nephrolepidaceae, Oleandraceae, Schizeaceae, Tectariaceae), there are enough other, phylogenetically old families that do occur under such conditions (e.g., Anemiaceae, Equisetaceae, Ophioglossaceae), so that a wide range of phylogenetic lineages is represented in the majority of fern assemblages. As a result of this, we did not find a clear phylogenetic structure as seen for the epiphytic ferns.

An even more striking result, is the fact that whereas among epiphytes sMPD showed a much stronger signal relative to climatic factors ($R^2m = 0.43$) than relative to latitude ($R^2m = 0.13$) or elevation ($R^2m = 0.17$), the reverse was true for terrestrial assemblages, with low values for elevation ($R^2m = 0.13$) and even lower values for climatic factors (temperature only; $R^2m = 0.09$). This suggests that the community composition of epiphytic ferns is much more strongly determined by climatic factors than that of terrestrial ferns. This makes ecological sense, since epiphytic plants are directly exposed to climatic factors and strongly depend on water availability and drought avoidance to be able to survive in the canopy habitat (Zotz 2016). Terrestrial ferns, in contrast, appear to be much less dependent on climatic factors, but rather are influenced by such factors as soil conditions or vegetation structure. For instance, the distribution of many fern species is well known to be closely linked to soil conditions (Tuomisto *et al.* 2002, 2014) and microtopography, which influences microclimate and light availability (Jones *et al.* 2011). Because these factors are unavailable at the scale of our study plots, we were unable to include them in our study, but we suspect that if such data were available, we would find that the latitudinal and elevational patterns of the phylogenetic structure of terrestrial ferns seen by us are in fact driven by ecological factors that are still undisclosed.

We found that overall, fern assemblages in the Neotropics show a pattern of phylogenetic niche conservatism, with phylogenetically more diverse assemblages under wet and warm to cool conditions at low latitudes and elevations. This suggests that environmental filtering (Donogue 2008, habitat filtering sensu Harper 1977) is a main process for structuring fern assemblages. This is in accordance with findings that the global diversification of ferns was strongly influenced by extinction events driven by unfavourable climatic conditions in the past (Lehtonen *et al.* 2017), thus limiting many fern lineages to the remaining suitable habitats. However, whereas epiphytic fern assemblages appear to be strongly influenced by climatic factors, this is not the case for terrestrial ones, suggesting that edaphic conditions and vegetation structure may have a stronger influence on the evolution and diversification of terrestrial ferns. Thus, although the overall pattern of niche conservatism and environmental filtering is in accordance with that observed in many groups of organisms, the striking divergence of the actual factors determining this among epiphytic and terrestrial ferns opens exciting research opportunities for unravelling generalities of how community assembly processes can be driven in similar (or different) directions by different sets of environmental factors.

Author contributions: A. H., J. K. & M. K. conceived the ideas, designed the methodology and analyzed the data; A. H., C. C., L. S., M. K., & T. K. collected the data; S. N. provided the phylogeny, A. H. led writing the manuscript. All authors contributed critically to the manuscript and gave final approval for publication.

# SYNTHESIS AND OUTLOOK

# 5 SYNTHESIS AND OUTLOOK

## 5.1 Synthesis

Although elevational-latitudinal patterns of plant and animal diversity have been studied for centuries, factors driving the observed patterns are still controversially discussed (Hillebrand 2004, Qian & Ricklefs 2011). Tropical mountains offer an excellent natural experiment to unravel these drivers of biogeographical patterns and the integration of multiple elevational gradients along an extended latitudinal gradient is an outstanding opportunity to decipher underlying mechanism of large-scale patterns of species richness. In this research, data obtained from elevational transects in Mexico was unified with data from transects in America, spanning 0° to 23°N degrees of latitude, mostly between sea level and mountain tops (200-4000 m a.s.l.). We aimed to describe species richness and range size patterns and to understand the broad scale distribution of other important components of biodiversity, such as the phylogenetic diversity and associated metrics, using a standardized methodology that allows the comparison of elevational transects.

The results are presented in a series of chapters starting from the detailed analysis of one gradient in Mexico (Chapter 2, published in 2018 in the American Fern Journal, Hernández-Rojas *et al.* 2018). Overall, we found that the richness per plot was low compared to other elevational gradients within the tropics closer to the Equator. This decline of species richness towards the subtropics and temperate regions appears to be rather abrupt within Central America, but additional data were needed to close the remaining gap of knowledge between Costa Rica and Mexico.

In the central work or of this research (Chapter 3, Hernández-Rojas *et al.* 2020), we assessed the richness and range size patterns of ferns and lycophytes along seven elevational gradients at different latitudes and searched for predictors of range size from a set of environmental factors. We found that species richness per plot increased with elevation up to about 1,500-2,000 m, with strong differences in overall species richness between transects and a reduction with increasing latitude. The mean weighted range size of species within assemblages declined with elevation and increased with latitude, and was highly correlated with the seasonality of both temperature and precipitation, and annual cloud cover. Thus, I demonstrated that latitudinal and elevational patterns of range size in fern assemblages are driven by an interplay of factors: factors favoring wide-ranging species (e.g., higher latitudes with increasing temperature seasonality and dryer habitat conditions) and those favoring species with restricted ranges (e.g., higher elevations with more humid habitat conditions), with additional variation introduced by the specific conditions of individual mountain ranges. Climatically stable, humid habitats apparently provide favorable conditions for small-ranged fern species, and should accordingly be given high priority in regional conservation planning.

Finally, this work showed that phylogenetic approaches should be seen as an integral component of studies of community structure. This allows to understand how communities have evolved through time, and to deeply understand biogeographical processes (Losos 1996). This aspect is included as the final part of this research (Chapter 4, invitation to the special issue on elevational gradients for Frontiers of biogeography, in preparation) that was aimed to unfold the complex changes in the phylogenetic structure along elevation (200-4000 m.a.s.l.) and latitude (0°-23° N). We compiled a comprehensive data set including 11 elevational transects closing the gap of information observed in Chapter 2 (Hernández-Rojas *et al.* 2018). At this point, I should highlight the relevance of this research as a product of the work of many researchers that I have the honor to synthesize to get a complete view of biogeographic and phylogenetic patterns. Our results showed that latitude and elevation per se are weak explanatory variables for phylogenetic diversity, but incorporating climatic variables clearly enhances the explanatory power of the models. Overall, the phylogenetic diversity decreased with increasing latitude and elevation, as could be observed by the increased clustering of closely related species. Additionally, it is worthwhile to look at taxonomic groups of ferns separately for the main lifeforms, as they are not only ecologically different, but also not congruent in their evolutionary history. The general pattern of phylogenetic diversity is mainly driven for the suppression of the old, basal tropical, terrestrial lineages rather than by recent evolutionary history and better explained by climatic variables.

This research shows that an integrative approach including very basic ecological and phylogenetic data and their analysis along an elevational and latitudinal gradients is necessary to provide a more complete overview of factors determining species distributions.

## 5.2 Outlook

The origins of biogeography (the “geography of nature”) must reach far back in the early history of our species, but the modern approach of this discipline dates back mainly to

Humboldt, Wallace and Darwin (Lomolino 2001). Up to date many studies on latitudinal and elevational gradients exist, but nature is complex, especially in the tropics where many regions are still unexplored in certain aspects.

Although elevational-latitudinal patterns of plant and animal diversity have been studied for centuries, factors driving the observed patterns are still controversially discussed (e.g., Hillebrand 2004, Qian & Ricklefs 2011). Recently considered, partly interlinked explanations for such large-scale richness patterns appear to involve mainly climatic variables (e.g., Heaney 2001, Kessler 2001a, Hawkins *et al.* 2003, Currie *et al.* 2004), and historical and evolutionary processes (e.g., Ricklefs 2004, Wiens & Donoghue 2004). My contribution to this research with the Mexican data and the integration of other transects from the Equator to Honduras was an opportunity to decipher drivers in range size, species richness and its phylogenetic composition. I here show the importance of climatic variables more than latitude and elevation per se, shaping the distribution and evolutionary history of ferns that serves as a model of how land plants have evolved and adapted to their environment (Kessler 2010). Climatically stable, humid habitats provide favorable conditions for small-ranged fern species and high phylogenetic diversity. These habitats should accordingly be given high priority in regional conservation planning. Also, the pattern of species richness is more complex that the simple decreasing with latitude. An abrupt change on species richness occurred towards the north inside of the tropics around 20° N. Further, I found transect-specific patterns that are not captured by the general relationships discussed so far. Individual mountain ranges are unique depending on their geology, topographical profiles, and past climatic fluctuations, resulting in individual “mountain fingerprints” (Flantua & Hooghiemstra, 2018) that should be analyzed in detail. Replicated sampling in the different mountain ranges is necessary, specially to fill the gaps of knowledge in tropical countries like Colombia or Venezuela. Additionally, it is necessary to complement the phylogenetic approach, including the rates of speciation and extinction occurring in that megadiverse areas. The tropics are museums and cradles of biodiversity and constitute a legacy of millions of years of evolution, and deserves a deep understanding to promote better human practices. With the development of new technics, tools in informatics, statistics and the addition of new information this understanding is now possible. However, it is still necessary to link the generated knowledge to the sphere of public policies and important social actors that have an impact on forests.

# REFERENCES

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Abotsi, K. E., Bose, R., Adjossou, K., Deblauwe, V., Rouhan, G., Segla, K. N., Atsri K. H. & Kokou, K. (2020) Ecological drivers of pteridophyte diversity and distribution in Togo (West Africa). Ecological Indicators, 108, 105741.

Acebey, A., Krömer, T. & Kessler, M. (2017) Species richness and vertical distribution of ferns and lycophytes along an elevational gradient in Los Tuxtlas, Veracruz, Mexico. 235, 83-91.

Addo-Bediako, A., Chown, S. & Gaston, K. (2000) Thermal tolerance, climatic variability and latitude. Proceedings of The Royal Society Series B: Biological sciences, 267, 739-745.

Alfonso Corrado, C., Naranjo-Luna, F., Clark-Tapia, R., Campos, J., Rojas-Soto, O., Luna-Krauletz, M., Bodenhorn, B., Gorgonio, 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.

Hemp, A. (2001) Ecology of the Pteridophytes on the Southern Slopes of Mt. Kilimanjaro. Part II: Habitat Selection. Plant Biology, 3, 493-523.

Hemp, A. (2002) Ecology of the pteridophytes on the southern slopes of Mt. Kilimanjaro – I. Altitudinal distribution. Plant Ecology 159, 211-239.

Antonelli, A., Nylander, J., Persson, C. & Sanmartin, I. (2009) Tracing the impact of the Andean uplift on Neotropical plant evolution. Proceedings of the National Academy of Sciences of the United States of America, 106, 9749-9754.

Arana, M.D., Larsen, C. & Ponce, M.M. (2016) Revisión y análisis panbiogeográfico de las Hymenophyllaceae de las Yungas meridionales de Argentina (Selva Tucumano-Boliviana). Rodriguésia, 67, 55-76.

Arriaga, L., Espinoza, J.M., Aguilar, C., Martínez, E., Gómez, L. & Loa, E. (2000) Regiones terrestres prioritarias de México. Comisión Nacional para el Conocimiento y uso de la Biodiversidad. México, México.

Barbosa-Silva, R., Labiak, P., Gil, A., Goldenberg, R., Michelangeli, F., Martinelli, G., Nadruz, M., Zappi, D. & Forzza, R. (2016) Over the hills and far away: New plant records for the Guayana Shield in Brazil. Brittonia, 68, 397–408.

Barrington, D.S. (1993) Ecological and Historical Factors in Fern Biogeography. Journal of Biogeography, 20, 275-279.

Barton, K. (2019). “MuMIn”: Multi-Model Inference, R package version 1.43.6.

Bates, D., Maechler, M., Bolker, B. & Walker, S. (2015) Fitting Linear Mixed-Effects Models Using “lme4". Journal of Statistical Software, 67, 1-48.

Behrensmeyer A. K., Damuth J. D., DiMichele W.A., Potts R. (1992) Terrestrial ecosystems through time: evolutionary paleoecology of terrestrial plants and animals. University of Chicago Press

Bhattarai, K.R. & Vetaas, O.R. (2006) Can Rapoport's rule explain tree species richness along the Himalayan elevation gradient, Nepal? Diversity and Distributions, 12, 373-378.

Bhattarai, K.R., Vetaas, O.R. & Grytnes, J.A. (2004) Fern species richness along a central Himalayan elevational gradient, Nepal. Journal of Biogeography, 31, 389-400.

Bivand, R. & Lewin-Koh, N. (2019) Maptools: Tools for Handling Spatial Objects. R package version 0.9-5.

Blackburn, T.M. & Gaston, K.J. (1996) Spatial patterns in the geographic range sizes of bird species in the New World. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 351, 897-912.

Böhm, M., Kemp, R., Williams, R., Davidson, A.D., Garcia, A., McMillan, K.M., Bramhall, H.R. & Collen, B. (2017) Rapoport's rule and determinants of species range size in snakes. Diversity and Distributions, 23, 1472-1481.

Boyle, B.L. (1996) Changes on altitudinal and latitudinal gradients in neotropical montane forests. Ph.D. Thesis. Washington University.

Brodribb, T. & McAdam, S. (2011) Passive Origins of Stomatal Control in Vascular Plants. Science, 331, 582-585.

Brodribb, T., McAdam, S., Jordan, G. & Feild, T. (2009) Evolution of stomata responsiveness to CO2 and optimization of water-use efficiency among land plants. The New phytologist, 183, 839-847.

Brown, J., Stevens, G. & Kaufman, D. (1996) The geographic range: Size, shape, boundaries, and internal structure. Annual Review of Ecology and Systematics, 27, 597-623.

Brown, J. H. (2014). Why are there so many species in the tropics?. Journal of biogeography, 41(1), 8-22.

Bruijnzeel, L.A. & Veneklaas, E.J. (1998) Climatic conditions and tropical montane forest productivity: The fog has not lifted yet. Ecology, 79, 3-9.

Brummitt, N., Aletrari, E., Syfert, M.M. & Mulligan, M. (2016) Where are threatened ferns found? Global conservation priorities for pteridophytes. Journal of Systematics and Evolution, 54, 604-616.

Bye, R., Lot, A., Fa, J. & Conzalez-Montagut, R. (1993) Biological diversity of Mexico: Origins and distribution. Oxford University Press. New York.

Cadotte, M.W. & Davies, T.J. (2016) Phylogenies in ecology: a guide to concepts and methods. Princeton University Press

Cardillo, M. (1999) Latitude and rates of diversification in birds and butterflies. Proceedings of the Royal Society of London. Series B: Biological Sciences, 266, 1221-1225.

Carlquist, S.J. (1974) Island Biology. Columbia Univeristy Press.

Carvajal-Hernández, C. & Krömer, T. (2015) Riqueza y distribución de helechos y licófitos en el gradiente altitudinal del Cofre de Perote, centro de Veracruz, México. Botanical Sciences, 93, 601-614.

Carvajal-Hernández, C., Krömer, T., Lopez Acosta, J.C., Gomez-Diaz, J. & Kessler, M. (2017) Conservation value of disturbed and secondary forests for ferns and lycophytes along an elevational gradient in Mexico. Applied Vegetation Science, 20(4), 662-672.

Carvajal-Hernández, C.I., Silva-Mijangos, L., Kessler, M. & Lehnert, M. (2018) Adiciones a la pteridoflora de Tabasco, México: la importancia del bosque mesófilo de montaña. Acta Botanica Mexicana, 124, 7-18.

Cavender-Bares, J., Kozak, K. H., Fine, P. V., & Kembel, S. W. (2009). The merging of community ecology and phylogenetic biology. Ecology letters, 12(7), 693-715.

Cicuzza, D., Krömer, T., Poulsen, A.D., Abrahamczyk, S., Delhotal, T., Piedra, H.M. & Kessler, M. (2013) A transcontinental comparison of the diversity and composition of tropical forest understory herb assemblages. Biodiversity and Conservation, 22, 755-772.

Crawley, M.J. (2013) The R book. Second edition. Chichester, West Sussex, United Kingdom: Wiley, 2013.

Currie, D.J., Mittelbach, G.G., Cornell, H.V., Field, R., Guégan, J.F., Hawkins, B.A., Kaufman, D.M., Kerr, J.T., Oberdorff, T. & O'Brien, E. (2004) Predictions and tests of climate-based hypotheses of broad-scale variation in taxonomic richness. Ecology letters, 7, 1121-1134.

Darwin, C. (1859) The origin of species by means of natural selection: or, the preservation of favored races in the struggle for life London: J. Murray.

De Bello, F., Lepš, J. & Sebastià, M.T. (2006) Variations in species and functional plant diversity along climatic and grazing gradients. Ecography, 29, 801-810.

Díaz, S. & Cabido, M. (1997) Plant functional types and ecosystem function in relation to global change. Journal of vegetation science, 8, 463-474.

Faith, D.P. (1992) Conservation evaluation and phylogenetic diversity. Biological conservation, 61, 1-10.

Fine, P.V. (2015) Ecological and evolutionary drivers of geographic variation in species diversity.Annual Review of Ecology, Evolution, and Systematics, 46, 369-392.

Fernández Carnevali, C.G., Tapia Muñoz, J.L., Dino de Stephano, R., Ramírez Morillo, I.M., Can Itzá, L., Hernandéz Aguilar, S. & Castillo, A. (2012) La flora de la Península de Yucatán Mexicana: 250 años de conocimiento florístico. Biodiversitas, 101, 6-10.

Flantua, S. & Henry, H. (2018) Historical Connectivity and Mountain Biodiversity (with special reference to the Northern Andes), 171-185.

Flantua, S.G.A., O'Dea, A., Onstein, R.E., Giraldo, C. & Hooghiemstra, H. (2019) The flickering connectivity system of the north Andean páramos. Journal of Biogeography, 46, 1808-1825.

Fleishman, E., Austin, G.T. & Weiss, A.D. (1998) An empirical test of rapoport’s rule: elevational gradients in montane butterfly communities. Ecology, 79, 2482-2493.

Gaston, K.J. (1998) Species-range size distributions: products of speciation, extinction and transformation. Philosophical Transactions of the Royal Society B: Biological Sciences, 353, 219-230.

Gaston, K.J. & Chown, S.L. (1999) Why Rapoport's Rule Does Not Generalise. Oikos, 84, 309-312.

Gaston, K. & Blackburn, T. (2008) Pattern and process in macroecology. John Wiley & Sons

GBIF: The Global Biodiversity Information Facility (2018) Occurence Download. Retrieved August-September, 2018. Available from: https://www.gbif.org

Gentry, A.H. & Dodson, C. (1987) Contribution of Nontrees to Species Richness of a Tropical Rain Forest. Biotropica, 19, 149-156.

Gifford, M.E. & Kozak, K.H. (2012) Islands in the sky or squeezed at the top? Ecological causes of elevational range limits in montane salamanders. Ecography, 35, 193-203.

Gotelli, N.J. (2000) Null model analysis of species co-occurrence patterns. Ecology, 81, 2606-2621.

Gotelli, N.J. & Graves, G.R. (1996) Nulls Models in Ecology. Smithsonian Institution Press. Washington, D.C.

Gradstein, R., & Van Zanten, B. (1999). High altitude dispersal of spores: an experimental approach. In XVI international botanical congress, St. Louis.

Gradstein, S., Nadkarni, N., Krömer, T., Holz, I. & Nöske, N. (2003) A Protocol for rapid and representative sampling of vascular and non-vascular epiphyte diversity of tropical rain forests. Selbyana, 24, 105-111.

Graham, C. H., Parra, J. L., Rahbek, C., & McGuire, J. A. (2009). Phylogenetic structure in tropical hummingbird communities. Proceedings of the National Academy of Sciences, 106(Supplement 2), 19673-19678.

Grau, O., Grytnes, J.A. & Birks, H. (2007) A comparison of altitudinal species richness patterns of bryophytes with other plant groups in Nepal, Central Himalaya. Journal of biogeography, 34, 1907-1915.

Grytnes, J.A. & Beaman, J.H. (2006) Elevational Species Richness Patterns for Vascular Plants on Mount Kinabalu, Borneo. Journal of Biogeography, 33, 1838-1849.

Gutiérrez- García, G. & Ricker, M. (2011) Climate and climate change in the region of Los Tuxtlas (Veracruz, Mexico): A statistical analysis. Atmósfera, 24, 347-373.

Halffter, G. & Morrone, J. (2017) An analytical review of Halffter's Mexican transition zone, and its relevance for evolutionary biogeography, ecology and biogeographical regionalization. Zootaxa, 4226(1), 1-46

Harrison, S. & Noss, R. (2017) Endemism hotspots are linked to stable climatic refugia. Annals of botany, 119(2), 207-214.

Harper, J. L. (1977). Population biology of plants. Population biology of plants.

Hartmann, D.L. (1993) Radiative effects of clouds on Earth's climate. In: International Geophysics, 151-173. Academic Press.

Hassler, M. 2018. World Ferns: Checklist of ferns and lycophytes of the world (version Feb 2017), in Y. Roskov, L. Abucay, T. Orrell, D. Nicolson, N. Bailly, P. M. Kirk, T. Bourgoin, R. E. DeWalt, W. Decock, A. De Wever, E. van Nieukerken, J. Zarucchi, and L. Penev (eds.), Species 2000 and ITIS Catalogue of Life, 2017 Annual Checklist. Digital resource at www.catalogueoflife.org/annual-checklist/2017. Species 2000: Naturalis, Leiden, the Netherlands. ISSN 2405–884X.

Hawkins, B.A., Diniz-Filho, J.A.F. & Soeller, S.A. (2005) Water links the historical and contemporary components of the Australian bird diversity gradient. Journal of Biogeography, 32, 1035-1042.

Hawkins, B.A., Diniz-Filho, J.A.F., Jaramillo, C.A. & Soeller, S.A. (2006) Post-Eocene climate change, niche conservatism, and the latitudinal diversity gradient of New World birds. Journal of Biogeography, 33, 770-780.

Hawkins, B.A., Field, R., Cornell, H.V., Currie, D.J., Guégan, J.-F., Kaufman, D.M., Kerr, J.T., Mittelbach, G.G., Oberdorff, T. & O'Brien, E.M. (2003) Energy, water, and broad-scale geographic patterns of species richness. Ecology, 84, 3105-3117.

Heaney, L.R. (2001) Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. Global ecology and Biogeography, 10, 15-39.

Hernández-Rojas, A., Kessler, M., Krömer, T., Carvajal-Hernández, C., Weigand, A. & Kluge, J. (2018) Richness patterns of ferns along an elevational gradient in the Sierra de Juárez, Oaxaca, Mexico: a comparison with Central and South America. American Fern Journal, 108, 76-94.

Hernández-Rojas, A.C., Kluge, J., Krömer, T., Carvajal-Hernández, C., Silva-Mijangos, L., Miehe, G., Lehnert, M., Weigand, A. & Kessler, M. (2020) Latitudinal patterns of species richness and range size of ferns along elevational gradients at the transition from tropics to subtropics. Journal of Biogeography, 47, 1383-1397.

Hietz, P. (2010) Fern adaptations to xeric environments. In: Fern Ecology (ed. by Mehltreter, L., Walker, R. & Sharpe, J.M.). Cambridge University Press.

Hillebrand, H. (2004) On the generality of the latitudinal diversity gradient. The American Naturalist, 163, 192-211.

Hoorn, C., Mosbrugger, V., Mulch, A., & Antonelli, A. (2013) Biodiversity from mountain building. Nature Geoscience, 6(3), 154-154.

Hooper, D.U., Chapin Iii, F., Ewel, J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D., Loreau, M. & Naeem, S. (2005) Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological monographs, 75, 3-35.

Humbolt, A.V. (1828 [2004]) Die Kosmosvorträge 1827/28 in der Berliner Singakademie. Frankfurt: Insel-Verlag.

Jablonski, D., Roy, K. & Valentine, J.W. (2006) Out of the Tropics: Evolutionary Dynamics of the Latitudinal Diversity Gradient. Science, 314, 102-106.

Jansson, R., Rodríguez-Castañeda, G. & Harding, L.E. (2013) What can multiple phylogenies say about the latitudinal diversity gradient? A new look at the tropical conservatism, out of the tropics, and diversification rate hypotheses. Evolution, 67, 1741-1755.

Janzen, D.H. (1967) Why Mountain Passes are Higher in the Tropics. The American Naturalist, 101, 233-249.

Johannson, D. (1974) Ecology of vascular epiphytes in West African rain forest. Acta Phytogeographica Suecica 59, 1-136.

Jones, M.M., Szyska, B. & Kessler, M. (2011) Microhabitat partitioning promotes plant diversity in a tropical montane forest. Global Ecology and Biogeography, 20, 558-569.

Jorge, A.M., Armando, R.-G., Guillermo, I.-M., Claudia, G.-H. & Marco Antonio, R.-R. (2017) Checklist of the vascular flora of a portion of the hyper-humid region of La Chinantla, Northern Oaxaca Range, Mexico. Botanical Sciences, 95(4), 722-759

Karger, D.N., Kluge, J., Krömer, T., Hemp, A., Lehnert, M. & Kessler, M. (2011) The effect of area on local and regional elevational patterns of species richness. Journal of Biogeography, 38, 1177-1185.

Karger, D.N., Weigelt, P., Amoroso, V.B., Darnaedi, D., Hidayat, A., Kreft, H. & Kessler, M. (2014) Island biogeography from regional to local scales: evidence for a spatially scaled echo pattern of fern diversity in the Southeast Asian archipelago. Journal of Biogeography, 41, 250-260.

Kembel, S. (2010) An introduction to the picante package. Retrieved from picante. r-forge. r-project. org/picante-intro. pdf.

Kembel, S.W. & Hubbell, S.P. (2006) The phylogenetic structure of a neotropical forest tree community. Ecology, 87, S86-S99.

Kessler, M. (2000a) Altitudinal zonation of Andean cryptogam communities. Journal of biogeography, 27, 275-282.

Kessler, M. (2000b) Elevational gradients in species richness and endemism of selected plant groups in the central Bolivian Andes. Plant ecology, 149, 181-193.

Kessler, M. (2001) Pteridophyte species richness in Andean forests in Bolivia. Biodiversity & Conservation, 10, 1473-1495.

Kessler, M. (2001) Patterns of diversity and range size of selected plant groups along an elevational transect in the Bolivian Andes. Biodiversity & Conservation, 10, 1897-1921.

Kessler, M. (2002) Range size and its ecological correlates among the pteridophytes of Carrasco National Park, Bolivia. Global Ecology and Biogeography, 11, 89-102.

Kessler, M. (2010) Biogrography of ferns. In: Fern ecology (ed. by Mehltreter, L., Walker, R. & Sharpe, J.M.). 22-60. Cambridge University Press.

Kessler, M. & Bach, K. (1999) Using indicator groups for vegetation classification in species-rich Neotropical forests. Phytocoenologia, 29, 485-502.

Kessler, M. & Smith, A. (2017) Prodromus of a fern flora for Bolivia. I. General introduction and key to families. Phytotaxa, 327, 57.

Kessler, M., Karger, D.N. & Kluge, J. (2016) Elevational diversity patterns as an example for evolutionary and ecological dynamics in ferns and lycophytes. Journal of Systematics and Evolution, 54, 617-625.

Kessler, M., Kluge, J., Hemp, A. & Ohlemüller, R. (2011) A global comparative analysis of elevational species richness patterns of ferns. Global ecology and biogeography, 20, 868-880.

Kessler, M., Salazar, L., Homeier, J. & Kluge, J. (2014) Species richness–productivity relationships of tropical terrestrial ferns at regional and local scales. Journal of Ecology, 102, 1623-1633.

Kessler, M., Hofmann, S., Krömer, T., Cicuzza, D. & Kluge, J. (2010) The impact of sterile populations on the perception of elevational richness patterns in ferns. Ecography, 34, 123-131.

Khine, P.K., Kluge, J., Kessler, M., Miehe, G. & Karger, D.N. (2019) Latitude-independent, continent-wide consistency in climate–richness relationships in Asian ferns and lycophytes. Journal of Biogeography, 46, 981-991.

Kier, G., Kreft, H., Lee, T.M., Jetz, W., Ibisch, P.L., Nowicki, C., Mutke, J. & Barthlott, W. (2009) A global assessment of endemism and species richness across island and mainland regions. Proceedings of the National Academy of Sciences, 106, 9322-9327.

Killeen, T.J., Douglas, M., Consiglio, T., Jørgensen, P.M. & Mejia, J. (2007) Dry spots and wet spots in the Andean hotspot. Journal of Biogeography, 34, 1357-1373.

Kissling, W.D., Eiserhardt, W.L., Baker, W.J., Borchsenius, F., Couvreur, T.L., Balslev, H. & Svenning, J.-C. (2012) Cenozoic imprints on the phylogenetic structure of palm species assemblages worldwide. Proceedings of the National Academy of Sciences, 109, 7379-7384.

Kluge, J. & Kessler, M. (2005) Inventory of pteridophytes along an elevational transect in Braulio Carrillo National Park, Biological Station La Selva and Cerro de la Muerte, Costa Rica. Brenesia, 63-64, 11-34.

Kluge, J. & Kessler, M. (2006) Fern endemism and its correlates: contribution from an elevational transect in Costa Rica. Diversity and Distributions, 12, 535-545.

Kluge, J. & Kessler, M. (2011) Influence of niche characteristics and forest type on fern species richness, abundance and plant size along an elevational gradient in Costa Rica. Plant Ecology, 212, 1109-1121.

Kluge, J. & Kessler, M. (2011a) Phylogenetic diversity, trait diversity and niches: species assembly of ferns along a tropical elevational gradient. Journal of Biogeography, 38, 394-405.

Kluge, J., Kessler, M. & Dunn, R.R. (2006) What drives elevational patterns of diversity? A test of geometric constraints, climate and species pool effects for pteridophytes on an elevational gradient in Costa Rica. Global ecology and biogeography, 15, 358-371.

Körner, C. (2000). Why are there global gradients in species richness? Mountains might hold the answer. Trends Ecol Evol, 15, 513-514.

Kreft, H., Jetz, W., Mutke, J. & Barthlott, W. (2010) Contrasting environmental and regional effects on global pteridophyte and seed plant diversity. Ecography, 33, 408-419.

Krömer, T., Kessler, M. & Gradstein, S.R. (2007) Vertical stratification of vascular epiphytes in submontane and montane forest of the Bolivian Andes: the importance of the understory. Plant Ecology, 189, 261-278.

Krömer, T., Kessler, M., Robbert Gradstein, S. & Acebey, A. (2005) Diversity patterns of vascular epiphytes along an elevational gradient in the Andes. Journal of Biogeography, 32, 1799-1809.

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.

Krömer, T., Carvajal-Hernández, C., Acebey, A. & Smith, A. (2015) A Decade of New Pteridophyte Records for the State of Veracruz, Mexico. American Fern Journal, 105, 162-175.

Kruckeberg, A.R. & D., R. (1985) Biological Aspects of Endemism in Higher Plants. Annual Review of Ecology and Systematics, 16, 447-479.

Labiak, P. (2009) New Records of Pteridophytes from Bolivia and Brazil. American Fern Journal, 97, 113-123.

Labiak, P.H. (2011) Stenogrammitis, a new genus of grammitid ferns segregated from Lellingeria (Polypodiaceae). Brittonia, 63, 139-149.

Lawrence, E.R. & Fraser, D.J. (2020) Latitudinal biodiversity gradients at three levels: Linking species richness, population richness and genetic diversity. Global Ecology and Biogeography, 29, 770-788.

Lehnert, M. (2013) Grammitid Ferns (Polypodiaceae) II. Melpomene. Flora Neotropica Monograph, 112, 1-121.

Lehtonen, S., Silvestro, D., Karger, D. N., Scotese, C., Tuomisto, H., Kessler, M., ... & Antonelli, A. (2017) Environmentally driven extinction and opportunistic origination explain fern diversification patterns. Scientific reports, 7(1), 1-12.

Linares-Palomino, R., Cardona, V., Hennig, E.I., Hensen, I., Hoffmann, D., Lendzion, J., Soto, D., Herzog, S.K. & Kessler, M. (2008) Non-woody life-form contribution to vascular plant species richness in a tropical American forest. Plant Ecology, 201, 87.

Llorente-Bousquets, J., Escalante-Pliego, P., Darwin, S.P. & Welden, A.L. (1992) Insular biogeography of submontane humid forests in Mexico. In: Biogeography of Mesoamerica (ed. by Darwin, S.P. & Welden, A.L.), 139-146. University of Louisiana.

Lomolino, M.V. (2001) Elevation gradients of species-density: historical and prospective views. Global Ecology and biogeography, 10, 3-13.

Lomolino, M.V., Riddle, B.R. & Brown, J.H. (2006) Biogeography. Sinauer Associates. Inc., Sunderland.

Lóriga, J., Vasco, A., Regalado, L., Heinrichs, J. & Moran, R.C. (2014) Phylogeny and classification of the Cuban species of Elaphoglossum (Dryopteridaceae), with description of Elaphoglossum sect. Wrightiana sect. nov. Plant Systematics and Evolution, 300, 937-951.

Losos, J.B. (1996) Phylogenetic Perspectives on Community Ecology. Ecology, 77, 1344-1354.

Lott, E. & Atkinson, T. (2006) Mexican and Central American Seasonally Dry Tropical Forests: Chamela-Cuixmala, Jalisco, as a Focal Point for Comparison. In: Neotropical savannas and seasonally dry forests: Plant diversity, biogeography, and conservation, 315-342.

Lüdecke, D. (2018) ggeffects: Tidy Data Frames of Marginal Effects from Regression Models. The Journal of Open Source Software, 3(26), 772.

Luke, S.G. (2017) Evaluating significance in linear mixed-effects models in R. Behavior research methods, 49, 1494-1502.

Maddison, D.R., Schulz, K.S. & Maddison, W.P. (2007) The tree of life web project. Zootaxa, 1668, 19-40.

Major, J. (1988) Endemism: A botanical perspective. In: Analytical Biogeography 117-146. Springer, Dordrecht.

McCain, C.M. (2009a) Global analysis of bird elevational diversity. Global Ecology and Biogeography, 18, 346-360.

McCain, C.M. (2009b) Vertebrate range sizes indicate that mountains may be ‘higher’ in the tropics. Ecology Letters, 12, 550-560.

McCormack, J.E., Huang, H., Knowles, L.L., Gillespie, R. & Clague, D. (2009) Encyclopedia of Islands. University of California Press

Meave, J.A., Rincón, A. & Romero-Romero, M.A. (2006) Oak Forests of the Hyper-Humid Region of La Chinantla, Northern Oaxaca Range, Mexico. In: Ecology and Conservation of Neotropical Montane Oak Forests (ed. by M., K.), 113-125. Springer, Berlin, Heidelberg.

Mehltreter, K. (1996) Species richness and geographical distribution of montane pteridophytes of Costa Rica, Central America. Feddes Repertorium, 106, 563-584.

Mehltreter, K., Walker, L. R., & Sharpe, J. M. (Eds.). (2010). Fern ecology. Cambridge University Press.

Meyer, C. (2016) Limitations in global information on species occurrences. Frontiers of biogeography, 8, e28195.

Meyer, C., Weigelt, P. & Kreft, H. (2016) Multidimensional biases, gaps and uncertainties in global plant occurrence information. Ecology Letters, 19, 992-1006.

Mickel, J.T. & Beitel, J.M. (1988) Pteridophyte flora of Oaxaca, Mexico. New York Botanical Garden.

Mickel, J.T. & Smith, A. (2004) The Pteridophytes of Mexico. The New York Botanical Garden Press. Bronx, New York, USA.

Miklós, I. & Podani, J. (2004) Randomization of presence–absence matrices: comments and new algorithms. Ecology, 85, 86-92.

Molina-Venegas, R. (2019) Avoiding potential biases in ses. PD estimations with the Picante software package. BioRxiv, 579300.

Moran, R.C. (1998) The genera of neotropical ferns, a guide for students. Organization for Tropical Studies. San José, Costa Rica.

Moran, R.C. & Riba. R. (1995) Psilotaceae a Salviniaceae. In: Flora Mesoamericana (ed. by Davidse, G., M. S. Sousa y S. Knapp (eds.)). Universidad Nacional Autónoma de México, México, D.F., México.

Moran, R.C. & Prado, J. (2010) Megalastrum (Dryopteridaceae) in Central America. Kew Bulletin, 65, 137-188.

Morin, X. & Lechowicz, M.J. (2011) Geographical and ecological patterns of range size in North American trees. Ecography, 34, 738-750.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) Biodiversity hotspots for conservation priorities. Nature, 403, 853-858.

Naimi, B., Hamm, N.A.S., Groen, T.A., Skidmore, A.K. & Toxopeus, A.G. (2014) Where is positional uncertainty a problem for species distribution modelling? Ecography, 37, 191-203.

Nakagawa, S. & Schielzeth, H. (2013) A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods in Ecology and Evolution, 4, 133-142.

Noben, S., Testo, W., Sundue, M. & Kessler, M. (2020) Epiphytic ferns evolved in montane forest environments. New Phytologist (on submission).

Oksanen, J., Guillaume Blanchet, F., Friendly, M., et al. (2019) “vegan”: Community Ecology Package. from https://CRAN.R-project.org/package=vegan.

Page, C.N. (2002) Ecological strategies in fern evolution: a neopteridological overview. Review of Palaeobotany and Palynology, 119, 1-33.

Parris, B.S., Beaman, R.S. & Beaman, J.H. (1992) The Plants of Mount Kinabalu 1: Ferns and Ferns Allies. Kew, UK: Royal Botanic Gardens, Kew.

Peck, J.H., Peck, C.J. & Farrar, D.R. (1990) Influences of Life History Attributes on Formation of Local and Distant Fern Populations. American Fern Journal, 80, 126-142.

Perrigo, A., Hoorn, C., & Antonelli, A. (2020) Why mountains matter for biodiversity. Journal of Biogeography, 47(2), 315-325.

Pianka, E. R. (1966) Latitudinal gradients in species diversity: a review of concepts. The American Naturalist, 100(910), 33-46.

Pintor, A.F.V., Schwarzkopf, L. & Krockenberger, A.K. (2015) Rapoport's Rule: Do climatic variability gradients shape range extent? Ecological Monographs, 85, 643-659.

Ponce, M.M., Del Rio, C., Ebihara, A. & Dubuisson, J.Y. (2017) Discussion on taxonomy of the fern genera Crepidomanes and Polyphlebium (Hymenophyllaceae) in Argentina and south-eastern South America, and description of a new local variety for Crepidomanes pyxidiferum. Botany Letters, 164, 5-18.

PPG I. (2016) A community-derived classification for extant lycophytes and ferns. Journal of Systematics and Evolution, 54, 563-603.

Purvis, A., Gittleman, J.L., Cowlishaw, G. & Mace, G.M. (2000) Predicting extinction risk in declining species. Proceedings of the Royal Society of London. Series B: Biological Sciences, 267, 1947-1952.

Qian, H. & Ricklefs, R.E. (2011) Latitude, tree species diversity and the metabolic theory of ecology. Global Ecology and Biogeography, 20, 362-365.

Qian, H., Deng, T., Beck, J., Sun, H., Xiao, C., Jin, Y. & Ma, K. (2018) Incomplete species lists derived from global and regional specimen-record databases affect macroecological analyses: A case study on the vascular plants of China. Journal of Biogeography, 45, 2718-2729.

Qian, H., J. Zhang, B. Sandel & Y. Jin. (2020) Phylogenetic structure of angiosperm trees in local forest communities along latitudinal and elevational gradients in eastern North America. Ecography, 43(3), 419-430

Rahbek, C. (1995) The elevational gradient of species richness: a uniform pattern? Ecography, 18(2), 200-205.

Rahbek, C. (2005) The role of spatial scale and the perception of large-scale species-richness patterns. Ecology letters, 8, 224-239.

Ribas, C.R. & Schoereder, J.H. (2006) Is the Rapoport effect widespread? Null models revisited. Global Ecology and Biogeography, 15, 614-624.

Richardson, J.E. & Pennington, R.T. (2016) Origin of tropical diversity: from clades to communities. Frontiers in genetics, 7, 186.

Ricklefs, R.E. (2004) A comprehensive framework for global patterns in biodiversity. Ecology letters, 7, 1-15.

Ricklefs, R.E. & Schluter, D. (1993) Species diversity: regional and historical influences. In Species Diversity in Ecological Communities: Historical and Geographical Perspectives (Ricklefs, R.E. and Schluter, D., eds). University of Chicago Press, pp. 350–363.

Ricklefs, R. (2005) Phylogenetic perspectives on patterns of regional and local species richness. Rainforest: Past, Present and Future, 3-40.

Rincón-Gutiérrez, A. (2007) Estructura y composición florística de los bosque húmedos de montaña de Santa Cruz Tepetotutla, Oaxaca, México. B. Sc., Universidad Nacional Autónoma de México.

Rohde, K. (1996) Rapoport's Rule is a Local Phenomenon and Cannot Explain Latitudinal Gradients in Species Diversity. Biodiversity Letters, 3, 10-13.

Rohde, K. & Heap, M. (1996) Latitudinal Ranges of Teleost Fish in the Atlantic and Indo-Pacific Oceans. The American Naturalist, 147, 659-665.

Rohde, K., Heap, M. & Heap, D. (1993) Rapoport's Rule Does Not Apply to Marine Teleosts and Cannot Explain Latitudinal Gradients in Species Richness. The American Naturalist, 142, 1-16.

Rojas-Alvarado, A.F. (2003) Notes on Elaphoglossum (Lomariopsidaceae) section Polytrichia subsection Hybrida in Mexico and Central America. Revista de Biología Tropical, 51, 33-48.

Rosete-Vergés, F.A., Pérez-Damián, J.L., Villalobos-Delgado, M., Navarro-Salas, E.N., Salinas-Chávez, E. & Remond-Noa, R. (2014) El avance de la deforestación en México 1976-2007. Madera y bosques, 20, 21-35.

Roy, K. & Goldberg, E.E. (2007) Origination, extinction, and dispersal: integrative models for understanding present-day diversity gradients. the american naturalist, 170, S71-S85.

Ruggiero, A. (1994) Latitudinal Correlates of the Sizes of Mammalian Geographical Ranges in South America. Journal of Biogeography, 21, 545-559.

Rzedowski, J. (1962) Contribuciones a la fitogeografía florística e histórica de México. I. Algunas consideraciones acerca del elemento endémico en la flora mexicana. Botanical Sciences, 27, 52-65.

Rzedowski, J. (2006) Vegetación de México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. México.

Rzedowski, J. & Palacios-Chávez, R. (1977) El bosque de Engelhardtia (Oreomunnea) mexicana en la región de La Chinantla (Oaxaca, México). Una reliquia del cenozoico. Botanical Sciences, 36, 93-127.0.

Saefken, B., Ruegamer, D., Kneib, T. & Greven, S. (2018) cAIC4: Conditional Akaike information criterion for lme4. R Packag. version 0.2.

Saefken, B., & Ruegamer, D. (2018). “cAIC4”: Conditional Akaike information criterion for lme4, R package version 0.3

Saefken, B., Ruegamer, D., Kneib, T., & Greven, S. (2018). Conditional Model Selection in Mixed-Effects Models with cAIC4, ArXiv e-prints 1803.05664.

Salazar, L., Homeier, J., Kessler, M., Abrahamczyk, S., Lehnert, M., Krömer, T. & Kluge, J. (2015) Diversity patterns of ferns along elevational gradients in Andean tropical forests. Plant Ecology & Diversity, 8, 13-24.

Sanginés-Franco, C., Luna-Vega, I., Contreras-Medina, R., Espinosa, D., Tejero-Díez, J.D. & Rivas, G. (2015) Diversity, endemism and conservation of ferns (Polypodiales) in the Mexican Mountain Component. Journal of Mountain Science, 12, 891-904.

Santelices, B. & Marquet, P. (1998) Seaweeds, latitudinal diversity patterns, and Rapoport's Rule. Diversity and Distributions, 4, 71-75.

Sarmento Cabral, J., Petter, G., Mendieta-Leiva, G., Wagner, K., Zotz, G. & Kreft, H. (2015) Branchfall as a Demographic Filter for Epiphyte Communities: Lessons from Forest Floor-Based Sampling. PLOS ONE, 10, e0128019.

Schneider, H., Schuettpelz, E., Pryer, K.M., Cranfill, R., Magallón, S. & Lupia, R. (2004) Ferns diversified in the shadow of angiosperms. Nature, 428, 553-557.

Schneider, H., Kreier, H.-P., Janssen, T., Otto, E., Muth, H. & Heinrichs, J. (2010) Key innovations versus key opportunities: identifying causes of rapid radiations in derived ferns. In: Evolution in action, 61-75. Springer.

Schuettpelz, E. & Pryer, K.M. (2009) Evidence for a Cenozoic radiation of ferns in an angiosperm-dominated canopy. Proceedings of the National Academy of Sciences, 106, 11200-11205.

Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M. S. (2019). “afex”: Analysis of Factorial Experiments. R package version 0.24-1.

Sklenar, P. & Jorgensen, P.M. (1999) Distribution Patterns of Paramo Plants in Ecuador. Journal of Biogeography, 26, 681-691.

Slatyer, R.A., Hirst, M. & Sexton, J.P. (2013) Niche breadth predicts geographical range size: a general ecological pattern. Ecology Letters, 16, 1104-1114.

Smith, A.R. (1993) Phytogeographic Principles and Their Use in Understanding Fern Relationships. Journal of Biogeography, 20, 255-264.

Smith, A.R. & Tejero-Díez, J.D. (2014) Pleopeltis (Polypodiaceae), a redifinition of the genus and nomenclatural novelties. Botanical Sciences, 92, 43-58.

Smith, A.R., Pryer, K.M., Schuettpelz, E., Korall, P., Schneider, H. & Wolf, P.G. (2008) Fern classification. In: Biology and Evolution of Ferns and Lycophytes (ed. by Haufler, C.H. & Ranker, T.A.), 417-467. Cambridge University Press, Cambridge.

Smith, A., Kessler, M., León, B., Almeida, T., Jiménez-Pérez, I. & Lehnert, M. (2018) Prodromus of a fern flora for Bolivia. XL. Polypodiaceae. Phytotaxa, 354(1), 1-67.

Sosa, V. & Nova, J.A.D. (2012) Endemic angiosperm lineages in Mexico: hotspots for conservation. Acta Botanica Mexicana, 100, 293-315.

Sosa, V., De-Nova, J.A. & Vásquez-Cruz, M. (2018) Evolutionary history of the flora of Mexico: Dry forests cradles and museums of endemism. Journal of Systematics and Evolution, 56, 523-536.

Steinbauer, M.J., Field, R., Grytnes, J.-A., et al. (2016) Topography-driven isolation, speciation and a global increase of endemism with elevation. Global Ecology and Biogeography, 25, 1097-1107.

Stevens, G.C. (1989) The Latitudinal Gradient in Geographical Range: How so Many Species Coexist in the Tropics. The American Naturalist, 133, 240-256.

Stevens, G.C. (1992) The Elevational Gradient in Altitudinal Range: An Extension of Rapoport's Latitudinal Rule to Altitude. The American Naturalist, 140, 893-911.

Stevens, G.C. (1996) Extending Rapoport's Rule to Pacific Marine Fishes. Journal of Biogeography, 23, 149-154.

Stubbs, W.J. & Bastow Wilson, J. (2004) Evidence for limiting similarity in a sand dune community. Journal of Ecology, 92, 557-567.

Sundue, M.A. (2017) Three New Species of Grammitid Ferns (Polypodiaceae) from the Fern Hunter's Paradise: Sierra Juárez, Oaxaca, Mexico. Systematic Botany, 42(1), 160-168.

Sundue, M.A., Parris, B.S., Ranker, T.A., Smith, A.R., Fujimoto, E.L., Zamora-Crosby, D., Morden, C.W., Chiou, W.-L., Chen, C.-W. & Rouhan, G. (2014) Global phylogeny and biogeography of grammitid ferns (Polypodiaceae). Molecular Phylogenetics and Evolution, 81, 195-206.

Swaegers, J., Janssens, S.B., Ferreira, S., Watts, P.C., Mergeay, J., McPeek, M.A. & Stoks, R. (2014) Ecological and evolutionary drivers of range size in Coenagrion damselflies. Journal of Evolutionary Biology, 27, 2386-2395.

Sylvester, S.P., Sylvester, M.D.P.V. & Kessler, M. (2014) The world’s highest epiphytes found in the Peruvian Andes. Alpine Botany, 124, 179-185.

Team, R.C. (2016) A language and environment for statistical computing. R Foundation for Statistical Computing. from https://www.R-project.org/.

Team, R.C. (2019) R: A language and environment for statistical computing. R Foundation for Statistical Computing. from https://www.R-project.org/.

Tejero-Díez, J.D., Torres-Díaz, A.N. & Gual-Díaz, M. (2014) Licopodios y helechos en el bosque mesófilo de montaña de México. In: Bosques mesófilos de montaña de México: diversidad, ecología y manejo (ed. by Gual-Díaz, M. & Rendón-Correa, A.), 197-220. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México, DF, México.

Testo, W. & Sundue, M. (2016) A 4000-species dataset provides new insight into the evolution of ferns. Molecular Phylogenetics and Evolution, 105, 200-211.

Tomašových, A., Jablonski, D., Berke, S.K., Krug, A.Z. & Valentine, J.W. (2015) Nonlinear thermal gradients shape broad-scale patterns in geographic range size and can reverse Rapoport's rule. Global Ecology and Biogeography, 24, 157-167.

Tomašových, A., Kennedy, J.D., Betzner, T.J., et al. (2016) Unifying latitudinal gradients in range size and richness across marine and terrestrial systems. Proceedings of the Royal Society B: Biological Sciences, 283, 20153027.

Tropicos (2020) Retrieved 06 Mar 2020 from http://www.tropicos.org/Name/40001786.

Tryon, R. (1962) Taxonomic fern notes. II. Pityrogramma (including Trismeria) and Anogramma. Contributions from the Gray Herbarium of Harvard University, 189, 52-76.

Tryon, A. F., & Lugardon, B. (2012). Spores of the Pteridophyta: surface, wall structure, and diversity based on electron microscope studies. Springer Science & Business Media.

Tryon, R.M. & Tryon, A.F. (2012) Ferns and allied plants: with special reference to tropical America. Springer Science & Business Media

Tuomisto, H., Ruokolainen, K., Poulsen, A. D., Moran, R. C., Quintana, C., Cañas, G., & Celi, J. (2002) Distribution and diversity of pteridophytes and melastomataceae along edaphic gradients in Yasuní National Park, Ecuadorian Amazonia1. Biotropica, 34(4), 516-533.

Tuomisto, H., Zuquim, G., & Cárdenas, G. (2014) Species richness and diversity along edaphic and climatic gradients in Amazonia. Ecography, 37(11), 1034-1046.

Vasco, A. (2011) Taxonomic revision of Elaphoglossum subsection Muscosa (Dryopteridaceae). Blumea - Biodiversity, Evolution and Biogeography of Plants, 56, 165-202.

Vasco, A., Moran, R. & Rouhan, G. (2009) Monograph of the Elaphoglossum ciliatum group (Dryopteridaceae). Brittonia, 61, 241-272.

Villaseñor, J.L. (2016) Checklist of the native vascular plants of Mexico. Revista Mexicana de Biodiversidad, 87, 559-902.

Wang, J., Soininen, J., He, J. & Shen, J. (2012) Phylogenetic clustering increases with elevation for microbes. Environ Microbiol Rep, 4, 217-226.

Watkins, J.E., Catherine, C., Colwell, R.K. & Moran, R.C. (2006) Species Richness and Distribution of Ferns along an Elevational Gradient in Costa Rica. American Journal of Botany, 93, 73-83.

Watkins Jr, J.E., Mack, M.C., Sinclair, T.R. & Mulkey, S.S. (2007) Ecological and evolutionary consequences of desiccation tolerance in tropical fern gametophytes. New Phytologist, 176, 708-717.

Webb, C.O., Ackerly, D.D. & Kembel, S.W. (2008) Phylocom: software for the analysis of phylogenetic community structure and trait evolution. Bioinformatics, 24, 2098-2100.

Webb, C.O., Ackerly, D.D. & Kembel, S.W. (2011) Phylocom: software for the analysis of phylogenetic community structure and character evolution (with phylomatic and ecoevolve). User's manual, version, 4.

Webb, C.O., Ackerly, D.D., McPeek, M.A. & Donoghue, M.J. (2002) Phylogenies and community ecology. Annual review of ecology and systematics, 33, 475-505.

Weigand, A., Abrahamczyk, S., Aubin, et al. (2020) Global fern and lycophyte richness explained: How regional and local factors shape plot richness. Journal of Biogeography, 47(1), 59-71.

Weiher, E. & Keddy, P.A. (1995) Assembly rules, null models, and trait dispersion: new questions from old patterns. Oikos, 159-164.

Wiens, J.J. & Donoghue, M.J. (2004) Historical biogeography, ecology and species richness. Trends in ecology & evolution, 19, 639-644.

Wilson, A.M. & Jetz, W. (2016) Remotely Sensed High-Resolution Global Cloud Dynamics for Predicting Ecosystem and Biodiversity Distributions. PLOS Biology, 14, e1002415.

Winter, B. (2019) “Statistics for linguists: An introduction using R”.

Yu, G. (2020) Using ggtree to Visualize Data on Tree-Like Structures. Current protocols in bioinformatics, 69, e96.

Yu, G., Lam, T.T.-Y., Zhu, H. & Guan, Y. (2018) Two methods for mapping and visualizing associated data on phylogeny using ggtree. Molecular biology and evolution, 35, 3041-3043.

Yu, G., Smith, D.K., Zhu, H., Guan, Y. & Lam, T.T.Y. (2017) ggtree: an R package for visualization and annotation of phylogenetic trees with their covariates and other associated data. Methods in Ecology and Evolution, 8, 28-36.

Zhou, Y., Ochola, A.C., Njogu, A.W., Boru, B.H., Mwachala, G., Hu, G., Xin, H. & Wang, Q. (2019) The species richness pattern of vascular plants along a tropical elevational gradient and the test of elevational Rapoport's rule depend on different life-forms and phytogeographic affinities. Ecology and Evolution, 9, 4495-4503.

# APPENDIX

# 7 APPENDIX

## List of Figures

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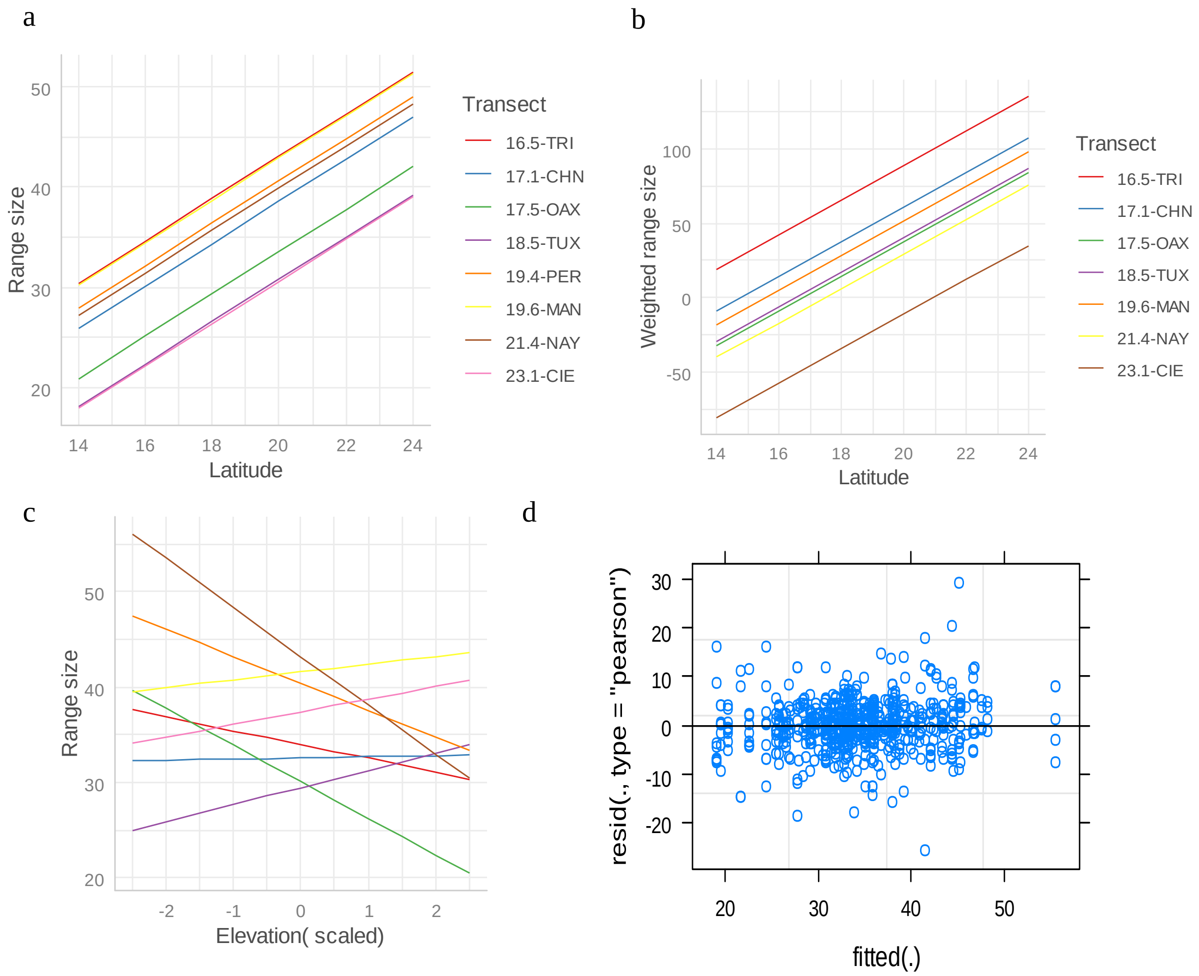
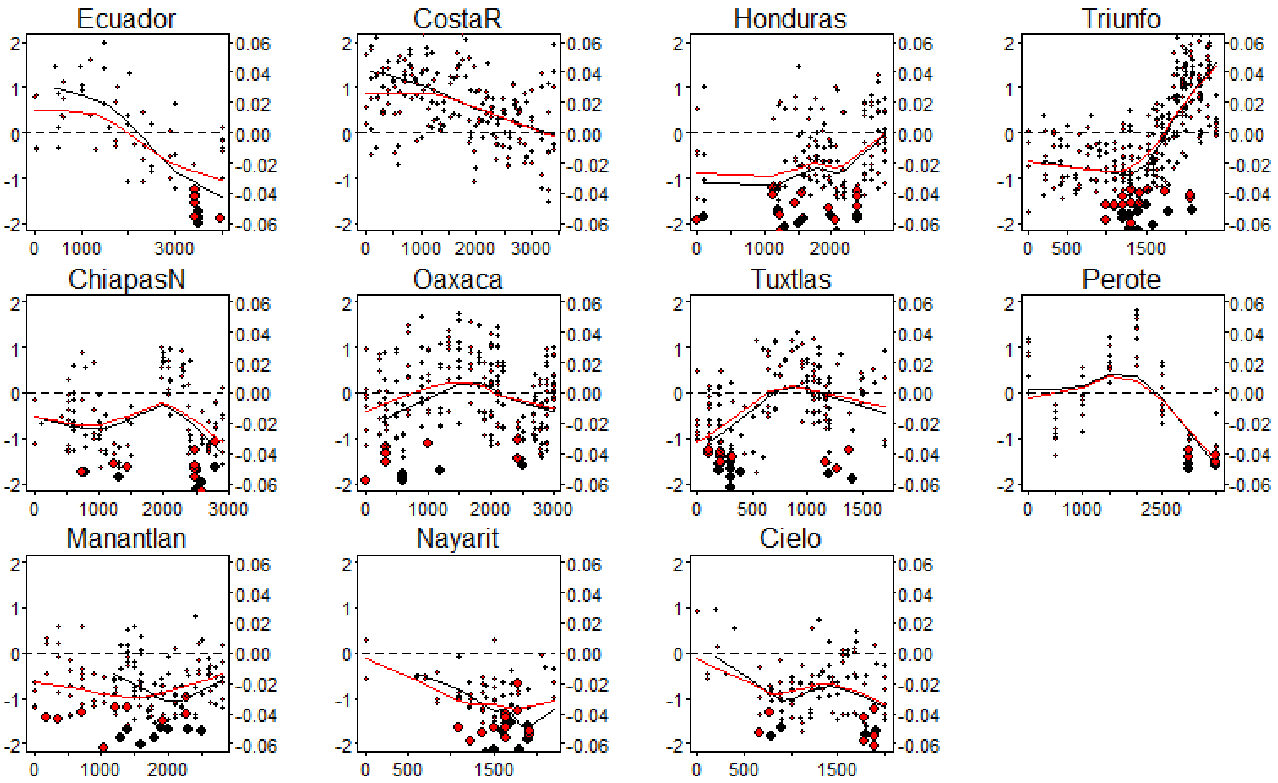
Appendix F 2-1 Example of diversification on the genus *Elaphoglossum* (Lomariopsidaceae) at Sierra de Juárez Oaxaca. From left to right: *Elaphoglossum peltatum*, *Elaphoglossum tenuifolium*, *Elaphoglossum alansmithii*, *Elaphoglossum muscossum*, *Elaphoglossum lonchophyllum* and *Elaphoglossum paleaceum*.



Appendix F 3-1 Predicted values of range size of ferns changing latitude using a random intercept model with (a) non-weighted and, (b) weighted range sizes per abundance; changing elevation using a random slope and random intercept model with (c), non-weighted ranges per abundance, and (d) Residuals versus fitted values in the elevation model.



Appendix F 4-1 Comparison of mpd using two null models: red constrained model (trial-swap algorithm using 9999 runs and 1000 iterations) black unconstrained model (taxa.labels using 999 runs and 1000 iterations). Presence data including 12 transects (the two transects from los Tuxtlas were merged). Bigger points are the plots with significant value ($p<0.05$).

Appendix F 5 *Cyathea fulva*, *Lomariopsis recurvata*, *Plagiogyria pectinata*, *Pleopeltis polypodioides*, and *Abrodictium rigidum*.

Appendix F 6 *Tectaria heracleifolia* (baby), *Diplazium ternatum, Selaginella mosorongensis, Microgramma lycopodioides (Ecuador), Elaphoglossum leonardii and Polypodium muenchii.*

Appendix F 7 *Sphaeropteris horrida*, *Sticherus bifidus*, *Cyathea liebmanii*, and *Alsophila salvinii*.

Appendix F 8 Sierra de Juárez Oaxaca, Mexico. Upper: Vegetation structure in the tropical forest of San Mateo Yetla. Lower: Panoramic view from Cerro Pelón and La Esperanza, Comaltepec

Appendix F 9 Field work in La Esperanza, Comaltepec; Cerro Marin, Valle Nacional; Jaltianguis, Ixtlan de Juárez; Cerro Tejón, Valle Nacional, Santa Cruz Tepetotutla, San Felipe Usila and Cerro Quemado

Appendix F 10 Field work close to Yankuam, Ecuador to know the standardized methodology used by the research group.

Appendix T 2-1 Location of the study sites along the elevational gradient in Sierra de Juarez, Oaxaca, Mexico.

| **Locality, Municipality** | **Elevational band (m)** | **Coordinates** | **Type of forest** |
|---|---|---|---|
| Cerro Tejón, Paso Nuevo la Hamaca, Valle Nacional | 300 | 17.78685 N, 96.23103 W | Rain Forest |
| Cerro Marin, Valle Nacional | 500 | 17.82863 N, 96.25282 W | Rain Forest |
| Cerro Quemado, Vega del Sol, Jacatepec | 600 | 17.79322 N, 96.17304 W | Rain Forest |
| Yetla, Valle Nacional | 1,000 | 17.72213 N, 96.3089 W | Rain Forest |
| Puerto Antonio, Comaltepec | 1,300 | 17.67064 N, 96.33496 W | Transition Rain Forest –Cloud Forest |
| Cerro Redondo, La Esperanza, Comaltepec | 1,500 | 17.62129 N, 96.34547 W | Cloud Forest |
| Santa Cruz Tepetotutla, San Felipe Usila | 1,800 | 17.71802 N, 96.5587 W | Cloud Forest with (*Oreomunnea Mexicana)* |
| San Isidro, San Pedro Yolox | 2,000 | 17.60485 N, 96.41625 W | Monodominant (*Oreomunnea* Forest) |
| Santa Cruz Tepetotutla, San Felipe Usila | 2,100 | 17.68011 N, 96.55075 W | Cloud Forest |
|  | 2,200 | 17.68041 N, 96.55442 W | Cloud Forest |
| Jatianguis, Ixtlán | 2,500 | 17.3804 N, 96.51286 W | Pine Forest |
| Cerro Zacate, San Pedro Yolox | 2,700 | 17.61111 N, 96.53198 W | Oak Forest |
| Cerro Pelón, Comaltepec | 2,800 | 17.58451 N, 96.51245 W | Oak forest |
| Cerro Zacate, San Pedro Yolox | 2,900 | 17.61381 N, 96.53339 W | Pine-Oak Forest |
| Unknown, San Pedro Yolox | 3,000 | 17.60825 N, 96.52305 W | Elfin Forest (tree line) |

Appendix T3-1 (Continuation). Likelihood ratio test results (Non- weighted range sizes), with p values for all fix effects in the Linear mixed models (Coefficients), by transects, sides (A= Atlantic and P= Pacific), and elevational groups, using Step or group of plots in the same elevation as random factors. For all transects together the Transect / Step random factor structure was used. Similar values in the marginal ($R^2$m) and conditional R2 ($R^2$c) indicates that a linear model is the adequate model with the same coefficients. P: Pacific side, A: Atlantic side, Bio1, Bio4: annual mean temperature and its seasonality, Bio12, Bio15: annual precipitation and its seasonality and CloudA, CloudS: annual cloud cover and its seasonality. Significance codes: *** P <0.001, * *P<0.01, *P<0.05.

| **Transect (latitude)** | **Side** | **Bio1** | **Bio4** | **Bio12** | **Bio15** | **CloudA** | **CloudS** | **$R^2$m** | **$R^2$c** |
|---|---|---|---|---|---|---|---|---|---|
| Triunfo (16.5) | | | 196.28** | | | | | 0.32 | 0.39 |
| Manantlan (19.6) | | | | -100.21** | 50.15* | -19.52*** | | 0.31 | 0.31 |
| Nayarit (21.4) | | 48.16*** | | 75.36** | -112.83** | | | 0.60 | 0.72 |
| ChiapasN (17.1) | | | | -7.45** | | | -37.43*** | 0.48 | 0.48 |
| Oaxaca (17.5) | | | | | | | | 0.46 | 0.62 |
| Tuxtlas (18.5)b | | | 72.28* | -22.82** | -462.44** | | | 0.34 | 0.34 |
| Perote (19.4) | | 23.24* | | | | 46.97* | | 0.58 | 0.62 |
| Cielo (23.1) | | -77.93* | | -200.12* | | | -56.49* | 0.29 | 0.53 |
| Pacific- all plots | | | | | | -8.21*** | -7.40*** | 0.40 | 0.52 |
| Atlantic- all plots | | | | -3.64*** | | | | 0.22 | 0.63 |
| **Atlantic per elevational groups** | | | | | | | | | |
| 0-700 | | -14.97** | -27.99** | -13.66*** | | -10.30** | | 0.47 | 0.58 |
| 701-1300 | | | | -5.16*** | 3.73* | 5.06** | | 0.56 | 0.65 |
| 1301-1800 | | | | | | | | 0.54 | 0.58 |
| 1801-1400 | | | | | | | | 0.31 | 0.65 |
| | | | 22.24* | | -29.39* | | | 0.54 | 0.64 |
| **Pacific per elevational groups** | | | | | | | | | |
| 0-700 | | | | | | -62.97* | | 0.63 | 0.63 |
| 701-1300 | | | | 81.45* | | 42.98 | -62.16* | 0.79 | 0.79 |
| 1301-1800 | | | | | | -6.39* | | 0.56 | 0.56 |
| 1801-1400 | | 30.76*** | 91.91*** | 29.59** | -67.49*** | | | 0.36 | 0.67 |
| 2401-3500 | | | | | | | | 0.38 | 0.38 |
| **By elevational groups (no division between Atlantic and Pacific)** | | | | | | | | | |
| 0-700 | | | -8.63* | -7.19** | | -6.01* | | 0.31 | 0.59 |
| 701-1300 | | | | -2.53* | | | | 0.48 | 0.75 |
| 1301-1800 | | | | -2.17* | | -4.66** | | 0.50 | 0.59 |
| 1801-1400 | | | | -2.19* | | | | 0.17 | 0.43 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2401-3500 | | | | | 6.46* | | | 0.43 | 0.64 |
| **All transects (no division between Atlantic and Pacific)** | | | | | | -2.25** | | 0.18 | 0.67 |
| **All transects (Transect/Step as random effects)** | | | | | | | | | |
| | A- 19.20*** | | 3.7** | | -4.83* | -2.49** | | 0.31 | 0.65 |
| **Best model** (climatic variables Random effect:Step ) | P- 17.16*** | | 3.45*** | | -4.11*** | -2.36*** | | 0.28 | 0.62 |
| **Latitude model** | | | | | | | | | |
| | A- 7.39* | 3.42* | | | | | | 0.24 | 0.61 |
| **Elevation model** | | | | | | | | | |
| | | -1.65** | | | | | | 0.13 | 0.62 |

Appendix T 3-2. Species list of ferns and lycophytes recorded along nine elevational gradients in the Mexican Transition Zone. Data are presented with range size, north and south limits (in degress of latitude) and the frequency of every species (the number of plots in which the species was recorded). Transects 1-6 belong to the Atlantic side in the next order ChiapasN, Oaxaca, Tuxtlas a, Tuxtlas b, Perote, and El Cielo, and 7-9 belong to the Pacific side in the next order El Triunfo, Manantlán, and Nayarit.

|  | **Taxa** | **Range size** | **North limit** | **South limit** | CHI | OAX | TX-a | TX-b | PER | CIE | TRI | MAN | NAY | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. | **Anemiaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 1 | *Anemia adiantifolia* (L.) Sw. | 25.01 | 28,89 | 3.88 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 2 | *Anemia phyllitidis* (L.) Sw. | 55,91 | 23.11 | -32.80 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 3 | 0 | 9 |
|  | **Aspleniaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 3 | *Asplenium abscissum* Willd. | 59.76 | 29.65 | -30.11 | 0 | 3 | 15 | 9 | 0 | 0 | 9 | 5 | 0 | 41 |
| 4 | *Asplenium athyrioides* Fée | 29.16 | 23.54 | -5.62 | 1 | 0 | 1 | 1 | 0 | 0 | 15 | 0 | 0 | 18 |
| 5 | *Asplenium auriculatum* Sw. | 51.51 | 22.00 | -29.51 | 0 | 2 | 15 | 22 | 2 | 0 | 74 | 2 | 0 | 117 |
| 6 | *Asplenium blepharophorum* Bertol. | 12.24 | 21.02 | 8.78 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 6 | 0 | 8 |
| 7 | *Asplenium castaneum* Schltdl. & Cham. | 43.71 | 24.87 | -18.85 | 0 | 0 | 0 | 0 | 4 | 0 | 7 | 0 | 0 | 11 |
| 8 | *Asplenium cirrhatum* Rich. ex Willd. | 47.11 | 20.01 | -27.10 | 2 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 9 | *Asplenium cristatum* Lam. | 48.49 | 23.95 | -24.54 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 10 | *Asplenium cuspidatum* Lam. | 54.83 | 24.83 | -30.00 | 0 | 8 | 17 | 26 | 0 | 12 | 36 | 0 | 8 | 107 |
| 11 | *Asplenium feei* Kunze ex Fée | 50.07 | 21.62 | -28.45 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 12 | *Asplenium flabellulatum* Kunze | 46.87 | 20.87 | -26.00 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 13 | *Asplenium formosum* Willd. | 50.83 | 23.49 | -27.33 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| 14 | *Asplenium fragrans* Sw. | 54.06 | 23.95 | -30.11 | 1 | 6 | 0 | 1 | 0 | 0 | 0 | 23 | 0 | 31 |
| 15 | *Asplenium hallbergii* Mickel & Beitel | 9.30 | 25.21 | 15.91 | 0 | 2 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 7 |
| 16 | *Asplenium harpeodes* Kunze | 49.65 | 19.92 | -29.73 | 5 | 1 | 0 | 0 | 10 | 0 | 18 | 0 | 0 | 34 |
| 17 | *Asplenium hoffmannii* Hieron. | 19.24 | 21.47 | 2.23 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| 18 | *Asplenium lamprocaulon* Fée | 9.49 | 19.12 | 9.63 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 10 |
| 19 | *Asplenium miradorense* Liebm. | 15.17 | 23.95 | 8.78 | 7 | 4 | 16 | 11 | 1 | 0 | 46 | 0 | 0 | 85 |
| 20 | *Asplenium monanthes* L. | 70.03 | 29.33 | -40.70 | 20 | 5 | 1 | 0 | 4 | 33 | 0 | 28 | 23 | 114 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | *Asplenium munchii* A.R. Sm. | 3.40 | 19.61 | 16.21 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 7 |
| 22 | *Asplenium nigripes* (Fée) Hook | 7.53 | 23.00 | 15.47 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 23 | *Asplenium polyphyllum* Bertol. | 37.30 | 19.98 | -17.32 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 24 | *Asplenium potosinum* Hieron. | 12.50 | 24.32 | 11.82 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 12 |
| 25 | *Asplenium praemorsum* Sw. | 50.09 | 23.14 | -26.95 | 8 | 0 | 0 | 0 | 0 | 25 | 1 | 0 | 0 | 34 |
| 26 | *Asplenium pteropus* Kaulf. | 51.62 | 21.62 | -30.00 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 3 |
| 27 | *Asplenium pumilum* Sw. | 53.82 | 26.98 | -26.84 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 28 | *Asplenium radicans* L. | 51.97 | 21.98 | -29.99 | 0 | 2 | 0 | 0 | 0 | 0 | 14 | 0 | 0 | 16 |
| 29 | *Asplenium salicifolium* L. | 47.92 | 22.83 | -25.08 | 0 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 4 |
| 30 | *Asplenium seileri* C.D. Adams | 6.01 | 15.64 | 9.63 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| 31 | *Asplenium serra* Langsd. & Fischer | 55.28 | 20.99 | -34.29 | 5 | 0 | 0 | 0 | 4 | 0 | 36 | 0 | 0 | 45 |
| 32 | *Asplenium serratum* L. | 58.00 | 28.00 | -30.00 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| 33 | *Asplenium sessilifolium* Desv. | 40.80 | 23.42 | -17.38 | 14 | 0 | 0 | 0 | 1 | 0 | 0 | 6 | 0 | 21 |
| 34 | *Asplenium solmsii* Baker | 0.96 | 16.38 | 15.42 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 8 |
| 35 | *Asplenium sphaerosporum* A. R. Sm. | 47.27 | 23.14 | -24.13 | 4 | 0 | 0 | 0 | 0 | 34 | 1 | 0 | 8 | 47 |
| 36 | *Asplenium uniseriale* Raddi | 48.59 | 18.57 | -30.02 | 0 | 3 | 4 | 0 | 0 | 0 | 2 | 0 | 0 | 9 |
| 37 | *Asplenium venturae* A. R. Sm. | 0.00 | 18.58 | 18.58 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 38 | *Hymenasplenium riparium* (Liebm.) L. Regalado & Prada | 24.81 | 20.43 | -4.38 | 0 | 23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23 |
| | **Athyriaceae** | | | | | | | | | | | | | |
| 39 | *Athyrium arcuatum* Liebm. | 6.72 | 23.46 | 16.74 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 40 | *Athyrium bourgeaui* E. Fourn. | 19.07 | 28.64 | 9.57 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 41 | *Athyrium skinneri* (Baker) C. Chr. | 15.02 | 24.88 | 9.86 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 |
| 42 | *Diplazium diplazioides* (Klotzsch & H. Karst.) Alston | 37.00 | 19.88 | -17.12 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 43 | *Diplazium drepanolobium* A. R. Sm. | 5.76 | 19.59 | 13.83 | 1 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 8 |
| 44 | *Diplazium franconis* Liebm. | 15.28 | 21.29 | 6.01 | 13 | 2 | 2 | 1 | 5 | 0 | 9 | 0 | 0 | 32 |
| 45 | *Diplazium hians* Kunze ex Klotzsch | 34.36 | 19.59 | -14.77 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 46 | *Diplazium lonchophyllum* Kunze | 26.82 | 22.50 | -4.32 | 0 | 3 | 25 | 7 | 0 | 0 | 1 | 1 | 0 | 37 |
| 47 | *Diplazium plantaginifolium* (L.) Urb. | 50.28 | 20.53 | -29.75 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48 | *Diplazium striatastrum* Lellinger | 23.63 | 21.23 | -2.40 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 4 |
| 49 | *Diplazium striatum* (L.) C. Presl | 49.84 | 22.75 | -27.09 | 0 | 1 | 0 | 1 | 4 | 0 | 0 | 0 | 0 | 6 |
| 50 | *Diplazium ternatum* Liebm. | 9.21 | 21.05 | 11.84 | 12 | 20 | 0 | 0 | 5 | 0 | 9 | 0 | 0 | 46 |
| 51 | *Diplazium urticifolium* Christ | 13.89 | 21.02 | 7.13 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 52 | *Diplazium werckleanum* Christ | 10.77 | 19.27 | 8.50 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | **Blechnaceae** | | | | | | | | | | | | | |
| 53 | *Austroblechnum lehmannii* (Hieron.) Gasper & V. A. O. Dittrich | 50.23 | 20.5 | -29.73083 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 54 | *Austroblechnum stoloniferum* (Mett. ex E. Fourn.) Gasper & V. A. O. Dittrich | 41.91 | 24.08 | -17.83 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 0 | 0 | 8 |
| 55 | *Austroblechnum wardiae* (Mickel & Beitel) Gasper & V. A. O. Dittrich | 23.40 | 19.83 | -3.58 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 6 |
| 56 | *Blechnum appendiculatum* Willd. | 57.25 | 27.32 | -29.93 | 7 | 0 | 1 | 3 | 0 | 27 | 27 | 36 | 9 | 110 |
| 57 | *Blechnum gracile* Kaulf. | 52.58 | 23.06 | -29.51 | 0 | 0 | 0 | 0 | 0 | 1 | 20 | 7 | 3 | 31 |
| 58 | *Blechnum occidentale* L. | 54.51 | 23.13 | -31.38 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 59 | *Lomaridium ensiforme* (Liebm.) Gasper & V. A. O. Dittrich | 46.93 | 19.83 | -27.10 | 11 | 8 | 0 | 0 | 0 | 0 | 42 | 0 | 0 | 61 |
| 60 | *Lomaridium fragile* (Liebm.) Gasper & V. A. O. Dittrich | 40.63 | 22.79 | -17.84 | 0 | 4 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 7 |
| 61 | *Parablechnum falciforme* (Liebm.) Gasper & Salino | 38.40 | 20.64 | -17.76 | 12 | 8 | 0 | 0 | 3 | 0 | 15 | 0 | 0 | 38 |
| 62 | *Parablechnum schiedeanum* (Schltdl. ex C. Presl) | 20.06 | 20.98 | 0.92 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| 63 | *Woodwardia spinulosa* M. Martens & Galeotti | 15.92 | 29.33 | 13.42 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 |
| | **Culcitaceae** | | | | | | | | | | | | | |
| 64 | *Culcita coniifolia* (Hook.) Maxon | 42.80 | 20.02 | -22.78 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| | **Cyatheaceae** | | | | | | | | | | | | | |
| 65 | *Alsophila firma* (Baker) D. S. Conant | 25.41 | 23.95 | -1.46 | 5 | 2 | 5 | 8 | 7 | 0 | 0 | 0 | 0 | 27 |
| 66 | *Alsophila salvinii* Hook. | 40.76 | 20.69 | -20.07 | 4 | 4 | 0 | 0 | 0 | 0 | 35 | 0 | 0 | 43 |
| 67 | *Alsophila tryoniana* (Gastony) D. S. Conant | 5.65 | 18.57 | 12.92 | 0 | 0 | 4 | 2 | 0 | 0 | 9 | 0 | 0 | 15 |
| 68 | *Cyathea aristata* Domin | 11.40 | 18.42 | 7.02 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 69 | *Cyathea bicrenata* Liebm. | 23.22 | 20.18 | -3.03 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 70 | *Cyathea divergens* Kunze | 34.06 | 20.98 | -13.08 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71 | *Cyathea fulva* (Mart. & Gal.) Fée | 25.61 | 21.48 | -4.13 | 0 | 26 | 0 | 0 | 1 | 0 | 47 | 0 | 0 | 74 |
| 72 | *Cyathea godmanii* (Hook.) Domin | 5.94 | 19.96 | 14.03 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 8 |
| 73 | *Cyathea liebmannii* Domin | 3.81 | 18.39 | 14.58 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 74 | *Cyathea microdonta* (Desv.) Domin | 45.40 | 21.88 | -23.52 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 75 | *Cyathea schiedeana* (C. Presl) Domin | 16.37 | 20.37 | 4.00 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 17 |
| 76 | *Cyathea tuerckheimii* Maxon | 14.93 | 23.95 | 9.02 | 10 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 19 |
| 77 | *Sphaeropteris horrida* (Liebm.) R. M. Tryon | 6.60 | 19.96 | 13.37 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 78 | *Sphaeropteris myosuroides* (Liebm.) R. M. Tryon | 14.50 | 23.00 | 8.50 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
|  | **Cystopteridaceae** |  |  |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 79 | *Cystopteris fragilis* (L.) Bernh. | 138.26 | 83.27 | -54.99 | 2 | 0 | 0 | 0 | 5 | 13 | 0 | 5 | 0 | 25 |
|  | **Dennstaedtiaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 80 | *Dennstaedtia bipinnata* (Cav.) Maxon | 48.13 | 23.08 | -25.05 | 9 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 11 |
| 81 | *Dennstaedtia cicutaria* (Sw.) T. Moore | 50.67 | 22.95 | -27.72 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 82 | *Dennstaedtia cornuta* (Kaulf.) Mett. | 42.02 | 19.52 | -22.50 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| 83 | *Histiopteris incisa* (Thunb.) J. Sm. | 54.03 | 20.38 | -33.65 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 84 | *Hypolepis nigrescens* Hook. | 38.02 | 20.32 | -17.70 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 85 | *Pteridium arachnoideum* (Kaulf.) Maxon | 58.31 | 24.65 | -33.66 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 4 |
| 86 | *Pteridium feei* (W. Schaffn. ex Fée) Faull | 22.95 | 28.50 | 5.55 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 4 | 16 | 32 |
|  | **Dicksoniaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 87 | *Dicksonia navarrensis* Christ | 53.96 | 21.09 | -32.87 | 10 | 0 | 0 | 0 | 5 | 0 | 2 | 0 | 0 | 17 |
| 88 | *Lophosoria quadripinnata* (J. F. Gmel.) C. Chr. | 65.29 | 21.29 | -44.00 | 22 | 4 | 0 | 0 | 7 | 0 | 2 | 0 | 0 | 35 |
|  | **Didymochlaenaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 89 | *Didymochlaena truncatula* (Sw.) J. Sm. | 52.73 | 22.79 | -29.94 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
|  | **Dryopteridaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 90 | *Arachniodes denticulata* (Sw.) Ching | 48.45 | 21.05 | -27.40 | 14 | 36 | 0 | 1 | 10 | 0 | 41 | 0 | 0 | 102 |
| 91 | *Bolbitis hastata* (E. Fourn.) Hennipman | 9.98 | 19.90 | 9.92 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 92 | *Bolbitis portoricensis* (Spreng.) Hennipman | 21.93 | 22.75 | 0.82 | 0 | 1 | 0 | 0 | 1 | 0 | 23 | 0 | 0 | 25 |
| 93 | *Ctenitis baulensis* A. R. Sm. | 0.89 | 16.57 | 15.68 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| 94 | *Ctenitis equestris* (Kunze) Ching | 15.26 | 24.06 | 8.80 | 0 | 0 | 1 | 0 | 2 | 0 | 39 | 37 | 4 | 83 |
| 95 | *Ctenitis excelsa* (Desv.) Proctor | 38.92 | 19.59 | -19.33 | 0 | 7 | 7 | 1 | 0 | 0 | 7 | 0 | 0 | 22 |
| 96 | *Ctenitis hemsleyana* (Baker ex Hemsl.) Copel. | 13.73 | 21.03 | 7.30 | 3 | 6 | 0 | 0 | 3 | 0 | 34 | 0 | 0 | 46 |
| 97 | *Ctenitis interjecta* (C. Chr.) Ching | 9.43 | 19.98 | 10.55 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 98 | *Ctenitis melanosticta* (Kunze) Copel. | 14.55 | 23.23 | 8.68 | 5 | 5 | 9 | 9 | 0 | 2 | 0 | 0 | 0 | 30 |
| 99 | *Ctenitis mexicana* A. R. Sm. | 2.73 | 21.28 | 18.55 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 100 | *Ctenitis nigrovenia* (Christ) Copel. | 39.82 | 21.92 | -17.90 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 101 | *Ctenitis salvinii* (Baker) Stolze | 2.48 | 17.98 | 15.50 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 102 | *Dryopteris futura* A. R. Sm. | 4.43 | 19.02 | 14.58 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 103 | *Dryopteris nubigena* Maxon & C. V. Morton | 8.36 | 17.61 | 9.26 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 104 | *Dryopteris patula* (Sw.) Underw. | 53.79 | 23.75 | -30.04 | 0 | 0 | 0 | 0 | 0 | 4 | 4 | 0 | 0 | 8 |
| 105 | *Dryopteris wallichiana* (Spreng.) Hyl. | 54.22 | 25.98 | -28.23 | 14 | 16 | 0 | 0 | 7 | 0 | 0 | 7 | 0 | 44 |
| 106 | *Elaphoglossum affine* (M. Martens & Galeotti) T. Moore | 35.15 | 20.25 | -14.89 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 107 | *Elaphoglossum alansmithii* Mickel | 2.35 | 17.68 | 15.33 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 108 | *Elaphoglossum albomarginatum* A. R. Sm | 2.01 | 15.74 | 13.74 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 109 | *Elaphoglossum dissitifrons* Mickel | 4.86 | 20.50 | 15.64 | 0 | 17 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 39 |
| 110 | *Elaphoglossum ellipticifolium* A. Rojas | 1.90 | 15.68 | 13.78 | 0 | 0 | 0 | 0 | 0 | 0 | 18 | 0 | 0 | 18 |
| 111 | *Elaphoglossum erinaceum* (Fée) T. Moore | 43.93 | 21.47 | -22.46 | 0 | 0 | 16 | 15 | 2 | 0 | 29 | 0 | 0 | 62 |
| 112 | *Elaphoglossum glabellum* J. Sm. | 47.25 | 21.95 | -25.30 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 113 | *Elaphoglossum glaucum* T. Moore | 6.95 | 21.27 | 14.32 | 0 | 24 | 0 | 0 | 1 | 0 | 5 | 9 | 0 | 39 |
| 114 | *Elaphoglossum guatemalense* (Klotzsch) T. Moore | 9.04 | 23.14 | 14.10 | 3 | 21 | 16 | 16 | 0 | 10 | 0 | 0 | 0 | 66 |
| 115 | *Elaphoglossum huacsaro* (Ruiz) Christ | 37.28 | 19.52 | -17.77 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 3 |
| 116 | *Elaphoglossum leonardii* Mickel | 0.29 | 17.59 | 17.30 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 117 | *Elaphoglossum lonchophyllum* (Fée) T. Moore | 10.99 | 19.52 | 8.52 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 118 | *Elaphoglossum monicae* Mickel | 5.10 | 19.65 | 14.55 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 119 | *Elaphoglossum muscosum* (Sw.) T. Moore | 8.59 | 22.37 | 13.78 | 0 | 1 | 0 | 2 | 1 | 0 | 14 | 0 | 0 | 18 |
| 120 | *Elaphoglossum paleaceum* (Hook. & Grev.) Sledge | 40.26 | 22.15 | -18.11 | 8 | 11 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 27 |
| 121 | *Elaphoglossum parduei* Mickel | 0.30 | 17.90 | 17.60 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 122 | *Elaphoglossum peltatum* (Sw.) Urb. | 42.05 | 22.97 | -19.08 | 0 | 24 | 12 | 13 | 5 | 0 | 69 | 0 | 0 | 123 |
| 123 | *Elaphoglossum petiolatum* (Sw.) Urb. | 46.76 | 24.83 | -21.92 | 2 | 1 | 3 | 15 | 0 | 6 | 7 | 12 | 3 | 49 |
| 124 | *Elaphoglossum pringlei* (Davenp.) C. Chr. | 4.30 | 19.98 | 15.69 | 0 | 4 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 6 |
| 125 | *Elaphoglossum sartorii* (Liebm.) Mickel | 50.58 | 24.83 | -25.75 | 17 | 35 | 13 | 16 | 9 | 0 | 12 | 13 | 0 | 115 |
| 126 | *Elaphoglossum seminudum* Mickel | 2.22 | 19.80 | 17.58 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 127 | *Elaphoglossum setosum* (Liebm.) T. Moore | 44.07 | 18.58 | -25.50 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 128 | *Elaphoglossum squamipes* (Hook.) T. Moore | 45.62 | 19.52 | -26.10 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 |
| 129 | *Elaphoglossum squarrosum* (Klotzsch) T. Moore | 15.90 | 19.52 | 3.62 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 130 | *Elaphoglossum tenuifolium* (Liebm.) T. Moore | 3.61 | 19.04 | 15.43 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 131 | *Elaphoglossum vestitum* (Schltdl. & Cham.) Schott | 20.97 | 20.72 | -0.25 | 0 | 37 | 22 | 21 | 5 | 0 | 0 | 0 | 0 | 85 |
| 132 | *Elaphoglossum viride* (E. Fourn.) C. Chr. | 1.94 | 19.54 | 17.60 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 5 |
| 133 | *Elaphoglossum yourkeorum* Mickel | 0.00 | 15.67 | 15.67 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| 134 | *Megalastrum galeottii* (M. Martens) R. C. Moran & J.Prado | 14.44 | 19.12 | 4.68 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 135 | *Megalastrum mexicanum* R.C. Moran & J. Prado | 1.75 | 18.58 | 16.83 | 1 | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 136 | *Mickelia bernoullii* (Kuhn ex Christ) R. C. Moran, Labiak & Sundue | 33.37 | 19.20 | -14.17 | 5 | 0 | 14 | 10 | 0 | 0 | 0 | 0 | 0 | 29 |
| 137 | *Mickelia hemiotis* (Maxon) R. C. Moran, Labiak & Sundue | 19.48 | 18.42 | -1.07 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 138 | *Parapolystichum effusum* (Sw.) Ching | 52.79 | 22.75 | -30.04 | 1 | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 139 | *Phanerophlebia gastonyi* Yatsk. | 5.01 | 20.63 | 15.62 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 4 |
| 140 | *Phanerophlebia juglandifolia* (Humb. & Bonpl. ex Willd.) J. Sm | 18.56 | 25.63 | 7.08 | 0 | 0 | 0 | 0 | 0 | 0 | 25 | 0 | 0 | 25 |
| 141 | *Phanerophlebia macrosora* (Baker) Underw. | 16.07 | 24.57 | 8.50 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 142 | *Phanerophlebia nobilis* (Schltdl. & Cham.) C. Presl | 13.07 | 28.50 | 15.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 |
| 143 | *Phanerophlebia umbonata* Underw. | 5.87 | 28.37 | 22.50 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 12 |
| 144 | *Polystichum alfaroi* (Christ) Barrington | 6.88 | 15.74 | 8.86 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| 145 | *Polystichum distans* E. Fourn. | 6.88 | 21.49 | 14.61 | 15 | 0 | 0 | 0 | 0 | 0 | 12 | 20 | 0 | 47 |
| 146 | *Polystichum erythrosorum* A. R. Sm. | 5.03 | 19.59 | 14.56 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 147 | *Polystichum fournieri* A. R. Sm. | 11.54 | 20.34 | 8.80 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 10 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 148 | *Polystichum hartwegii* (Klotzsch) Hieron. | 40.36 | 24.03 | -16.33 | 11 | 8 | 0 | 0 | 4 | 0 | 7 | 0 | 0 | 30 |
| 149 | *Polystichum mickelii* A. R. Sm. | 6.25 | 21.25 | 15.00 | 0 | 3 | 0 | 1 | 0 | 0 | 3 | 0 | 0 | 7 |
| 150 | *Polystichum rachichlaena* Fée | 10.12 | 23.99 | 13.87 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| 151 | *Polystichum speciosissimum* (A. Braun ex Kunze) Copel | 16.69 | 25.49 | 8.81 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| 152 | *Stigmatopteris longicaudata* (Liebm.) C. Chr. | 36.02 | 19.89 | -16.13 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | **Gleicheniaceae** | | | | | | | | | | | | | |
| 153 | *Diplopterygium bancroftii* (Hook.) A. R. Sm. | 40.30 | 23.95 | -16.35 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Hymenophyllaceae** | | | | | | | | | | | | | |
| 154 | *Abrodictyum rigidum* (Sw.) Ebihara & Dubuisson | 52.87 | 22.87 | -29.99 | 0 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| 155 | *Didymoglossum angustifrons* Fée | 48.02 | 22.72 | -25.30 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 156 | *Didymoglossum hymenoides* (Hedw.) Copel. | 52.08 | 20.87 | -31.22 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 157 | *Didymoglossum kraussii* (Hook. & Grev.)C. Presl | 57.40 | 28.00 | -29.40 | 0 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 158 | *Didymoglossum ovale* E. Fourn. | 49.77 | 20.64 | -29.13 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 159 | *Didymoglossum reptans* (Sw.) C. Presl | 53.02 | 23.13 | -29.89 | 0 | 12 | 8 | 8 | 8 | 1 | 56 | 1 | 0 | 94 |
| 160 | *Hymenophyllum asplenioides* (Sw.) Sw. | 49.68 | 20.50 | -29.18 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 161 | *Hymenophyllum crassipetiolatum* Stolze | 12.46 | 16.34 | 3.88 | 0 | 0 | 0 | 0 | 0 | 0 | 23 | 0 | 0 | 23 |
| 162 | *Hymenophyllum crispum* Kunth | 49.38 | 19.93 | -29.45 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 163 | *Hymenophyllum ectocarpon* Fée | 12.67 | 21.45 | 8.79 | 0 | 40 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 |
| 164 | *Hymenophyllum fragile* (Hedw.) C. V. Morton | 50.74 | 20.99 | -29.75 | 0 | 8 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 16 |
| 165 | *Hymenophyllum fucoides* (Sw.) Sw. | 61.56 | 21.39 | -40.17 | 1 | 8 | 4 | 5 | 5 | 0 | 9 | 0 | 0 | 32 |
| 166 | *Hymenophyllum hirsutum* (L.) Sw. | 51.93 | 22.75 | -29.18 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 167 | *Hymenophyllum polyanthos (Sw.) Sw.* | 53.03 | 22.85 | -30.18 | 0 | 16 | 13 | 16 | 2 | 0 | 59 | 0 | 0 | 106 |
| 168 | *Hymenophyllum lanatum* Fée | 25.59 | 20.59 | -5.00 | 0 | 13 | 1 | 4 | 0 | 0 | 5 | 0 | 0 | 23 |
| 169 | *Hymenophyllum maxonii* Christ ex C. V. Morton | 8.35 | 18.57 | 10.22 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 6 |
| 170 | *Hymenophyllum myriocarpum* Hook. | 45.19 | 19.65 | -25.54 | 8 | 20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 28 |
| 171 | *Hymenophyllum pulchellum* Schltdl. & Cham. | 49.01 | 19.33 | -29.68 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| 172 | *Hymenophyllum tegularis* (Desv.) Proctor & Lourteig | 40.19 | 20.67 | -19.52 | 0 | 1 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 6 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 173 | *Hymenophyllum trapezoidale* Liebm. | 38.26 | 20.43 | -17.82 | 0 | 14 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 17 |
| 174 | *Hymenophyllum tunbrigense* (L.) Sm. | 68.07 | 25.98 | -42.09 | 3 | 1 | 0 | 6 | 0 | 0 | 9 | 0 | 0 | 19 |
| 175 | *Hymenophyllum undulatum* (Sw.) Sw. | 47.95 | 23.95 | -24.00 | 0 | 5 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 9 |
| 176 | *Polyphlebium capillaceum* (L.) Ebihara & Dubuisson | 51.95 | 21.95 | -30.00 | 10 | 5 | 3 | 1 | 9 | 0 | 30 | 0 | 0 | 58 |
| 177 | *Polyphlebium hymenophylloides* (Bosch) Ebihara & Dubuisson | 51.09 | 21.93 | -29.16 | 0 | 7 | 0 | 3 | 2 | 0 | 15 | 0 | 0 | 27 |
| 178 | *Polyphlebium pyxidiferum* (L.) Ebihara & Dubuisson | 51.87 | 20.20 | -31.67 | 3 | 4 | 3 | 0 | 2 | 0 | 0 | 0 | 0 | 12 |
| 179 | *Trichomanes crispum* L. | 52.81 | 22.79 | -30.02 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 180 | *Trichomanes lucens* Sw. | 44.74 | 17.72 | -27.03 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 181 | *Trichomanes polypodioides* L. | 51.90 | 22.01 | -29.89 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 182 | *Vandenboschia collariata* (Bosch) Ebihara & K. Iwats. | 45.24 | 19.739722 | -25.5 | 4 | 3 | 2 | 3 | 0 | 0 | 0 | 0 | 0 | 12 |
| 183 | *Vandenboschia radicans* (Sw.) Copel. | 58.52 | 28.50 | -30.02 | 6 | 5 | 4 | 9 | 3 | 0 | 47 | 1 | 0 | 75 |
| | **Lindsaeaceae** | | | | | | | | | | | | | |
| 184 | *Lindsaea arcuata* Kunze | 46.31 | 19.25 | -27.06 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| 185 | *Lindsaea lancea* (L.) Bedd. | 51.80 | 22.00 | -29.80 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 186 | *Odontosoria schlechtendalii* (C. Presl) C. Chr. | 11.38 | 20.01 | 8.63 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | **Lomariopsidaceae** | | | | | | | | | | | | | |
| 187 | *Lomariopsis mexicana* Holttum | 2.45 | 18.57 | 16.12 | 6 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 9 |
| 188 | *Lomariopsis recurvata* Fée | 5.15 | 19.90 | 14.75 | 0 | 11 | 15 | 6 | 0 | 0 | 0 | 0 | 0 | 32 |
| | **Lonchitidaceae** | | | | | | | | | | | | | |
| 189 | *Lonchitis hirsuta* L. | 39.56 | 21.91 | -17.65 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| | **Lycopodiaceae** | | | | | | | | | | | | | |
| 190 | *Diphasiastrum thyoides* (Humb. & Bonpl. ex Willd.) Holub | 51.85 | 20.99 | -30.86 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 191 | *Lycopodium clavatum* L. | 122.27 | 78.50 | -43.77 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| 192 | *Phlegmariurus capillaris* (Sodiro) B. Øllg. | 28.08 | 17.68 | -10.40 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 193 | *Phlegmariurus cuernavacensis* (Underw. & F. E. Lloyd) B. Øllg. | 9.43 | 23.56 | 14.13 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 194 | *Phlegmariurus dichotomus* (Jacq.) W. H. Wagner | 48.45 | 23.11 | -25.34 | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 4 |
| 195 | *Phlegmariurus linifolius* (L.) B. Øllg. | 44.67 | 22.75 | -21.92 | 0 | 6 | 0 | 0 | 1 | 0 | 9 | 0 | 0 | 16 |
| 196 | *Phlegmariurus myrsinites* (Lam.) B. Øllg. | 37.27 | 19.58 | -17.70 | 3 | 3 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 15 |
| 197 | *Phlegmariurus pithyoides* (Schltdl. & Cham.) B. Øllg. | 19.64 | 23.11 | 3.47 | 0 | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 6 |
| 198 | *Phlegmariurus pringlei* (Underw. & F. E. Lloyd) B. Øllg. | 11.44 | 20.01 | 8.57 | 3 | 4 | 0 | 2 | 4 | 0 | 4 | 2 | 0 | 19 |
| 199 | *Phlegmariurus taxifolius* (Sm.) Á. Löve & D. Löve | 48.48 | 23.16 | -25.32 | 0 | 9 | 5 | 10 | 2 | 3 | 1 | 0 | 0 | 30 |
| 200 | *Phlegmariurus wilsonii* (Underw. & F. E. Lloyd) B. Øllg. | 36.21 | 19.07 | -17.14 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Lygodiaceae** | | | | | | | | | | | | | |
| 201 | *Lygodium heterodoxum* Kunze | 11.23 | 19.68 | 8.45 | 0 | 2 | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 10 |
| 202 | *Lygodium venustum* Sw. | 52.31 | 24.90 | -27.41 | 0 | 0 | 0 | 0 | 5 | 2 | 14 | 0 | 0 | 21 |
| | **Marattiaceae** | | | | | | | | | | | | | |
| 203 | *Danaea moritziana* C. Presl | 53.46 | 23.95 | -29.51 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 204 | *Marattia excavata* Underw | 9.18 | 17.63 | 8.45 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 205 | *Marattia laxa* Kunze | 18.23 | 20.46 | 2.23 | 0 | 0 | 0 | 0 | 9 | 0 | 0 | 0 | 0 | 9 |
| 206 | *Marattia weinmanniifolia* Liebm. | 38.61 | 21.48 | -17.14 | 10 | 4 | 0 | 0 | 0 | 0 | 54 | 2 | 0 | 70 |
| | **Ophioglossaceae** | | | | | | | | | | | | | |
| 207 | *Botrypus virginianus* (L.) Michx. | 94.45 | 65.00 | -29.45 | 3 | 0 | 0 | 0 | 0 | 19 | 1 | 3 | 0 | 26 |
| 208 | *Sceptridium decompositum* (M. Martens & Galeotti) Lyon | 15.54 | 24.99 | 9.45 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 4 |
| | **Polypodiaceae** | | | | | | | | | | | | | |
| 209 | *Alansmia cultrata* (Willd.) Moguel & M. Kessler | 45.35 | 20.00 | -25.35 | 0 | 14 | 0 | 0 | 2 | 0 | 14 | 0 | 0 | 30 |
| 210 | *Alansmia elastica* (Bory ex Willd.) Moguel & M. Kessler | 32.82 | 20.35 | -12.48 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 3 |
| 211 | *Ascogrammitis anfractuosa* (Kunze ex Klotzsch) Sundue | 36.17 | 19.03 | -17.14 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 8 |
| 212 | *Campyloneurum amphostenon* (Kunze ex Klotzsch) Fée | 43.52 | 23.95 | -19.57 | 24 | 4 | 0 | 0 | 6 | 0 | 1 | 0 | 0 | 35 |
| 213 | *Campyloneurum angustifolium* (Sw.) Fée | 55.02 | 25.00 | -30.02 | 13 | 22 | 2 | 7 | 2 | 0 | 64 | 14 | 22 | 146 |
| 214 | *Campyloneurum ensifolium* (Willd.) J. Sm. | 43.45 | 27.30 | -16.15 | 0 | 0 | 0 | 0 | 0 | 38 | 0 | 0 | 0 | 38 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 215 | *Campyloneurum phyllitidis* (L.) C. Presl | 58.86 | 28.75 | -30.11 | 2 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 8 |
| 216 | *Campyloneurum tenuipes* Maxon | 11.98 | 21.26 | 9.28 | 8 | 0 | 0 | 0 | 0 | 0 | 34 | 0 | 0 | 42 |
| 217 | *Campyloneurum xalapense* Fée | 20.50 | 23.95 | 3.45 | 7 | 18 | 22 | 27 | 0 | 0 | 44 | 15 | 0 | 133 |
| 218 | *Ceradenia oidiophora* (Mickel & Beitel) A. R. Sm. | 0.42 | 17.68 | 17.26 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 219 | *Ceradenia sacksii* Sundue | 0.00 | 17.59 | 17.58 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 220 | *Cochlidium linearifolium* (Desv.) Maxon | 36.92 | 20.42 | -16.50 | 0 | 37 | 0 | 4 | 3 | 0 | 26 | 0 | 0 | 70 |
| 221 | *Cochlidium serrulatum* (Sw.) L. E. Bishop | 52.24 | 24.36 | -27.88 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 3 |
| 222 | *Galactodenia delicatula* (M. Martens & Galeotti) Sundue & Labiak | 5.28 | 19.65 | 14.37 | 1 | 22 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 24 |
| 223 | *Loxogramme mexicana* (Fée) C. Chr. | 11.55 | 20.38 | 8.83 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 16 |
| 224 | *Melpomene deltata* (Mickel & Beitel) A. R. Sm. & R. C. Moran | 9.57 | 17.58 | 8.02 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 5 |
| 225 | *Melpomene firma* (J. Sm.) A. R. Sm. & R. C. Moran | 36.61 | 18.77 | -17.84 | 0 | 0 | 0 | 0 | 0 | 0 | 29 | 0 | 0 | 29 |
| 226 | *Melpomene leptostoma* (Fée) A. R. Sm. & R. C. Moran | 5.56 | 21.03 | 15.47 | 0 | 24 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 25 |
| 227 | *Melpomene moniliformis* (Lag. ex Sw.) A. R. Sm. & R. C. Moran | 42.96 | 20.22 | -22.74 | 5 | 11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 16 |
| 228 | *Melpomene peruviana* (Desv.) A. R. Sm. & R. C. Moran | 48.66 | 17.25 | -31.41 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 3 |
| 229 | *Melpomene pilosissima* (M. Martens & Galeotti) A. R. Sm. & R. C. Moran | 47.19 | 19.74 | -27.45 | 3 | 1 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 10 |
| 230 | *Melpomene xiphopteroides* (Liebm.) A. R. Sm. & R. C. Moran | 42.54 | 20.05 | -22.49 | 0 | 5 | 0 | 3 | 4 | 0 | 20 | 0 | 0 | 32 |
| 231 | *Microgramma nitida (J. Sm.) A. R. Sm.* | 23.05 | -20.49 | 43.54 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 5 |
| 232 | *Moranopteris basiattenuata* (Jenm.) R. Y. Hirai & J. Prado | 32.74 | 18.11 | -14.63 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 233 | *Moranopteris taenifolia* (Jenm.) R. Y. Hirai & J. Prado | 35.80 | 18.55 | -17.25 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 234 | *Moranopteris trichomanoides* (Sw.) R. Y. Hirai & J. Prado | 43.83 | 20.87 | -22.97 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 |
| 235 | *Mycopteris semihirsuta* (Klotzsch) Sundue | 41.60 | 19.12 | -22.49 | 0 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 8 |
| 236 | *Niphidium crassifolium* (L.) Lellinger | 52.37 | 22.00 | -30.37 | 0 | 17 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 18 |
| 237 | *Pecluma alfredii* (Rosenst.) M. G. Price | 17.77 | 25.93 | 8.17 | 9 | 0 | 0 | 0 | 0 | 45 | 16 | 31 | 26 | 127 |
| 238 | *Pecluma atra* (A. M. Evans) M. G. Price | 12.62 | 21.64 | 9.02 | 0 | 3 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 5 |
| 239 | *Pecluma bourgeauana* (E. Fourn.) L. A. Triana | 19.32 | 23.07 | 3.75 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 |
| 240 | *Pecluma consimilis* (D. C. Eaton ex Mett.) M. G. Price | 35.92 | 19.19 | -16.73 | 0 | 5 | 16 | 16 | 0 | 0 | 0 | 0 | 0 | 37 |
| 241 | *Pecluma dispersa* (A. M. Evans) M. G. Price | 43.53 | 22.81 | -20.72 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 242 | *Pecluma divaricata* (E. Fourn.) Mickel & Beitel | 38.03 | 19.86 | -18.17 | 0 | 2 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 5 |
| 243 | *Pecluma hartwegiana* (Hook.) F. C. Assis & Salino | 14.62 | 28.40 | 13.78 | 8 | 25 | 0 | 0 | 7 | 0 | 5 | 7 | 0 | 52 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 244 | *Pecluma hygrometrica* (Splitg.) M. G. Price | 45.45 | 23.00 | -22.45 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 245 | *Pecluma longepinnulata* (E. Fourn.) F. C. Assis & Salino | 12.33 | 21.23 | 8.90 | 31 | 16 | 13 | 16 | 1 | 0 | 17 | 0 | 0 | 94 |
| 246 | *Pecluma rhachipterygia* (Liebm.) F. C. Assis & Salino | 3.83 | 19.33 | 15.50 | 2 | 8 | 15 | 5 | 0 | 0 | 0 | 0 | 0 | 30 |
| 247 | *Pecluma sursumcurrens* (Copel.) M. G. Price | 5.86 | 21.47 | 15.61 | 0 | 1 | 17 | 26 | 4 | 0 | 0 | 0 | 0 | 48 |
| 248 | *Phlebodium aureum* (L.) J. Sm. | 58.27 | 28.64 | -29.63 | 5 | 25 | 4 | 10 | 10 | 0 | 2 | 7 | 3 | 66 |
| 249 | *Pleopeltis alansmithii* (R. C. Moran) A. R. Sm. & Tejero | 8.23 | 17.68 | 9.46 | 0 | 32 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 38 |
| 250 | *Pleopeltis angusta* Humb. & Bonpl. ex Willd. | 55.54 | 23.68 | -31.87 | 6 | 8 | 6 | 8 | 5 | 0 | 70 | 21 | 0 | 124 |
| 251 | *Pleopeltis astrolepis* (Liebm.) E. Fourn. | 53.72 | 23.65 | -30.07 | 11 | 5 | 0 | 6 | 0 | 0 | 58 | 1 | 0 | 81 |
| 252 | *Pleopeltis collinsii* (Maxon) A. R. Sm. & Tejero | 3.65 | 19.59 | 15.94 | 6 | 0 | 12 | 19 | 0 | 0 | 0 | 0 | 0 | 37 |
| 253 | *Pleopeltis conzattii* (Weath.) R. M. Tryon & A. F. Tryon | 1.66 | 17.74 | 16.08 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 254 | *Pleopeltis crassinervata* (Fée) T. Moore | 13.60 | 23.14 | 9.54 | 0 | 17 | 16 | 20 | 4 | 50 | 0 | 0 | 0 | 107 |
| 255 | *Pleopeltis fallax* (Schltdl. & Cham.) Mickel & Beitel | 13.12 | 21.57 | 8.45 | 0 | 3 | 7 | 2 | 0 | 0 | 0 | 0 | 0 | 12 |
| 256 | *Pleopeltis furfuracea* (Schltdl. & Cham.) A. R. Sm. & Tejero | 42.66 | 25.93 | -16.73 | 0 | 4 | 0 | 0 | 5 | 0 | 71 | 0 | 27 | 107 |
| 257 | *Pleopeltis lepidotricha* (Fée) A. R. Sm. & Tejero | 3.84 | 21.03 | 17.19 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 258 | *Pleopeltis lindeniana* (Kunze) A. R. Sm. & Tejero | 8.51 | 17.21 | 8.70 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 11 |
| 259 | *Pleopeltis madrensis* (J. Sm) A. R. Sm. & Tejero | 9.78 | 25.96 | 16.18 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 6 |
| 260 | *Pleopeltis mexicana* (Fée) Mickel & Beitel | 12.88 | 25.93 | 13.05 | 31 | 34 | 0 | 0 | 3 | 0 | 20 | 0 | 0 | 88 |
| 261 | *Pleopeltis michauxiana* (Weath.) Hickey & Sprunt | 32.75 | 41.95 | 9.20 | 0 | 0 | 0 | 0 | 0 | 24 | 0 | 0 | 0 | 24 |
| 262 | *Pleopeltis muenchii* (Christ) A. R. Sm. | 3.54 | 17.67 | 14.13 | 15 | 26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 41 |
| 263 | *Pleopeltis platylepis* (Mett. ex Kuhn) A. R. Sm. & Tejero | 12.53 | 21.40 | 8.87 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 11 |
| 264 | *Pleopeltis plebeia* (Schltdl. & Cham.) A. R. Sm. & Tejero | 16.92 | 25.42 | 8.50 | 30 | 32 | 15 | 24 | 17 | 38 | 6 | 0 | 0 | 162 |
| 265 | *Pleopeltis polylepis* (Roem. ex Kunze) T. Moore | 15.65 | 29.85 | 14.20 | 5 | 0 | 0 | 0 | 11 | 0 | 0 | 13 | 20 | 49 |
| 266 | *Pleopeltis polypodioides* (L.) E. G. Andrews & Windham | 74.43 | 41.95 | -32.48 | 13 | 14 | 2 | 9 | 3 | 0 | 0 | 51 | 38 | 130 |
| 267 | *Pleopeltis pyrrholepis* (Fée) A. R. Sm. & Tejero | 4.82 | 20.43 | 15.62 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 268 | *Pleopeltis rzedowskiana* (Mickel) A. R. Sm. & Tejero | 4.80 | 21.00 | 16.20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| 269 | *Pleopeltis sanctae-rosae* (Maxon) A. R. Sm. & Tejero | 9.47 | 22.33 | 12.87 | 20 | 0 | 0 | 0 | 0 | 0 | 11 | 18 | 0 | 49 |
| 270 | *Pleopeltis thyssanolepis* (A. Braun ex Klotzsch) E. G. Andrews & Windham | 52.45 | 34.00 | -18.45 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33 | 34 |
| 271 | *Polypodium arcanum* Maxon | 9.19 | 25.38333 | 16.195552 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 272 | *Polypodium californicum* Kaulf. | 22.52 | 41.93 | 19.41 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 273 | *Polypodium conterminans* Liebm. | 6.93 | 21.13 | 14.20 | 0 | 0 | 0 | 0 | 9 | 0 | 32 | 0 | 0 | 41 |
| 274 | *Polypodium echinolepis* Fée | 24.58 | 20.50 | -4.08 | 0 | 11 | 13 | 8 | 0 | 0 | 1 | 0 | 0 | 33 |
| 275 | *Polypodium eperopeutes* Mickel & Beitel | 3.19 | 18.89 | 15.70 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 |
| 276 | *Polypodium fissidens* Maxon | 4.82 | 18.61 | 13.78 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 |
| 277 | *Polypodium liebmannii* C. Chr. | 4.94 | 23.14 | 18.20 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 11 |
| 278 | *Polypodium martensii* Mett. | 8.53 | 24.72 | 16.19 | 0 | 21 | 0 | 0 | 0 | 11 | 0 | 0 | 0 | 32 |
| 279 | *Polypodium plesiosorum* Kunze | 18.23 | 27.00 | 8.77 | 20 | 2 | 0 | 0 | 4 | 20 | 52 | 0 | 0 | 98 |
| 280 | *Polypodium pleurosorum* Kunze ex Mett. | 8.09 | 18.09 | 10.00 | 0 | 24 | 0 | 0 | 0 | 0 | 143 | 0 | 0 | 167 |
| 281 | *Polypodium puberulum* Schltdl. & Cham. | 7.43 | 21.22 | 13.78 | 0 | 16 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 22 |
| 282 | *Polypodium rhodopleuron* Kunze | 12.01 | 21.48 | 9.47 | 9 | 2 | 10 | 18 | 2 | 0 | 34 | 0 | 0 | 75 |
| 283 | *Polypodium subpetiolatum* Hook. | 18.72 | 28.30 | 9.58 | 2 | 2 | 0 | 0 | 0 | 6 | 8 | 0 | 0 | 18 |
| 284 | *Serpocaulon falcaria* (Kze.) A. R. Sm. | 21.29 | 19.83 | -1.46 | 9 | 28 | 0 | 0 | 7 | 0 | 57 | 0 | 0 | 101 |
| 285 | *Serpocaulon triseriale* (Sw.) A. R. Sm. | 55.24 | 27.33 | -27.90 | 7 | 8 | 2 | 3 | 4 | 0 | 0 | 0 | 0 | 24 |
| 286 | *Stenogrammitis delitescens* (Maxon) Labiak | 2.86 | 20.54 | 17.68 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 287 | *Stenogrammitis hellwigii* (Mickel & Beitel) Labiak | 6.69 | 17.61 | 10.92 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 |
| 288 | *Stenogrammitis prionodes* (Mickel & Beitel) Labiak | 7.41 | 20.33 | 12.92 | 1 | 18 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 20 |
| 289 | *Terpsichore asplenifolia* (L.) A. R. Sm. | 37.35 | 20.68 | -16.67 | 0 | 0 | 0 | 0 | 4 | 0 | 8 | 0 | 0 | 12 |
| | **Plagiogyriaceae** | | | | | | | | | | | | | |
| 290 | *Plagiogyria pectinata* (Liebm.) Lellinger | 56.74 | 28.45 | -28.30 | 3 | 12 | 0 | 0 | 5 | 0 | 0 | 2 | 0 | 22 |
| | **Psilotaceae** | | | | | | | | | | | | | |
| 291 | *Psilotum complanatum* Sw. | 45.50 | 29.33 | -16.17 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 6 |
| | **Pteridaceae** | | | | | | | | | | | | | |
| 292 | *Adiantopsis radiata* (L.) Fée | 55.94 | 23.08 | -32.87 | 0 | 0 | 0 | 0 | 0 | 1 | 7 | 0 | 0 | 8 |
| 293 | *Adiantum amplum* Presl | 21.98 | 25.88 | 3.90 | 0 | 0 | 0 | 0 | 0 | 0 | 49 | 0 | 1 | 50 |
| 294 | *Adiantum andicola* Liebm. | 25.80 | 28.21 | 2.41 | 21 | 0 | 0 | 0 | 5 | 0 | 4 | 55 | 27 | 112 |
| 295 | *Adiantum concinnum* Humb. & Bonpl. ex Willd. | 49.66 | 27.66 | -22.00 | 0 | 0 | 0 | 0 | 1 | 0 | 12 | 10 | 23 | 46 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 296 | *Adiantum feei* T. Moore | 10.09 | 23.14 | 13.05 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 297 | *Adiantum latifolium* Lam. | 48.37 | 22.69 | -25.68 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 298 | *Adiantum macrophyllum* Sw. | 47.40 | 22.86 | -24.54 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 299 | *Adiantum patens* Willd. | 47.97 | 30.47 | -17.50 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 10 |
| 300 | *Adiantum philippense* L. | 46.55 | 23.65 | -22.90 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 10 |
| 301 | *Adiantum poiretii* Wikstr. | 67.07 | 31.26 | -35.82 | 0 | 2 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 3 |
| 302 | *Adiantum pulverulentum* L. | 51.83 | 22.83 | -29.00 | 0 | 17 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 23 |
| 303 | *Adiantum tenerum* Sw. | 60.17 | 28.72 | -31.45 | 0 | 1 | 0 | 0 | 5 | 4 | 0 | 0 | 0 | 10 |
| 304 | *Adiantum tetraphyllum* Humb. & Bonpl. ex Will. | 50.18 | 22.97 | -27.22 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 305 | *Adiantum trapeziforme* L. | 53.32 | 23.59 | -29.73 | 0 | 1 | 0 | 0 | 0 | 2 | 21 | 0 | 0 | 24 |
| 306 | *Adiantum wilesianum* Hook. | 13.69 | 23.95 | 10.26 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 307 | *Aleuritopteris farinosa* (Forssk.) Fée | 35.54 | 28.50 | -7.04 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 308 | *Ananthacorus angustifolius* (Sw.) Underw. & Maxon | 49.79 | 22.79 | -27.00 | 0 | 2 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 5 |
| 309 | *Aspidotis meifolia* (D. C. Eaton) Pic. Serm. | 7.41 | 28.56 | 21.15 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| 310 | *Astrolepis sinuata* (Lag. ex Sw.) D.M. Benham & Windham | 58.58 | 35.00 | -23.58 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 311 | *Gaga angustifolia* (Kunth) Fay W. Li & Windham | 23.62 | 28.44 | 4.82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 8 | 10 |
| 312 | *Gaga hirsuta* (Link) Fay W. Li & Windham | 20.42 | 29.20 | 8.78 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 313 | *Gaga pellaeopsis* (Mickel) Fay W. Li & Windham | 4.53 | 24.00 | 19.47 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| 314 | *Gastoniella chaerophylla* (Desv.) Li Bing Zhang & Liang Zhang | 55.12 | 20.50 | -34.62 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 0 | 4 |
| 315 | *Jamesonia hirta* (Kunth) Christenh. | 36.72 | 19.99 | -16.73 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 316 | *Mildella intramarginalis* (Kaulf. ex Link) Trevis. | 25.60 | 25.18 | -0.42 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 317 | *Myriopteris lendigera* (Cav.) J. Sm. | 47.33 | 47.00 | -0.33 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 318 | *Myriopteris mexicana* (Davenp.) Grusz & Windham | 13.49 | 29.23 | 15.74 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 4 |
| 319 | *Myriopteris notholaenoides* (Desv.) Grusz & Windham | 53.31 | 28.56 | -24.75 | 0 | 0 | 0 | 0 | 3 | 9 | 0 | 0 | 0 | 12 |
| 320 | *Pityrogramma calomelanos* (L.) Link | 59.73 | 28.88 | -30.86 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 321 | *Polytaenium chlorosporum* (Mickel & Beitel) E. H. Crane | 11.29 | 17.83 | 6.53 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 |
| 322 | *Polytaenium feei* (W. Schaffn. ex Fée) Maxon | 25.04 | 22.02 | -3.02 | 2 | 5 | 15 | 17 | 0 | 0 | 0 | 0 | 0 | 39 |
| 223 | *Polytaenium lineatum* (Sw.) J. Sm. | 51.68 | 21.98 | -29.71 | 0 | 0 | 3 | 2 | 0 | 0 | 0 | 0 | 0 | 5 |
| 324 | *Pteris altissima* Poir. | 55.36 | 25.68 | -29.68 | 21 | 4 | 9 | 11 | 0 | 0 | 7 | 0 | 0 | 52 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 325 | *Pteris biaurita* L. | 58.21 | 22.39 | -35.82 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| 326 | *Pteris cretica* L. | 80.42 | 45.67 | -34.75 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 0 | 0 | 6 |
| 327 | *Pteris erosa* Mickel & Beitel | 7.69 | 21.48 | 13.78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 3 |
| 328 | *Pteris muricata* Hook. | 38.61 | 19.61 | -19.00 | 0 | 0 | 0 | 0 | 1 | 0 | 19 | 0 | 0 | 20 |
| 329 | *Pteris muricella* Fée | 10.43 | 18.93 | 8.50 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 4 |
| 330 | *Pteris orizabae* Mart. & Gal. | 14.22 | 25.24 | 11.02 | 15 | 0 | 0 | 11 | 0 | 0 | 14 | 0 | 0 | 40 |
| 331 | *Pteris podophylla* Sw. | 47.53 | 20.47 | -27.06 | 4 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 9 |
| 332 | *Pteris pungens* Willd. | 48.20 | 31.00 | -17.20 | 0 | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 0 | 16 |
| 333 | *Pteris quadriaurita* Retz. | 47.73 | 23.11 | -24.62 | 0 | 0 | 0 | 0 | 0 | 13 | 11 | 5 | 0 | 29 |
| 334 | *Scoliosorus ensiformis* (Hook.) T. Moore | 12.12 | 20.63 | 8.51 | 0 | 11 | 23 | 22 | 8 | 0 | 24 | 0 | 0 | 88 |
| 335 | *Vittaria flavicosta* Mickel & Beitel | 4.77 | 21.27 | 16.50 | 0 | 9 | 11 | 11 | 0 | 0 | 0 | 0 | 0 | 31 |
| 336 | *Vittaria graminifolia* Kaulf. | 53.14 | 23.14 | -30.00 | 28 | 50 | 0 | 10 | 12 | 15 | 55 | 12 | 3 | 185 |
| 337 | *Vittaria lineata* (L.) Sw. | 61.93 | 29.89 | -32.03 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| | **Saccolomataceae** | | | | | | | | | | | | | |
| 338 | *Saccoloma galeottii* (Fée) A. Rojas | 4.14 | 17.19 | 13.05 | 10 | 0 | 0 | 0 | 0 | 0 | 8 | 0 | 0 | 18 |
| 339 | *Saccoloma inaequale* (Kunze) Mett. | 49.96 | 21.97 | -27.99 | 1 | 21 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 24 |
| | **Schizaeaceae** | | | | | | | | | | | | | |
| 340 | *Schizaea elegans* (Vahl) Sw. | 48.54 | 18.57 | -29.98 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| | **Selaginellaceae** | | | | | | | | | | | | | |
| 341 | *Selaginella delicatissima* Linden | 13.87 | 28.37 | 14.50 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 7 |
| 342 | *Selaginella extensa* Underw. | 9.94 | 24.63 | 14.69 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 |
| 343 | *Selaginella flagellata* Spring | 40.83 | 23.16 | -17.67 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| 344 | *Selaginella flexuosa* Spring | 47.72 | 17.72 | -29.99 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 |
| 345 | *Selaginella harrisii* Underw. & Hieron. | 7.61 | 22.52 | 14.92 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 5 |
| 346 | *Selaginella hoffmannii* Hieron. | 14.87 | 23.68 | 8.81 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
| 347 | *Selaginella martensii* Spring | 46.52 | 22.56 | -23.96 | 4 | 0 | 0 | 0 | 1 | 0 | 40 | 0 | 0 | 45 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 348 | *Selaginella mickelii* Valdespino | 3.25 | 19.33 | 16.08 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 |
| 349 | *Selaginella mosorongensis* Hieron. | 0.84 | 17.84 | 17.00 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 |
| 350 | *Selaginella oaxacana* Spring | 21.39 | 19.78 | -1.62 | 0 | 8 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 10 |
| 351 | *Selaginella pallescens* (C. Presl) Spring | 55.64 | 29.33 | -26.31 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 5 |
| 352 | *Selaginella porphyrospora* A. Braun | 28.79 | 27.32 | -1.47 | 0 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 | 13 |
| 353 | *Selaginella pulcherrima* Liebm. ex E. Fourn. | 4.44 | 19.87 | 15.43 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 |
| 354 | *Selaginella sertata* Spring | 14.62 | 22.94 | 8.31 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 |
| 355 | *Selaginella stellata* Spring | 37.28 | 21.07 | -16.21 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 5 |
| 356 | *Selaginella subrugosa* Mickel & Beitel | 0.77 | 17.93 | 17.16 | 0 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 8 |
|  | **Tectariaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 357 | *Tectaria heracleifolia* (Willd.) Underw. | 40.44 | 28.69 | -11.75 | 4 | 19 | 12 | 3 | 6 | 5 | 0 | 0 | 1 | 50 |
| 358 | *Tectaria incisa* Cav. | 56.37 | 26.70 | -29.67 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 359 | *Tectaria mexicana* (Fée) C. V. Morton | 24.43 | 22.65 | -1.78 | 5 | 0 | 0 | 0 | 0 | 0 | 44 | 2 | 0 | 51 |
|  | **Thelypteridaceae** |  |  |  |  |  |  |  |  |  |  |  |  |  |
| 360 | *Amauropelta concinna* (Willd.) Pic. Serm. | 53.72 | 25.67 | -28.05 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 361 | *Amauropelta deflexa* (C. Presl) Á. Löve & D. Löve | 33.50 | 18.17 | -15.33 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 362 | *Amauropelta oligocarpa* (Humb. & Bonpl. ex Willd.) Pic. Serm. | 54.97 | 25.29 | -29.68 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 4 |
| 363 | *Amauropelta pilosula* (Klotzsch & H. Karst. Ex Mett.) Á. Löve & D. Löve | 40.56 | 21.47 | -19.09 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 6 |
| 364 | *Amauropelta rudis* (Kunze) Pic. Serm. | 50.35 | 28.17 | -22.19 | 7 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 14 |
| 365 | *Christella dentata* (Forssk.) Brownsey & Jermy | 64.14 | 30.48 | -33.66 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 5 |
| 366 | *Christella normalis* (C. Chr.) Holttum | 51.80 | 34.00 | -17.80 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 367 | *Christella quadrangularis* (Fée Holttum | 66.15 | 33.59 | -32.55 | 0 | 0 | 0 | 0 | 0 | 11 | 0 | 3 | 0 | 14 |
| 368 | *Goniopteris biolleyi* (Christ) Pic. Serm. | 47.72 | 23.02 | -24.71 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 369 | *Goniopteris blanda* (Fée) Salino & T. E. Almeida | 13.65 | 23.95 | 10.30 | 3 | 0 | 5 | 1 | 0 | 0 | 0 | 0 | 0 | 9 |
| 370 | *Goniopteris ghiesbreghtii* (Linden) J. Sm. | 10.71 | 19.33 | 8.62 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| 371 | *Goniopteris hatchii* (A. R. Sm.) Á. Löve & D. Löve | 9.59 | 19.18 | 9.59 | 11 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| 372 | *Goniopteris imbricata* (Liebm.) Á. Löve & D. Löve | 14.03 | 21.53 | 7.50 | 0 | 6 | 3 | 1 | 0 | 0 | 35 | 0 | 1 | 46 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 373 | *Goniopteris liebmannii* (Maxon & C. V. Morton) Salino & T. E. Almeida | 3.83 | 19.33 | 15.50 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 |
| 374 | *Goniopteris obliterata* (Sw.) C. Presl | 14.23 | 22.86 | 8.63 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| 375 | *Goniopteris paucipinnata* (Donn. Sm.) Salino & T. E. Almeida | 6.00 | 21.28 | 15.28 | 6 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 7 |
| 376 | *Goniopteris resiliens* (Maxon) Salino & T. E. Almeida | 4.04 | 19.33 | 15.30 | 1 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 5 |
| 377 | *Goniopteris rhachiflexuosa* (Riba) & T. E. Almeida | 0.26 | 18.61 | 18.35 | 0 | 0 | 18 | 9 | 0 | 0 | 0 | 0 | 0 | 27 |
| 378 | *Goniopteris schaffneri* (Fée) Salino & T. E. Almeida | 7.00 | 24.00 | 17.00 | 0 | 0 | 7 | 0 | 0 | 4 | 0 | 0 | 0 | 11 |
| 379 | *Goniopteris tuxtlensis* (T. Krömer, Acebey & A. R. Sm.) Salino & T. E. Almeida | 0.06 | 18.58 | 18.52 | 0 | 0 | 0 | 13 | 0 | 0 | 0 | 0 | 0 | 13 |
| 380 | *Macrothelypteris torresiana* (Gaudich.) Ching | 69.49 | 34.97 | -34.52 | 6 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 8 |

Appendix T 3-3 Location of the eight elevational transects at the transition from tropics to the subtropics in Mexico.

| **Transect name** | **Coordinates (range)** | **Continental side** | **Localities, state** | **Plot numbers** | **Elevational range (m) and elevational steps** |
|---|---|---|---|---|---|
| ChiapasN | 16.74 N- 92.69 W<br>to 17.58 N-93.04 W | Atlantic | Sierra Norte, Chiapas | 67 | 25-2850 (15) |
| Oaxaca | 17.37 N- 96.51 to 17.82-96.25 | | Sierra de Juárez, Oaxaca | 121 | 300-3100 (15) |
| Tuxtlas a | 18.54 N-95.15 W to 18.58 N-95.07W | | Reserva de la Biosfera Los Tuxtlas, Veracruz | 41 | 200-1300 (5) |
| Tuxtlas b | | | | 42 (presence) | 140-1675 (10) |
| Perote | 19.42 W-96.78 N to 19.83 W- 96.73 N | | Cofre de Perote, Veracruz | 40 (presence) | 0-3500 (8) |
| Cielo | 23.10N-99.20W | | Reserva de la Biósfera El Cielo, Tamaulipas | 59 | 200-1900 (14) |
| Triunfo | 15.53 N -92.89 W to17.52 N- 92.86 W | Pacific | Reserva de la Biósfera El Triunfo, Chiapas | 163 | 200-2400 (23) |
| Manantlán | 19.57N-104.24W | | Reserva de la Biósfera Sierra de Manantlán, Jalisco | 78 | 1200-2800 (17) |
| Nayarit | 21.48N-104.97W | | Cerro San Juan, Nayarit | 47 | 600-2200 (11) |

Appendix T 4-1 Species list including the closest relatives for the absent species in our phylogeny. The species authors follow PPG (2016) and Hassler & Schmitt (2020) with some exceptions. **Table S.1** Species list including the closest relatives for the absent species in our phylogeny. The species authors follow PPG (2016) and Hassler & Schmitt (2020) with some exceptions.

| | **Species name** | **Original name in database** | **Name chosen in the phylogeny** |
|---|---|---|---|
| 1 | *Abrodictyum rigidum* (Sw.) Ebihara & Dubuisson | *Abrodictyum rigidum* | *Abrodictyum rigidum* |
| 2 | *Adiantopsis radiata* (L.) Fée | *Adiantopsis radiata* | *Adiantopsis radiata* |
| 3 | *Adiantum amplum* C. Presl | *Adiantum amplum* | *Adiantum galeottianum* |
| 4 | *Adiantum andicola* Liebm. | *Adiantum andicola* | *Adiantum andicola* |
| 5 | *Adiantum concinnum* Humb. & Bonpl. ex Willd. | *Adiantum concinnum* | *Adiantum concinnum* |
| 6 | *Adiantum feei* Moore | *Adiantum feei* | *Adiantum tricholepis* |
| 7 | *Adiantum latifolium* Lam. | *Adiantum latifolium* | *Adiantum latifolium* |
| 8 | *Adiantum macrophyllum* Sw. | *Adiantum macrophyllum* | *Adiantum macrophyllum* |
| 9 | *Adiantum obliquum* Willd. | *Adiantum obliquum* | *Adiantum obliquum* |
| 10 | *Adiantum patens* Willd. | *Adiantum patens* | *Adiantum patens* |
| 11 | *Adiantum philippense* L. | *Adiantum philippense* | *Adiantum philippense* |
| 12 | *Adiantum poiretii* Wikstr. | *Adiantum poiretti* | *Adiantum poiretii* |
| 13 | *Adiantum pulverulentum* L. | *Adiantum pulverulentum* | *Adiantum terminatum* |
| 14 | *Adiantum tenerum* Sw. | *Adiantum tenerum* | *Adiantum tenerum* |
| 15 | Adiantum terminatum Kunze ex Miq. | Adiantum terminatum | Adiantum terminatum |
| 16 | *Adiantum tetraphyllum* Humb. & Bonpl. ex Willd. | *Adiantum tetraphyllum* | *Adiantum tetraphyllum* |
| 17 | *Adiantum trapeziforme* L. | *Adiantum trapeziforme* | *Adiantum trapeziforme* |
| 18 | *Adiantum wilesianum* Hook. | *Adiantum wilesianum* | *Adiantum polyphyllum* |
| 19 | *Alansmia canescens* (A. Rojas) Moguel & M. Kessler | *Alansmia canescens* | *Alansmia canescens* |
| 20 | Alansmia cultrata (Bory ex Willd.) Moguel & M. Kessler | Terpsichore cultrata | Alansmia cultrata |
| | | Alansmia cultrata | Alansmia cultrata |
| 21 | *Alansmia diaphana* (Moguel & M. Kessler) Moguel & M. Kessler | *Alansmia diaphana* | *Alansmia diaphana* |
| 22 | *Alansmia elastica* (Bory ex Willd.) Moguel & M. Kessler | *Terpsichore mollissima* | *Terpsichore mollissima* |
| | | *Alansmia elastica* | *Alansmia elastica* |
| 23 | *Alansmia heteromorpha* (Hook. & Grev.) Moguel & M. Kessler | *Alansmia heteromorpha* | *Alansmia heteromorpha* |

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|---|---|---|---|
| 24 | *Alansmia lanigera* (Desv.) Moguel & M. Kessler | *Terpsichore lanigera* | *Alansmia lanigera* |
| | | *Alansmia lanigera* | *Alansmia lanigera* |
| 25 | *Alansmia longa* (C. Chr.) Moguel & M. Kessler | *Terpsichore longa* | *Alansmia canescens* |
| 26 | *Alansmia monosora* (Moguel & M. Kessler) Moguel & M. Kessler | *Alansmia monosora* | *Alansmia monosora* |
| 27 | *Alansmia senilis* (Fée) Moguel & M. Kessler | *Terpsichore senilis* | *Alansmia senilis* |
| 28 | *Alansmia smithii* (A. Rojas) Moguel & M. Kessler | *Alansmia smithii* | *Alansmia smithii* |
| 29 | *Alansmia* sp. | *Alansmia spec 3* | *Alansmia spec 3* |
| 30 | *Alansmia stella* (Copel.) Moguel & M. Kessler | *Alansmia stella* | *Alansmia stella* |
| 31 | *Alansmia turrialbae* (Christ) Moguel & M. Kessler | *Terpsichore turrialbae* | *Alansmia stella stella* |
| 32 | *Aleuritopteris farinosa* (Forssk.) Fée | *Aleuritopteris farinosa* | *Aleuritopteris farinosa* |
| 33 | *Alsophila cuspidata* (Kunze) D. S. Conant | *Alsophila cuspidata* | *Alsophila cuspidata* |
| 34 | *Alsophila erinacea* (H. Karst.) D. S. Conant | *Alsophila erinacea* | *Alsophila erinacea* |
| 35 | *Alsophila firma* (Baker) D. S. Conant | *Alsophila firma* | *Alsophila firma* |
| 36 | *Alsophila imrayana* (Hook.) D.S. Conant | *Alsophila imrayana* | *Alsophila imrayana* |
| 37 | *Alsophila polystichoides* Christ | *Alsophila polystichoides* | *Cyathea mexicana* |
| 38 | *Alsophila salvinii* Hook. | *Alsophila salvinii* | *Alsophila salvinii* |
| 39 | *Alsophila tryoniana* (G.J. Gastony) D.S. Conant | *Alsophila tryoniana* | *Alsophila erinacea* |
| 40 | *Amauropelta atrovirens* (C. Chr.) Salino & T. E. Almeida | *Thelypteris atrovirens* | *Amauropelta scalaris* |
| 41 | *Amauropelta barvae* (A. R. Sm.) Salino & T. E. Almeida | *Thelypteris barvae* | *Amauropelta strigosa* |
| 42 | *Amauropelta caucaensis* (Hieron.) A. R. Sm. | *Amauropelta caucaensis* | *Amauropelta caucaensis* |
| 43 | *Amauropelta concinna* (Willd.) Pic. Serm. | *Amauropelta concinna* | *Amauropelta caucaensis* |
| 44 | *Amauropelta deflexa* (C. Presl) Á Löve. & D. Löve | *Thelypteris deflexa* | *Amauropelta heteroptera* |
| | | *Amauropelta deflexa* | *Amauropelta pilosohispida* |
| 45 | *Amauropelta delasotae* (A. R. Sm. & Lellinger) Salino & T. E. Almeida | *Thelypteris delasotae* | *Amauropelta caucaensis* |
| 46 | *Amauropelta enigmatica* (A. R. Sm.) Salino & T. E. Almeida | *Amauropelta enigmatica* | *Amauropelta enigmatica* |
| 47 | *Amauropelta euchlora* (Sodiro) A. R. Sm. | *Amauropelta euchlora* | *Amauropelta euchlora* |
| 48 | *Amauropelta frigida* (Christ) A. R. Sm. | *Thelypteris frigida* | *Amauropelta rustica* |
| 49 | *Amauropelta funckii* (Mett.) A. R. Sm. | *Thelypteris funckii* | *Thelypteris funckii* |
| 50 | *Amauropelta germaniana* (Fée) Salino & T. E. Almeida | *Thelypteris germaniana* | *Amauropelta tomentosa* |
| 51 | *Amauropelta glandulosolanosa* (C. Chr.) Salino & T. E. Almeida | *Thelypteris glandulosolanosa* | *Amauropelta glandulosolanosa* |
| | | *Amauropelta glandulosolanosa* | *Amauropelta glandulosolanosa* |

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|---|---|---|---|
| 52 | *Amauropelta gomeziana* (A. R. Sm. & Lellinger) Salino & T. E. Almeida | *Thelypteris gomeziana* | *Amauropelta pilosohispida* |
| 53 | *Amauropelta inaequans* (C. Chr.) Salino & T. E. Almeida | *Thelypteris inaequans* | *Amauropelta ruiziana* |
| 54 | *Amauropelta jimenezii* (Maxon & C. Chr.) Salino & T. E. Almeida | *Thelypteris jimenezii* | *Amauropelta salazica* |
| 55 | *Amauropelta micula* (A. R. Sm.) Salino & T. E. Almeida | *Amauropelta micula* | *Amauropelta micula* |
| 56 | *Amauropelta oligocarpa* (Humb. & Bonpl. ex Willd.) Pic. Serm. | *Thelypteris oligocarpa* | *Amauropelta oligocarpa* |
|  |  | *Amauropelta oligocarpa* | *Amauropelta oligocarpa* |
| 57 | *Amauropelta pilosohispida* (Hook.) A. R. Sm. | *Amauropelta pilosohispida* | *Amauropelta pilosohispida* |
| 58 | *Amauropelta pilosula* (Klotzsch & H. Karst. ex Mett.) Á. Löve & D. Löve | *Amauropelta pilosula* | *Amauropelta cheilanthoides* |
|  |  | *Thelypteris pilosula* | *Amauropelta linkiana* |
| 59 | *Amauropelta proboscidea* (A. R. Sm.) Salino & T. E. Almeida | *Amauropelta proboscidea* | *Amauropelta proboscidea* |
| 60 | *Amauropelta prolatipedis* (Lellinger) A. R. Sm. | *Thelypteris prolatipedis* | *Amauropelta oppositiformis* |
| 61 | *Amauropelta pusilla* (Mett.) A. R. Sm. | *Thelypteris pusilla* | *Amauropelta micula* |
| 62 | *Amauropelta resinifera* (Desv.) Pic. Serm. | *Amauropelta resinifera* | *Amauropelta pachyrhachis* |
| 63 | *Amauropelta rudis* (Kunze) Pic. Serm. | *Thelypteris rudis* | *Amauropelta rudis* |
|  |  | *Amauropelta rudis* | *Amauropelta rudis* |
| 64 | *Amauropelta scalaris* (Christ) Á. Löve & D. Löve | *Amauropelta scalaris* | *Amauropelta scalaris* |
| 65 | *Amauropelta subscandens* (A. R. Sm.) Salino & T. E. Almeida | *Thelypteris subscandens* | *Amauropelta globulifera* |
| 66 | *Amauropelta supina* (Sodiro) Salino & T. E. Almeida | *Amauropelta supina* | *Amauropelta supina* |
| 67 | *Amauropelta supranitens* (Christ) Á. & D. Löve | *Thelypteris supranitens* | *Amauropelta proboscidea* |
| 68 | *Amauropelta villana* (L. D. Gómez) Salino & T. E. Almeida | *Thelypteris villana* | *Amauropelta saxicola* |
| 69 | *Ananthacorus angustifolius* (Sw.) Underw. & Maxon | *Vittaria costata* | *Ananthacorus angustifolius* |
|  |  | *Ananthacorus angustifolius* | *Ananthacorus angustifolius* |
| 70 | *Anemia adiantifolia* (L.) Sw. | *Anemia adiantifolia* | *Anemia adiantifolia* |
| 71 | *Anemia karwinskyana* (C. Presl) Prantl | *Anemia karwinskyana* | *Anemia karwinskyana* |
| 72 | *Anemia phyllitidis* (L.) Sw. | *Anemia phyllitidis* | *Anemia phyllitidis* |
| 73 | *Arachniodes denticulata* (Sw.) Ching | *Arachniodes denticulata* | *Arachniodes denticulata* |
| 74 | *Arachniodes ochropteroides* (Baker) Lellinger | *Arachniodes ochropteroides* | *Arachniodes ochropteroides* |
| 75 | *Ascogrammitis anfractuosa* (Kunze ex Klotzsch) Sundue | *Melpomene anfractuosa* | *Ascogrammitis anfractuosa* |
|  |  | *Ascogrammitis anfractuosa* | *Ascogrammitis anfractuosa* |
| 76 | *Ascogrammitis colombiensis* Sundue | *Ascogrammitis columbiensis* | *Ascogrammitis colombiensis* |
| 77 | *Ascogrammitis loxensis* Sundue | *Ascogrammitis loxensis* | *Ascogrammitis loxensis* |

| | | | |
|---|---|---|---|
| 78 | *Ascogrammitis pichinchae* (Sodiro) Sundue | *Ascogrammitis pichinchae* | *Ascogrammitis pichinchae* |
| 79 | *Aspidotis meifolia* (D. C. Eaton) Pic. Serm. | *Aspidotis meifolia* | *Aspidotis meifolia* |
| 80 | *Asplenium abscissum* Willd. | *Asplenium abscissum* | *Asplenium abscissum* |
| 81 | *Asplenium alatum* Humb. & Bonpl. ex Willd. | *Asplenium alatum* | *Asplenium alatum* |
| 82 | *Asplenium athyrioides* Fée | *Asplenium athyrioides*<br>*Asplenium achellifolium* | *Asplenium myriophyllum*<br>*Asplenium myriophyllum* |
| 83 | *Asplenium auriculatum* Sw. | *Asplenium auriculatum* | *Asplenium auriculatum* |
| 84 | *Asplenium auritum* Sw. | *Asplenium auritum* | *Asplenium auritum* |
| 85 | *Asplenium auritum* var. *macilentum* (Kunze ex Klotzsch) T. Moore | *Asplenium macilentum* | *Asplenium abscissum* |
| 86 | *Asplenium barbaense* Hieron. | *Asplenium barbaense* | *Asplenium soleirolioides* |
| 87 | *Asplenium blepharophorum* Bertol. | *Asplenium blephaphorum* | *Asplenium rutaceum* |
| 88 | *Asplenium castaneum* Schltdl. & Cham. | *Asplenium castaneum* | *Asplenium castaneum* |
| 89 | *Asplenium cirrhatum* Rich. ex Willd. | *Asplenium cirrhatum* | *Asplenium alatum* |
| 90 | *Asplenium cristatum* Lam. | *Asplenium cristatum* | *Asplenium cristatum* |
| 91 | *Asplenium cuneatum* Lam. | *Asplenium cuneatum* | *Asplenium cuneatum* ECU |
| 92 | *Asplenium cuspidatum* Lam. | *Asplenium cuspidatum*<br>*Asplenium rigidum* | *Asplenium cuspidatum*<br>*Asplenium cuspidatum* |
| 93 | *Asplenium dissectum* Sw. | *Asplenium dissectum* | *Asplenium dissectum* |
| 94 | *Asplenium drepanophyllum* Kunze | *Asplenium drepanophyllum* | *Asplenium drepanophyllum* |
| 95 | *Asplenium feei* Kunze ex Fée | *Asplenium feei* | *Asplenium feei* |
| 96 | *Asplenium flabellulatum* Kunze | *Asplenium flabellulatum* | *Asplenium flabellulatum* |
| 97 | *Asplenium formosum* Willd. | *Asplenium formosum* | *Asplenium formosum* |
| 98 | *Asplenium fragrans* Sw. | *Asplenium fragrans*<br>*Asplenium foeniculaceum* | *Asplenium foeniculaceum*<br>*Asplenium foeniculaceum* |
| 99 | *Asplenium gomezianum* Lellinger | *Asplenium gomezianum* | *Asplenium inaequilaterale* vel aff 1 |
| 100 | *Asplenium hallbergii* Mickel & Beitel | *Asplenium hallbergii* | *Asplenium hallbergii* |
| 101 | *Asplenium hallii* Hook. | *Asplenium hallii* | *Asplenium hallii* |
| 102 | *Asplenium harpeodes* Kunze | *Asplenium harpeodes* | *Asplenium harpeodes* |
| 103 | *Asplenium hastatum* Klotzsch ex Kunze | *Asplenium hastatum* | *Asplenium hastatum* |
| 104 | *Asplenium holophlebium* Baker | *Asplenium holophlebium* | *Asplenium capillipes* |
| 105 | *Asplenium juglandifolium* Lam. | *Asplenium juglandifolium* | *Asplenium juglandifolium* |

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| 106 | *Asplenium kunzeanum* Klotzsch ex Rosenst. | *Asplenium kunzeanum* | *Asplenium kunzeanum* |
| 107 | *Asplenium lamprocaulon* Fée | *Asplenium lamprocaulon* | *Asplenium fibrillosum* |
| 108 | *Asplenium maxonii* Lellinger | *Asplenium maxonii* | *Asplenium hallii* |
| 109 | *Asplenium miradorense* Liebm. | *Asplenium miradorense* | *Asplenium juglandifolium* |
| 110 | *Asplenium monanthes* L. | *Asplenium monanthes* | *Asplenium monanthes* |
| 111 | *Asplenium munchii* A. R. Sm. | *Asplenium muenchii* | *Asplenium lividum* |
| 112 | *Asplenium nigripes* (Fée) Hook. | *Asplenium nigripes* | *Asplenium nigripes* |
| 113 | *Asplenium oellgaardii* Stolze | *Asplenium oellgaardii* | *Asplenium abscissum* |
| 114 | *Asplenium polyphyllum* Bertol. | *Asplenium polyphyllum* | *Asplenium polyphyllum* |
| 115 | *Asplenium potosinum* Hieron. | *Asplenium potosinum* | *Asplenium dissectum* |
| 116 | *Asplenium praemorsum* Sw. | *Asplenium praemorsum* | *Asplenium hastatum* |
| 117 | *Asplenium pteropus* Kaulf. | *Asplenium pteropus* | *Asplenium pteropus* |
| 118 | *Asplenium pulchellum* Raddi | *Asplenium pulchellum* | *Asplenium lunulatum* |
| 119 | *Asplenium pululahuae* Sodiro | *Asplenium pululahuae* | *Asplenium pululahuae* |
| 120 | *Asplenium pumilum* Sw. | *Asplenium pumilum* | *Asplenium pumilum* |
| 121 | *Asplenium quitense* Hook. | *Asplenium quitense* | *Asplenium quitense* |
| 122 | *Asplenium radicans* L. | *Asplenium radicans* | *Asplenium radicans* |
| 123 | *Asplenium repens* Hook. | *Asplenium repens* | *Asplenium repens* |
| 124 | *Asplenium rosenstockianum* Brade | *Asplenium rosenstockianum* | *Asplenium inaequilaterale* vel aff 1 |
| 125 | *Asplenium rutaceum* (Willd.) Mett. | *Asplenium rutaceum* | *Asplenium rutaceum* |
| 126 | *Asplenium salicifolium* L. | *Asplenium salicifolium* | *Asplenium salicifolium* |
| 127 | *Asplenium seileri* C. D. Adams | *Asplenium seileri* | *Asplenium resiliens* |
| 128 | *Asplenium serra* Langsd. & Fisch. | *Asplenium serra* | *Asplenium serra* |
| 129 | *Asplenium serratum* L. | *Asplenium serratum* | *Asplenium serratum* |
| 130 | *Asplenium sessilifolium* Desv. | *Asplenium sessilifolium* | *Asplenium sessilifolium* |
| 131 | *Asplenium solmsii* Baker ex Hemsl. | *Asplenium solmsii* | *Asplenium hallii* |
| 132 | *Asplenium sphaerosporum A. R. Sm.* | *Asplenium sphaerosporum* | *Asplenium cuneatum ECU* |
| 133 | *Asplenium squamosum* L. | *Asplenium squamosum* | *Asplenium squamosum* |
| 134 | *Asplenium uniseriale* Raddi | *Asplenium uniseriale* | *Asplenium uniseriale* |
| 135 | *Asplenium venturae A. R. Sm.* | *Asplenium venturae* | *Asplenium squamosum* |
| 136 | *Astrolepis sinuata* (Lag. ex Sw.) D. M. Benham & Windham | *Astrolepis sinuata* | *Astrolepis sinuata* |

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| 137 | *Athyrium arcuatum* Liebm. | *Athyrium arcuatum* | *Athyrium distentifolium* |
| 138 | *Athyrium bourgeaui* E. Fourn. | *Athyrium bourgeaui* | *Athyrium filix femina* |
| 139 | *Athyrium dombeyi* Desv. | *Athyrium dombeyi* | *Athyrium filix femina* |
| 140 | *Athyrium filix-femina* (L.) Roth | *Athyrium filix-femina* | *Athyrium filix femina* |
| 141 | *Austroblechnum divergens* (Kunze) Gasper & V. A. O. Dittrich | *Blechnum divergens* | *Austroblechnum divergens* |
| 142 | *Austroblechnum lehmannii* (Hieron.) Gasper & V. A. O. Dittrich | *Austrobechnum lehmannii* | *Austroblechnum lehmannii* |
| 143 | *Austroblechnum lherminieri* (Bory) Gasper & V. A. O. Dittrich | *Blechnum lherminieri* | *Austroblechnum squamipes* |
| 144 | *Austroblechnum stoloniferum* (Mett. ex E. Fourn.) Gasper & V. A. O. Dittrich | *Blechnum stoloniferum* | *Austroblechnum stoloniferum* |
| | | *Austroblechnum stoloniferum* | *Austroblechnum stoloniferum* |
| 145 | *Austroblechnum wardiae* (Mickel & Beitel) Gasper & V. A. O. Dittrich | *Blechnum wardiae* | *Austroblechnum wardiae* |
| | | *Austroblechnum wardiae* | *Austroblechnum wardiae* |
| 146 | *Blechnum appendiculatum* Willd. | *Blechnum glandulosum* | *Blechnum glandulosum* |
| | | *Blechnum appendiculatum* | *Blechnum appendiculatum* |
| 147 | *Blechnum chilense* (Kaulf.) Mett. | *Blechnum chilense* | *Parablechnum chilense* |
| 148 | *Blechnum gracile* Kaulf. | *Blechnum gracile* | *Blechnum gracile* |
| 149 | *Blechnum occidentale* L. | *Blechnum occidentale* | *Blechnum occidentale* |
| 150 | *Blechnum polypodioides* Raddi | *Blechnum polypodioides* | *Blechnum polypodioides* |
| 151 | *Blechnum* sp. | *Blechnum spec* | *Blechnum spec F1342* |
| 152 | *Blotiella lindeniana* (Hook.) R. M. Tryon | *Blotiella lindeniana* | *Blotiella glabra* |
| 153 | *Bolbitis hastata* (Liebm. ex E. Fourn.) Hennipman | *Bolbitis hastata* | *Bolbitis aliena* |
| 154 | *Bolbitis portoricensis* (Spreng.) Hennipman | *Bolbitis portoricensis* | *Bolbitis portoricensis* |
| 155 | *Botrypus virginianus* (L.) Michx. | *Botrypus virginianus* | *Botrypus virginianus* |
| | | *Botrychium virginianum* | *Botrypus virginianus* |
| 156 | *Campyloneurum aglaolepis* (Alston) de la Sota | *Campyloneurum aglaolepis* | *Campyloneurum aglaolepis* |
| 157 | *Campyloneurum amphostenon* (Kunze ex Klotzsch) Fée | *Campyloneurum amphostenon* | *Campyloneurum amphostenon* |
| 158 | *Campyloneurum angustifolium* (Sw.) Fée | *Campyloneurum angustifolium* | *Campyloneurum angustifolium* |
| 159 | *Campyloneurum angustipaleatum* (Alston) M. Mey. ex Lellinger | *Campyloneurum angustipaleatum* | *Campyloneurum angustipaleatum* |
| 160 | *Campyloneurum asplundii* (C. Chr.) Ching | *Campyloneurum asplundii* | *Campyloneurum asplundii* |
| 161 | *Campyloneurum brevifolium* (Lodd. ex Link) Link | *Campyloneurum brevifolium* | *Campyloneurum brevifolium* |
| 162 | *Campyloneurum densifolium* (Hieron.) Lellinger | *Campyloneurum densifolium* | *Campyloneurum densifolium* |
| 163 | *Campyloneurum ensifolium* (Willd.) J. Sm. | *Campyloneurum ensifolium* | *Campyloneurum angustipaleatum* |

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| 164 | *Campyloneurum falcoideum* (Kuhn ex Hieron.) M. Mey. ex Lellinger | *Campyloneurum falcoideum* | *Campyloneurum solutum* |
| 165 | *Campyloneurum fasciale* C. Presl | *Campyloneurum fasciale* | *Campyloneurum fasciale* |
| 166 | *Campyloneurum ophiocaulon* (Klotzsch) Fée | *Campyloneurum ophiocaulon* | *Campyloneurum ophiocaulon* |
| 167 | *Campyloneurum phyllitidis* (L.) C. Presl | *Campyloneurum phyllitidis* | *Campyloneurum phyllitidis* |
| 168 | *Campyloneurum repens* (Aubl.) C. Presl | *Campyloneurum repens* | *Campyloneurum repens* |
| 169 | *Campyloneurum solutum* (Klotzsch) Fée | *Campyloneurum solutum* | *Campyloneurum solutum* |
| 170 | *Campyloneurum* sp. | *Campyloneurm spec* | *Campyloneurum spec* |
| 171 | *Campyloneurum sphenodes* (Kunze ex Klotzsch) Fée | *Campyloneurum sphenodes* | *Campyloneurum magnificum* |
| 172 | Campyloneurum aff. sphenodes (Kunze ex Klotzsch) Fée | *Campyloneurum vel. aff. sphenodes* | *Campyloneurum sphenodes vel aff* |
| 173 | *Campyloneurum sublucidum* (Christ) Ching | *Campyloneurum sublucidum* | *Campyloneurum sublucidum* |
| 174 | *Campyloneurum tenuipes* Maxon | *Campyloneurum tenuipes* | *Campyloneurum repens* |
| 175 | *Campyloneurum xalapense* Fée | *Campyloneurum xalapense* | *Campyloneurum xalapense* |
| 176 | *Ceradenia aulaeifolia* L. E. Bishop ex A. R. Sm. | *Ceradenia aulaeifolia* | *Ceradenia aulaeifolia* |
| 177 | *Ceradenia farinosa* (Hook.) L. E. Bishop | *Ceradenia farinosa* | *Ceradenia farinosa* |
| 178 | *Ceradenia fucoides* (Christ) L. E. Bishop | *Ceradenia fucoides* | *Ceradenia fucoides* |
| 179 | *Ceradenia intricata* (C. V. Morton) L. E. Bishop ex A. R. Sm. | *Ceradenia intricata* | *Ceradenia intricata* |
| 180 | *Ceradenia jungermannioides* (Klotzsch) L. E. Bishop | *Ceradenia jungermannioides* | *Ceradenia jungermannioides* |
| 181 | *Ceradenia kalbreyeri* (Baker) L. E. Bishop | *Ceradenia kalbreyeri* | *Ceradenia kalbreyeri* |
| 182 | *Ceradenia kookenamae* (Jenman) L. E. Bishop | *Ceradenia kookenamae* | *Ceradenia kookenamae* |
| 183 | *Ceradenia meridensis* (Klotzsch) L. E. Bishop | *Ceradenia meridensis* | *Ceradenia meridensis* |
| 184 | *Ceradenia nubigena* (Maxon) L. E. Bishop | *Ceradenia nubigena* | *Ceradenia ayapoyana* |
| 185 | *Ceradenia oidiophora* (Mickel & Beitel) A. R. Sm. | *Ceradenia oidiophora* | *Ceradenia pilipes* |
| 186 | *Ceradenia pearcei* (Baker) L. E. Bishop | *Ceradenia pearcei* | *Ceradenia pearcei* |
| 187 | *Ceradenia pilipes* (Hook.) L. E. Bishop | *Ceradenia pilipes* | *Ceradenia pilipes* |
| 188 | *Ceradenia sacksii* Sundue | *Ceradenia sacksii* | *Ceradenia curvata* |
| 189 | *Ceradenia spixiana* (M. Martens ex Mett.) L. E. Bishop | *Ceradenia spixiana* | *Ceradenia spixiana* |
| 190 | *Ceradenia tristis* A. R. Sm. | *Ceradenia tristis* | *Ceradenia madidiense* |
| 191 | *Cheiroglossa palmata* (L.) C. Presl | *Ophioglossum palmatum* | *Ophioglossum palmatum* |
| 192 | *Christella dentata* (Forssk.) Brownsey & Jermy | *Christella dentata* | *Christella dentata* |
| 193 | *Christella normalis* (C. Chr.) Holttum | *Christella normalis* | *Thelypteris kunthii* |

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| 194 | *Christella quadrangularis* (Fée) Holttum | *Christella quadrangularis* | *Christella hispidula* |
| 195 | *Cibotium regale* Linden ex J. Sm. | *Cibotium regale* | *Cibotium regale* |
| 196 | *Cochlidium linearifolium* (Desv.) Maxon | *Cochlidium linearifolium* | *Cochlidium punctatum* |
| 197 | *Cochlidium rostratum* (Hook.) Maxon ex C. Chr. | *Cochlidium rostratum* | *Cochlidium rostratum* |
| 198 | *Cochlidium serrulatum* (Sw.) L. E. Bishop | *Cochlidium serrulatum* | *Cochlidium serrulatum* |
| 199 | *Cranfillia caudata* (Baker) V. A. O. Dittrich & Gasper | *Blechnum sprucei* | *Cranfillia sprucei* |
| 200 | *Ctenitis baulensis* A. R. Sm. | *Ctenitis baulensis* | *Ctenitis glandulosa* |
| 201 | *Ctenitis equestris* (Kunze) Ching | *Ctenitis equestris* | *Ctenitis equestris* |
| 202 | *Ctenitis excelsa* (Desv.) Proctor | *Ctenitis excelsa* | *Ctenitis excelsa* |
| 203 | *Ctenitis grisebachii* (Baker) Ching | *Ctenitis griesenbachii* | *Ctenitis ampla* |
| 204 | *Ctenitis hemsleyana* (Baker ex Hemsl.) Copel. | *Ctenitis hemsleyana* | *Ctenitis hemsleyana* |
| 205 | *Ctenitis interjecta* (C. Chr.) Ching | *Ctenitis interjecta* | *Ctenitis sloanei* |
| 206 | *Ctenitis leonii* A. Rojas | *Ctenitis leonii* | *Ctenitis lanceolata* |
| 207 | *Ctenitis melanosticta* (Kunze) Copel. | *Ctenitis melanostica* | *Ctenitis melanosticta* |
| 208 | *Ctenitis mexicana* A. R. Sm. | *Ctenitis mexicana* | *Ctenitis ampla* |
| 209 | *Ctenitis microchlaena* (Fée) Stolze | *Ctenitis microchlaena* | *Ctenitis eatonii* |
| 210 | *Ctenitis nigrovenia* (Christ) Copel. | *Ctenitis nigrovenia* | *Ctenitis refulgens* |
| 211 | *Ctenitis salvinii* (Baker) Stolze | *Ctenitis salvinii* | *Ctenitis submarginalis* |
| 212 | *Culcita coniifolia* (Hook.) Maxon | *Culcita coniifolia* | *Culcita coniifolia* |
| 213 | *Cyathea aemula* Lehnert | *Cyathea aemula* | *Cyathea aemula* |
| 214 | *Cyathea andicola* Domin | *Cyathea quitensis* | *Cyathea andicola* |
| 215 | *Cyathea aristata* Domin | *Cyathea aristata* | *Cyathea andicola* |
| 216 | *Cyathea bicrenata* Liebm. | *Cyathea bicrenata* | *Cyathea bicrenata* |
| 217 | *Cyathea bipinnatifida* (Baker) Domin | *Cyathea bipinnatifida* | *Cyathea bipinnatifida* |
| 218 | *Cyathea caracasana* (Klotzsch) Domin | *Cyathea caracasana* | *Cyathea caracasana* |
| 219 | *Cyathea catacampta* Alston | *Cyathea catacampta* | *Cyathea catacampta* |
| 220 | *Cyathea choricarpa* (Maxon) R.M. Tryon | *Cnemidaria choricarpa* | *Cyathea ewanii* |
| 221 | *Cyathea crenata* Christ | *Cyathea crenata* | *Cyathea crenata* |
| 222 | *Cyathea decurrentiloba* Domin | *Cyathea liebmannii* | *Cyathea mutica* |
| 223 | *Cyathea delgadii* Pohl ex Sternb. | *Cyathea delgadii squamipes* | *Cyathea delgadii squamipes* |

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|  |  | *Cyathea delgadii* | *Cyathea delgadii squamipes* |
| 224 | *Cyathea divergens* Kunze | *Cyathea divergens* | *Cyathea divergens* |
| 225 | *Cyathea ewanii* Alston | *Cyathea ewanii* | *Cyathea ewanii* |
| 226 | *Cyathea fulva* (M. Martens & Galeotti) Fée | *Cyathea fulva* | *Cyathea fulva* |
| 227 | *Cyathea gibbosa* (Klotzsch) Domin | *Cyathea gibbosa* | *Cyathea gibbosa* |
| 228 | *Cyathea godmanii* (Hook.) Domin | *Cyathea godmanii* | *Cyathea gracilis* |
| 229 | *Cyathea gracilis* Griseb. | *Cyathea gracilis* | *Cyathea gracilis* |
| 230 | *Cyathea guentheriana* Lehnert | *Cyathea guentheriana* | *Cyathea guentheriana* |
| 231 | *Cyathea holdridgeana* Nisman & L. D. Gómez | *Cyathea holdrigiana* | *Cyathea catacampta* |
| 232 | *Cyathea lasiosora* (Mett. ex Kuhn) Domin | *Cyathea lasiosora* | *Cyathea lasiosora* |
| 233 | *Cyathea microdonta* (Desv.) Domin | *Cyathea microdonta* | *Cyathea microdonta* |
| 234 | *Cyathea mucilagina* R. C. Moran | *Cyathea mucilagina* | *Cyathea mucilagina* |
| 235 | *Cyathea multiflora* Sm. | *Cyathea multiflora* | *Cyathea multiflora* |
| 236 | *Cyathea mutica* (Christ) Domin | *Cnemidaria mutica* | *Cyathea mutica* |
| 237 | *Cyathea nigripes* (C. Presl) Domin | *Cyathea nigripes* | *Cyathea nigripes* |
| 238 | Cyathea onusta Christ | *Cyathea onusta* | *Cyathea tenera* |
| 239 | *Cyathea paucifolia* (Baker) Domin | *Alsophila paucifolia* | *Alsophila paucifolia* |
| 240 | *Cyathea peladensis* (Hieron.) Domin | *Cyathea peladensis* | *Cyathea peladensis* |
| 241 | *Cyathea pinnula* (Christ) R. C. Moran | *Cyathea pinnula* | *Cyathea planadae* |
| 242 | *Cyathea planadae* N.C. Arens & A.R. Sm. | *Cyathea planadae* | *Cyathea planadae* |
| 243 | *Cyathea pungens* (Willd.) Domin | *Cyathea pungens* | *Cyathea pungens* |
| 244 | *Cyathea schiedeana* (C. Presl) Domin | *Cyathea schiedeana* | *Cyathea schiedeana* |
| 245 | *Cyathea* sp. | *Cyathea spec 2* | *Cyathea andina* |
| 246 | *Cyathea squamipes* H. Karst | *Cyathea squamipes* | *Cyathea squamipes* |
| 247 | *Cyathea squamulosa* (I. Losch) R. C. Moran | *Cyathea squamulosa* | *Cyathea notabilis* |
| 248 | *Cyathea squarrosa* (Rosenst.) Domin | *Cyathea squarrosa* | *Cyathea poeppigii* |
| 249 | *Cyathea suprastrigosa* (Christ) Maxon | *Cyathea suprastrigosa* | *Cyathea suprastrigosa* |
| 250 | *Cyathea tortuosa* R. C. Moran | *Cyathea tortuosa* | *Cyathea tortuosa* |
| 251 | *Cyathea tuerckheimii* Maxon | *Cyathea tuerckheimii* | *Cyathea squamipes* |
| 252 | *Cyathea wendlandii* (Mett. ex Kuhn) Domin | *Cyathea wendlandii* | *Cyathea crenata* |

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| 253 | *Cyathea xenoxyla* Lehnert | *Cyathea xenoxyla* | *Cyathea xenoxyla* |
| 254 | *Cyclodium meniscioides* (Willd.) C. Presl | *Cyclodium meniscioides* | *Cyclodium meniscioides* |
| 255 | *Cyclodium trianae* (Mett.) A. R. Sm. | *Cyclodium trianae* | *Cyclodium inerme* |
| 256 | *Cystopteris fragilis* (L.) Bernh. | *Cystopteris fragilis* | *Cystopteris fragilis* |
| 257 | *Danaea carillensis* Christ | *Danaea carillensis* | *Danaea carillensis* |
| 258 | *Danaea crispa* Endrés & Rchb. f. | *Danaea crispa* | *Danaea crispa* |
| 259 | *Danaea humilis* Moore | *Danaea humilis* | *Danaea nodosa* |
| 260 | *Danaea leprieurii* Kunze | *Danaea leprieurii* | *Danaea leprieurii* |
| 261 | *Danaea moritziana* C. Presl | *Danaea moritziana* | *Danaea moritziana* |
| | | *Danaea cuspidata* | *Danaea moritziana* |
| 262 | *Danaea nodosa* (L.) Sm. | *Danaea nodosa* | *Danaea nodosa* |
| | | *Danaea elliptica* | *Danaea elliptica* |
| 263 | *Danaea plicata* Christ | *Danaea plicata* | *Danaea trifoliata* |
| 264 | *Danaea wendlandii* Rchb. f. | *Danaea wendlandii* | *Danaea wendlandii* |
| 265 | *Dennstaedtia auriculata* Navarr. & B. Øllg. | *Dennstaedtia auriculata* | *Dennstaedtia auriculata* |
| 266 | *Dennstaedtia bipinnata* (Cav.) Maxon | *Dennstaedtia bipinnata* | *Dennstaedtia kalbreyeri* |
| 267 | *Dennstaedtia cicutaria* (Sw.) T. Moore | *Dennstaedtia cicutaria* | *Dennstaedtia dissecta* |
| 268 | *Dennstaedtia cornuta* (Kaulf.) Mett. | *Dennstaedtia cornuta* | *Dennstaedtia kalbreyeri* |
| 269 | *Dennstaedtia dissecta* (Sw.) Moore | *Dennstaedtia dissecta* | *Dennstaedtia dissecta* |
| 270 | *Dennstaedtia globulifera* (Poir.) Hieron. | *Dennstaedtia globulifera* | *Dennstaedtia auriculata* |
| 271 | *Dennstaedtia obtusifolia* (Willd.) T. Moore | *Dennstaedtia kalbreyeri* | *Dennstaedtia kalbreyeri* |
| 272 | *Dennstaedtia paucirrhiza* Navarr. & B. Øllg. | *Dennstaedtia paucirhiza* | *Dennstaedtia paucirhiza* |
| 273 | *Dennstaedtia werckleana* (Christ) Navarr. & B. Øllg. | *Dennstaedtia werckleana* | *Dennstaedtia paucirhiza* |
| 274 | *Desmophlebium lechleri* (Mett.) Mynssen, A. Vasco, Sylvestre, R.C. Moran & Rouhan | *Diplazium lechleri* | *Diplazium macrodictyon* |
| 275 | *Desmophlebium longisorum* (Baker) Mynssen, A. Vasco, Sylvestre, R. C. Moran & Rouhan | *Diplazium longisorum* | *Diplazium striatum* |
| 276 | *Dicksonia karsteniana* (Klotzsch) Moore | *Dicksonia karsteniana* | *Dicksonia karsteniana* |
| 277 | *Dicksonia navarrensis* Christ | *Dicksonia navarrensis* | *Dicksonia sellowiana* |
| 278 | *Didymochlaena truncatula* (Sw.) J. Sm. | *Didymochlaena truncatula* | *Didymochlaena truncatula* |
| 279 | *Didymoglossum angustifrons* Fée | *Didymoglossum angustifrons* | *Didymoglossum membranaceum* |
| 280 | *Didymoglossum curtii* (Rosenst.) Pic. Serm. | *Trichomanes curtii* | *Didymoglossum gourlianum* |

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| 281 | *Didymoglossum ekmanii* (Wess. Boer) Ebihara & Dubuisson | *Trichomanes ekmanii* | *Didymoglossum ekmanii* |
| 282 | *Didymoglossum godmanii* (Hook. ex Baker) Ebihara & Dubuisson | *Trichomanes godmanii* | *Didymoglossum pinnatinervium* |
| 283 | *Didymoglossum hymenoides* (Hedw.) Copel. | *Didymoglossum hymenoides* | *Didymoglossum hymenoides* |
| 284 | *Didymoglossum kraussii* (Hook. & Grev.) C. Presl | *Trichomanes krausii*<br>*Didymoglossum kraussii* | *Trichomanes krausii*<br>*Trichomanes krausii* |
| 285 | Didymoglossum membranaceum (L.) Vareschi | *Trichomanes membranaceum* | *Didymoglossum membranaceum* |
| 285 | Didymoglossum ovale E. Fourn. | *Didymoglossum ovale* | *Trichomanes ovale* |
| 287 | *Didymoglossum punctatum* (Poir.) Desv. | *Didymoglossum punctatum* | *Didymoglossum punctatum* |
| 288 | *Didymoglossum reptans* (Sw.) C. Presl | *Didymoglossum reptans* | *Didymoglossum reptans* |
| 289 | *Diplazium alienum* (Mett.) Hieron. | *Diplazium alienum* | *Diplazium lindbergii* |
| 290 | *Diplazium ambiguum* Raddi | *Diplazium ambiguum* | *Diplazium ambiguum* |
| 291 | *Diplazium angulosum* C. Chr. | *Diplazium angulosum* | *Diplazium angulosum* |
| 292 | *Diplazium atirrense* (Donn. Sm.) Lellinger | *Diplazium atirrense* | *Diplazium prominulum* |
| 293 | *Diplazium brausei* Rosenst. | *Diplazium brausei* | *Diplazium laffanianum* |
| 294 | *Diplazium carnosum* Christ | *Diplazium carnosum* | *Diplazium balliviani* |
| 295 | *Diplazium ceratolepis* (Christ) Christ | *Diplazium ceratolepis* | *Diplazium unilobum* |
| 296 | *Diplazium costale* (Sw.) C. Presl | *Diplazium costale* | *Diplazium costale* |
| 297 | *Diplazium cristatum* (Desr.) Alston | *Diplazium cristatum* | *Diplazium cristatum* |
| 298 | *Diplazium croatianum* C. D. Adams | *Diplazium croatianum* | *Diplazium leptocarpon* |
| 299 | *Diplazium diplazioides* (Klotzsch & H. Karst.) Alston | *Diplazium diplazioides* | *Diplazium diplazioides* |
| 300 | *Diplazium drepanolobium* A. R. Sm. | *Diplazium drepanolobium* | *Diplazium cristatum* |
| 301 | *Diplazium expansum* Willd. | *Diplazium expansum* | *Diplazium expansum* |
| 302 | *Diplazium franconis* Liebm. | *Diplazium franconis* | *Diplazium costale* |
| 303 | *Diplazium grandifolium* (Sw.) Sw. | *Diplazium grandifolium* | *Diplazium longifolium* |
| 304 | *Diplazium hians* Kunze ex Klotzsch | *Diplazium hians* | *Diplazium hians* |
| 305 | *Diplazium lindbergii* (Mett.) Christ | *Diplazium lindbergii* | *Diplazium lindbergii* |
| 306 | *Diplazium lonchophyllum* Kunze | *Diplazium lonchophyllum* | *Diplazium lonchophyllum* |
| 307 | *Diplazium macrophyllum* Desv. | *Diplazium macrophyllum* | *Diplazium macrophyllum* |
| 308 | *Diplazium multigemmatum* Lellinger | *Diplazium multigemmatum* | *Diplazium venulosum* |
| 309 | *Diplazium neglectum* (H. Karst.) C. Chr. | *Diplazium neglectum* | *Diplazium tungurahue* |

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| 310 | *Diplazium obscurum* Christ | *Diplazium obscurum* | *Diplazium immensum* |
| 311 | *Diplazium palmense* Rosenst. | *Diplazium palmense* | *Diplazium sanderi* |
| 312 | *Diplazium paucipinnum* Stolze | *Diplazium paucipinnum* | *Diplazium paucipinnum* |
| 313 | *Diplazium pinnatifidum* Kunze | *Diplazium pinnatifidum* | *Diplazium pinnatifidum* |
| 314 | *Diplazium plantaginifolium* (L.) Urb. | *Diplazium plantaginifolium* | *Diplazium plantaginifolium* |
| 315 | *Diplazium robustum* (Sodiro) A. Rojas | *Diplazium robustum* | *Diplazium robustum* |
| 316 | *Diplazium solutum* (Christ) Lellinger | *Diplazium solutum* | *Diplazium robustum* |
| 317 | *Diplazium sprucei* (Baker) C. Chr. | *Diplazium sprucei* | *Diplazium sprucei* |
| 318 | *Diplazium striatastrum* Lellinger | *Diplazium striatastrum* | *Diplazium expansum* |
| 319 | *Diplazium striatum* (L.) C. Presl | *Diplazium striatum* | *Diplazium striatum* |
| 320 | *Diplazium ternatum* Liebm. | *Diplazium ternatum* | *Diplazium bombonasae* |
| 321 | *Diplazium tungurahuae* (Sodiro) C. Chr. | *Diplazium tungurahue* | *Diplazium tungurahue* |
| 322 | *Diplazium urticifolium* Christ | *Diplazium urticifolium* | *Diplazium lindbergii* |
| 323 | *Diplazium venulosum* (Baker) Diels | *Diplazium venulosum* | *Diplazium venulosum* |
| 324 | *Diplazium werckleanum* Christ | *Diplazium werckleanum* | *Diplazium prominulum* |
| 325 | *Diplazium wilsonii* (Baker) Diels | *Diplazium wilsonii* | *Diplazium divergens* |
| 326 | *Diplopterygium bancroftii* (Hook.) A. R. Sm. | *Diplopterygium bancroftii* | *Diplopterygium bancroftii* |
| 327 | *Dracoglossum plantagineum* (Jacq.) Christenh. | *Tectaria plantaginea* | *Tectaria incisa* |
| 328 | *Draconopteris draconoptera* (D. C. Eaton) Li Bing Zhang & Liang Zhang | *Tectaria draconoptera* | *Tectaria fimbriata* |
| 329 | *Dryopteris flaccisquama* A. Rojas | *Dryopteris flaccisquama* | *Dryopteris flaccisquama* |
| 330 | *Dryopteris futura* A. R. Sm. | *Dryopteris futura* | *Dryopteris futura* |
| 331 | *Dryopteris nubigena* Maxon & C. V. Morton | *Dryopteris nubigena* | *Dryopteris nubigena* |
| 332 | *Dryopteris patula* (Sw.) Underw. | *Dryopteris patula* | *Dryopteris patula* |
| 333 | *Dryopteris wallichiana* (Spreng.) Hyl. | *Dryopteris wallichiana* | *Dryopteris wallichiana* |
| 334 | *Elaphoglossum acutifolium* Rosenst. | *Elaphoglossum acutifolium* | *Elaphoglossum acutifolium* |
| 335 | *Elaphoglossum affine* (M. Martens & Galeotti) T. Moore | *Elaphoglossum affine* | *Elaphoglossum affine* |
| 336 | *Elaphoglossum alansmithii* Mickel | *Elaphoglossum alansmithii* | *Elaphoglossum ciliatum* |
| 337 | *Elaphoglossum albomarginatum* A. R. Sm. | *Elaphoglossum albomarginatum* | *Elaphoglossum kessleri* |
| 338 | *Elaphoglossum alfredii* Rosenst. | *Elaphoglossum alfredii* | *Elaphoglossum rufum* |
| 339 | *Elaphoglossum alipes* Mickel | *Elaphoglossum alipes* | *Elaphoglossum alipes* |

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| 340 | *Elaphoglossum amphioxys* Mickel | *Elaphoglossum amphioxys* | *Elaphoglossum punae* |
| 341 | *Elaphoglossum amygdalifolium* (Mett. ex Kuhn) Christ | *Elaphoglossum amygdalifolium* | *Elaphoglossum amygdalifolium* |
| 342 | *Elaphoglossum andicola* (Fée) T. Moore | *Elaphoglossum andicola* | *Elaphoglossum andicola* |
| 343 | *Elaphoglossum antisanae* (Sodiro) C. Chr. | *Elaphoglossum antisanae* | *Elaphoglossum antisanae* |
| 344 | *Elaphoglossum aschersonii* Hieron. | *Elaphoglossum aschersonii* | *Elaphoglossum aschersonii* |
| 345 | *Elaphoglossum atropunctatum* Mickel | *Elaphoglossum atropunctatum* | *Elaphoglossum atropunctatum* |
| 346 | *Elaphoglossum auripilum* Christ | *Elaphoglossum auripilum* | *Elaphoglossum auripilum* |
| 347 | *Elaphoglossum backhouseanum* T. Moore | *Elaphoglossum backhousianum* | *Elaphoglossum backhousianum* |
| 348 | *Elaphoglossum bakeri* (Sodiro) Christ | *Elaphoglossum bakeri* | *Elaphoglossum bakeri* |
| 349 | *Elaphoglossum baquianorum* A. Rojas | *Elaphoglossum baquianorum* | *Elaphoglossum kessleri* |
| 350 | *Elaphoglossum bellermannianum* (Klotzsch) Moore | *Elaphoglossum bellermannianum* | *Elaphoglossum bellermannianum* |
| 351 | *Elaphoglossum biolley*i Christ | *Elaphoglossum biolleyi* | *Elaphoglossum biolleyi* |
| 352 | *Elaphoglossum blepharoglottis* Mickel | *Elaphoglossum blepharoglottis* | *Elaphoglossum concinnum* |
| 353 | *Elaphoglossum boragineum* (Sodiro) Christ | *Elaphoglossum boragineum* | *Elaphoglossum setigerum* |
| 354 | *Elaphoglossum caroliae* Mickel | *Elaphoglossum caroliae* | *Elaphoglossum aubertii* |
| 355 | *Elaphoglossum castaneum* (Baker) Diels | *Elaphoglossum castaneum* | *Elaphoglossum castaneum* |
| 356 | *Elaphoglossum ciliatum* (C. Presl) T. Moore | *Elaphoglossum ciliatum* | *Elaphoglossum ciliatum* |
| 357 | *Elaphoglossum cismense* Rosenst. | *Elaphoglossum cismense* | *Elaphoglossum cismense* |
| 358 | *Elaphoglossum conspersum* Christ | *Elaphoglossum conspersum* | *Elaphoglossum conspersum* |
| 359 | *Elaphoglossum coriifolium* Mickel | *Elaphoglossum coriifolium* | *Elaphoglossum malgassicum* |
| 360 | *Elaphoglossum correae* Mickel | *Elaphoglossum correae* | *Elaphoglossum minutum* |
| 361 | *Elaphoglossum costaricense* Christ | *Elaphoglossum costaricense* | *Elaphoglossum piloselloides* |
| 362 | *Elaphoglossum crassipes* (Hieron.) Diels | *Elaphoglossum crassipes* | *Elaphoglossum crassipes* |
| 363 | *Elaphoglossum crinitum* (L.) Christ | *Elaphoglossum crinitum* | *Elaphoglossum crinitum* |
| 364 | *Elaphoglossum croatii* Mickel | *Elaphoglossum croatii* | *Elaphoglossum croatii* |
| 365 | *Elaphoglossum curtii* Rosenst. | *Elaphoglossum curtii* | *Elaphoglossum spatulatum* |
| 366 | *Elaphoglossum curvans* (Kunze) A. Rojas | *Elaphoglossum curvans* | *Elaphoglossum moranii* |
| 367 | *Elaphoglossum cuspidatum* (Willd.) T. Moore | *Elaphoglossum subcuspidatum* | *Elaphoglossum palorense* |
| | | *Elaphoglossum cuspidatum* | *Elaphoglossum palorense* |
| 368 | *Elaphoglossum davidsei* Mickel | *Elaphoglossum davidsei* | *Elaphoglossum davidsei* |

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| 369 | *Elaphoglossum decoratum* (Kunze) T. Moore | *Elaphoglossum decoratum* | *Elaphoglossum decoratum* |
| 370 | *Elaphoglossum decursivum* Mickel | *Elaphoglossum decursivum* | *Elaphoglossum williamsiorum* |
| 371 | *Elaphoglossum dissitifrons* Mickel | *Elaphoglossum dissitifrons* | *Elaphoglossum latifolium* |
| 372 | *Elaphoglossum doanense* L. D. Gómez | *Elaphoglossum doanense* | *Elaphoglossum doanense* |
| 373 | *Elaphoglossum elegantipes* Mickel | *Elaphoglossum elegantipes* | *Elaphoglossum elegantipes* |
| 374 | *Elaphoglossum ellipticifolium* A. Rojas | *Elaphoglossum ellipticifolium* | *Elaphoglossum lindenii* |
| 375 | *Elaphoglossum engelii* (H. Karst.) Christ | *Elaphoglossum engelii* | *Elaphoglossum engelii* |
| 376 | *Elaphoglossum erinaceum* (Fée) T. Moore | *Elaphoglossum erinaceum* | *Elaphoglossum erinaceum* |
| 377 | *Elaphoglossum eximiiforme* Mickel | *Elaphoglossum eximiiforme* | *Elaphoglossum cardenasii* |
| 378 | *Elaphoglossum eximium* (Mett.) Christ | *Elaphoglossum eximium* | *Elaphoglossum eximium* |
| 379 | *Elaphoglossum fournierianum* L. D. Gómez | *Elaphoglossum fournierianum* | *Elaphoglossum fournierianum* |
| 380 | *Elaphoglossum furfuraceum* (Mett. ex Kuhn) Christ | *Elaphoglossum furfuraceum* | *Elaphoglossum furfuraceum* |
| 381 | *Elaphoglossum glabellum* J. Sm. | *Elaphoglossum glabellum* | *Elaphoglossum glabellum* |
| 382 | *Elaphoglossum glaucum* T. Moore | *Elaphoglossum glaucum* | *Elaphoglossum glaucum* |
| 383 | *Elaphoglossum gloeorrhizum* Mickel | *Elaphoglossum gloeorrhizum* | *Elaphoglossum hornei* |
| 384 | *Elaphoglossum glossophyllum* Hieron. | *Elaphoglossum glossophyllum* | *Elaphoglossum glossophyllum* |
| 385 | *Elaphoglossum gratum* (Fée) T. Moore | *Elaphoglossum gratum* | *Elaphoglossum pringlei* |
| 386 | *Elaphoglossum grayumii* Mickel | *Elaphoglossum grayumii* | *Elaphoglossum grayumii* |
| 387 | *Elaphoglossum guamanianum* (Sodiro) C. Chr. | *Elaphoglossum guamanianum* | *Elaphoglossum guamanianum* |
| 388 | *Elaphoglossum guatemalense* (Klotzsch) T. Moore | *Elaphoglossum guatemalense* | *Elaphoglossum guatemalense* |
| 389 | *Elaphoglossum guentheri* Rosenst. | *Elaphoglossum guentheri* | *Elaphoglossum guentheri* |
| 390 | *Elaphoglossum hammelianum* A. Rojas | *Elaphoglossum hammelianum* | *Elaphoglossum lonchophyllum* |
| 391 | *Elaphoglossum hayesii* (Mett. ex Kuhn) Maxon | *Elaphoglossum hayesii* | *Elaphoglossum pusillum* |
| 392 | *Elaphoglossum herminieri* (Bory & Fée) T. Moore | *Elaphoglossum herminieri* | *Elaphoglossum herminieri* |
| 393 | *Elaphoglossum heterochroum* Mickel | *Elaphoglossum heterochroum* | *Elaphoglossum rufidulum* |
| 394 | *Elaphoglossum hoffmannii* (Mett. ex Kuhn) Christ | *Elaphoglossum hoffmannii* | *Elaphoglossum hoffmannii* |
| 395 | *Elaphoglossum horridulum* (Kaulf.) J. Sm. | *Elaphoglossum aff.horridulum* | *Elaphoglossum horridulum aff* |
| 396 | *Elaphoglossum huacsaro* (Ruiz) Christ | *Elaphoglossum huacsaro* | *Elaphoglossum huacsaro* |
| 397 | *Elaphoglossum kessleri* A. Rojas | *Elaphoglossum kessleri* | *Elaphoglossum kessleri* |
| 398 | *Elaphoglossum lalitae* L. D. Gómez | *Elaphoglossum lalitae* | *Elaphoglossum pteropus* |

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| 399 | *Elaphoglossum lanceiforme* Mickel | *Elaphoglossum lanceiforme* | *Elaphoglossum fournierianum* |
| 400 | *Elaphoglossum lanceum* Mickel | *Elaphoglossum lanceum* | *Elaphoglossum rufum* |
| 401 | *Elaphoglossum lankesteri* Mickel | *Elaphoglossum lankesteri* | *Elaphoglossum elegantipes* |
| 402 | *Elaphoglossum latifolium* (Sw.) J. Sm. | *Elaphoglossum latifolium* | *Elaphoglossum latifolium* |
| 403 | *Elaphoglossum latum* (Mickel) Atehortua ex Mickel | *Elaphoglossum latum* | *Elaphoglossum alvaradoanum* |
| 404 | *Elaphoglossum leonardii* Mickel | *Elaphoglossum leonardii* | *Elaphoglossum eximium* |
| 405 | *Elaphoglossum lindigii* (H. Karst.) Moore | *Elaphoglossum argyrophyllum* | *Elaphoglossum argyrophyllum* |
| 406 | *Elaphoglossum lingua* (Raddi) Brack. | *Elaphoglossum lingua* | *Elaphoglossum lingua* |
| 407 | *Elaphoglossum litanum* (Sodiro) C. Chr. | *Elaphoglossum litanum* | *Elaphoglossum litanum* |
| 408 | *Elaphoglossum lloense* (Hook.) Moore | *Elaphoglossum lloense* | *Elaphoglossum lloense* |
| 409 | *Elaphoglossum lonchophyllum* (Fée) T. Moore | *Elaphoglossum lonchophyllum* | *Elaphoglossum lonchophyllum* |
| 410 | *Elaphoglossum longicrure* Christ | *Elaphoglossum longicrure* | *Elaphoglossum odontolepis* |
| 411 | *Elaphoglossum longistipitatum* A. Rojas | *Elaphoglossum longistipitatum* | *Elaphoglossum longistipitatum* |
| 412 | *Elaphoglossum luridum* (Fée) Christ | *Elaphoglossum luridum* | *Elaphoglossum luridum* |
| 413 | *Elaphoglossum luteum* A. Rojas | *Elaphoglossum luteum* | *Elaphoglossum ovatum* |
| 414 | *Elaphoglossum maritzae* A. Rojas | *Elaphoglossum maritzae* | *Elaphoglossum alismifolium* |
| 415 | *Elaphoglossum mexicanum* (E. Fourn.) A. Rojas | *Elaphoglossum mexicanum* | *Elaphoglossum hybridum* |
| 416 | *Elaphoglossum micropogon* Mickel | *Elaphoglossum micropogon* | *Elaphoglossum micropogon* |
| 417 | *Elaphoglossum mitorrhizum* Mickel | *Elaphoglossum mitorrhizum* | *Elaphoglossum mitorrhizum* |
| 418 | *Elaphoglossum molle* (Sodiro) C. Chr. | *Elaphoglossum molle* | *Elaphoglossum molle* |
| 419 | *Elaphoglossum monicae* Mickel | *Elaphoglossum monicae* | *Elaphoglossum setigerum* |
| 420 | *Elaphoglossum montgomeryi* Mickel | *Elaphoglossum montgomeryi* | *Elaphoglossum lingua* |
| 421 | *Elaphoglossum moranii* Mickel | *Elaphoglossum moranii* | *Elaphoglossum moranii* |
| 422 | *Elaphoglossum muscosum* (Sw.) T. Moore | *Elaphoglossum muscosum* | *Elaphoglossum aschersonii* |
| 423 | *Elaphoglossum nigrescens* (Hook.) Moore ex Diels | *Elaphoglossum palmense* | *Elaphoglossum nigrescens* |
| | | *Elaphoglossum nigrescens* | *Elaphoglossum nigrescens* |
| 424 | *Elaphoglossum notatum* (Fée) Moore | *Elaphoglossum notatum* | *Elaphoglossum notatum* |
| 425 | *Elaphoglossum novogranatense* A. Vasco | *Elaphoglossum novogranatense* | *Elaphoglossum novogranatense* |
| 426 | *Elaphoglossum obovatum* Mickel | *Elaphoglossum obovatum* | *Elaphoglossum obovatum* |
| 427 | *Elaphoglossum odontolepis* Mickel | *Elaphoglossum odontolepis* | *Elaphoglossum odontolepis* |

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| 428 | *Elaphoglossum omissum* Mickel | *Elaphoglossum omissum* | *Elaphoglossum hybridum* |
| 429 | *Elaphoglossum oxyglossum* Mickel | *Elaphoglossum oxyglossum* | *Elaphoglossum oxyglossum* |
| 430 | *Elaphoglossum pachyrrhizum* Mickel | *Elaphoglossum pachyrrhizum* | *Elaphoglossum pachyrrhizum* |
| 431 | *Elaphoglossum paleaceum* (Hook. & Grev.) Sledge | *Elaphoglossum palaceum* | *Elaphoglossum paleaceum* |
| 432 | *Elaphoglossum pallidum* (Baker ex Jenman) C. Chr. | *Elaphoglossum pallidum* | *Elaphoglossum burchellii* |
| 433 | *Elaphoglossum palorense* Rosenst. | *Elaphoglossum palorense* | *Elaphoglossum palorense* |
| 434 | *Elaphoglossum papillosum* (Baker) Christ | *Elaphoglossum papillosum* | *Elaphoglossum papillosum* |
| 435 | *Elaphoglossum parduei* Mickel | *Elaphoglossum parduei* | *Elaphoglossum tectum* |
| 436 | *Elaphoglossum peltatum* (Sw.) Urb. | *Peltapteris peltata*<br>*Elaphoglossum peltatum* | *Elaphoglossum peltatum*<br>*Elaphoglossum peltatum* |
| 437 | *Elaphoglossum petiolatum* (Sw.) Urb. | *Elaphoglossum petiolatum* | *Elaphoglossum petiolatum* |
| 438 | *Elaphoglossum phoras* Mickel | *Elaphoglossum phoras* | *Elaphoglossum phoras* |
| 439 | *Elaphoglossum pilosius* Mickel | *Elaphoglossum pilosius* | *Elaphoglossum pilosius* |
| 440 | *Elaphoglossum pringlei* (Davenp.) C. Chr. | *Elaphoglossum pringlei* | *Elaphoglossum pringlei* |
| 441 | *Elaphoglossum productum* Rosenst. | *Elaphoglossum productum* | *Elaphoglossum productum* |
| 442 | *Elaphoglossum proximum* (J. Bommer) Christ | *Elaphoglossum proximum* | *Elaphoglossum mitorrhizum* |
| 443 | *Elaphoglossum raywaense* (Jenman) Alston | *Elaphoglossum raywaense* | *Elaphoglossum raywaense* |
| 444 | *Elaphoglossum rimbachii* (Sodiro) Christ | *Elaphoglossum rimbachii* | *Elaphoglossum rimbachii* |
| 445 | *Elaphoglossum rosenstockii* Christ | *Elaphoglossum rosenstockii* | *Elaphoglossum rosenstockii* |
| 446 | *Elaphoglossum rufum* Mickel | *Elaphoglossum rufum* | *Elaphoglossum rufum* |
| 447 | *Elaphoglossum russelliae* Mickel | *Elaphoglossum russelliae* | *Elaphoglossum russelliae* |
| 448 | *Elaphoglossum sartorii* (Liebm.) Mickel, Mickel & Beitel | *Elaphoglossum sartorii* | *Elaphoglossum sartorii* |
| 449 | *Elaphoglossum seminudum* Mickel | *Elaphoglossum seminudum* | *Elaphoglossum glossophyllum* |
| 450 | *Elaphoglossum setigerum* (Sodiro) Diels | *Elaphoglossum setigerum* | *Elaphoglossum setigerum* |
| 451 | *Elaphoglossum setosum* (Liebm.) T. Moore | *Elaphoglossum setosum* | *Elaphoglossum davidsei* |
| 452 | *Elaphoglossum silencioanum* A. Rojas | *Elaphoglossum silencioanum* | *Elaphoglossum erinaceum* |
| 453 | *Elaphoglossum siliquoides* (Jenman) C. Chr. | *Elaphoglossum siliquioides* | *Elaphoglossum cubense* |
| 454 | *Elaphoglossum* sp. 1 | *Elaphoglossum spec* | *Elaphoglossum spec F1452* |
| 455 | *Elaphoglossum* sp. 2 | *Elaphoglossum spec 20* | *Elaphoglossum spec 20* |
| 456 | *Elaphoglossum* sp. 3 | *Elaphoglossum spec 28* | *Elaphoglossum spec 28* |

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| 457 | *Elaphoglossum* sp. 4 | *Elaphoglossum spec 47* | *Elaphoglossum spec 47* |
| 458 | *Elaphoglossum* sp. 5 | *Elaphoglossum spec 5* | *Elaphoglossum spec 5* |
| 459 | *Elaphoglossum* sp. 6 | *Elaphoglossum spec 50* | *Elaphoglossum tectum* |
| 460 | *Elaphoglossum squamipes* (Hook.) T. Moore | *Elaphoglossum squamipes* | *Elaphoglossum squamipes* |
| 461 | *Elaphoglossum squarrosum* (Klotzsch) T. Moore | *Elaphoglossum squarrosum* | *Elaphoglossum squarrosum* |
| 462 | *Elaphoglossum stenoglossum* Mickel | *Elaphoglossum stenoglossum* | *Elaphoglossum papillosum* |
| 463 | *Elaphoglossum succubus* Mickel | *Elaphoglossum succubus* | *Elaphoglossum caricifolium* |
| 464 | *Elaphoglossum talamancanum* A. Rojas | *Elaphoglossum talamancanum* | *Elaphoglossum subsessile* |
| 465 | *Elaphoglossum tenuiculum* (Fée) T. Moore ex C. Chr. | *Elaphoglossum tenuiculum* | *Elaphoglossum tenuiculum* |
| 466 | *Elaphoglossum terrestre* A. Rojas | *Elaphoglossum terrestre* | *Elaphoglossum latifolium* |
| 467 | *Elaphoglossum trivittatum* (Sodiro) Christ | *Elaphoglossum trivittatum* | *Elaphoglossum trivittatum* |
| 468 | *Elaphoglossum unduaviense* Rosenst. | *Elaphoglossum atrosquamatum* | *Elaphoglossum guentheri* |
| 469 | *Elaphoglossum variabile* A.Rojas | *Elaphoglossum variabile* | *Elaphoglossum variabile* |
| 470 | *Elaphoglossum vestitum* (Schltdl. & Cham.) Schott | *Elaphoglossum vestitum* | *Elaphoglossum vestitum* |
| 471 | *Elaphoglossum viride* (E. Fourn.) C. Chr. | *Elaphoglossum viride* | *Elaphoglossum andicola* |
| 472 | *Elaphoglossum vulcanicum* Christ | *Elaphoglossum vulcanicum* | *Elaphoglossum vulcanicum* |
| 473 | *Elaphoglossum wardiae* Mickel | *Elaphoglossum wardiae* | *Elaphoglossum wardiae* |
| 474 | *Elaphoglossum williamsiorum* Mickel | *Elaphoglossum williamsiorum* | *Elaphoglossum williamsiorum* |
| 475 | *Elaphoglossum yourkeorum* Mickel | *Elaphoglossum yourkeorum* | *Elaphoglossum herminieri* |
| 476 | *Elaphoglossum zebrinum* Mickel | *Elaphoglossum zebrinum* | *Elaphoglossum zebrinum* |
| 477 | *Enterosora campbellii* Baker | *Enterosora campbellii* | *Enterosora enterosoroides* |
| 478 | *Enterosora cornuta* (Lellinger) Shalisko & Sundue | *Zygophlebia cornuta* | *Zygophlebia mathewsii* |
| 479 | *Enterosora percrassa* (Baker) L. E. Bishop | *Enterosora percrassa* | *Enterosora percrassa* |
| 480 | *Enterosora sectifrons* (Kunze ex Mett.) Shalisko & Sundue | *Zygophlebia sectifrons* | *Zygophlebia sectifrons* |
| 481 | *Enterosora trichosora* (Hook.) L. E. Bishop | *Enterosora trichosora* | *Enterosora trichosora* |
| 482 | *Enterosora trifurcata* (L.) L. E. Bishop | *Enterosora trifurcata* | *Enterosora trifurcata* |
| 483 | *Ephemeropteris skinneri* (Baker) R. C. Moran & Sundue | *Athyrium skinneri* | *Athyrium skinneri* |
| 484 | *Equisetum bogotense* Kunth | *Equisetum bogotense* | *Equisetum bogotense* |
| 485 | *Equisetum myriochaetum* Cham. & Schltdl. | *Equisetum myriochaetum* | *Equisetum myriochaetum* |
| 486 | *Eupodium laeve* (Sm.) Murdock | *Marattia laevis* | *Eupodium laeve* |

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| | | *Eupodium laeve* | *Eupodium laeve* |
| 487 | *Gaga angustifolia* (Kunth) Fay W. Li & Windham | *Gaga angustifolia* | *Gaga angustifolia* |
| 488 | *Gaga hirsuta* (Link) Fay W. Li & Windham | *Gaga hirsuta* | *Gaga apiacea* |
| 489 | *Gaga marginata* (Kunth) Fay W. Li & Windham | *Cheilanthes marginata* | *Gaga marginata* |
| 490 | *Gaga pellaeopsis* (Mickel) Fay W. Li & Windham | *Gaga pellaeopsis* | *Gaga pellaeopsis* |
| 491 | *Galactodenia delicatula* (M. Martens & Galeotti) Sundue & Labiak | *Galactodenia delicatula* | *Galactodenia delicatula* |
| 492 | *Galactodenia subscabra* (Klotzsch) Sundue & Labiak | *Terpsichore subscabra* | *Galactodenia subscabra* |
| | | *Terpsichore jamesonioides* | *Galactodenia subscabra* |
| 493 | *Gastoniella chaerophylla* (Desv.) Li Bing Zhang & Liang Zhang | *Gastoniella chaerophylla* | *Anogramma chaerophylla* |
| 494 | *Goniopteris biformata* (Rosenst.) Salino & T. E. Almeida | *Thelypteris biformata* | *Thelypteris biformata* |
| 495 | *Goniopteris biolleyi* (Christ) Pic. Serm. | *Goniopteris biolleyi* | *Goniopteris biolleyi* |
| 496 | *Goniopteris blanda* (Fée) Salino & T. E. Almeida | *Goniopteris blanda* | *Goniopteris reptans* |
| 497 | *Goniopteris costaricensis* Salino & T. E. Almeida | *Thelypteris crenata* | *Goniopteris poiteana* |
| 498 | *Goniopteris ghiesbreghtii* (Linden) J. Sm. | *Goniopteris ghiesbreghtii* | *Goniopteris poiteana* |
| 499 | *Goniopteris hatchii* (A. R. Sm.) Á. Löve & D. Löve | *Goniopteris hatchii* | *Thelypteris biformata* |
| 500 | *Goniopteris imbricata* (Liebm.) Á. Löve & D. Löve | *Goniopteris imbricata* | *Goniopteris tetragona* |
| 501 | *Goniopteris liebmannii* (Maxon & C. V. Morton) Salino & T. E. Almeida | *Goniopteris liebmannii* | *Goniopteris liebmannii* |
| 502 | *Goniopteris nicaraguensis* (E. Fourn.) Salino & T. E. Almeida | *Goniopteris nicaraguensis* | *Goniopteris tristis* |
| 503 | *Goniopteris obliterata* (Sw.) C. Presl | *Goniopteris obliterata* | *Goniopteris vivipara* |
| 504 | *Goniopteris paucipinnata* (Donn. Sm.) Salino & T. E. Almeida | *Goniopteris paucipinnata* | *Goniopteris goeldii* |
| 505 | *Goniopteris resiliens* (Maxon) Salino & T. E. Almeida | *Goniopteris resiliens* | *Goniopteris pennata* |
| 506 | *Goniopteris rhachiflexuosa* (Riba) Salino & T. E. Almeida | *Goniopteris rhachiflexuosa* | *Thelypteris meniscioides* |
| 507 | *Goniopteris schaffneri* (Fée) Salino & T. E. Almeida | *Goniopteris schaffneri* | *Goniopteris scabra* |
| 508 | *Goniopteris tuxtlensis* (T. Krömer, Acebey & A. R. Sm.) Salino & T. E. Almeida | *Goniopteris tuxtlensis* | *Goniopteris lugubris* |
| 509 | *Grammitis bryophila* (Maxon) F. Seym. | *Grammitis bryophila* | *Grammitis bryophila* |
| 510 | *Grammitis leptopoda* (C. H. Wright) Copel. | *Grammitis leptopoda* | *Grammitis paramicola* |
| 511 | *Grammitis marginella* (Sw.) Sw. | *Grammitis marginella* | *Grammitis marginelloides* |
| 512 | *Hecistopteris pumila* (Spreng.) J. Sm. | *Hecistopteris pumila* | *Hecistopteris pumila* |
| 513 | *Histiopteris incisa* (Thunb.) J. Sm. | *Histiopteris incisa* | *Histiopteris incisa* |
| 514 | *Hiya nigrescens* (Hook.) H. Shang | *Hypolepis nigrescens* | *Hypolepis bogotensis* |

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| 515 | *Hymenasplenium hoffmannii* (Hieron.) L. Regalado & Prada | *Asplenium hoffmannii* | *Asplenium heterochroum* |
| 516 | *Hymenasplenium laetum* (Sw.) L. Regalado & Prada | *Asplenium laetum* | *Asplenium cristatum* |
| 517 | *Hymenasplenium riparium* (Liebm.) L. Regalado & Prada | *Hymenasplenium riparium* | *Asplenium riparium* |
| 518 | *Hymenasplenium volubile* (N. Murak. & R. C. Moran) L. Regalado & Prada | *Asplenium volubile* | *Asplenium kunzeanum* |
| 519 | *Hymenophyllum apiculatum* Mett. ex Kuhn | *Hymenophyllum apiculatum* | *Hymenophyllum apiculatum* |
| 520 | *Hymenophyllum asplenioides* (Sw.) Sw. | *Hymenophyllum asplenioides*<br>*Hymenophyllum axillare* | *Hymenophyllum elegantulum*<br>*Hymenophyllum myriocarpum* |
| 521 | *Hymenophyllum consanguineum* C. V. Morton | *Hymenophyllum consanguineum* | *Hymenophyllum lindenii* |
| 522 | *Hymenophyllum crassipetiolatum* Stolze | *Hymenophyllum crassipetiolatum* | *Hymenophyllum lindenii* |
| 523 | *Hymenophyllum crispum* Kunth | *Hymenophyllum crispum* | *Hymenophyllum trichophyllum* |
| 524 | *Hymenophyllum cristatum* Hook. & Grev. | *Hymenophyllum cristatum* | *Hymenophyllum plicatum* |
| 525 | *Hymenophyllum ectocarpon* Fée | *Hymenophyllum ectocarpon* | *Hymenophyllum peltatum* |
| 526 | *Hymenophyllum elegans* Spreng. | *Hymenophyllum elegans* | *Hymenophyllum cocosense* |
| 527 | *Hymenophyllum fragile* (Hedw.) Morton | *Hymenophyllum fragile* | *Hymenophyllum fragile* |
| 528 | *Hymenophyllum fucoides* (Sw.) Sw. | *Hymenophyllum fucoides* | *Hymenophyllum fucoides* |
| 529 | *Hymenophyllum hemipteron* Rosenst. | *Hymenophyllum hemipteron* | *Hymenophyllum simplex* |
| 530 | *Hymenophyllum hirsutum* (L.) Sw. | *Hymenophyllum hirsutum* | *Hymenophyllum hirsutum* |
| 531 | *Hymenophyllum horizontale* C. V. Morton | *Hymenophyllum horizontale* | *Hymenophyllum multialatum* |
| 532 | *Hymenophyllum lanatum* Fée | *Hymenophyllum lanatum* | *Hymenophyllum plumieri* |
| 533 | *Hymenophyllum lindenii* Hook. | *Hymenophyllum lindenii* | *Hymenophyllum lindenii* |
| 534 | *Hymenophyllum lineare* (Sw.) Sw. | *Hymenophyllum lineare* | *Hymenophyllum capillare* |
| 535 | *Hymenophyllum matthewsii* Bosch | *Hymenophyllum mattheswsii* | *Hymenophyllum mattheswsii* |
| 536 | *Hymenophyllum maxonii* Christ ex Morton | *Hymenophyllum maxonii* | *Hymenophyllum microcarpum* |
| 537 | *Hymenophyllum microcarpum* Desv. | *Hymenophyllum microcarpum* | *Hymenophyllum microcarpum* |
| 538 | *Hymenophyllum multialatum* C. V. Morton | *Hymenophyllum multialatum* | *Hymenophyllum multialatum* |
| 539 | *Hymenophyllum myriocarpum* Hook. | *Hymenophyllum myriocarpum* | *Hymenophyllum myriocarpum* |
| 540 | *Hymenophyllum paucicarpum* Jenman | *Hymenophyllum siliquosum* | *Hymenophyllum apiculatum* |
| 541 | *Hymenophyllum plumieri* Hook. & Grev. | *Hymenophyllum plumieri* | *Hymenophyllum plumieri* |
| 542 | *Hymenophyllum plumosum* Kaulf. | *Hymenophyllum plumosum* | *Hymenophyllum elegantulum* |
| 543 | *Hymenophyllum polyanthos* (Sw.) Sw. | *Hymenophyllum polyanthos* | *Hymenophyllum polyanthos* |

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| 544 | *Hymenophyllum pulchellum* Schltdl. & Cham. | *Hymenophyllum pulchellum* | *Hymenophyllum ferrugineum* |
| 545 | *Hymenophyllum ruizianum* (Klotzsch) Kunze | *Hymenophyllum ruizianum* | *Hymenophyllum ruizianum* |
| 546 | *Hymenophyllum sericeum* (Sw.) Sw. | *Hymenophyllum speciosum* | *Hymenophyllum speciosum* |
| 547 | *Hymenophyllum sieberi* (C. Presl) Bosch | *Hymenophyllum sieberi* | *Hymenophyllum plumieri* |
| 548 | *Hymenophyllum simplex* C. V. Morton | *Hymenophyllum simplex* | *Hymenophyllum simplex* |
| 549 | *Hymenophyllum* sp. 1 | *Hymenophyllum spec 1* | *Hymenophyllum spec 1* |
| 550 | *Hymenophyllum subrigidum* Christ | *Hymenophyllum subrigidum* | *Hymenophyllum fuciforme* |
| 551 | *Hymenophyllum tegularis* (Desv.) Proctor & Lourteig | *Hymenophyllum tegularis* | *Hymenophyllum speciosum* |
| 552 | *Hymenophyllum trapezoidale* Liebm. | *Hymenophyllum trapezoidale* | *Hymenophyllum ruizianum* |
| 553 | *Hymenophyllum trichomanoides* Bosch | *Hymenophyllum trichomanoides* | *Hymenophyllum trichomanoides* |
| 554 | *Hymenophyllum trichophyllum* Kunth | *Hymenophyllum trichophyllum* | *Hymenophyllum trichophyllum* |
| 555 | *Hymenophyllum tunbrigense* (L.) Sm. | *Hymenophyllum tunbrigense* | *Hymenophyllum tunbrigense* |
| 556 | *Hymenophyllum undulatum* (Sw.) Sw. | *Hymenophyllum undulatum* | *Hymenophyllum mattheswsii* |
| 557 | *Hypoderris brauniana* (H. Karst.) F. G. Wang & Christenh. | *Tectaria brauniana* | *Tectaria apiifolia* |
| 558 | *Hypolepis bogotensis* H. Karst. ex Mett. | *Hypolepis bogotensis* | *Hypolepis bogotensis* |
| 559 | *Hypolepis crassa* Maxon | *Hypolepis crassa* | *Hypolepis rugosula* |
| 560 | *Hypolepis hostilis* (Kunze) C. Presl | *Hypolepis hostilis* | *Hypolepis obtusata* |
| 561 | *Hypolepis obtusata* (C. Presl) Kuhn | *Hypolepis obtusata* | *Hypolepis obtusata* |
| 562 | *Hypolepis rugosula* subsp. *pulcherrima* (Underw. & Maxon) Schwartsb. & J. Prado | *Hypolepis pulcherrima* | *Hypolepis sparsisora* |
| 563 | *Hypolepis stuebelii* Hieron. | *Hypolepis stuebelii* | *Histiopteris sinuata* |
| 564 | *Hypolepis trichobacilliformis* R. C. Moran | *Hypolepis trichobacilliformis* | *Histiopteris incisa* |
| 565 | *Jamesonia flexuosa* (Humb. & Bonpl.) Christenh. | *Jamesonia flexuosa*<br>*Eriosorus flexuosus* | *Jamesonia flexuosa*<br>*Jamesonia flexuosa* |
| 566 | *Jamesonia glaberrima* (Maxon) Christenh. | *Eriosorus glaberrimus* | *Jamesonia hirta* |
| 567 | *Jamesonia hirta* (Kunth) Christenh. | *Jamesonia hirta* | *Jamesonia hirta* |
| 568 | *Jamesonia rotundifolia* Fée | *Jamesonia rotundifolia* | *Jamesonia rotundifolia* |
| 569 | *Jamesonia scammaniae* A. F. Tryon | *Jamesonia scammanae* | *Jamesonia alstonii* |
| 570 | *laphoglossum albescens* Christ | *Elaphoglossum albescens* | *Elaphoglossum albescens* |
| 571 | *Lastreopsis killipii* (C. Chr. & Maxon) Tindale | *Lastreopsis killipii* | *Parapolystichum killipii* |
| 572 | *Lellingeria barbensis* (Lellinger) A.R. Sm. & R.C. Moran | *Lellingeria barbensis* | *Lellingeria pendula* |

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| 573 | *Lellingeria isidrensis* (Maxon ex Copel.) A. R. Sm. & R. C. Moran | *Lellingeria isidrensis* | *Lellingeria isidrensis* |
| 574 | *Lellingeria major* (Copel.) A. R. Sm. & R. C. Moran | *Lellingeria major* | *Lellingeria major* |
| 575 | *Lellingeria melanotrichia* (Baker) A. R. Sm. & R. C. Moran | *Lellingeria melanotrichia* | *Lellingeria melanotrichia* |
| 576 | *Lellingeria subsessilis* (Baker) A. R. Sm. & R. C. Moran | *Lellingeria subsessilis* | *Lellingeria subsessilis* |
| 577 | *Lellingeria suprasculpta* (Christ) A. R. Sm. & R. C. Moran | *Lellingeria suprasculpta* | *Lellingeria suprasculpta* |
| 578 | *Lellingeria suspensa* (L.) A. R. Sm. & R. C. Moran | *Lellingeria suspensa* | *Lellingeria suspensa* |
| 579 | *Lellingeria tmesipteris* (Copel.) A. R. Sm. & R. C. Moran | *Lellingeria tmesipteris* | *Lellingeria tamandarei* |
| 580 | *Lindsaea arcuata* Kunze | *Lindsaea arcuata* | *Lindsaea arcuata* |
| 581 | *Lindsaea divaricata* Klotzsch | *Lindsaea divaricata* | *Lindsaea divaricata* |
| 582 | *Lindsaea imrayana* (Hook.) Pérez | *Ormoloma imrayanum* | *Lindsaea imrayana* |
| 583 | *Lindsaea lancea* (L.) Bedd. | *Lindsaea lancea* | *Lindsaea arcuata* |
| 584 | *Lindsaea portoricensis* Desv. | *Lindsaea portoricensis* | *Lindsaea portoricensis* |
| 585 | *Lindsaea schomburgkii* Klotzsch | *Lindsaea schomburgkii* | *Lindsaea schomburgkii* |
| 586 | *Lindsaea taeniata* K. U. Kramer | *Lindsaea taeniata* | *Lindsaea taeniata* |
| 587 | *Lomaridium acutum* (Desv.) Gasper & V. A. O. Dittrich | *Blechnum acutum* | *Lomaridium acutum* |
| 588 | *Lomaridium ensiforme* (Liebm.) Gasper & V. A. O. Dittrich | *Lomaridium ensiforme* | *Lomaridium ensiforme* |
| | | *Blechnum ensiforme* | *Lomaridium ensiforme* |
| 589 | *Lomaridium fragile* (Liebm.) Gasper & V. A. O. Dittrich | *Lomaridium fragile* | *Lomaridium fragile* |
| | | *Blechnum fragile* | *Lomaridium fragile* |
| 590 | *Lomariocycas aurata* (Fée) Gasper & A. R. Sm. | *Blechnum auratum* | *Blechnum auratum* |
| | | *Blechnum buchtienii* | *Lomariocycas aurata* |
| 591 | *Lomariocycas columbiensis* (Hieron.) Gasper & A. R. Sm. | *Blechnum columbiense* | *Blechnum columbiense* |
| 592 | *Lomariocycas werckleana* (Christ) Gasper & A. R. Sm. | *Blechnum werckleanum* | *Lomariocycas werckleana* |
| 593 | *Lomariopsis fendleri* D. C. Eaton | *Lomariopsis fendleri* | *Lomariopsis fendleri* |
| 594 | *Lomariopsis latipinna* Stolze | *Lomariopsis latipinna* | *Lomariopsis latipinna* |
| 595 | *Lomariopsis maxonii* (Underw.) Holttum | *Lomariopsis maxonii* | *Lomariopsis maxonii* |
| 596 | *Lomariopsis mexicana* Holttum | *Lomariopsis mexicana* | *Lomariopsis vestita* |
| 597 | *Lomariopsis recurvata* Fée | *Lomariopsis recurvata* | *Lomariopsis maxonii* |
| 598 | *Lomariopsis vestita* E. Fourn. | *Lomariopsis vestita* | *Lomariopsis vestita* |
| 599 | *Lonchitis hirsuta* L. | *Lonchitis hirsuta* | *Lonchitis hirsuta* |

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| 600 | *Lophosoria quadripinnata* (J. F. Gmel.) C. Chr. | *Lophosoria quadripinnata* | *Lophosoria quadripinnata* |
| 601 | *Loxogramme mexicana* (Fée) C. Chr. | *Loxogramme mexicana* | *Loxogramme mexicana* |
| 602 | *Lygodium heterodoxum* Kunze | *Lygodium heterodoxum* | *Lygodium heterodoxum* |
| 603 | *Lygodium venustum* Sw. | *Lygodium venustum* | *Lygodium venustum* |
| 604 | *Macrothelypteris torresiana* (Gaudich.) Ching | *Macrothelypteris torresiana* | *Macrothelypteris torresiana* |
| 605 | *Marattia excavata* Underw. | *Marattia excavata* | *Marattia fraxinea* |
| 606 | *Marattia interposita* Christ | *Marattia interposita* | *Marattia douglasii* |
| 607 | *Marattia laxa* Kunze | *Marattia laxa* | *Marattia laxa* |
| 608 | *Marattia weinmanniifolia* Liebm. | *Marattia weinmanniifolia* | *Marattia weinmanniifolia* |
| 609 | *Maxonia apiifolia* (Sw.) C. Chr. | *Maxonia apiifolia* | *Maxonia apiifolia* |
| 610 | *Megalastrum acrosorum* (Hieron.) A. R. Sm. & R. C. Moran | *Megalastrum acrosorum* | *Megalastrum macrotheca* |
| 611 | *Megalastrum andicola* (C. Chr.) A. R. Sm. & R. C. Moran | *Megalastrum andicola* | *Megalastrum andicola* |
| 612 | *Megalastrum atrogriseum* (C. Chr.) A. R. Sm. & R. C. Moran | *Megalastrum atrogriseum* | *Megalastrum atrogriseum* |
| 613 | *Megalastrum biseriale* (Baker) A. R. Sm. & R. C. Moran | *Megalastrum biseriale* | *Megalastrum biseriale* |
| 614 | *Megalastrum fibrillosum* (Baker) R. C. Moran, J. Prado & Sundue | *Megalastrum fibrillosum* | *Megalastrum fibrillosum* |
| 615 | *Megalastrum galeottii* (M. Martens) R. C. Moran & J. Prado | *Megalastrum galeottii* | *Megalastrum subincisum* |
| 616 | *Megalastrum insigne* R. C. Moran, J. Prado & Sundue | *Megalastrum inisgne* | *Megalastrum abundans* |
| 617 | *Megalastrum mexicanum* R. C. Moran & J. Prado | *Megalastrum mexicanum* | *Megalastrum atrogriseum* |
| 618 | *Megalastrum palmense* (Rosenst.) A. R. Sm. & R. C. Moran | *Megalastrum palmense* | *Megalastrum subtile* |
| 619 | *Megalastrum pulverulentum* (Poir.) A. R. Sm. & R. C. Moran | *Megalastrum pulverulentum* | *Megalastrum fugaceum* |
| 620 | *Megalastrum subincisum* (Willd.) A. R. Sm. & R. C. Moran | *Megalastrum subincisum* | *Megalastrum subincisum* |
| 621 | *Melpomene deltata* (Mickel & Beitel) A. R. Sm. & R. C. Moran | *Melpomene deltata* | *Melpomene melanosticta* |
| 622 | *Melpomene firma* (J. Sm.) A. R. Sm. & R. C. Moran | *Melpomene firma* | *Melpomene firma* |
| 623 | *Melpomene flabelliformis* (Poir.) A. R. Sm. & R. C. Moran | *Melpomene flabelliformis* | *Melpomene flabelliformis* |
| 624 | *Melpomene leptostoma* (Fée) A. R. Sm. & R. C. Moran | *Melpomene leptostoma* | *Melpomene leptostoma* |
| 625 | *Melpomene moniliformis* (Lag. ex Sw.) A. R. Sm. & R. C. Moran | *Melpomene moniliformis* | *Melpomene moniliformis* |
| 626 | *Melpomene peruviana* (Desv.). A. R. Sm. & R. C. Moran | *Melpomene peruviana* | *Melpomene peruviana* |
| 627 | *Melpomene pilosissima* (M. Martens & Galeotti) A. R. Sm. & R. C. Moran | *Melpomene pilosissima* | *Melpomene pilosissima* |
| 628 | *Melpomene pseudonutans* (Christ & Rosenst.) A. R. Sm. & R. C. Moran | *Melpomene pseudonutans* | *Melpomene pseudonutans* |
| 629 | *Melpomene sodiroi* (Christ & Rosenst.) A. R. Sm. & R. C. Moran | *Melpomene sodiroi* | *Melpomene sodiroi* |

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| 630 | *Melpomene vernicosa* (Copel.) A. R. Sm. & R. C. Moran | *Melpomene vernicosa* | *Melpomene vernicosa* |
| 631 | *Melpomene vulcanica* Lehnert | *Melpomene vulcanica* | *Melpomene vulcanica* |
| 632 | *Melpomene wolfii* (Hieron.) A. R. Sm. & R. C. Moran | *Melpomene wolfii* | *Melpomene wolfii* |
| 633 | *Melpomene xiphopteroides* (Liebm.) A. R. Sm. & R. C. Moran | *Melpomene xiphopteroides* | *Melpomene xiphopteridoides* |
| 634 | *Meniscium falcatum* Liebm. | *Thelypteris falcata* | *Meniscium angustifolium* |
| 635 | *Meniscium giganteum* Mett. | *Thelypteris gigantea* | *Meniscium serratum* |
| 636 | *Meniscium lingulatum* (C. Chr.) Pic. Serm. | *Thelypteris lingulata* | *Meniscium reticulatum* |
| 637 | *Meniscium macrophyllum* Kunze | *Thelypteris macrophylla* | *Meniscium macrophyllum* |
| 638 | *Metaxya rostrata* (Kunth) C. Presl | *Metaxya rostrata* | *Metaxya rostrata* |
| 639 | *Mickelia bernoullii* (Kuhn ex Christ) R. C. Moran, Labiak & Sundue | *Mickelia bernoullii* | *Mickelia bernoullii* |
| 640 | *Mickelia hemiotis* (Maxon) R. C. Moran, Labiak & Sundue | *Mickelia hemiotis*<br>*Bolbitis hemiotis* | *Mickelia hemiotis*<br>*Mickelia hemiotis* |
| 641 | *Mickelia lindigii* (Mett.) R. C. Moran, Labiak & Sundue | *Mickelia lindigii*<br>*Bolbitis lindigii* | *Mickelia lindigii*<br>*Bolbitis aliena* |
| 642 | *Mickelia nicotianifolia* (Sw.) R. C. Moran, Labiak & Sundue | *Bolbitis nicotianifolia* | *Mickelia nicotianifolia* |
| 643 | *Mickelia oligarchica* (Baker) R. C. Moran, Labiak & Sundue | *Bolbitis oligarchica* | *Mickelia oligarchica* |
| 644 | *Microgramma dictyophylla* (Kunze ex Mett.) de la Sota | *Microgramma fuscopunctata* | *Microgramma fuscopunctata* |
| 645 | *Microgramma lycopodioides* (L.) Copel. | *Microgramma lycopodioides* | *Microgramma lycopodioides* |
| 646 | Microgramma nitida (J.Sm.) A.R.Sm. | Microgramma nitida | Microgramma nitida |
| 647 | Microgramma percussa (Cav.) de la Sota | Microgramma percussa | Microgramma percussa |
| 648 | *Microgramma piloselloides* (L.) Copel. | *Microgramma piloselloides* | *Microgramma piloselloides* |
| 649 | *Microgramma reptans* (Cav.) A. R. Sm. | *Microgramma reptans* | *Microgramma piloselloides* |
| 650 | *Microgramma thurnii* (Baker) R. M. Tryon & Stolze | *Microgramma thurnii* | *Microgramma thurnii* |
| 651 | *Mildella intramarginalis* (Kaulf. ex Link) Trevis. | *Mildella intramarginalis* | *Mildella intramarginalis* |
| 652 | *Moranopteris aphelolepis* (C. V. Morton) R. Y. Hirai & J. Prado | *Moranopteris aphelolepis* | *Moranopteris aphelolepis* |
| 653 | *Moranopteris basiattenuata* (Jenman) R. Y. Hirai & J. Prado | *Moranopteris bassiatenuata* | *Moranopteris basiattenuata* |
| 654 | *Moranopteris caucana* (Hieron.) R. Y. Hirai & J. Prado | *Micropolypodium caucanum* | *Moranopteris caucana* |
| 655 | *Moranopteris cookii* (Underw. & Maxon) R. Y. Hirai & J. Prado | *Micropolypodium cookii* | *Moranopteris cookii* |
| 656 | *Moranopteris hyalina* (Maxon) R. Y. Hirai & J. Prado | *Micropolypodium hyalinum* | *Moranopteris hyalina* |
| 657 | *Moranopteris nana* (Fée) R. Y. Hirai & J. Prado | *Micropolypodium nanum* | *Moranopteris nana* |

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| 658 | *Moranopteris plicata* (A. R. Sm.) R. Y. Hirai & J. Prado | *Moranopteris plicata* | *Moranopteris plicata* |
| 659 | *Moranopteris taenifolia* (Jenman) R. Y. Hirai & J. Prado | *Moranopteris taenifolia* | *Moranopteris taenifolia* |
| | | *Micropolypodium taenifolium* | *Moranopteris taenifolia* |
| 660 | *Moranopteris trichomanoides* (Sw.) R. Y. Hirai & J. Prado | *Moranopteris trichomanoides* | *Moranopteris trichomanoides* |
| 661 | *Moranopteris truncicola* (Klotzsch) R. Y. Hirai & J. Prado | *Micropolypodium truncicola* | *Moranopteris truncicola* |
| | | *Moranopteris truncicola* | *Moranopteris truncicola* |
| 662 | *Moranopteris zurquina* (Copel.) R. Y. Hirai & J. Prado | *Micropolypodium zurquinum* | *Moranopteris zurquina* |
| 663 | *Mycopteris alsopteris* (C. V. Morton) Sundue | *Mycopteris alsopteris* | *Mycopteris alsopteris* |
| 664 | *Mycopteris leucosticta* (J. Sm.) Sundue | *Mycopteris leucosticta* | *Mycopteris leucosticta* |
| 665 | *Mycopteris semihirsuta* (Klotzsch) Sundue | *Terpsichore semihirsuta* | *Mycopteris semihirsuta* |
| | | *Mycopteris semihirsuta* | *Mycopteris semihirsuta* |
| 666 | *Mycopteris subtilis* (Kunze ex Klotzsch) Sundue | *Terpsichore subtilis* | *Mycopteris subtilis* |
| 667 | *Mycopteris taxifolia* (L.) Sundue | *Terpsichore taxifolia* | *Mycopteris taxifolia* |
| | | *Mycopteris taxifolia* | *Mycopteris taxifolia* |
| 668 | *Mycopteris zeledoniana* (Lellinger) Sundue | *Terpsichore zeledoniana* | *Mycopteris zeledoniana* |
| 669 | *Myriopteris lendigera* (Cav.) J. Sm. | *Myriopteris lendigera* | *Myriopteris lendigera* |
| 670 | *Myriopteris mexicana* (Davenp.) Grusz & Windham | *Myriopteris mexicana* | *Myriopteris mexicana* |
| 671 | *Myriopteris notholaenoides* (Desv.) Grusz & Windham | *Myriopteris notholaenoides* | *Myriopteris notholaenoides* |
| 672 | *Nephrolepis biserrata* (Sw.) Schott | *Nephrolepis biserrata* | *Nephrolepis biserrata* |
| 673 | *Nephrolepis brownii* (Desv.) Hovenkamp & Miyam. | *Nephrolepis multiflora* | *Nephrolepis multiflora* |
| 674 | *Nephrolepis cordifolia* (L.) C. Presl | *Nephrolepis cordifolia* | *Nephrolepis cordifolia* |
| 675 | *Nephrolepis pectinata* (Willd.) Schott | *Nephrolepis pectinata* | *Nephrolepis pectinata* |
| 676 | *Nephrolepis rivularis* (Vahl) Mett. ex Krug | *Nephrolepis rivularis* | *Nephrolepis rivularis* |
| 677 | *Niphidium crassifolium* (L.) Lellinger | *Niphidium crassifolium* | *Niphidium crassifolium* |
| 678 | *Odontosoria gymnogrammoides* Christ | *Odontosoria gymnogrammoides* | *Odontosoria guatemalensis* |
| 679 | *Odontosoria schlechtendalii* (C. Presl) C. Chr. | *Odontosoria schlechtendalii* | *Odontosoria schlechtendalii* |
| 680 | *Oleandra articulata* (Sw.) C. Presl | *Oleandra articulata* | *Oleandra articulata* |
| 681 | *Oleandra bradei* Christ | *Oleandra bradei* | *Oleandra distenta* |
| 682 | *Oleandra* sp. 1 | *Oleandra spec 1* | *Oleandra pistillaris* |
| 683 | *Olfersia cervina* (L.) Kunze | *Olfersia cervina* | *Olfersia cervina* |
| 684 | *Osmunda regalis* L. | *Osmunda regalis* | *Osmunda regalis* |

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| 685 | *Parablechnum chiriquanum* (Broadh.) Gasper & Salino | *Blechnum chiriquanum* | *Parablechnum chiriquanum* |
| 686 | *Parablechnum christii* (C. Chr.) Gasper & Salino | *Blechnum christii* | *Parablechnum christii* |
| 687 | *Parablechnum cordatum* (Desv.) Gasper & Salino | *Blechnum cordatum* | *Blechnum cordatum* |
| 688 | *Parablechnum falciforme* (Liebm.) Gasper & Salino | *Parablechnum falciforme* | *Parablechnum falciforme* |
|  |  | *Blechnum falciforme* | *Parablechnum falciforme* |
| 689 | *Parablechnum monomorphum* (R. C. Moran & B. Øllg.) Gasper & Salino | *Blechnum monomorphum* | *Blechnum monomorphum* |
| 690 | *Parablechnum proliferum* (Rosenst.) Gasper & Salino | *Blechnum proliferum* | *Parablechnum proliferum* |
| 691 | *Parablechnum schiedeanum* (Schltdl. ex C. Presl) Gasper & Salino | *Blechnum varians* | *Parablechnum schiedeanum* |
|  |  | *Blechnum schiedeanum* | *Parablechnum schiedeanum* |
| 692 | *Parablechnum schiedeanum* (Schltdl. ex C.Presl) Gasper & Salino | *Parablechnum schiedeanum* | *Parablechnum schiedeanum* |
| 693 | *Parablechnum stipitellatum* (Sodiro) Gasper & Salino | *Blechnum stipellatum* | *Blechnum stipellatum* |
| 694 | *Parapolystichum effusum* (Sw.) Ching | *Parapolystichum effusum* | *Parapolystichum effusum* |
| 695 | *Parrisia parietina* (Klotzsch) Shalisko & Sundue | *Enterosora parietina* | *Enterosora parietina* |
| 696 | *Pecluma alfredii* (Rosenst.) M. G. Price | *Pecluma alfredii* | *Pecluma alfredii* |
| 697 | *Pecluma atra* (A. M. Evans) M. G. Price | *Pecluma atra* | *Pecluma plumula* |
| 698 | *Pecluma bourgeauana* (E. Fourn.) L. A. Triana | *Pecluma bourgeauana* | *Pecluma bourgeauana* |
| 699 | *Pecluma camptophyllaria* (Fée) M. G. Price | *Pecluma camptophyllaria* | *Pecluma camptophyllaria* |
| 700 | *Pecluma consimilis* (Eaton ex Mett.) M. G. Price | *Pecluma consimilis* | *Pecluma consimilis* |
| 701 | *Pecluma dispersa* (A. M. Evans) M. G. Price | *Pecluma dispersa* | *Pecluma dispersa* |
| 702 | *Pecluma divaricata* (E. Fourn.) Mickel & Beitel | *Pecluma eurybasis* | *Pecluma eurybasis* |
|  |  | *Pecluma divaricata* | *Pecluma divaricata* |
| 703 | *Pecluma dulcis* (Poir.) F. C. Assis & Salino | *Serpocaulon dulce* | *Pecluma dulcis* |
| 704 | *Pecluma hartwegiana* (Hook.) F. C. Assis & Salino | *Polypodium hartwegianum* | *Pecluma hartwegiana* |
|  |  | *Pecluma hartwegiana* | *Pecluma hartwegiana* |
| 705 | *Pecluma hygrometrica* (Splitg.) M. G. Price | *Pecluma hygrometrica* | *Pecluma hygrometrica* |
| 706 | *Pecluma liebmannii* (C. Chr.) | *Polypodium liebmannii* | *Pecluma dulcis* |
| 707 | *Pecluma longepinnulata* (E. Fourn.) F. C. Assis & Salino | *Pecluma longepinnulata* | *Pecluma longepinnulata* |
| 708 | *Pecluma pectinata* (L.) M. G. Price | *Pecluma pectinata* | *Pecluma pectinata* |
| 709 | *Pecluma ptilota* (Kunze) M. G. Price | *Pecluma ptilotos* | *Pecluma ptilota* |
| 710 | *Pecluma rhachipterygia* (Liebm.) F. C. Assis & Salino | *Pecluma rhachipterygia* | *Pecluma rhachipterygia* |

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| 711 | *Pecluma* sp. 1 | *Pecluma spec 1* | *Pecluma spec 1* |
| 712 | *Pecluma sursumcurrens* (Copel.) M. G. Price | *Pecluma sursumcurrens* | *Pecluma sursumcurrens* |
| 713 | *Pecluma venturii* (de la Sota) M. G. Price | *Pecluma venturii* | *Pecluma venturii* |
| 714 | *Phanerophlebia gastonyi* Yatsk. | *Phanerophlebia gastonyi* | *Phanerophlebia umbonata* |
| 715 | *Phanerophlebia juglandifolia* (Humb. & Bonpl. ex Willd.) J. Sm. | *Phanerophlebia juglandifolia* | *Phanerophlebia juglandifolia* |
| 716 | *Phanerophlebia macrosora* (Baker) Underw. | *Phanerophlebia macrosora* | *Phanerophlebia juglandifolia* |
| 717 | *Phanerophlebia nobilis* (Schltdl. & Cham.) C. Presl | *Phanerophlebia nobilis* | *Phanerophlebia nobilis* |
| 718 | *Phanerophlebia umbonata* Underw. | *Phanerophlebia umbonata* | *Phanerophlebia umbonata* |
| 719 | *Phlebodium areolatum* (Humb. & Bonpl. ex Willd.) J. Sm. | *Phlebodium pseudoaureum* | *Phlebodium areolatum* |
| 720 | Pityrogramma calomelanos (L.) Link | *Pityrogramma calomelanos* | *Pityrogramma calomelanos* |
| 721 | *Pityrogramma ebenea* (L.) Proctor | *Pityrogramma ebena* | *Pityrogramma ebenea* |
| 722 | Pityrogramma tartarea (Cav.) Maxon | *Pityrogramma tartarea* | *Pityrogramma ochracea* |
| 723 | *Plagiogyria pectinata* (Liebm.) Lellinger | *Plagiogyria pectinata* | *Plagiogyria pectinata* |
| | | *Plagiogyria semicordata* | *Plagiogyria pectinata* |
| | | *Plagiogyria costaricensis* | *Plagiogyria pectinata* |
| 724 | *Pleopeltis alansmithii* (R. C. Moran) A. R. Sm. & Tejero | *Polypodium alansmithii* | *Polypodium guttatum* |
| | | *Pleopeltis alansmithii* | *Polypodium guttatum* |
| 725 | *Pleopeltis angusta* Humb. & Bonpl. ex Willd. | *Pleopeltis angusta* | *Pleopeltis angusta* |
| 726 | *Pleopeltis astrolepis* (Liebm.) E. Fourn. | *Pleopeltis astrolepis* | *Pleopeltis astrolepis* |
| 727 | *Pleopeltis christensenii* A. R. Sm. | *Dicranoglossum panamense* | *Pleopeltis christensenii* |
| 728 | *Pleopeltis collinsii* (Maxon) A. R. Sm. & Tejero | *Pleopeltis collinsii* | *Pleopeltis collinsii* |
| 729 | *Pleopeltis conzattii* (Weath.) R. M. Tryon & A. F. Tryon | *Pleopeltis conzattii* | *Pleopeltis conzattii* |
| 730 | *Pleopeltis crassinervata* (Fée) T. Moore | *Pleopeltis crassinervata* | *Pleopeltis crassinervata* |
| 731 | *Pleopeltis fallax* (Schltdl. & Cham.) Mickel & Beitel | *Pleopeltis fallax* | *Pleopeltis fallax* |
| 732 | *Pleopeltis fructuosa* (Maxon & Weath.) Lellinger | *Pleopeltis fructuosa* | *Pleopeltis fructuosa* |
| 733 | *Pleopeltis furfuracea* (Schltdl. & Cham.) A. R. Sm. & Tejero | *Pleopeltis furfuracea* | *Pleopeltis furfuracea* |
| 734 | *Pleopeltis lepidotricha* (Fée) A. R. Sm. & Tejero | *Pleopeltis lepidotricha* | *Pleopeltis lepidotricha* |
| 735 | *Pleopeltis lindeniana* (Kunze) A. R. Sm. & Tejero | *Pleopeltis lindeniana* | *Polypodium hirsutissimum* |
| 736 | *Pleopeltis macrocarpa* (Bory ex Willd.) Kaulf. | *Pleopeltis macrocarpa* | *Pleopeltis macrocarpa ECU* |
| 737 | *Pleopeltis macrolepis* (Maxon) A. R. Sm. & Tejero | *Polypodium macrolepis* | *Pleopeltis macrolepis* |

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| 738 | *Pleopeltis madrensis* (J. Sm.) A. R. Sm. & Tejero | *Pleopeltis madrensis* | *Pleopeltis madrensis* |
| 739 | *Pleopeltis marginata* A. R. Sm. & Tejero | *Neurodium lanceolatum* | *Neurodium lanceolatum* |
| 740 | *Pleopeltis mexicana* (Fée) Mickel & Beitel | *Pleopeltis mexicana* | *Pleopeltis mexicana* |
| 741 | *Pleopeltis michauxiana* (Weath.) Hickey & Sprunt | *Pleopeltis michauxiana* | *Pleopeltis remota* |
| 742 | *Pleopeltis monosora* (Desv.) A. R. Sm. | *Pleopeltis monosora* | *Pleopeltis monosora* |
| 743 | *Pleopeltis montigena* (Maxon) A. R. Sm. & Tejero | *Polypodium montigenum* | *Pleopeltis montigena* |
| 744 | *Pleopeltis munchii* (Christ) A.R.Sm. | *Pleopeltis muenchii* | *Pleopeltis munchii* |
| 745 | *Pleopeltis murora* (Hook.) A. R. Sm. & Tejero | *Polypodium murorum* | *Pleopeltis murorum* |
| 746 | *Pleopeltis myriolepis* (Christ) A. R. Sm. & Tejero | *Polypodium myriolepis* | *Pleopeltis myriolepis* |
| 747 | *Pleopeltis platylepis* (Mett. ex Kuhn) A. R. Sm. & Tejero | *Pleopeltis platylepis* | *Pleopeltis platylepis* |
| 748 | *Pleopeltis plebeia* (Schltdl. & Cham.) A. R. Sm. & Tejero | *Polypodium plebeium*<br>*Pleopeltis plebeia* | *Pleopeltis plebeia*<br>*Pleopeltis plebeia* |
| 749 | *Pleopeltis polylepis* (Roem. ex Kunze) T. Moore | *Pleopeltis polylepis* | *Pleopeltis polylepis* |
| 750 | *Pleopeltis polypodioides* (L.) E. G. Andrews & Windham | *Pleopeltis polypodioides* | *Pleopeltis polypodioides* |
| 751 | *Pleopeltis pycnocarpa* (C. Chr.) A. R. Sm. | *Pleopeltis pycnocarpa* | *Pleopeltis pycnocarpa* |
| 752 | *Pleopeltis pyrrholepis* (Fée) A. R. Sm. & Tejero | *Pleopeltis pyrrholepis* | *Pleopeltis pyrrholepis* |
| 753 | *Pleopeltis remota* (Desv.) A. R. Sm. | *Polypodium remotum*<br>*Pleopeltis remota* | *Pleopeltis remota*<br>*Pleopeltis remota* |
| 754 | *Pleopeltis rosei* (Maxon) A. R. Sm. & Tejero | *Polypodium rosei* | *Pleopeltis rosei* |
| 755 | *Pleopeltis rzedowskiana* (Mickel) A. R. Sm. & Tejero | *Pleopeltis rzedowskiana* | *Pleopeltis rzedowskiana* |
| 756 | *Pleopeltis sanctae-rosae* (Maxon) A. R. Sm. & Tejero | *Polypodium sanctae-rosae*<br>*Pleopeltis sanctae-rosae* | *Pleopeltis sanctae rosae*<br>*Pleopeltis sanctae rosae* |
| 757 | *Pleopeltis thyssanolepis* (A. Braun ex Klotzsch) E. G. Andrews & Windham | *Pleopeltis thyssanolepis* | *Pleopeltis thyssanolepis* |
| 758 | *Pleopeltis wiesbaurii* (Sodiro) Lellinger | *Pleopeltis wiesbaurii* | *Pleopeltis wiesbaurii* |
| 759 | *Pleopeltis wiesbaurii* (Sodiro) Lellinger | *Polypodium wiesbaueri* | *Polypodium wiesbaueri* |
| 760 | *Polybotrya aequatoriana* R. C. Moran | *Polybotrya aequatoriana* | *Polybotrya aequatoriana* |
| 761 | *Polybotrya alfredii* Brade | *Polybotrya alfredii* | *Polybotrya alfredii* |
| 762 | *Polybotrya altescandens* C. Chr. | *Polybotrya altescandens* | *Polybotrya andina* |
| 763 | *Polybotrya appressa* R. C. Moran | *Polybotrya appressa* | *Polybotrya appressa* |
| 764 | *Polybotrya caudata* Kunze | *Polybotrya caudata* | *Polybotrya caudata* |

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| 765 | *Polybotrya crassirhizoma* Lellinger | *Polybotrya crassirhizoma* | *Polybotrya crassirhizoma* |
| 766 | *Polybotrya gomezii* R. C. Moran | *Polybotrya gomezii* | *Polybotrya gomezii* |
| 767 | *Polybotrya osmundacea* Humb. & Bonpl. ex Willd. | *Polybotrya osmundacea* | *Polybotrya osmundacea* |
| 768 | *Polybotrya polybotryoides* (Baker) Christ | *Polybotrya polybotryoides* | *Polybotrya polybotryoides* |
| 769 | *Polybotrya puberulenta* R. C. Moran | *Polybotrya puberulenta* | *Polybotrya puberulenta* |
| 770 | *Polyphlebium angustatum* (Carmich.) Ebihara & Dubuisson | *Polyphlebium angustatum* | *Polyphlebium angustatum* |
| 771 | *Polyphlebium capillaceum* (L.) Ebihara & Dubuisson | *Trichomanes capillaceum* | *Polyphlebium capillaceum* |
| | | *Polyphlebium capillaceum* | *Polyphlebium capillaceum* |
| 772 | *Polyphlebium diaphanum* (Kunth) Ebihara & Dubuisson | *Trichomanes diaphanum* | *Polyphlebium diaphanum* |
| | | *Polyphlebium diaphanum* | *Polyphlebium diaphanum* |
| 773 | *Polyphlebium hymenophylloides* (Bosch) Ebihara & Dubuisson | *Trichomanes hymenophylloides* | *Polyphlebium hymenophylloides* |
| | | *Polyphlebium hymenophylloides* | *Polyphlebium hymenophylloides* |
| 774 | *Polyphlebium pyxidiferum* (L.) Ebihara & Dubuisson | *Polyphlebium pyxidiferum* | *Polyphlebium diaphanum* |
| 775 | *Polypodium arcanum* Maxon | *Polypodium arcanum* | *Polypodium arcanum* |
| 776 | *Polypodium californicum* Kaulf. | *Polypodium californicum* | *Polypodium californicum* |
| 777 | *Polypodium conterminans* Liebm. | *Polypodium conterminans* | *Pecluma camptophyllaria* |
| 778 | *Polypodium echinolepis* Fée | *Polypodium echinolepis* | *Polypodium echinolepis* |
| 779 | *Polypodium eperopeutes* Mickel & Beitel | *Polypodium eperopeutes* | *Pecluma eurybasis* |
| 780 | *Polypodium fissidens* Maxon | *Polypodium fissidens* | *Polypodium wiesbaueri* |
| 781 | *Polypodium fraternum* Schltdl. & Cham. | *Polypodium fraternum* | *Polypodium californicum* |
| 782 | *Polypodium martensii* Mett. | *Polypodium martensii* | *Polypodium martensii* |
| 783 | *Polypodium pinnatissimum* R. C. Moran | *Polypodium pinnatissimum* | *Pecluma dulcis* |
| 784 | *Polypodium plesiosorum* Kunze | *Polypodium plesiosorum* | *Polypodium plesiosorum* |
| 785 | *Polypodium pleurosorum* Kunze ex Mett. | *Polypodium pleurosorum* | *Serpocaulon fraxinifolium* |
| 786 | *Polypodium puberulum* Schltdl. & Cham. | *Polypodium puberulum* | *Pecluma filicula* |
| 787 | *Polypodium rhodopleuron* Kunze | *Polypodium rhodopleuron* | *Polypodium rhodopleuron* |
| 788 | *Polypodium sororium* Willd. | *Serpocaulon sororium* | *Serpocaulon latissimum* |
| 789 | *Polypodium subpetiolatum* Hook. | *Polypodium subpetiolatum* | *Polypodium subpetiolatum* |
| 790 | *Polypodium ursipes* Moritz ex C. Chr. | *Polypodium ursipes* | *Polypodium rhodopleuron* |
| 791 | Polystichum alfaroi (Christ) Barrington | *Polystichum alfaroi* | *Polystichum alfaroi* |

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| 792 | *Polystichum concinnum* Lellinger ex Barrington | *Polystichum concinnum* | *Polystichum concinnum* |
| 793 | Polystichum distans E. Fourn. | *Polystichum distans* | *Polystichum turrialbae* |
| 794 | *Polystichum dubium* (H. Karst.) Diels | *Polystichum dubium* | *Polystichum dubium* |
| 794 | *Polystichum erythrosorum* A. R. Sm. | *Polystichum erythrosorum* | *Polystichum muricatum* |
| 796 | *Polystichum fournieri* A. R. Sm. | *Polystichum fournieri* | *Polystichum fournieri* |
| 797 | *Polystichum hartwegii* (Klotzsch) Hieron. | *Polystichum hartwegii* | *Polystichum hartwegii* |
| 798 | *Polystichum lehmannii* Hieron. | *Polystichum lehmannii* | *Polystichum lehmannii* |
| 799 | *Polystichum mickelii* A. R. Sm. | *Polystichum mickelii* | *Polystichum montevidense* |
| 800 | *Polystichum muricatum* (L.) Fée | *Polystichum muricatum* | *Polystichum montevidense* |
| 801 | *Polystichum orbiculatum* (Desv.) J. Rémy & Fée | *Polystichum orbiculatum* | *Polystichum orbiculatum* |
| 802 | *Polystichum rachichlaena* Fée | *Polystichum rachichlaena* | *Polystichum lehmannii* |
| 803 | *Polystichum speciosissimum* (A. Braun ex Kunze) Copel. | *Polystichum speciosissimum* | *Polystichum speciosissimum* |
| 804 | *Polystichum talamancanum* Barrington | *Polystichum talamancanum* | *Polystichum talamancanum* |
| 805 | *Polystichum turrialbae* Christ | *Polystichum turrialbae* | *Polystichum turrialbae* |
| 806 | *Polytaenium brasilinum* Benedict | *Polytaenium brasiliense* | *Polytaenium lineatum* |
| 807 | *Polytaenium cajenense* (Desv.) Benedict | *Antrophyum cajenense* | *Antrophyum cajenense* |
| 808 | *Polytaenium chlorosporum* (Mickel & Beitel) E. H. Crane | *Polytaenium chlorosporum* | *Polytaenium chlorosporum* |
| 809 | *Polytaenium citrifolium* (L.) Schuettp. | *Anetium citrifolium* | *Polytaenium citrifolium* |
| 810 | *Polytaenium feei* (W. Schaffn. ex Fée) Maxon | *Antrophyum lanceolatum* | *Polytaenium feei* |
| | | *Polytaenium feei* | *Polytaenium feei* |
| 811 | *Polytaenium guayanense* (Hieron.) Alston | *Antrophyum guayanense* | *Antrophyum guayanense* |
| 812 | *Polytaenium lineatum* (Sw.) J. Sm. | *Antrophyum lineatum* | *Antrophyum smithii* |
| | | *Polytaenium lineatum* | *Polytaenium lineatum* |
| 813 | *Psilotum complanatum* Sw. | *Psilotum complanatum* | *Psilotum complanatum* |
| 814 | *Pteridium aquilinum* ssp. *feei* (W. Schaffn. ex Fée) J. A. Thomson, Mickel & Mehltr. | *Pteridium feei* | *Pteridium aquilinum* |
| 815 | *Pteridium arachnoideum* (Kaulf.) | *Pteridium arachnoideum* | *Pteridium aquilinum capense* |
| 816 | *Pteridium caudatum* (L.) Maxon | *Pteridium caudatum* | *Pteridium caudatum* |
| 817 | *Pteris altissima* Poir. | *Pteris altissima* | *Pteris altissima* |
| 818 | *Pteris biaurita* L. | *Pteris biaurita* | *Pteris biaurita* |
| 819 | *Pteris coriacea* Desv. | *Pteris coriacea* | *Pteris coriacea* |

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| 820 | *Pteris cretica* ssp. *cretica* L. | *Pteris cretica* | *Pteris cretica* |
| 821 | *Pteris erosa* Mickel & Beitel | *Pteris erosa* | *Pteris propinqua* |
| 822 | *Pteris livida* Mett. | *Pteris livida* | *Pteris livida* |
| 823 | *Pteris muricata* Hook. | *Pteris muricata* | *Pteris muricata* |
| 824 | *Pteris muricella* Fée | *Pteris muricella* | *Pteris deflexa* |
| 825 | *Pteris navarrensis* Christ | *Pteris navarrensis* | *Pteris navarrensis* |
| 826 | *Pteris oppositipinnata* Fée | *Pteris asperula* | *Pteris asperula* |
| 827 | *Pteris orizabae* M. Martens & Galeotti | *Pteris orizabae* | *Pteris orizabae* |
| 828 | *Pteris podophylla* Sw. | *Pteris podophylla* | *Pteris podophylla* |
| 829 | *Pteris praestantissima* (Bory ex Fée) Christenh. | *Neurocallis praestantissima* | *Pteris praestantissima* |
| 830 | *Pteris pungens* Willd. | *Pteris pungens* | *Pteris pungens* |
| 831 | *Pteris quadriaurita* Retz. | *Pteris quadriaurita* | *Pteris quadriaurita* |
| 832 | *Pteris speciosa* Mett. ex Kuhn | *Pteris speciosa* | *Pteris speciosa* |
| 833 | *Pteris transparens* Mett. | *Pteris transparens* | *Pteris transparens* |
| 834 | *Pteris vittata* ssp. *vittata* L. | *Pteris vittatus* | *Pteris vittata* |
| 835 | *Radiovittaria gardneriana* (Fée) E. H. Crane | *Vittaria gardneriana*<br>*Radiovittaria gardneriana* | *Radiovittaria gardneriana*<br>*Radiovittaria gardneriana* |
| 836 | *Radiovittaria minima* (Baker) E. H. Crane | *Vittaria minima* | *Radiovittaria minima* |
| 837 | *Radiovittaria moritziana* (Mett.) E. H. Crane | *Radiovittaria moritziana* | *Radiovittaria moritzinana* |
| 838 | *Radiovittaria remota* (Fée) E. H. Crane | *Vittaria remota* | *Radiovittaria remota* |
| 839 | *Radiovittaria* sp. 1 | *Radiovittaria spec 1* | *Radiovittaria spec 1* |
| 840 | *Radiovittaria stipitata* (Kunze) E. H. Crane | *Vittaria stipitata* | *Radiovittaria stipitata* |
| 841 | *Saccoloma elegans* ssp. *elegans* Kaulf. | *Saccoloma elegans* | *Saccoloma elegans* |
| 842 | *Saccoloma galeottii* (Fée) A. Rojas | *Saccoloma galeottii* | *Saccoloma elegans* |
| 843 | *Saccoloma inaequale* (Kunze) Mett. | *Saccoloma inaequale* | *Saccoloma inaequale* |
| 844 | *Saccoloma nigrescens* (Mett.) Kaulf. | *Saccoloma nigrescens* | *Saccoloma nigrescens* |
| 845 | *Salpichlaena hookeriana* (Kuntze) Alston | *Salpichlaena hookeriana* | *Salpichlaena hookeriana* |
| 846 | *Salpichlaena volubilis* ssp. *volubilis* (Kaulf.) J. Sm. | *Salpichlaena volubilis* | *Salpichlaena volubilis* |
| 847 | *Sceptridium decompositum* (M. Martens & Galeotti) Lyon | *Sceptridium decompositum* | *Sceptridium schaffneri* |
| 848 | *Schizaea dichotoma* (L.) Sm. | *Schizaea dichotoma* | *Schizaea dichotoma* |

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| 849 | *Schizaea elegans* (Vahl) Sw. | *Schizaea elegans* | *Schizaea elegans* |
| 850 | *Scoliosorus ensiformis* (Hook.) T. Moore | *Antrophyum ensiforme* | *Scoliosorus ensiformis* |
|  |  | *Scoliosorus ensiformis* | *Scoliosorus ensiformis* |
| 851 | *Serpocaulon concolorum* (M. Kessler & A. R. Sm.) A. R. Sm. | *Serpocaulon concolorum* | *Serpocaulon concolorum* |
| 852 | Serpocaulon dissimile (L.) A. R. Sm. | *Serpocaulon dissimile* | *Serpocaulon dissimile* |
|  |  | *Polypodium dissimile* | *Serpocaulon dissimile* |
| 853 | *Serpocaulon falcaria* (Kunze) A. R. Sm. | *Serpocaulon falcaria* | *Serpocaulon falcaria* |
| 854 | *Serpocaulon fraxinifolium* (Jacq.) A. R. Sm. | *Polypodium fraxinifolium* | *Serpocaulon fraxinifolium* |
|  |  | *Serpocaulon fraxinifolium* | *Serpocaulon fraxinifolium* |
| 855 | *Serpocaulon giganteum* (Desv.) A.R. Sm. | *Polypodium giganteum* | *Serpocaulon giganteum* |
| 856 | *Serpocaulon levigatum* (Cav.) A. R. Sm. | *Serpocaulon levigatum* | *Serpocaulon levigatum* |
| 857 | *Serpocaulon loriceum* (L.) A. R. Sm. | *Serpocaulon loriceum* | *Serpocaulon loriceum* |
|  |  | *Polypodium loriceum* | *Serpocaulon loriceum* |
| 858 | *Serpocaulon loriciforme* (Rosenst.) A. R. Sm. | *Polypodium loriciforme* | *Serpocaulon loriciforme* |
|  |  | *Serpocaulon loriciforme* | *Serpocaulon loriciforme* |
| 859 | *Serpocaulon maritimum* (Hieron.) A. R. Sm. | *Polypodium maritimum* | *Serpocaulon maritimum* |
| 860 | *Serpocaulon ptilorhizon* (Christ) A. R. Sm. | *Polypodium ptilorhizon* | *Serpocaulon ptilorhizon* |
|  |  | *Serpocaulon ptilorhizon* | *Serpocaulon ptilorhizon* |
| 861 | *Serpocaulon sessilifolium* (Desv.) A. R. Sm. | *Polypodium sessilifolium* | *Serpocaulon sessilifolium* |
| 862 | *Serpocaulon* sp. 1 | *Serpocaulon spec 1* | *Serpocaulon appressum* |
| 863 | *Serpocaulon subandinum* (Sodiro) A. R. Smith | *Serpocaulon subandinum* | *Serpocaulon subandinum* |
| 864 | *Serpocaulon triseriale* (Sw.) A. R. Sm. | *Serpocaulon triseriale* | *Serpocaulon triseriale* |
|  |  | *Polypodium triseriale* | *Serpocaulon triseriale* |
| 865 | *Sphaeropteris horrida* (Liebm.) R. M. Tryon | *Sphaeropteris horrida* | *Sphaeropteris horrida* |
| 867 | *Sphaeropteris myosuroides* (Liebm.) R. M. Tryon | *Sphaeropteris myosuroides* | *Sphaeropteris quindiuensis* |
| 868 | *Sphaeropteris quindiuensis* (H. Karst.) R. M. Tryon | *Sphaeropteris quindiuensis* | *Sphaeropteris quindiuensis* |
| 869 | *Steiropteris decussata* (L.) A. R. Sm. | *Thelypteris decussata* | *Steiropteris decussata* |
| 870 | *Steiropteris gardneriana* (Baker) Pic. Serm. | *Thelypteris gardneriana* | *Steiropteris gardneriana* |
| 871 | *Steiropteris glandulosa* (Desv.) Pic. Serm. | *Thelypteris glandulosa* | *Steiropteris glandulosa* |
| 872 | *Steiropteris leprieurii* (Hook.) Pic. Serm. | *Thelypteris leprieurii* | *Steiropteris leprieurii* |
|  |  | *Steiropteris leprieurii* | *Steiropteris leprieurii* |

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| 873 | *Steiropteris pennellii* (A. R. Sm.) Salino & T. E. Almeida | *Steiropteris pennellii* | *Steiropteris gardneriana* |
| 874 | *Steiropteris valdepilosa* (Baker) Pic. Serm. | *Thelypteris valdepilosa* | *Steiropteris valdepilosa* |
| 875 | *Stenogrammitis delitescens* (Maxon) Labiak | *Stenogrammitis delitescens* | *Stenogrammitis limula* |
| 876 | *Stenogrammitis hellwigii* (Mickel & Beitel) Labiak | *Stenogrammitis hellwigii* | *Stenogrammitis hellwigii* |
| 877 | *Stenogrammitis limula* (Christ) Labiak | *Lellingeria limula* | *Stenogrammitis limula* |
| 878 | *Stenogrammitis myosuroides* (Sw.) Labiak | *Lellingeria myosuroides* | *Stenogrammitis myosuroides* |
| 879 | *Stenogrammitis prionodes* (Mickel & Beitel) Labiak | *Stenogrammitis prionodes* | *Stenogrammitis prionodes* |
| 880 | *Sticherus compactus* (Christ) Nakai | *Sticherus compactus* | *Sticherus flabellatus* |
| 881 | *Sticherus hypoleucus* (Sodiro) Copel. | *Sticherus hypoleucus* | *Sticherus hypoleucus* |
| 882 | *Stigmatopteris heterophlebia* (Baker) R. C. Moran | *Stigmatopteris heterophlebia* | *Stigmatopteris heterophlebia* |
| 883 | *Stigmatopteris lechleri* (Mett.) C. Chr. | *Stigmatopteris lechleri* | *Stigmatopteris lechleri* |
| 884 | *Stigmatopteris longicaudata* (Liebm.) C. Chr. | *Stigmatopteris longicaudata* | *Stigmatopteris longicaudata* |
| 885 | *Stigmatopteris sordida* (Maxon) C. Chr. | *Stigmatopteris sordida* | *Stigmatopteris sordida* |
| 886 | *Stigmatopteris* sp. 1 | *Stigmatopteris spec 1* | *Stigmatopteris spec 1* |
| 887 | *Tectaria acerifolia* R. C. Moran | *Tectaria acerifolia* | *Tectaria acerifolia* |
| 888 | *Tectaria antioquiana* (Baker) C. Chr. | *Tectaria antioquiana* | *Tectaria antioquoiana* |
| 889 | *Tectaria athyrioides* (Baker) C. Chr. | *Tectaria athyrioides* | *Tectaria dilacerata* |
| 890 | *Tectaria heracleifolia* (Willd.) Underw. | *Tectaria heracleifolia* | *Tectaria heracleifolia* |
| 891 | *Tectaria incisa* Cav. | *Tectaria incisa* | *Tectaria incisa* |
| 892 | *Tectaria mexicana* (Fée) C. V. Morton | *Tectaria mexicana* | *Tectaria mexicana* |
| 893 | *Tectaria rivalis* (Mett. ex Kuhn) Maxon | *Tectaria rivalis* | *Tectaria panamensis* |
| 894 | *Terpsichore alfaroi* (Donn. Sm.) A. R. Sm. | *Terpsichore alfarii* | *Mycopteris cretata* |
| 895 | *Terpsichore alsophilicola* (Christ) A. R. Sm. | *Terpsichore alsophilicola* | *Alansmia smithii* |
| 896 | *Terpsichore asplenifolia* (L.) A. R. Sm. | *Terpsichore asplenifolia* | *Terpsichore aspleniifolia* |
| 897 | *Terpsichore atroviridis* (Copel.) A. R. Sm. | *Terpsichore atroviridis* | *Terpsichore chrysleri* |
| 898 | *Terpsichore lehmanniana* (Hieron.) A. R. Sm. | *Terpsichore lehmanniana* | *Terpsichore lehmanniana* |
| 899 | *Trichomanes anadromum* Rosenst. | *Trichomanes anadromum* | *Trichomanes holopterum* |
| 900 | *Trichomanes crinitum* Sw. | *Trichomanes crinitum* | *Trichomanes crinitum* |
| 901 | *Trichomanes crispum* L. | *Trichomanes crispum* | *Trichomanes crispum* |
| 902 | *Trichomanes cristatum* Kaulf. | *Trichomanes cristatum* | *Trichomanes ankersii* |

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| 903 | *Trichomanes diversifrons* (Bory) Mett. | *Trichomanes diversifrons* | *Trichomanes diversifrons* |
| 905 | *Trichomanes elegans* Rich. | *Trichomanes elegans* | *Trichomanes elegans* |
| 905 | *Trichomanes galeottii* E. Fourn. | *Trichomanes galeottii* | *Trichomanes galeottii* |
| 906 | *Trichomanes hostmannianum* (Klotzsch) Kunze | *Trichomanes hostmannianum* | *Trichomanes hostmannianum* |
| 907 | *Trichomanes kalbreyeri* Baker | *Trichomanes kalbreyeri* | *Trichomanes alatum* |
| 908 | *Trichomanes lucens* Sw. | *Trichomanes lucens* | *Trichomanes lucens* |
| 909 | *Trichomanes ludovicinum* Rosenst. | *Trichomanes ludovicinum* | *Trichomanes trigonum* |
| 910 | *Trichomanes pinnatum* Hedw. | *Trichomanes pinnatum* | *Trichomanes pinnatum* |
| 911 | *Trichomanes plumosum* Kunze | *Trichomanes plumosum* | *Trichomanes osmundoides* |
| 912 | *Trichomanes polypodioides* L. | *Trichomanes polypodioides* | *Trichomanes polypodioides* |
| 913 | *Trichomanes tuerckheimii* Christ | *Trichomanes tuerckheimii* | *Trichomanes tuerckheimii* |
| 914 | *Vandenboschia collariata* (Bosch) Ebihara & K. Iwats. | *Vandenboschia collariata* | *Vandenboschia collariata* |
| 915 | *Vandenboschia radicans* (Sw.) Copel. | *Vandenboschia radicans* | *Vandenboschia radicans* |
| | | *Trichomanes radicans* | *Vandenboschia radicans* |
| | | *Trichomanes collariatum* | *Vandenboschia radicans* |
| 916 | *Vittaria flavicosta* Mickel & Beitel | *Vittaria flavicosta* | *Vittaria scabrida* |
| 917 | *Vittaria bradeorum* Rosenst | *Vittaria bradeorum* | *Vittaria bradeorum* |
| 918 | *Vittaria graminifolia* Kaulf. | *Vittaria dimorpha* | *Vittaria dimorpha* |
| | | *Vittaria graminifolia* | *Vittaria graminifolia* |
| 919 | *Vittaria lineata* (L.) J. E. Sm. | *Vittaria lineata* | *Vittaria lineata* |
| 920 | *Woodwardia spinulosa* M. Martens & Galeotti | *Woodwardia spinulosa* | *Woodwardia spinulosa* |

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