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Research article

Running head: Non-native vascular flora of Ecuador

Compiling and analyzing the non-native flora of a megadiverse Neotropical country: a new catalogue for continental Ecuador

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Abstract

The aim of this study is to describe the non-native vascular flora of continental Ecuador and analyze its basic biogeographic and ecological attributes to inform biological invasion management. We found records for 497 non-native wild plant taxa, 53% of which are naturalized, while the rest are casual. This comprehensive inventory was based on field observations, published work, scientific reports, and online databases. It includes data on taxonomy, life form, lifespan, origin, first year record, and spatial-temporal distribution. The families with the highest number of non-native taxa growing spontaneously were Poaceae (16.2%), Asteraceae (9.8%), and Fabaceae (8.4%). Most non-native plant taxa in the wild (ca 60%) originated from Asia and/or Africa. Non-native flora in Ecuador is dominated by herbs (67%). First introductions are from the late 18th century, and they increased exponentially starting from 1915. Only 13% of the taxa have a minimum residence time of more than 125 years. The largest number of taxa were reported in the Andes region of Ecuador (94%, including taxa shared with other regions). We found documented uses in continental Ecuador for ca 80% of reported non-native taxa in the wild. The most commonly reported uses were ornamental (41%) and medical (39%). Our study revealed that naturalized taxa often have longer residence time and reported economic uses compared with casual ones, suggesting that both variables might influence the likelihood of the naturalization process. As some of the traits of non-native plants of Ecuador (low amount of non-native species, low percentage of casual plants relative to the naturalized ones, predominance of Asia and Africa as the main origins, or a total lack of archaeophytes) are shared with those of other megadiverse Neotropical countries, the results of this study provide valuable insights for the early detection, prioritization, and management of non-native plants not only for continental Ecuador but the whole region.

Key words: checklist, first record, geographic origin, invasive alien plants, megadiverse country, Neotropic, pathways, residence time

Introduction

Biological invasions have become a significant threat to biodiversity, human health, and the economy. Non-native invasive species have contributed, solely or together with other drivers, to 60% of documented global extinctions (IPBES 2023); for a review, see Roy et al. (2024). Despite the known impacts attributed to non-native invasive species on the environment (e.g., Vilà et al. 2011; McCary et al. 2016; Zhou and Staver 2019; Torres et al. 2021), there is enough evidence to indicate a global increase in the number of new introductions (Seebens et al. 2017, 2021; Mormul et al. 2022), which may rise to over 200 species per year (IPBES 2023). The increase in non-native plants introduced as a consequence of human activity—whether intentionally (e.g., agriculture, forestry, horticulture) or unintentionally (e.g., contaminants) (Blackburn et al. 2011; van Kleunen et al. 2019), coupled with the current rates of habitat loss and degradation, forest fragmentation, and land conversion, are transforming ecosystems (even in tropical regions) making them more susceptible and less resistant to biological invasions (Ackerman et al. 2017; Chong et al. 2021; Rojas-Sandoval et al. 2022).

First records of non-native vascular plant species have increased significantly during the 20th century. Moreover, 37% of initial recorded global occurrences took place between 1970 and 2014 (Seebens et al. 2017). Additionally, it has been predicted that from 2005 to 2050, the number of non-native plant species will increase by 6% to 41% depending on the continent (excluding Pacific Islands; Seebens et al. 2017). In angiosperms, the doubling time of the number of new records is just 17 years (Mormul et al. 2022). Approximately 4% (≈ 13,168 species) of the total plant species on Earth (≈ 368,000 species) have become naturalized (i.e., established) in some place (van Kleunen et al. 2015; Seebens et al. 2018). Thus, non-native plants are becoming a significant component of regional and national floras, with some cases of extremely high percentages, as is the case of New Zealand where non-alien species make up nearly 90% of the country's plant diversity (Cáceres-Polgrossi et al. 2023).

Comprehensive and updated inventories of non-native species are essential for the development of regional prevention and management strategies (McGeoch et al. 2012; Lucy

et al. 2016; Roy et al. 2019). Prevention, early detection, management, and control strategies require the development of an updated catalogue of non-native species to (i) restrict the entry of new non-native species through the creation of blacklists, decrees, and regulations and (ii) prioritize and categorize species that have already been naturalized. In addition, understanding taxonomic, biogeographic (i.e., delimiting native and invaded ranges), and temporal trends (i.e., accumulation of first records) of introduced species in a given region contributes to producing updated databases and calculating estimates of introduction rates (see Pyšek et al. 2017; Seebens et al. 2017, 2021). Inventorying non-native species is, however, even more important considering Target 6 on invasive non-native species of the Kunming-Montreal Global Biodiversity Framework (adopted in 2022), which calls for "reducing the rates of introduction and establishment of other known or potentially invasive non-native species by at least 50 percent" (CBD 2022). Therefore, knowing the distribution of the invasive species in a given region is a mandatory previous step to complying with this goal.

In some parts of the world, such as North America, Europe, Australia, New Zealand, and South Africa, the non-native flora is relatively well known (Qian and Ricklefs 2006; Lambdon et al. 2008; van Kleunen et al. 2015). Historically, local, regional, or country-level inventories are abundant for temperate and Mediterranean regions but still relatively rare for tropical regions (Pyšek et al. 2017). Even more worrying is that information on non-native plant species is not available for at least 17% of the earth's surface (van Kleunen et al. 2015, 2019). Like other megadiverse Neotropical countries, Ecuador has been poorly studied in terms of biological invasions. For example, in the global-scale Alien Species First Records Database v3.1 there are no records for mainland Ecuador (see Seebens 2023). Jørgensen and León-Yánez (1999) reported 595 introduced species of vascular plants for Ecuador (including Galapagos). Of these, 346 species were recorded as cultivated, and 249 as accidental introductions. The second attempt to produce a checklist of non-native species for Ecuador (but excluding the Galapagos Islands) was published in the Global Register of Introduced and Invasive Species (GRIIS-Checklist of Introduced and Invasive Species – Ecuador), reporting 737 non-native species, of which 577 species were of vascular plants (Herrera et al. 2021). Despite being valuable, this work was an incomplete species checklist which did not distinguish between wild and captive/cultivated plant taxa. Therefore, a more comprehensive inventory and catalogue of non-native plant species in Ecuador is still needed (Zenni et al. 2022), even more so when one considers that Ecuador is megadiverse, with part of the

country's continental territory being included within two of the four biodiversity hotspots in South America; i.e., the Tropical Andes, and the Tumbes–Chocó–Magdalena regions (Myers et al. 2000; Mittermeier et al. 2011). The lack of comprehensive catalogues is, unfortunately, a common issue among the megadiverse Neotropical countries, some of which only have preliminary or partial ones (e.g. Peru, Venezuela).

While the aim of this study is to provide an updated and comprehensive inventory of non-native vascular flora for continental Ecuador, it provides more than a taxa catalog. We integrate and analyze data from multiple sources, including citizen science, expert knowledge scientific literature, herbarium records, global and regional databases, and expert knowledge, to fill a significant data gap in a megadiverse country lacking a consolidated database of non-native plant taxa. Our analysis encompasses key ecological and biogeographical dimensions, such as taxonomy, geographic origin, local uses, life history traits, distribution patterns across bioregions, and invasion status. This multifaceted approach does not only offer critical insights into the processes driving the establishment and spread of non-native plants but also provides a robust methodological framework. Our methodology can serve as a valuable guide for developing national inventories of priority non-native species in other countries where data remains scarce or fragmented**.**

Methods

Study area

Ecuador lies in tropical South America between the Pacific Ocean and the Amazon basin, covering an area of ca 250,000 km^2. It is the smallest of the 17 megadiverse countries (Ripple et al. 2017), and with only 0.06% of the world's land area hosts approximately 18,600 taxa of vascular plants (Zapata et al. 2017). Despite its high biodiversity, land use change increases the vulnerability of Ecuador's species richness, the country having lost about 18% of its forests between 1991 and 2018 (Sierra et al. 2021).

Continental Ecuador is biogeographically divided into three principal regions ("bioregions"): the Coastal, the Andean, and the Amazon bioregion (Fig. 1). The Andean Mountain range runs through the country from north to south, creating a barrier with a myriad of peaks exceeding 4,000 m (the tallest mountain is Chimborazo, about 6,300 m). Coastal and lowland

regions receive approximately 1,600 mm of annual precipitation, while the Andes receive less than 900 mm, and in the Amazon basin precipitation averages around 4,600 mm annually (Morán-Tejeda et al. 2016). Average temperatures range from 12 °C in the mountains to 26 °C on the coast (Morán-Tejeda et al. 2016). The principal three bioregions of continental Ecuador are further subdivided into ten natural regions: Amazon, Andean Shrub, Chocó Tropical Rainforest, Deciduous Forest, Dry Shrub, Eastern Foothill, Eastern Montane, Páramo, Western Foothill, and Western Montane (Ron 2020; Fig. 1).

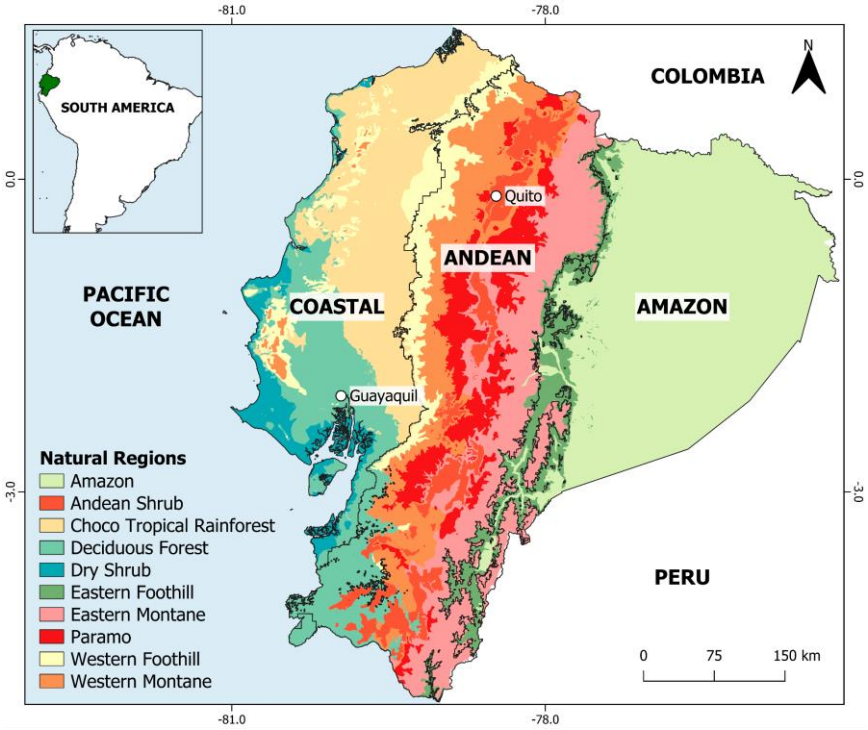

Figure 1. The three principal bioregions (Amazon, Andean, and Coastal), the ten natural regions, and the most populated cities (white dots) in continental Ecuador.

Data collection

To compile our dataset, we first created a preliminary list of non-native plant taxa for continental Ecuador using the following main sources of information: (1) the global and national biodiversity databases, including the Global Register of Introduced and Invasive Species (GRIIS, Herrera et al. 2021), https://www.gbif.org/es/dataset/1df9467e-0c60-4e5a-a7b0-2b60bd6648ed), which served as starting point to produce the catalogue; (2) the Catalogue of Vascular Plants of Ecuador (W^3CEC) (Jørgensen and León-Yánez 1999) (http://www.tropicos.org/Project/CE; accessed from July 1, 2022, to December 31, 2023); (3) the Global Naturalized Alien Flora database (GloNAF, https://glonaf.org/, van Kleunen et al.

2019); (4) the Global Biodiversity Information Facility (GBIF; https://www.gbif.org/country/EC/summary; accessed from July 1, 2022, to December 31, 2023; (5) the Centre for Agricultural Bioscience International (CABI; https://www.cabi.org/; accessed from July 1, 2022, to December 31, 2023) database (i.e., the 'CABI Compendium'), (6) the Plants of the World Online database (POWO; https://powo.science.kew.org/; accessed from July 1, 2022, to December 31, 2023) and (7) the iNaturalist citizen science web portal (https://www.inaturalist.org/; accessed from July 1, 2022, to December 31, 2023) (Fig. 2).

This preliminary list was supplemented with data extracted from the literature review, which included research articles, books and gray literature, relevant floras, and anthropology papers or books discussing the documented uses of plants in Ecuador. These documents were retrieved through scholarly search engines and databases such as ISI Web of Knowledge, Scopus, SciELO, Google Scholar, and CABI Direct. Search queries were conducted in both English and Spanish, with no restriction on publication year, using the following strings: "Introduced plants," "Exotic plants," "Invasive plants," "Non-native plants." "Alien plants," and "Ecuador." Additional data was collected from academic (PhD, MSc, or undergraduate) dissertations and project reports sourced from repositories of public and private institutions in Ecuador. Herbarium collections were also searched through databases and platforms such as TROPICOS® of the Missouri Botanical Garden (https://www.tropicos.org) and GBIF (https://www.gbif.org).

The catalogue was further screened for taxonomic name standardization using the list of accepted names from the TROPICOS database (available at https://www.tropicos.org) and The World Checklist of Vascular Plants (WCVP, Govaerts et al. 2021) using the "rWCVP" package (Brown et al. 2023) in R version 4.2.0 (R Core Team 2021). WCVP is one of the most authoritative checklists for vascular plants, and it is used to feed the Plants of the World Online (POWO) web-base. For those species that differed in taxonomic classification between the two databases (TROPICOS and WCVP), an exhaustive search in the specialized literature was carried out. To provide insight into the taxonomic composition of the non-native flora of continental Ecuador, each taxon was classified by order, family, and genus. Families have been assigned according to APG IV (The Angiosperm Phylogeny Group et al. 2016).

To confirm that all taxa in the catalogue are non-native, we gathered information on the native geographic range for each plant taxon in CABI (Centre for Agricultural Bioscience International; https://www.cabidigitallibrary.org/journal/cabicompendium), POWO (Plants of the World Online; https://powo.science.kew.org/), and GRIN (Germplasm Resource Information Network; https://npgsweb.ars-grin.gov/gringlobal/taxon/taxonomysearch). We compared the information obtained in these databases and, for those species where the information on their native range was contradictory, we conducted an exhaustive search in the specialized literature. We categorized species with no certainty of being native or non-native in continental Ecuador as cryptogenic. In addition, taxa native to a particular region in Ecuador but growing in secondary habitats (i.e., apophytes) in other regions of the country beyond their natural distribution area were classified as regional non-native taxa.

After obtaining a list without duplicates, synonyms, or uncertain records, we asked local experts to review this standardized list and also add (or delete) taxa, to classify each non-native plant taxon into one of three categories: (1) wild (taxa with at least one occurrence outside cultivation); (2) cultivated; or (3) uncertain (for those taxa where it could not be corroborated whether their occurrences are cultivated or outside cultivation). The consultation phase was conducted over six months, with all participants being given an opportunity to contribute each taxa expertise through emails, video calls and workshop. In addition to our observations and personal communications with other researchers or experienced naturalists, we relied on the abovementioned literature sources, but using the descriptors “Cultivated [Species scientific name]”, “Naturalized [Species scientific name]”, “Invasive [Species scientific name]”, “Wild [Species scientific name]” and “Ecuador”. iNaturalist played a prominent role in distinguishing between cultivated and wild plant species; this popular tool, in addition to being the world’s largest citizen science website, enables us to mark the records as “cultivated.” However, if the iNaturalist user forgets to mark the “cultivated” tag, the images included in every record often make it possible to see whether the observed plant is wild or cultivated (Vargas et al. 2022). Nonetheless, the status of all doubtful occurrences was confirmed by asking each user who uploaded them (iNaturalist allows direct contact between users; López-Guillén et al. 2024).

Also based on expert knowledge and literature review, and considering only the species that were reported as growing in the wild, we categorized the plant taxa in the next level of the classification: (1) “casual,” when they are capable of surviving in the wild and even to

occasionally reproduce outside cultivation, but eventually die out because they do not form self-replacing populations and rely on repeated introductions for their persistence, and (2) "naturalized," when they produce self-sustaining and viable populations, without direct intervention by humans, or despite human intervention (see complete definitions of these two terms in Pyšek et al. 2004; Blackburn et al. 2011; Rojas-Sandoval and Acevedo-Rodríguez 2015; Roy et al. 2024; Soto et al. 2024). We did not classify non-native species as invasive due to the lack of data on dispersal and impacts.

Finally, the following descriptive attributes for the wild non-native taxa (casual and naturalized) were added to the dataset:

1. Geographic origin. The native area was defined using the "World geographical scheme for recording plant distributions" (WGSRPD; Brummitt 2001). For analytical purposes, we employed the first level of the WGSRPD, which consists of nine biogeographical global regions: North America, South America, Europe, Africa, Asia-Temperate, Asia-Tropical, Australasia, Pacific Islands, and Antarctica. The origin of hybrids resulting from non-native parents was categorized based on the origin of those parents.

2. Life history. Non-native plant taxa were categorized based on two life history traits: lifespan (annual, biennial, or perennial) and life form (aquatic, herb, shrub, tree, succulent, or vine). Palms were included in the tree category. Assignment of species to these categories is based on our observations as well as on Ecuadorian floras, scientific literature, or databases, such as the Catalogue of Vascular Plants of Ecuador. For those species where this information was not available, we used the floras from their native areas.

3. Locality and year of first record. We used the "minimum residence time" as a proxy to indicate the possible date on which each species could have been introduced to Ecuador. Information was obtained from several sources, including scientific literature, databases (including Tropicos and GBIF), and iNaturalist (from which we extracted the date of the oldest available record). Also, an exhaustive search of herbarium sheets was carried out in several online and offline herbaria. For those cases where the first record was based on a herbarium specimen (which occurred for more than half of the species), a picture of the voucher was requested to corroborate the veracity of the data. We excluded records with

confusing identifications, no dates, or lacking georeferencing information. By utilizing the first record for each taxon, we categorized these species based on their residence time as archaeophytes (i.e., introduced before 1500 AD) and neophytes (introduced after 1500 AD; Pyšek et al. 2012). We used the year and region of the first record to generate accumulation curves of the first records on the national scale and for the three bioregions of continental Ecuador (Amazon, Andean, and Coastal). When a record did not provide any specific place, the region was categorized as "Undetermined" and was excluded from regional accumulation curves. Also, to find any relation between residence time and the invasion status we divided the residence time into four categories: old (<1900), mid-term (1900–1949), recent (1950–1999), and very recent (>1999).

4. Local uses. To identify the potential reasons for the introduction and/or expansion of each non-native wild taxon, we conducted a comprehensive search to record its uses in continental Ecuador. Information sources to determine species uses included scientific papers, books (e.g., *Enciclopedia de las plantas útiles del Ecuador* [Encyclopedia of useful plants of Ecuador] by de la Torre et al. 2008), personal blogs, and other non-scientific websites. Uses were classified into nine categories: (1) ornamental (including plants cultivated in gardens, parks, and avenues); (2) forestry (encompassing plants utilized for soil restoration, afforestation, and living fences); (3) medicinal (for humans and/or animals); (4) ancestral (plants used in rituals, ceremonies, and cultural activities); (5) food crops (for human consumption); (6) animal food (including forage and fodder for domestic animal food); (7) industrial (for textile and industrial purposes); (8) fuel (such as wood for heating or cooking); and (9) toxic (plants used for their toxic properties) (adopted from Pyšek et al. 2002).

5. Occurrences by bioregions and natural regions. We estimated the number of non-native plant taxa in continental Ecuador for each of the three bioregions and each of the 10 natural regions. For this, we downloaded occurrences of non-native plant taxa in the wild (excluding cultivated taxa) from both the GBIF and iNaturalist. Also, records in research articles, books, and gray literature were consulted, as well as personal observations. A preliminary database was generated with at least the following information for each record: (1) taxon name, (2) coordinates, (3) occurrence year, (4) political province, and (5) source of record. This database was uploaded to QGIS 3.28.3 where occurrences (1) with spatial errors (outside continental Ecuador or in the sea), (2) duplicated, and/or (3)

without coordinates or locality, were deleted. Finally, each record was updated with the natural region and bioregion.

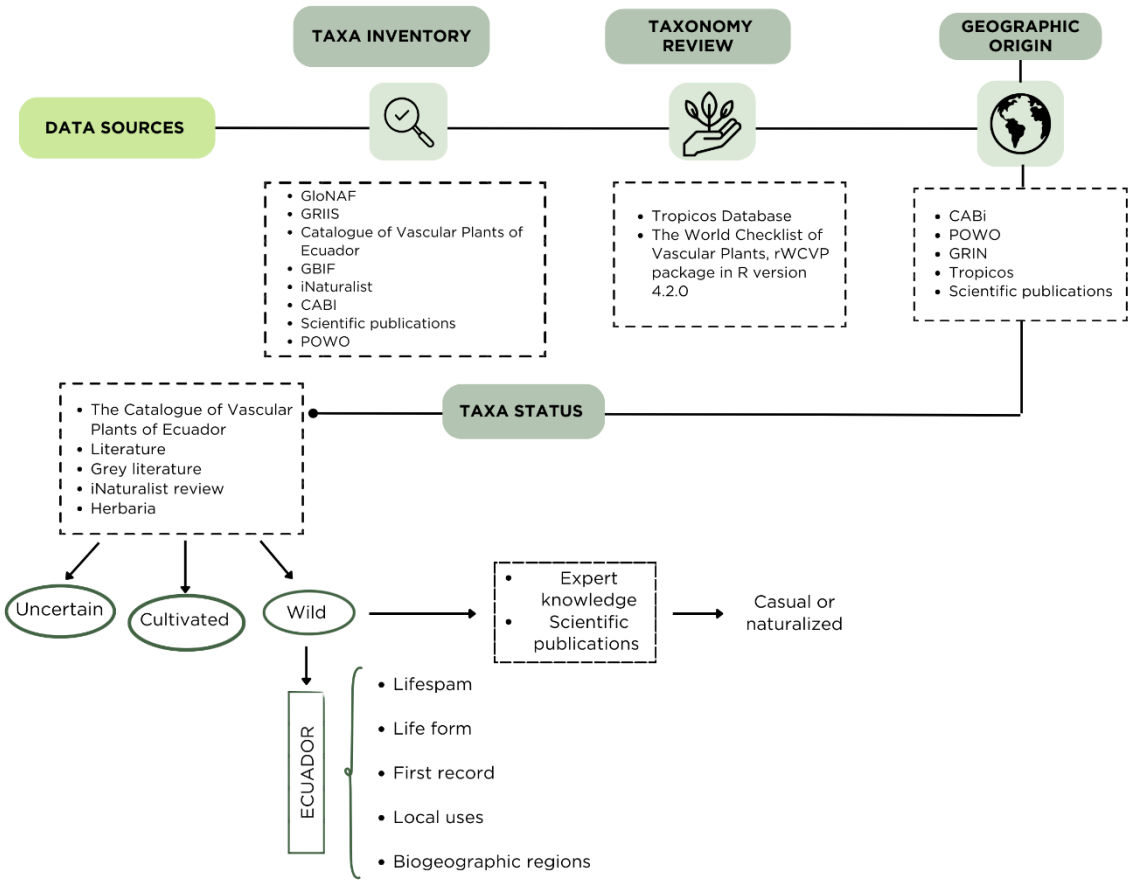

Figure 2. Methodology and data source to construct the catalogue.

Data analysis

Beyond merely cataloging non-native plant taxa, we conducted a comprehensive analysis exploring their frequencies across multiple dimensions, including taxonomy (e.g., families), life form, lifespan, geographic origin, residence time, and distribution patterns (covering both bioregions and natural regions). To evaluate the relationship between invasion status (i.e., casual and naturalized), the analyses were carried out only on a national scale due to a lack of information on the bioregional scale (Andes, Amazon, and Coast). We used Pearson's chi-squared test of independence for (1) all life forms, (2) life form divided into herbs (both terrestrial and aquatic) and other life forms (shrub, tree, herb, succulent, vine), (3) lifespan, (4) overall use (any use = yes; no use = no), and (5) residence time. Interactions between

these variables were tested using log-linear models of the frequency of values for all combinations of categories. We compared an independent model (all additive terms) with a full model (multiplicative terms between status and the other four variables) and intermediate models summarizing association with each combination of one, two, or three variables. We tested model assumptions by diagnosing the residuals and compared models using the Akaike information criterion (AIC). We fitted a logistic regression to determine what uses or origin region of the non-native plant taxa are associated with naturalization. The status of the non-native plant taxa in the dataset was formatted to a binary response (non-native plants scored 1 if they were classified as naturalized, while all casual taxa scored 0), and employed different overlapping uses as predictors.

To evaluate the relationships between the life forms, geographic origin, invasion status, natural regions, and residence time, we carried out correspondence analyses (CA) in RStudio version 4.3.3 using the Factoshiny package (Vaissie et al. 2023). The first CA was grouped by natural regions and a second analysis by residence time.

Results

Non-native plant taxa in continental Ecuador

We documented a comprehensive catalogue of 1,253 non-native plants, 14 cryptogenic, and four regional non-native taxa in continental Ecuador (for a total of 1,271 taxa). Most of them (770 taxa, 61%) were cultivated (i.e., not having any record as escaped from cultivation), while 0.3% (four taxa) had an unknown status. Of the total non-native plant taxa, 39% (497 taxa) were reported in the wild; these included 488 species, four subspecies, and five hybrids (Suppl. material: table S1). Of the 497 non-native wild plant taxa, we found that 234 taxa (47%) have been recorded exclusively as casual, and 263 (53%) have at least one report as naturalized at the scale of continental Ecuador.

The non-native plant taxa occurring in the wild in continental Ecuador belonged to 33 orders, 89 families and 338 genera. Poaceae (81 taxa, 19%), Asteraceae (49 taxa, 10%), and Fabaceae (42 taxa, 9%) were the families with the largest numbers of non-native plant taxa in continental Ecuador (Fig. 3). Forty-seven families were represented by only one or two non-native taxa. The genus with the highest number of non-native taxa was *Kalanchoe* (nine taxa,

2%), followed by *Eragrostis*, *Rumex*, *Digitaria*, and *Solanum* (seven species each, 1%), while 60% of the genera (298) were represented by fewer than two taxa.

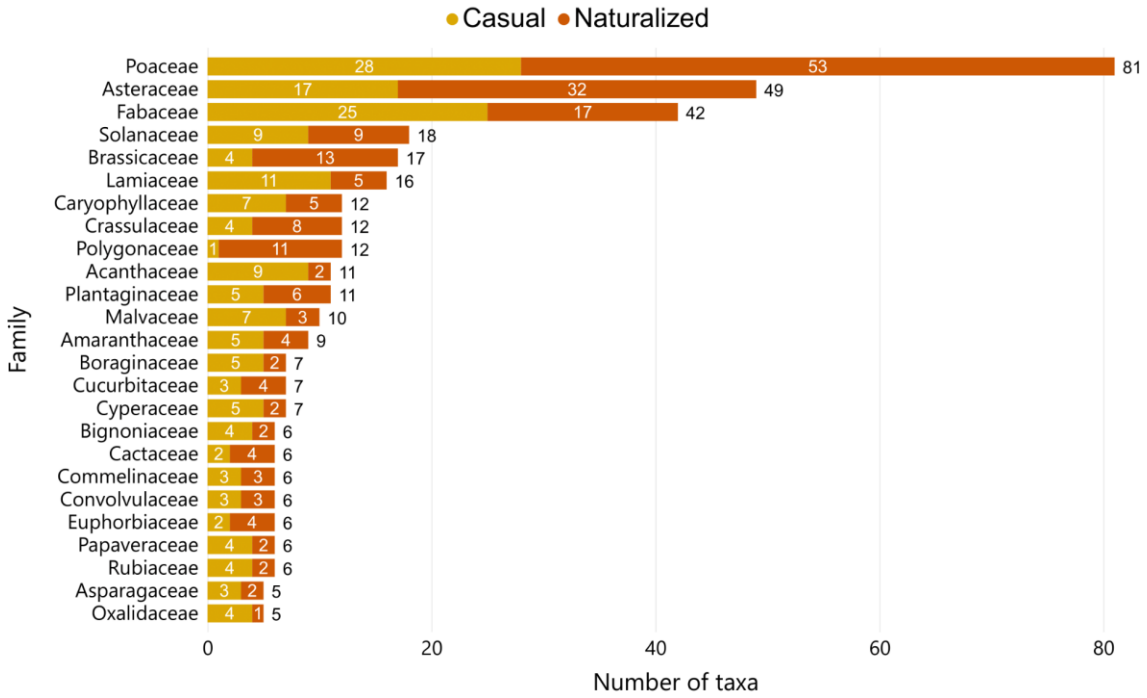

Figure 3. Number of non-native plant taxa of the most diverse plant families in the non-native flora (naturalized and casual) of continental Ecuador. For each family, taxa are categorized as either casual or naturalized.

Geographic origin

Most of the non-native flora of continental Ecuador came from multiple regions (i.e., a combination of regions) rather than a single region (Suppl. material: Fig. S1). The Old World (i.e., temperate and tropical Asia plus Africa and Europe) followed by North and South America were the two most significant sources of non-native species of continental Ecuador, with 15.7% and 13.7%, respectively. As single regions, Africa and South America contributed the most (9.9% and 8.9%, respectively). When summing all possible combinations in which each of the eight WGSRPD regions are included (i.e., among the 40 possible cases included in the x-axis of Suppl. material: Fig. S1), these regions ranked as follows (Fig. 4): Asia-Temperate (21.6%), Africa (20.8%), Asia-Tropical (17.1%), Europe (14.3%), South America (10.8%), North America (8.7%), Australasia (4.3%), and Pacific Islands (2.4%).

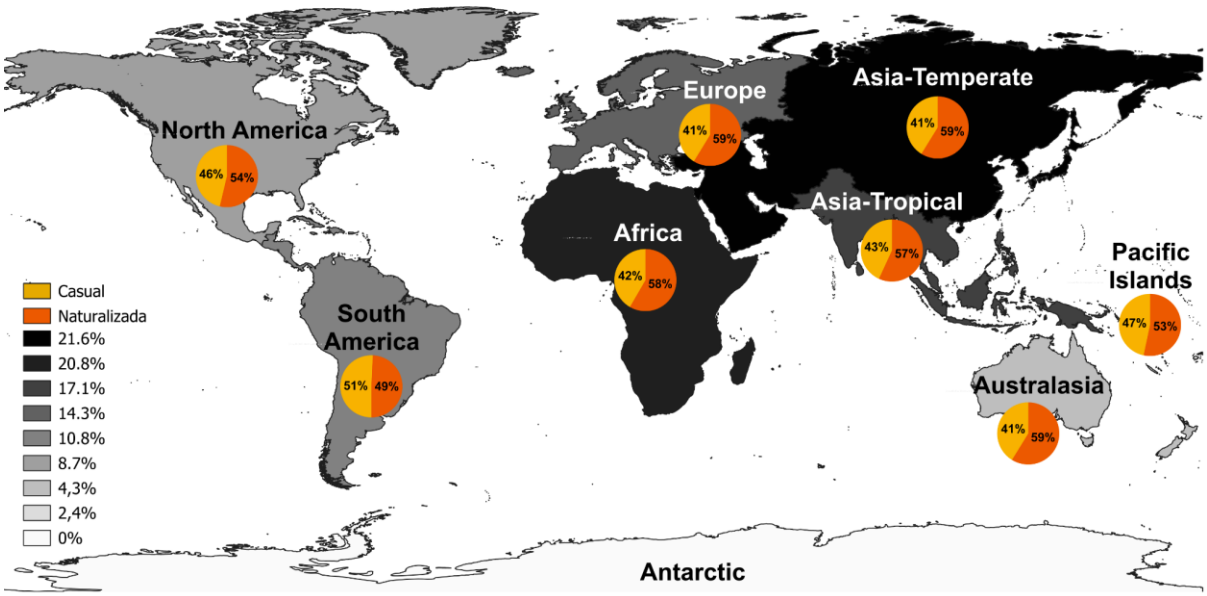

Figure 4. Percentage of the contribution of each WGSRPD geographic region to the total number of non-native taxa in continental Ecuador. The pie charts show the percentage of casual and naturalized non-native taxa per continent. Percentages were calculated considering all recorded origins for each species (i.e., a given species can come from more than one continent; see Suppl. material: Fig. S1).

Occurrences by bioregions and natural regions

In terms of bioregions, most non-native wild plant species were found in the Andean region (461 taxa, 94%), followed by the Coastal region (263 taxa, 53%), and the Amazon region (190 taxa, 39%) (see Fig. 5A). Some species were shared between regions, while others were exclusive to a single region. A total of 192 taxa were exclusive to the Andes, 27 taxa were only found in the Coastal region, and four taxa were solely present in the Amazon region (see Fig. 5A). There were 143 non-native plant taxa shared among all three bioregions (see Fig. 5A).

Of the natural regions in continental Ecuador, Andean Shrub showed the highest number of non-native plant taxa (375 taxa) (Fig. 5B), while the Dry Shrub had the fewest (142 taxa) (Fig. 5B); the Andean Shrub also showed the largest number of non-native plant taxa detected exclusively in a single region (25 taxa) (Fig. 5B). We found that most of the taxa that come from Europe (99%), Asia-Temperate (93%), and Africa (92%) were present in the Andean region, while few taxa from Europe occurred in the Coastal (23%) and Amazon (18%) bioregions (Fig. 5C).

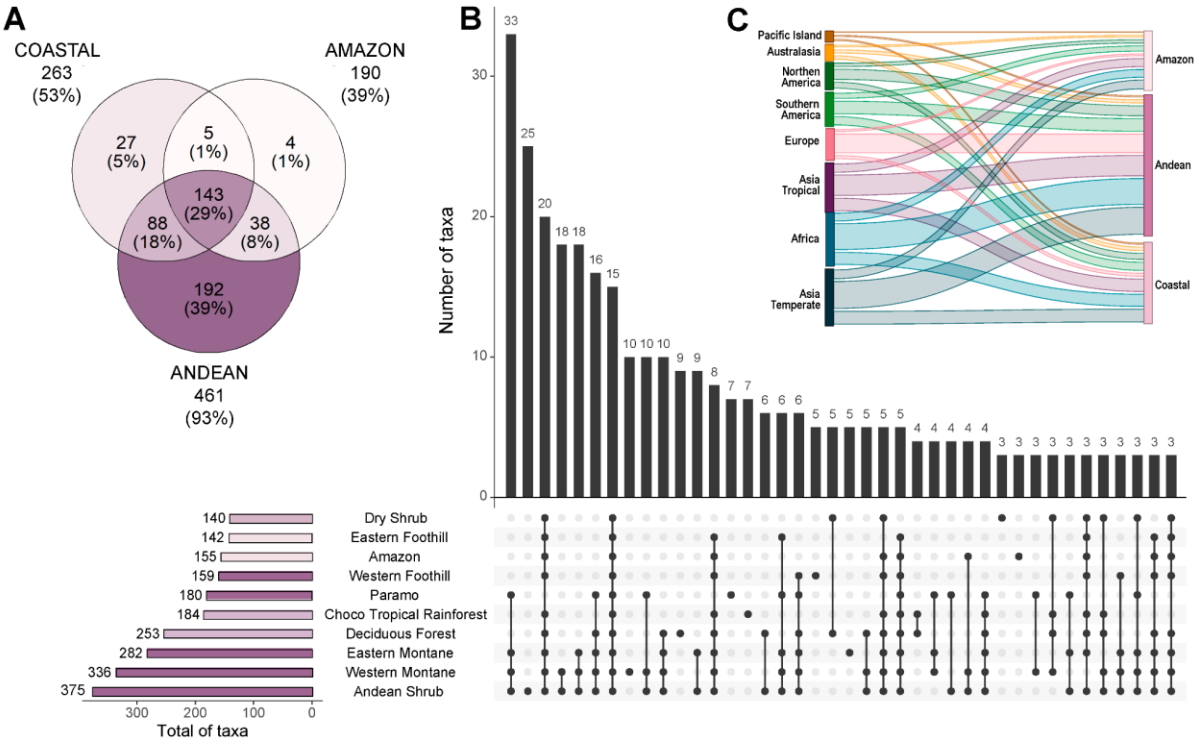

Figure 5. A Number and percentage of non-native wild taxa found in each of the three Ecuadorian bioregions and those shared by two or three bioregions; **B** number of non-native taxa found in each of the 10 natural regions of Ecuador and those shared by two or more of these regions; **C** percentage of non-native taxa present in the Amazon, Andean, and Coastal bioregions by geographic origin.

Lifespan and life form

Over half (51.1%) of the non-native wild plant taxa in continental Ecuador had a perennial lifespan (254 taxa), while the other 48.9% of the taxa could complete their life cycle in one or two years (annuals and/or biennials, 243 taxa) (Fig. 6A). In terms of life form, there was a dominance of herbs (66.8%, 332 taxa), followed by shrubs (11.7%), trees (8.2%), vines (7.8%), succulents (4.4%), and aquatic herbs (1.0%) (Fig. 6B).

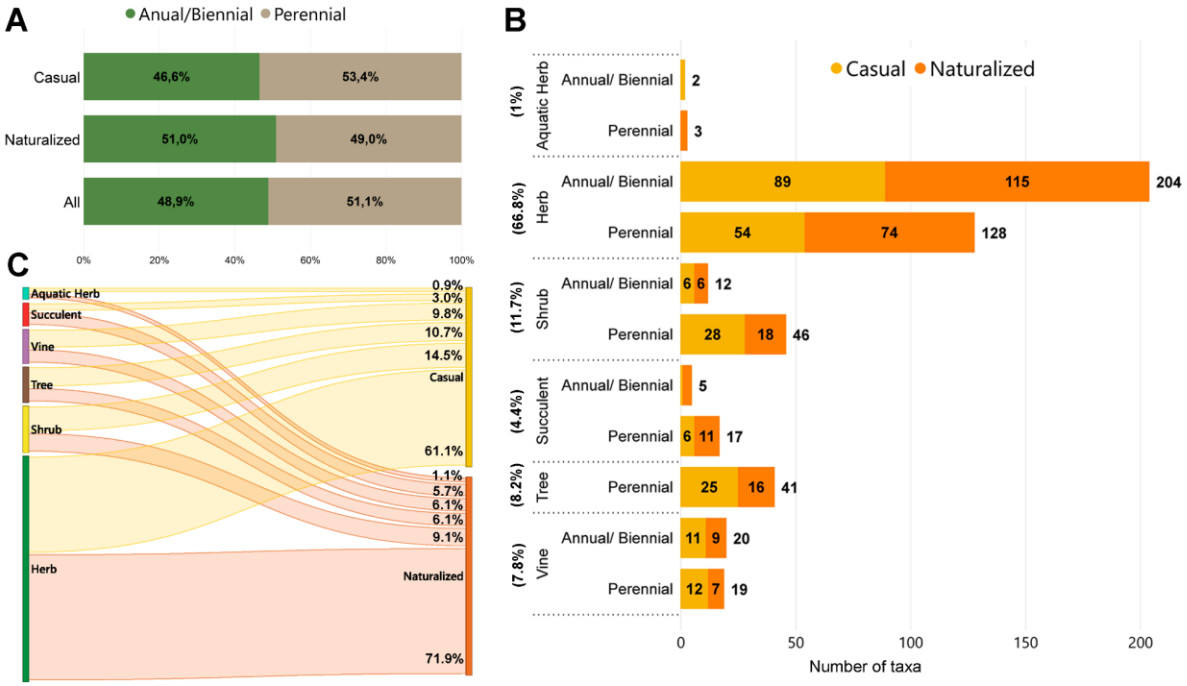

Figure 6. Total, naturalized, and casual taxa according to their lifespan and life form: **A** percentage of total, naturalized, and casual taxa by lifespan; **B** number of taxa per lifespan and their corresponding life form; **C** percentage of casual and naturalized taxa by life form (and, within each category of life form, by lifespan).

Residence time and accumulation of first records

Taking the first record as an approximation of the year of introduction, the majority of non-native wild taxa (430 taxa, 86.5%) have been present in continental Ecuador for less than 125 years. About half of these (207 taxa, with 36.7% classified as casual, and 63.3% as naturalized) showed a residence time between 75 and 125 years, being classified as mid-term, while 66 taxa (of which 63.6% were classified as casual and 36.4% as naturalized) have been in continental Ecuador for less than 25 years, and are classified as very recent (Fig. 7A). We also found a positive association between the proportion of naturalized species and residence time (very recent, recent, and mid-term), with a slight decrease in this proportion for older taxa (Fig. 7B). There was a continuous increase in the cumulative number of first records from 1799 (represented by two herbarium specimens, of *Anacardium occidentale* L. and *Heliotropium indicum* L., without reported location or region) to 1910 for the non-native wild species (Fig. 7C); from this year on, the cumulative number of first records increased exponentially, mostly for the Andean region (Fig. 7D). For the present time, the accumulation curve of first records appeared to have reached a plateau (i.e., showing signs of stabilization) for the Coastal region, but not the Andean or Amazon bioregions (Fig. 7D). Most of the first

records (325 taxa, 65.4%) were from the Andean region, with the earliest occurrence recorded in 1817 (Fig. 5B), followed by the Coastal region (123 taxa, 24.7%), where the earliest record was for 1836 (Fig. 7D). A significantly lower percentage (12 taxa, 2.4%) of first records was detected in the Amazon region, with the earliest record dating back to 1962 and increasing from 1985 onwards (Fig. 7D). The biogeographical region associated with the first record could not be determined for 37 taxa (7.4%) (including the earliest ones; data not shown). We were not able to find records of any archaeophytes; thus, all taxa were neophytes (i.e., those with the first record after 1500 AD). Six species had the oldest records in continental Ecuador, reaching back over two centuries (*Anacardium occidentale* and *Heliotropium indicum* in 1799, *Sphenoclea zeylanica* in 1800, *Oplismenus burmanni* in 1802, *Ageratum conyzoides* in 1817, and *Oxalis corniculata* in 1824).

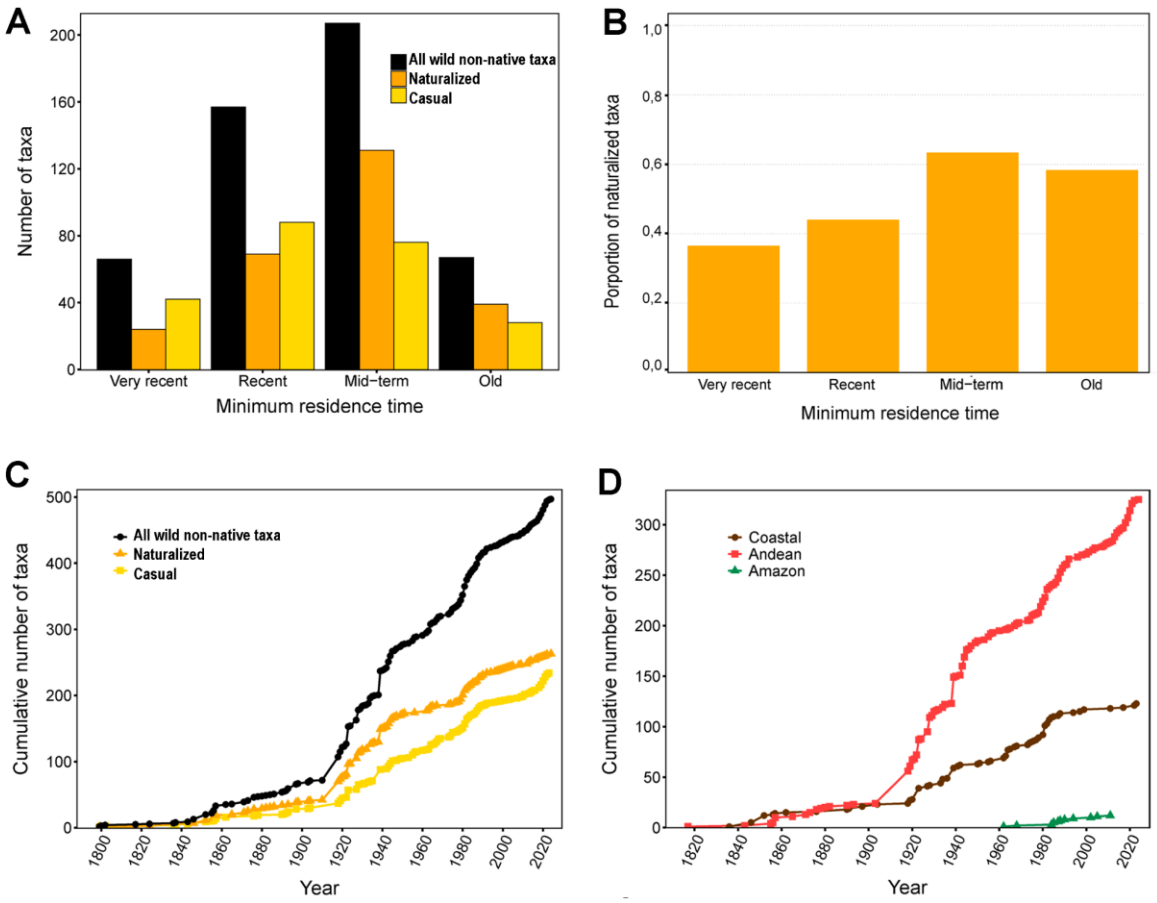

Figure 7. Accumulation of first records of non-native wild plants in a **A** minimum residence time for all taxa recorded in continental Ecuador categorized as old (<1900), mid-term (1900–1949), recent (1950–1999), and very recent (>1999); **B** proportion of naturalized taxa by each category in continental Ecuador, and accumulation curves of first records in the wild for **C** continental Ecuador; and the **D** Coastal, Andean, and Amazon regions.

Local uses

We recorded local uses for 392 (ca. 80%) wild taxa in continental Ecuador. The most frequent uses of these taxa were ornamental (205 taxa, 41%) and medicinal (191 taxa, 39%). Fewer than 40% of the useful taxa were employed as food crops, for ancestral purposes, as animal food, or in forestry (Suppl. material: Table S2). When the casual and naturalized taxa were considered separately, the main uses were also ornamental (205 taxa; casual: 25% and naturalized: 20%) and medicinal (191 taxa; casual: 20% and naturalized 21%) (Suppl. material: Table S2).

Casual vs. naturalized

We did not detect significant effects of any geographic origin on the proportions of casual and naturalized taxa in the logistic regression model (data not shown). There were also no statistical differences in lifespan between casual and naturalized taxa (χ^2 = 0.59, df = 1, P = 0.44) (Table 1; Fig. 6A). In contrast, statistical differences were detected between casual and naturalized taxa with respect to life form, as herbs were over-represented in naturalized taxa (χ^2 = 12.79, df = 5, P = 0.03) (Table 1; Fig. 6C). When the life form was simplified to only two categories, herbaceous and non-herbaceous, we also found significant differences (χ^2 = 6.42, df = 1, P = 0.01; Table 1); naturalized herbs were significantly ($P < 0.05$) over-represented compared to casual herbs; in contrast, casual non-herbs (shrubs, trees, and vines) were significantly over-represented.

Table 1. Frequency of attributes of non-native flora in continental Ecuador: differences between casual and naturalized taxa. Values of Pearson's chi-squared statistic, P value and degrees of freedom (df) are shown.

Attribute	**Frequency**			**Pearson's Chi-squared**		
	Casual	**Naturalized**	**Total**	χ^2	***P value***	**df**
Lifespan				0.59	0.44	1
Annual or biennial	75	94	132			
Perennial	159	169	254			

Life form (all categories)				12.79	0.03	5
Aquatic Herb	2	3	5			
Herb†	143	189	332			
Shrub	34	24	58			
Succulent	7	15	22			
Tree	25	16	41			
Vine	23	16	39			
Life form (simplified categories)				6.42	0.01	1
Herbs†	145	192	337			
Non-herbs‡	89	71	160			
Residence time				22.01	0.00006	3
Old	28	39	67			
Mid-term†	76	131	207			
Recent‡	88	69	157			
Very Recent‡	42	24	66			
Uses				2.48	0.12	1
Yes	177	215	392			
No	57	48	105			

†Standardized residuals when naturalized taxa were over-represented
‡Standardized residuals when casual taxa were over-represented

Broadly speaking, the proportion of naturalized taxa tended to increase with residence time (Fig. 5d). There was a non-random distribution of categories of residence time (χ^2 = 22.01, df = 3, P < 0.001; Table 1) among casual and naturalized non-native flora in continental Ecuador. Among the non-native naturalized taxa, those with a mid-term residence time (1900–1949) were significantly over-represented (P < 0.05; Table 1). In contrast, casual taxa were significantly (P < 0.05; Table 1) over-represented in the recent (1950–1999) and very recent residence times (since the 2000s) (Table 1). In taxa with an old residence time, there were no significant differences between the number of naturalized and casual taxa (P > 0.05; Table 1).

There were no statistical differences in local uses reported between casual and naturalized taxa (χ^2 = 2.48, df = 1, P = 0.12). A logistic regression of the status (0, casual; 1, naturalized) with life form, residence time, and local uses as explanatory variables found that only forage use had a significant effect increasing the likelihood of the species being naturalized. Ancestral use also had a large positive effect although it was not significant, probably due to the correlation between ancestral use and residence time (the other significant variable in the regression model).

We used log-linear models to test the assumption of independence of these effects (life form, lifespan, local use, and residence time). Comparison between several log-linear models suggested that the full model (AIC = 431.70) had better support than an independent model (AIC = 449.60). However, the best model included only three variables associated with naturalized status: residence time, life form, and local use (AIC = 430.94; data not shown), suggesting that lifespan did not have a true association with naturalized status when the other three variables are included. The apparent effect of herbs was, nevertheless, not significant in the log-linear model, suggesting a frequency effect (more herbs than other life forms in the list) rather than a real relationship. In contrast, local use and residence time were both significantly associated with naturalization status: the fact that a species had a recorded use in continental Ecuador was significantly linked to its naturalization status and similarly, the frequency of naturalization increased linearly with residence time categories (very recent < recent < mid-term < old).

Multiple correspondence analysis

The correspondence analysis (CA) including life form, geographic origin, and local uses grouped by natural regions is shown in Suppl. material: Fig. S2. The association between these variables explained 88.92% of the total variance. The first dimension explained the vast majority (82.6%) of the total variance, separating the first group formed by the highland Andean natural regions (Andean Shrub, Eastern Montane, Western Montane and Páramo) from the second group made up of the Amazonian natural regions (Amazon and Eastern Foothill), Coastal natural regions (Dry Shrub, Deciduous Forest, and Chocó Tropical Rainforest) and one Andean natural region (Western Foothill). The CA showed that the non-native wild taxa occurring in the highland Andean natural regions (Suppl. material: Fig. S2)

were frequently (1) herbs or succulents, (2) came from Africa, Asia-Temperate, or Europe and (3) had forage, fuel, medicinal, ornamental, or toxic uses.

The CA including life form, geographic origin, invasion status (casual and naturalized), local uses, and natural regions grouped by residence time explained 63.39% of the total variance (Suppl. material: Fig. S3). The first dimension of the CA explained 40.6% of this variance, separating the taxa with recent residence time (≤74 years) and casual status from those with the oldest residence time (≥75 years) and naturalized status. Additionally, we detected that casual status was more closely associated with ornamental use, alimentary use, and unknown use than with the other uses, which were more linked to naturalized status (Suppl. material: Fig. S3). The second dimension explained 22.2% of the total variance. The two dimensions of the CA defined four groups. First, taxa with a residence time from 25 to 74 years were frequently shrubs or trees with casual status, coming from the Pacific Islands or Australasia, present in the Amazon, and locally used as food. Second, taxa with a residence time of less than 25 years were frequently herbs or succulents, coming from Africa, Asia-Temperate, or Asia-Tropical, present in the Andean Shrub, and used locally as ornamentals. Third, taxa with a residence time greater than 175 years were frequently vines native to North and/or South America, present in Dry Shrub, Deciduous Forest, Chocó Tropical Rainforest, Eastern or Western Foothill, and locally used as fuel, toxic, or forage plants. Fourth, taxa with a residence time from 75 to 124 years were frequently naturalized, native to Europe, present in Eastern Montane and/or Páramo, and used for medicinal, industrial, forestry, and/or ancestral purposes.

Discussion

Amount of non-native plants in Ecuador: Why are there so few non-native wild plant taxa in Ecuador and in other megadiverse Neotropical countries?

Our updated catalogue of non-native plants (1,271 taxa, with 770 occurring exclusively as cultivated plants, 497 taxa with populations in the wild, and four taxa with an unknown status) in continental Ecuador doubles the number of taxa previously reported in the Catalogue of the Vascular Plants of Ecuador (595 taxa, 346 as cultivated and 249 as wild; Jørgensen and León-Yánez 1999) and the GRIIS checklist (577 taxa without distinguishing between cultivated and wild species; Herrera et al. 2021). Herein we are reporting the

presence of 497 non-native plant taxa that grow spontaneously and represent 2.7% of the flora of Ecuador, considering that the native flora of continental Ecuador comprises approximately 18,600 taxa (Zapata et al. 2017). This percentage is much lower compared with other regions, particularly from the Northern Hemisphere; for example, 17.8% in Italy (Galasso et al. 2024), 21.6% in Norway (Sandvik et al. 2019), or 37.7% in Czech Republic (Pyšek et al. 2022). Nonetheless, the rate of Ecuadorian non-native/native taxa reported in this study is not much smaller than those reported in other countries of tropical America (including the regional megadiverse countries), such as the Caatinga area of Brazil (4.6% in an area of 800,000 km^2; Almeida et al. 2015), Colombia (1.7%; recalculated from raw data of Bernal et al. 2016), Mexico (5.5%; obtained through the most recent non-native flora of the country [Ramírez-Albores and Badano 2021], the total flora as recorded in *efloraMEX* [https://efloramex.ib.unam.mx/]), and Central America (7.5%; Rojas-Sandoval et al. 2023). Notably, this pattern is congruent with the hypothesis of biotic resistance to non-native species in species-rich communities, particularly those of tropical latitudes (Rejmánek 1996; Teo et al. 2003; Mungi et al. 2021). Nevertheless, the biotic resistance hypothesis has been considered controversial and dependent on the spatial scale (Peng et al. 2019), and current reviews indicate that the differences between tropical and temperate regions regarding their invasibility, though existing, are weak (Chong et al. 2021). Thus, other factors could also be responsible for the low percentages of non-native flora, and these may include (1) the much shorter tradition of floristic research on non-native plants; (2) a lower gross domestic product (GDP); and (3) the much higher parts of these countries being lands managed and/or controlled by indigenous peoples.

The scarcity of studies focused on the non-native flora is common across the Neotropics (several countries only have preliminary checklists; e.g., the megadiverse countries of Peru and Venezuela, but also Bolivia and Paraguay; Speziale et al. 2012), and it may stem from two factors: (1) the generalized low investment in R&D, which is fully translated into a much better knowledge of plant diversity (Amano and Sutherland 2013; Meyer et al. 2016); and (2) the lack of interest by the local scientific community in non-native plant species (Pauchard et al. 2004).

Economic development—in terms of GDP—is a key driver of biological invasions, as it increases the probability of non-native species introduction and establishment through disturbances and trade (Hulme 2009; Pyšek et al. 2010; Amano et al. 2016; Rojas-Sandoval et

al. 2020). Like other megadiverse Neotropical countries, Ecuador has a low per capita GDP (6,533 USD for 2023, below the world mean of 13,138 USD; World Bank Group 2024a) and only joined global trade networks after the late 19th century, primarily via cocoa exports (Acosta 2006; Reyna Pérez 2023). Moreover, maps of land use over the past 12,000 years (the Anthromes 12K DGG; https://anthroecology.org/anthromes/12kdggv1/maps/ge/; Ellis et al. 2021) shows that most of Ecuador remained partially unaltered by humans until 1930s, a trend also shared for most megadiverse Neotropical countries.

Vast parts of Ecuador (nearly 30%) are indigenous peoples' lands (IPLs) (Garnett et al. 2018), which would partly explain the comparatively low percentage of non-native plant species (particularly in the Amazonian areas). Globally, IPLs host up to 30% fewer non-native species than other lands (Seebens et al. 2024). The same rationale would also apply to the other Neotropical countries, as they also show sizable percentages of ILPs (14% in Brazil, 28% in Colombia, 15% in Mexico, 29% in Peru, and 50% in Venezuela; Garnett et al. 2018). In addition, indigenous peoples are generally aware of invasive non-native species in their lands, and even have active policies of control and response although this is generally unrecognized (Ens et al. 2015; Reo et al. 2017). In Ecuador, this "indigenous protection" of the native flora may be shifting. A recent study revealed that nearly half of the medicinal plants sold in Andean and Amazonian markets are non-native (Rivero-Guerra 2021) in contrast to former studies indicating a very low use of non-native plants (Dávila et al. 2016; Hart-Fredeluces et al. 2017).

Although Ecuador hosts relatively few non-native plants for its rich flora, we should be aware that large parts of the country remain largely unexplored in terms of non-native plants, such as many coastal areas and, particularly, the Amazonian rainforest (Zenni et al. 2022). Thus, one would expect large increases in the Ecuadorian catalog of non-native plants—and in the catalogues of the other megadiverse Neotropical countries except Mexico, as all of them have large portions in the Amazonian rainforest—once extensive new fieldwork is completed. In contrast, countries with a long tradition of studying non-native floras, like the Czech Republic, show slower increases, with non-native taxa rising only 14.4% in 20 years (from 1,378 plant taxa in 2002 to 1,576 in 2022; Pyšek et al. 2022).

Not all the substantial rises in the number of non-native plant species in countries with limited baseline data are attributable to increased fieldwork. For example, in China, another megadiverse country, non-native species more than tripled in 12 years (from 420 in 2010 to

1375 in 2022; Wu et al. 2010; Lin et al. 2022), likely due to an “invasion debt” (Essl et al. 2011) accumulated during decades of rapid economic growth since 1978 (with mean yearly GDP growth rates of about 10%; World Bank Group 2024b). Similarly, Ecuador, despite its lower per capita GDP, experienced significant economic growth (averaging ~4% GDP growth from 2000–2019; World Bank Group 2024b), driving infrastructure expansion (e.g., roads, ports, airports; Anonymous 2016). Therefore, considerable increases in the number of both introduced and established non-native plants can be anticipated, which should not discourage Ecuadorian authorities from implementing policies of prevention, eradication, and containment/control.

Patterns of non-native flora in Ecuador

Nearly half of the non-native plant taxa detected have been recorded exclusively as casual (47%). This high percentage of casual plants, though similar to or even higher than those reported for other Neotropical countries (e.g., 32% for Central America [Rojas-Sandoval et al. 2023]; 19.8% for the megadiverse Mexico [Villaseñor and Espinosa-García 2004]), is much lower than those reported for countries with a high tradition of documenting their non-native plants (e.g., Belgium [74.6%; Verloove et al. 2004] or the Czech Republic [68.8%; Pyšek et al. 2022]). In the latter countries, extensive fieldwork has been carried out by the authors of their non-native flora catalogues, often consisting of repeated inventories over time. In Ecuador and in many other Neotropical countries, however, checklists often rely exclusively on revision of the existing literature, with very little *ad hoc* fieldwork; in such circumstances, casual taxa, which are more likely to have fewer occurrences and lower population sizes—and, importantly, survive only temporarily in the new region—can easily go unnoticed.

The top three families of non-native taxa in Ecuador—Poaceae, Asteraceae, and Fabaceae—align with global trends (Pyšek 1998) and findings in other parts of the Neotropics, including the megadiverse countries [Mexico (Ramírez-Albores and Badano 2021), Brazil (taking into account only naturalized plants; Zenni 2015), and Central America (Rojas-Sandoval et al. 2023)]. Surprisingly, the genus *Kalanchoe* (Crassulaceae) has the highest number of non-native taxa in continental Ecuador (nine out of a total of 497), which is likely an artifact because it was recently reviewed at the national scale(Vargas et al. 2022). In the recently published study of the non-native flora of Central America, the genus *Kalanchoe* has an even

lower number of representatives (eight) among a much larger non-native flora (1228 taxa; Rojas-Sandoval et al. 2023).

In continental Ecuador, most non-native plant taxa originate from the Old World, particularly temperate and tropical Asia and Africa, which account for nearly two-thirds of the 497 recorded taxa.These results are strikingly almost identical to those reported for the non-native flora of Central America (Rojas-Sandoval et al. 2023) but also similar to other megadiverse Neotropical countries; Asia and Africa are the main sources of both the non-native flora of Mexico (46%; calculated from raw data of Ramírez-Albores and Badano (2021) and the invasive non-native plant taxa of Brazil (about 65%; Zenni 2014). The prevalence of African and Asian taxa reflects climatic similarities with Ecuador's tropical and subtropical climates, a key factor in non-native plant establishment (Feng et al. 2016; Fristoe et al. 2023). Climate similarity would also explain why the European species are not predominant in Ecuador despite the early exchange of flora with Europe during the colonial period, which is also the norm with the other Neotropical areas for which we have data (Central America and the megadiverse Brazil and Mexico). Only in the Ecuadorian Andes does the European flora exhibit a notable presence (Fig. 5c), likely due to climatic similarities between the Andes and certain regions of Europe (they share the temperate climate Cfb of the Köppen-Geiger climate classification; https://koppen.earth/).

The lack of archaeophytes in the present catalogue can be attributed to the inexistence of written records prior to the Spanish colonization in the 16th century, a common issue in Neotropical countries. In Mexico, for example, the first documented introductions, despite being about three centuries older than that of Ecuador (Ramírez-Albores and Badano 2021), were also linked to the Spanish conquerors. Though generally a minor component of the non-native floras of the world, archaeophytes can still be a sizeable component of them; e.g., in the Czech Republic archaeophytes represent about one quarter of the total non-native flora (Pyšek et al. 2022). Adopting a conservative approach, herein we classified all the species as neophytes based on documentary evidence, although some of them could actually be archaeophytes. For example, *Agave americana* L. could have been present in the country much earlier than the European conquest (de la Torre et al. 2018), while *Opuntia ficus-indica* (L.) Mill. could have reached Ecuador at any time during the ca. 3000 years of pre-Columbian history of exchanges with Mesoamerican cultures (Ervin 2012). Most of the non-native species, however, reached Ecuador in recent times, with exponential increases around

1910–1920. These years were key for the arrival of goods to the country but also for their introduction inland. The Guayaquil–Quito railway was completed in 1908, which brought sweeping economic and social transformations and contributed decisively to national integration (Esvertit Cobes 2015). It is widely acknowledged that railways contribute to the diffusion of non-native plants from the entry ports (Ascensão and Capinha 2017). The opening of the Panama Canal in 1914 boosted the international maritime trade of Ecuador, which peaked in the period 1919–1920 (Acosta 2006).

Our survey shows the Andes as the richest of Ecuador's three bioregions, with over 90% of detected taxa . This probably explains why temperate Asia is a more prolific donor of non-native plants for continental Ecuador as a whole than tropical Asia, when one would expect the reverse (as the whole Amazonian and over three-quarters of the Coastal region have tropical climates in any of their variants, i.e., climates Af, Am, or Aw; https://koppen.earth/). The reasons for the concentration of non-native plants in the Andes could be various, and include historic, environmental, and climatic factors, among others. The arrival of the railway to Quito (located in the Andes) in 1908 not only likely favored the spread of non-native species in the Andes, but also boosted the trade and economy of the city (Miño Grijalva 2018), thus contributing to habitat disturbance (one of the main drivers of invasions; IPBES 2023). The Andean Shrub (with 375 of the total 497 non-native taxa), which dominates the Interandean valleys and is today the most populated area in Ecuador, is among the most human-degraded landscapes of Ecuador (Sarmiento and Frolich 2002). Accordingly, the Andes' species accumulation curve has grown exponentially since the 1910s, outpacing slower increases in the Coastal and Amazonian regions. In addition, the Andes' high diversity of regional climates and its rugged terrain create microclimates that support species with varying climate needs, from arid (e.g., *Aloe vera*, *Cotyledon orbiculata*) to wet tropical (*Colocasia esculenta*, *Musa velutina*). Finally, a sample bias may also have a role, as it is well known that mountains have attracted the attention of botanists and naturalists for centuries, including Alexander von Humboldt and Aimé Bonpland who centered their stay in the Andes of Ecuador in 1802 (Romoleroux 2010).

The non-native flora of continental Ecuador is dominated by herbaceous species, particularly by annual/biennial plants. Some studies support the hypothesis that herbaceous species exhibit greater invasiveness than other growth forms (e.g., Omer et al. 2021; Borokini et al. 2023; Sohrabi et al. 2023). This is attributed to their ability to quickly colonize disturbed

habitats through rapid and abundant seed production (Baker 1965; Schippers et al. 2001) and their relatively short generation time, which allows them to adapt more swiftly to novel ecological conditions (Compagnoni et al. 2021). Although herbaceous species were overrepresented among naturalized taxa compared to casual species in Ecuador, our log-linear models showed no significant association between life form and casual/naturalized status. In our study, this overrepresentation appears to be an artifact caused by the much larger number of non-native herbaceous species relative to other growth forms.

Naturalized plants in continental Ecuador are significantly associated with longer residence times compared to casual taxa, which aligns with global trends (Milbau and Stout 2008; Pyšek et al. 2009; Rojas-Sandoval and Acevedo-Rodríguez 2015; Schmidt et al. 2017; Gioria et al. 2023). Extended residence times increase propagule accumulation, enhancing the likelihood of population establishment and range expansion (Pyšek et al. 2009). Additionally, evolutionary adaptations to local conditions—often requiring many generations—can improve a species' competitive advantage over native species (Ahern et al. 2010), thus promoting naturalization. Longer residence times also tend to enhance local dominance, as positive feedback between aboveground populations and seed banks strengthens persistence and spread (Aldorfová et al. 2020). Naturalized status is also significantly linked to whether a non-native plant species has any recorded local use in Ecuador. Globally, species cultivated for economic purposes are 18 times more likely to naturalize, especially those used for animal feed or as ornamentals (van Kleunen et al. 2020). Economic plants experience higher propagule pressure due to repeated introductions and secondary releases via cultivation (Guo et al. 2024; Kowarik 2003). In fact, our results suggest that species without a known use are often casual.

Our findings suggest that species with longer residence times often have more uses, as reported in South Africa (van Kleunen et al. 2020; Yessoufou et al. 2022). These studies show a correlation between introduction time and medicinal uses, which in turn are positively associated with the total number of uses. In other words, the longer a given plant has been around, the more uses can be expected to be discovered by the local community (medicinal but also food, construction materials, etc.). However, in Ecuador, multivariate analyses indicate that not all uses correspond to the same residence time; for instance, ornamental species often have shorter residence times, a trend also observed in eastern Spain (Gómez-Bellver 2023) and the Caribbean (Rojas-Sandoval and Ackerman 2021). Such a pattern is

probably caused by changes in uses of introduced plants through time; more contemporary activities such as urbanization and tourism have driven the introduction of many ornamental plants (Rojas-Sandoval and Ackerman 2021).

Lessons learned from cataloguing the non-native flora of continental Ecuador: a way forward for other megadiverse countries

The non-native flora of continental Ecuador is sharing with other parts of the Neotropics, including some of this region's megadiverse countries, a series of traits: (1) a lower percentage with respect the total flora (i.e., native plus non-native plants) compared to other latitudes, particularly Europe; (2) a lower percentage of casual plants relative to the naturalized ones compared to Europe; (3) the predominance of Asia and Africa as the main origin of the non-native species; (4) a total lack of archaeophytes, and (5) significant geographical biases (which mainly correspond to the remote Amazonian areas). Most of these traits respond to a series of historical (e.g. a past colonial occupation) but especially socioeconomic factors, including low GDP, low investment in R&D, and large indigenous populations.

Traits (1), (2), and (3) can be clearly linked to two factors that will hardly change in the short-term (low GDP and low investment in R&D), given the region's endemic political instability. The low average R&D spending in Latin America (only 0.7% of GDP)—well below the average 2.3% for Organization for Economic Cooperation and Development (OECD) countries (Dobrzanski, 2020) leaves us no choice but to increase efficiency in investment and be as much innovative as possible in research aims and tasks. In Ecuador we decided to compile the present catalogue because, although incomplete, helped us to reach a series of goals: (1) bringing the issue to light. Global surveys indicate that the megadiverse Neotropics is one of the areas with less capacities to prevent and manage species invasions, as a result of a combination of factors such as lack of awareness, lack of cataloguing efforts, or insufficient border controls, among others (Early et al. 2016). This step is crucial, as in these countries large amounts of alien species remain to be introduced while they are centres of native species richness; in this sense, we urge to produce comprehensive lists of alien species in the megadiverse countries that still lack them or to complete the existing ones; (2) uncover the spatial (or other gaps such as the underrepresentation of casual taxa) in the catalogue presented herein. As mentioned above, key priorities include expanding fieldwork in

underexplored regions, such as the Coastal but particularly the Amazonian areas—a requirement also applicable to the remaining four megadiverse countries of South America, and addressing the lack of floristic surveys in urban and peri-urban centers such as Guayaquil. To achieve this, several citizen science (CZ) initiatives can be employed, which have the advantage that does not need governmental funding (or too small) but allows to carry out fieldwork that otherwise would not be possible (López-Guillén et al. 2024). Detecting and inventorying the non-native species through CZ-experiences has already proven their effectiveness in several areas of the world (e.g. Compagnone et al. 2024; González-Moreno et al. 2024; Pocock et al. 2024) and, if correctly trained and supervised by professionals (Aceves-Bueno et al. 2017; López-Guillén et al. 2024), would play a crucial role in surveying the most unexplored areas by the local people. In Ecuador, iNaturalist projects to survey local flora are showing some promising results, with some projects being implemented since late 2010s (e.g. Biodiversidad Mitad del Mundo by UEMM, with high school students that survey the flora and fauna of an area located northern of Quito; https://ecuador.inaturalist.org/projects/biodiversidad-mitad-del-mundo-uemm); (3) determining which of the naturalized plant taxa should be prioritized in terms of management. The selection of the most impactful species in continental Ecuador is already underway (and it will be published soon in a separate paper), and is a critical step for policy development. Having official (i.e., government-issued) lists of banned invasive species—which should be ideally based on scientific catalogues—is a prerequisite to prevent their introduction and to regulate their management (Early et al. 2016) and, unfortunately, there are lacking from most of the megadiverse Neotropical countries, including Ecuador (Zenni et al. 2022). In addition, having complete catalogues for each of the countries in a given region (the Neotropics for the present case) allows to implement much comprehensive prevention policies; plants that are still not present into a given country but which are already invading a neighboring country could be placed in a “watch” list or a list of “potentially invasive species”, a policy that for example is mandatory in the European Union countries (Genovesi & Shine, 2011).

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Conceptualization: IH, VL, JL-P. Data curation: IH, AV, KR, ID, BE-A, KP, IV, JL-P. Formal analysis: AV, KR, JRF-P. Funding acquisition: IH, VL, JL-P. Investigation: All authors. Methodology: IH, AV, JRF-P, JL-P. Project administration: IH, AV, VL. Writing - original draft: IH, AV, JL-P. Writing - review and editing: All authors.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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