Management of Biological Invasions (2021) Volume 12, Issue 4: 828–845

Research Article

Alien species as counterpart of a megadiverse country as Mexico

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Citation: Ramírez-Albores JE, Badano EI (2021) Alien species as counterpart of a megadiverse country as Mexico. *Management of Biological Invasions* 12(4): 828–845, https://doi.org/10.3391/mbi.2021.12.4.04

Received: 2 September 2020
Accepted: 21 May 2021
Published: 20 September 2021

Handling editor: Anna Gazda
Thematic editor: Catherine Jarnevich

Abstract

Improving the knowledge on the distribution and impacts of alien species in poorly studied regions is essential to raise national awareness as well as support effective management policies. Here we present a systematic review of the current state of knowledge regarding biological invasions in Mexico, providing a list of alien plant and animal species that can be considered either alien or invasive. Our search in scientific literature comprised a total of 2664 alien species recorded in Mexico, where approximately 36.2% of alien species were considered invasive, a much higher figure than previous estimates. Most alien species were introduced from the Europe, Asia, and Africa, primarily for ornamental use, food, or livestock fodder. The current data demonstrate that alien and invasive species continue to enter and spread within Mexico, and it also emphasizes the necessity and responsibility to develop scientific strategies to minimize the impact of biological invasions and to raise public awareness of the problem. This review will help fill some gaps in the knowledge about biological invasions in Mexico, where the list of species can serve as a scientific basis for future studies.

Key words: biological invasions, developing country, exotic, non-native, pathways

Introduction

The deliberate or accidental transport of species to new regions by humans has increased dramatically after the first half of the 20th century due to the increased commercial exchange across the world (Seebens et al. 2017). Since the publication of the Charles Elton's book *The Ecology of Invasions by Animals and Plants* (1958) there were an increasing effort in ecological science to determine what makes some species better invaders than others (Rejmanek and Richardson 1996; Heenan et al. 1998; Callaway and Aschehoug 2000; Pyšek and Richardson 2006). This is because determining what organisms can switch their population dynamics from naturalized species, with small and localized populations, to invasive species that aggressively colonize new sites provides valuable information to counter their potential detrimental effects on biodiversity and economic activities (Heenan et al. 1998; Richardson et al. 2000; Pyšek and Richardson 2006).

Thus, a current challenge for most countries is to assess how many alien species they harbour within their political limits, as well as to determine which species are naturalized and have the potential to become invasive. This is a key issue for megadiverse countries, which cover less than 10% of the surface of the planet but contain up to 70% of the Earth's biota (Mittermeier et al. 1997; Challenger 1998), because biological invasions can significantly threaten the environmental goods that such high biodiversity provides (Vitousek 1990; Charles and Dukes 2007; Vilà and Hulme 2017). In developed megadiverse countries, such as the United States of America, biological invasions currently constitute the major threat for biodiversity after land use change (Seebens et al. 2015, Lenzner et al. 2020). Nevertheless, little is yet known about the impacts of biological invasions in megadiverse countries with emergent economies (Ding et al. 2008).

Mexico is a megadiverse country (Challenger 1998). Recent estimates indicate that Mexico harbours 10–12% of the world's biodiversity (not including microbes), while it also contains the largest diversity of ecosystems in the world (Sarukhán et al. 2009; Martínez-Meyer et al. 2014). Nevertheless, many alien species have been introduced for different purposes, including to produce food and medicines, to ornamental uses and recreational hunting. The Mexican government distinguishes between alien species and invasive alien species with the latter defined as those that can cause diverse impacts on biodiversity (ecosystem, species, and genes), ecosystem services and damage to human health or the economy (Comité Asesor Nacional sobre Especies Invasoras 2010). By 2020, the National Commission for the Knowledge and Use of Biodiversity indicated that Mexico harbours more than 1300 alien species that are considered to pose a high risk to biodiversity and economic activities (see details at https://www.biodiversidad.gob.mx/invasoras). However, only 348 of these alien species are currently classified as invasive aliens in national policy documents, while the remaining species are considered only as naturalized because there is no information about their population dynamics or impacts in Mexico (National Commission for the Knowledge and Use of Biodiversity of Mexico 2020). Despite the efforts of governmental agencies, information regarding the number of alien species in Mexico is still incomplete because most studies on alien species have been focused on those organisms with detrimental effects on productive industries (e.g., agriculture and cattle raising), while scientific studies about the population dynamics and spread of alien species across natural ecosystems are still scarce. According to government agencies, an alien organism perforce requires it to have strong effects on native ecosystems or productive industries to be classified as "invasive", but not known whether this requirement is satisfied by most naturalized species that have not been studied to date. Several native species in Mexico have been translocated from their natural habitats to other regions of the country, either for economic purposes (e.g.,

forestry use) or other reasons (e.g., ornamental use), but majority of these organisms are not considered as alien species in their new geographic ranges. Additionally, many globally recognized invasive alien species occurring in Mexico have been considered solely as naturalized species due to a lack of detailed study, because there is no evidence on the impacts of these species.

Improving current knowledge of the distributions of alien species, both naturalized and invasive, in poorly studied regions is essential to raise national awareness as well as support effective management policies (Pyšek et al. 2008, 2017; van Kleunen et al. 2015). Only thoroughly compiled inventories that aim to obtain complete lists of alien species for individual regions, provide a robust basis for analyses of regional levels of invasions and underlying drivers (Pyšek et al. 2018). However, Mexico lacks scientific, systematic, and detailed knowledge of alien species living within its borders and data regarding which of them are invasive. In the absence of detailed knowledge, an alternative is to systematically review both the scientific literature and existing taxonomic databases to derive a baseline for future research. In this sense, this study carried out an extensive review of the current state of knowledge on biological invasions in Mexico, as well as providing a list of species that can be considered alien species (non-invasive alien and invasive alien species). This systematic review will help answer specific questions such as a) how many alien species occur in Mexico, according to scientific literature, b) to which taxonomic groups do they belong, c) where is the biogeographical origin of these species, d) what were the pathway(s) of their introduction and, e) can literature searches provide a complementary means of identifying alien species previously recorded in national and international databases?

Materials and methods

Systematic inventory database search of alien species in Mexico

A list of alien species recorded in Mexico we based on an extensive review of scientific literature from several academic databases were searched to gather the most information possible, considering both indexed and non-indexed publications. The searched databases included Web of Knowledge (Thomson Reuters; available at https://webofknowledge.com/), Scopus (Elsevier; available at https://www.scopus.com/), Current Contents Connect (Thomson Reuters; available at https://clarivate.com/), Biological Abstracts (Thomson Reuters; available at https://clarivate.com/), Zoological Record (Thomson Reuters; available at https://clarivate.com/), the Journal Storage Project-JSTOR (ITHAKA; available at https://www.jstor.org/), Google Scholar (Google; available at https://scholar.google.com/), the Scientific Electronic Library Online (BIREME-OPS-OMS; available at https://scielo.org/) and the Network of Scientific Journals from Latin America and the

Caribbean and from Spain and Portugal (Redalyc-Universidad Autónoma del Estado de México; available at https://www.redalyc.org/), as well as digital databases of theses of academic institutions. In each database, an extensive search of scientific references was performed using combinations of the following keywords: biological invasion OR invasion OR invasive OR invasiveness OR invader OR naturalized OR introduced OR alien OR exotic OR non-native OR feral OR non-indigenous OR pest OR ruderal OR weed in addition to AND Mexico or AND Mexican. Only publications in the research areas as agronomy, biology, biodiversity conservation, ecology, entomology, environmental sciences, fisheries, forestry, marine freshwater sciences, plant sciences and zoology were included (see Ramírez-Albores et al. 2019).

Data was obtained from scientific articles, reviews, books, book chapters, theses, technical brochures and conference proceedings (see Ramírez-Albores et al. 2019), and complemented with international and national databases including: Global Invasive Species Database (GISD 2021), Invasive Species Compendium (CABI 2018), Global Invasive Species Information Network (GISIN 2018), Information System Invasive Species in Mexico (National Commission for the Knowledge and Use of Biodiversity of Mexico 2020, available at https://www.biodiversidad.gob.mx/invasoras), Weeds of Mexico (available at http://www.conabio.gob.mx/malezasdemexico/2inicio/home-malezas-mexico.htm), and other technical and scientific publications made in Mexico (Supplementary material Table S1). The scientific names and synonyms of the species were verified in: a) algae with AlgaeBase (available at https://www.algaebase.org/); b) vascular plants with the Taxonomic Name Resolution Service (available at https://tnrs.iplantcollaborative.org/) and TROPICOS (available at https://www.tropicos.org/); c) mollusks, crustaceans, poriferans and poliquets with World Register of Marine Species (WoRMS, available at http://www.marinespecies.org/aphia.php?p=taxdetails&id=1066); d) birds with IOU World Bird List v.10.1 (available at https://www.worldbirdnames.org/); e) fishes with FishBase (available at https://www.fishbase.in/search.php); and, f) amphibians, mammals and reptiles with Global Biodiversity Information Facility (GBIF, available at https://www.gbif.org/). Alien species (whether naturalized or invasive species) were defined following IUCN recommendations (IUCN 2000): plants or animals that are introduced by man, accidentally or intentionally, outside of their natural geographic range into an area where they are not naturally present. Thus, inclusion criteria were the following: (i) that the species occurred outside its current or historical native distribution (intracountry invasion), in the case that it was native to parts of Mexico, that it occurred in a different region outside its original distribution; (ii) that the species maintained self-perpetuating populations in Mexico, such that species confined to zoos, botanical gardens, nurseries, controlled crops (such as greenhouses) and household pets were not

considered; (iii) we excluded species without scientific support (i.e., without scientific reference or database without affiliations to academic or government institutions); and (iv) we excluded species with literature under review and reports on informal websites, such as personal blogs and webpages without affiliations to academic or government institutions. The Mexican government defines invasive alien species as those that can cause diverse impacts on biodiversity (ecosystem, species, and genes), ecosystem services and damage to human health or the economy (Comité Asesor Nacional sobre Especies Invasoras 2010). Here, we follow this definition, which is closely aligned to that of the IUCN (IUCN 2000).

Alien species were categorized according to a) the taxonomic group used in the literature survey with the exception that microalgae, fungi, viruses, bacteria and helminths were excluded due to too few data; b) geographic origin categorized according to TDGW World Geographical Scheme for Recording Plant Distributions (Brummitt 2001); c) year or period for the documented record of its introduction, providing information on the minimum residence time (Pyšek and Jarošík 2005); and, d) for the pathway of introduction to Mexico, this information comes from scientific literature or databases that allowed the authors to collect this information for some species and for other species this information was inferred from the current use of the species: food resources (e.g., crops, raising animals for food), cattle food (livestock fodder), ornamental (e.g., pets, gardening, urban or rural reforestation), biocontrol (pest or weed control), forestry and substrate stabilization (commercial tree plantations and trees used to reforest degraded areas), recreational (sport hunting and fishing), medical (e.g., ethnobotanical and traditional use), unintentionally (i.e., species that arrived as stowaways by commercial pathways or by accident), other causes (e.g., handcraft, fur trade, scientific research, industrial, etc.), and unknown. To determine differences for biogeographic origin and pathway of introduction of alien species among taxonomic groups, a chi-square test (χ^2) for goodness of fit was made (Zar 1999).

Results

Systematic inventory database search of alien species in Mexico

A total of 2664 alien species (including hybrids and subspecies) were recorded as being in Mexico (see Table S2). From the descriptions of these species in the databases, only 962 species were classified as invasive aliens, the rest of the species can therefore only be considered as non-invasive alien species. Across taxonomic groups, there were 1584 vascular plant species (457 as invasive aliens), 559 invertebrates (247 invasive), 485 vertebrates (241 invasive), and 36 algae (17 invasive) (Figure 1). Our review added 770 more non-invasive alien species and 345 more invasive alien species than formally recorded in the current national database of alien

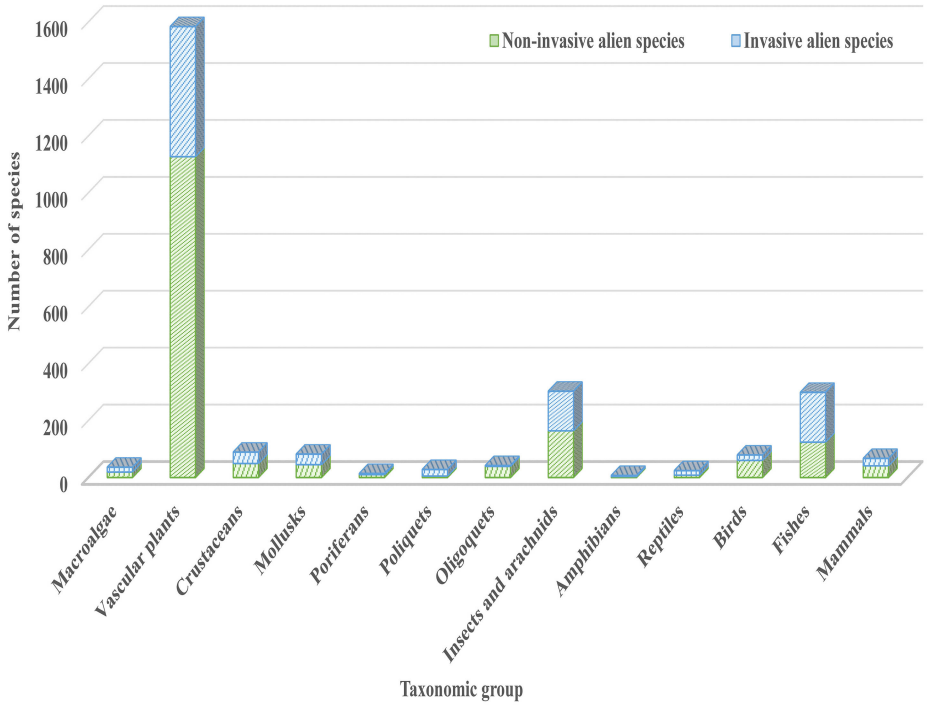

Figure 1. Number of alien species in Mexico by taxonomic group.

species (National Commission for the Knowledge and Use of Biodiversity of Mexico 2020; available at https://www.biodiversidad.gob.mx/invasoras). Of these species, only 620 are native to Mexico, i.e., traslocated species to new Mexican environments different to its natural distribution. Furthermore, for those species that were found in our review as in the national alien database most non-invasive alien species were similarly identified (932 out of 1702 species with same status, Table S2), while the number of invasive alien species were strongly underestimated (409 out of 962 species with same status; Table S2).

For vascular plants, vertebrates, and invertebrates there was significant heterogeneity in the biogeographic origin of non-invasive alien species and invasive alien species ($\chi^2 = 22.3$, df = 10, $p < 0.001$), but patterns were not consistent among taxa (Figure 2). Invasive alien species came disproportionately more often from Africa for vascular plants, from Asia-Temperate and from the Americas for invertebrates and the Americas (including Mexico) for vertebrates (Figure 2). Examples of native Mexican vertebrates naturalized in other parts of Mexico include the great-tailed grackle (*Quiscalus mexicanus*) and rufous-backed thrush (*Turdus rufopalliatus*). The cumulative number of alien species in Mexico over time has shown a consistent increment in all taxonomic groups since 19th century (Figure 3). Despite the temporal differences among taxonomic groups in their first records, slopes of invasion curves for non-invasive alien species did differ among taxonomic groups ($r^2 = 0.3$, $p < 0.001$), suggesting different rates of species accumulations. For the great majority of species (1936) no information was available for the year or period of introduction or first documented record

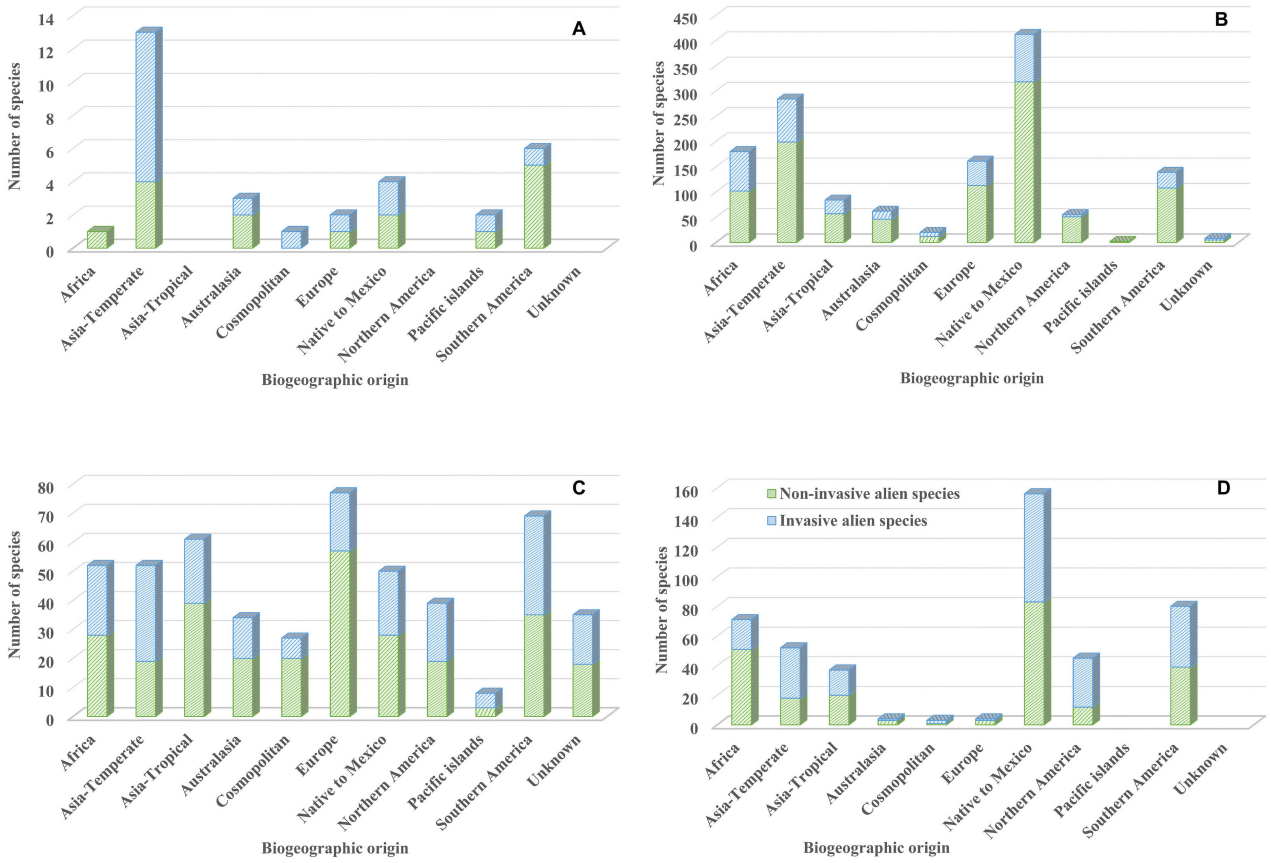

Figure 2. Number of alien species present in Mexico by biogeographic origin. Non-invasive alien species (green bars) and invasive alien species (blue bars) of taxonomic groups: (A) algae, (B) vascular plants ($\chi^2 = 44.6$, df = 10, $p < 0.001$), (C) invertebrates ($\chi^2 = 26.5$, df = 9, $p < 0.001$), and (D) vertebrates ($\chi^2 = 30.8$, df = 8, $p < 0.001$).

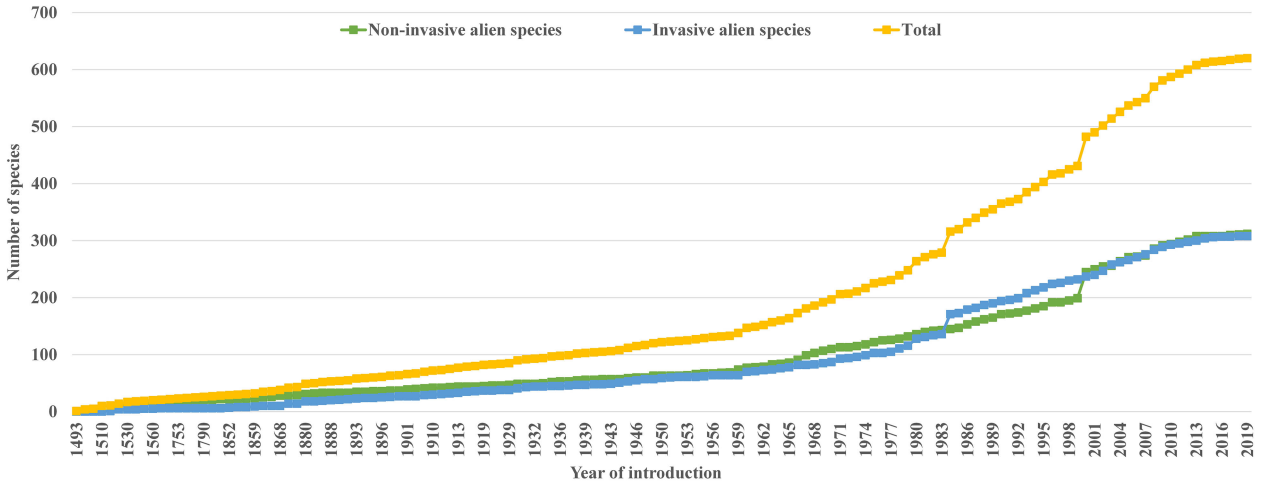

Figure 3. Cumulative numbers of alien species in Mexico. Total alien species (orange lines; $r^2 = 0.3$, $p < 0.001$), non-invasive alien species (green lines; $r^2 = 0.3$, $p < 0.001$) and invasive alien species (blue lines; $r^2 = 0.3$, $p < 0.001$) of taxonomic groups with known year of documented record of its introduction in Mexico (only the species that have their year or period for the documented record of its introduction are documented, n = 620).

in Mexico. Of those species that could be assigned a date, 156 were introduced before 1900, with 423 species found during the period 1900 to 2000, and as many as 147 species having been introduced since 2001 (Figure 3). The main pathway of introduction differed among taxa being primarily ornamental (e.g., garden escapes and plant nursery) for vascular

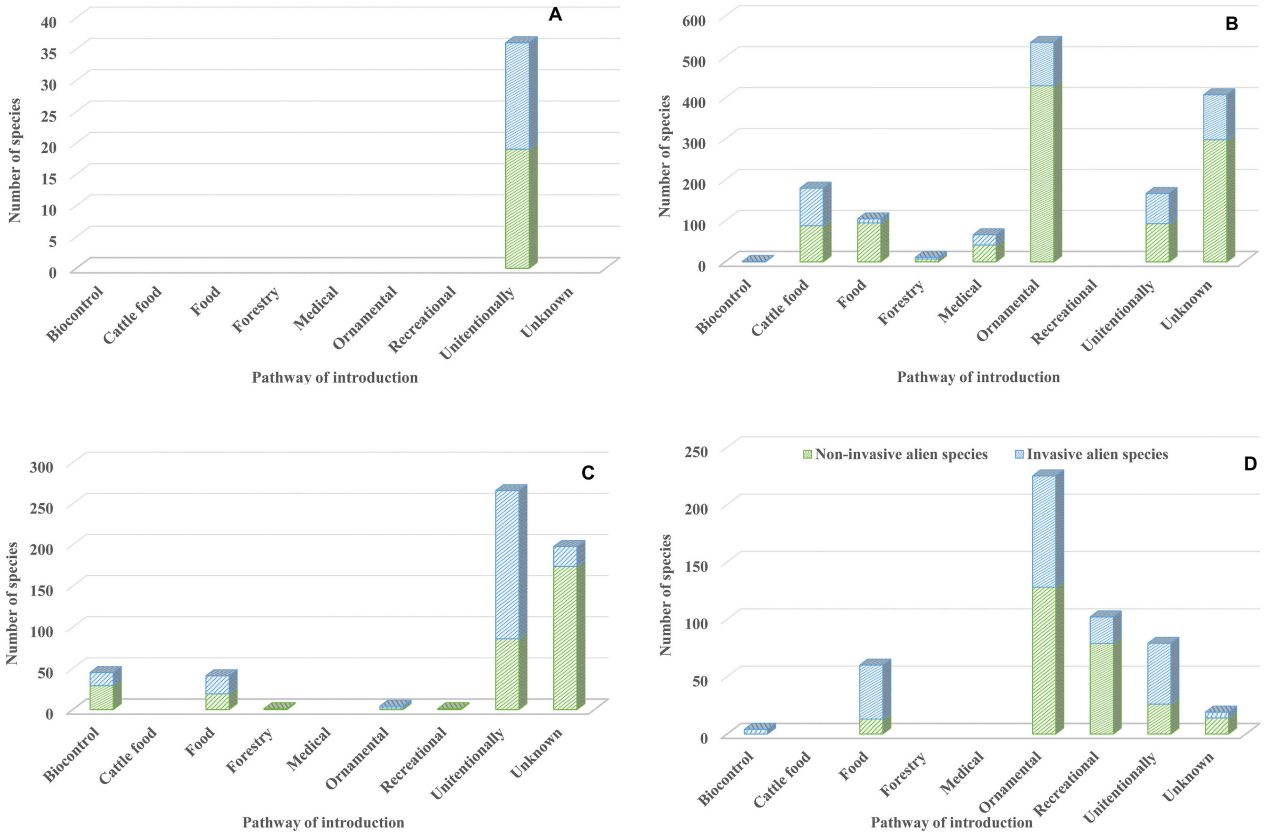

Figure 4. Number of alien species presents in Mexico by pathway of introduction. Non-invasive alien species (green bars) and invasive alien species (blue bars) of taxonomic groups: (A) algae, (B) vascular plants (χ^2 = 115.8, df = 6, p < 0.001), (C) invertebrates (χ^2 = 147.9, df = 5, p < 0.001), and (D) vertebrates (χ^2 = 50.9, df = 5, p < 0.001).

plants, unintentional (contaminants of commodities) for invertebrates and either as ornamental (e.g., pets) or recreational (e.g., game animals) for vertebrates (Figure 4). However, the pathways for non-invasive alien species and invasive alien introductions differed significantly for each taxonomic group (χ^2 = 230.1, df = 9, p < 0.001), with pasture plant introductions being more likely to be invasive, while for both animal group's unintentional introductions and species introduced for food were overrepresented as invasive (Figure 4).

Discussion

Although biological invasions are an intensively studied phenomenon, predictions of ongoing and future invasions are difficult (Williamson 1996; Mack et al. 2000; Kolar and Lodge 2001). This is particularly critical in Mexico because research on these issues has focused primarily on descriptive studies addressing natural history and distribution patterns. Our review of the scientific references on biological invasions in Mexico revealed a total of 1201 alien species was extracted, additional to those already in the current national database of alien species (National Commission for the Knowledge and Use of Biodiversity of Mexico 2020; available at https://www.biodiversidad.gob.mx/invasoras; see Table S2). So, literature-based approach can supplement standard approaches of

collecting alien data (e.g., herbarium/museum), expert knowledge these studies establish an important baseline to consolidate the ecological foundations of biological invasions in Mexico. The scarcity of historical references is likely since the study of biological invasions in Mexico did not attract the interest of ecologists until the late 1990s. During this period, biological invasions began to be recognised by the scientific community and society in general given the increasing rate, scale and magnitude of anthropogenic activities and their effects on ecosystems (Vitousek et al. 1997a, b). Despite the increase in the number of publications on biological invasions in Mexico in the last 20 years may be considered as an emerging discipline, so more knowledge is needed on the impacts of alien species on native biota and ecosystems. Seebens et al. (2015) predicted the highest average imports of naturalized plants by import value for Mexico (15 species per billion US dollars).

For other hand, several authors have made especially important contributions to the knowledge of alien species in Mexico as Villaseñor and Espinosa-García (2004) who made an important contribution to the knowledge of alien plant richness in Mexico, Álvarez-Romero et al. (2008) presented a review of the ecology, distribution, impacts and control of alien vertebrates, and Aguirre-Muñoz et al. (2009) conducted a review of alien species and their impacts on native biota and human activities. Most recently, Espinosa-García and Villaseñor (2017) then briefly reviewed current knowledge of the richness, ecology, distribution, and management of non-native weeds in Mexico and provided some data on their possible environmental and economic impacts, identifying approximately 700 alien species and 229 related references in Mexico; and Born-Schmidt et al. (2017) summarised the main challenges facing Mexico in combating alien species. Lastly, Ramírez-Albores et al. (2019) perform a comprehensive compilation of studies on biological invasion in Mexico, finding a total of 869 references focused mainly on the natural history, geographic distribution patterns and risk analysis of alien species. Additional of this, the National Strategy for the Prevention, Control and Eradication of Invasive Species was established to monitor and control invasive alien species in Mexico (Comité Asesor Nacional sobre Especies Invasoras 2010). This will permit better management and control of introduced species with invasive potential. Although Mexico is one of the four Latin American countries with the greatest scientific productivity in terms of biological invasions (Pauchard et al. 2011, Ramírez-Albores et al. 2019), when compared for similar time periods, the outputs from Mexico are approximately 11.8% of the publications produced in Brazil (Frehse et al. 2016) and 59.8% of the publications produced Chile (Quiroz et al. 2009).

Moreover, although this review resulted in a list of 2664 alien species in Mexico, it is noteworthy that many of them are not recognized officially either as non-invasive alien species or invasive alien species. Nevertheless,

Table 1. Alien species number comparison between American countries, classified by taxonomic group.

Country	Country area (km^2)	Taxonomic group			References
		Vascular plants	Vertebrates	Invertebrates	
Argentina	2,780,400	587	–	–	Fuentes et al. (2010)
Brazil	8,515,767	117	138	–	Rocha et al. (2011); Zenni and Ziller (2011)
Caribbean region	2,754,000	327	172	121	Kairo et al. (2003)
Colombia	1,141,748	597	284	20	Baptiste et al. (2010)
Costa Rica	51,100	1,054	461	–	Chacón-Madrigal (2009); Allen et al. (2017)
Chile	756,102	790	39	145	Fuentes et al. (2013, 2020); Iriarte et al. (2005); Jaksic (1998); PNUD (2017); Silva and Saavedra (2008)
Ecuador	283,561	595	–	–	Jørgensenn and León-Yáñez (1999)
Mexico	1,964,375	1,387	367	568	Present study
Panama	75,420	373	–	–	Lopez (2012)
United States of America	9,147,593	1,540	172	7,312	Cox 1999; Natural Environment Research Council (2013); Pimentel et al. (2000, 2001); Witmer and Fuller (2011); Swearingen and Bargeron (2016); Center for Invasive Species and Ecosystem Health (2017)

their presence may affect native biota and ecosystems or human activities. The number of alien species in Mexico is relatively low in relation to its megadiversity, representing only ~ 2.5% of the species in the country, more than 100 thousand native species (Llorente-Bousquets and Ocegueda 2008). This this situation could be due to latitudinal patterns of non-native species richness suggest fewer successful invasions in the tropics, relative to temperate regions. One main hypothesis for this pattern is that biotic resistance to invasion is stronger in the tropics than at higher latitudes (Freestone et al. 2013; Ackerman et al. 2017; Petruzzella et al. 2020). Biotic resistance can limit the distribution and abundance of non-native species and, in extreme cases, can prevent establishment. However, contrary to this, what we can observe in our country is that many species have been introduced to both tropical and temperate environments, initially subsidized by human activities, and later establishing and colonizing new environments such as the Eurasian collared dove (*Streptopelia decaocto*) and monk parakeet (*Myiopsitta monachus*). Nevertheless, this situation does not seem to be so serious when comparing these values with countries with a largest number of alien species such as the United States of America (Table 1). However, when comparing this with other Latin American countries, the knowledge about the number of alien species is still incomplete or research still scarce (Table 1). When comparing our results with other databases and scientific references (see Table 2), we found significant differences in terms of number of species, since these databases mainly contain high-risk invasive alien species, classified as such due to the strong negative impacts that they cause. These also do not include low-risk species, naturalized species (i.e., species that establishes itself at the new site and reproduces properly or species that have been in our country for many years and that for many people are already part of the natural landscape),

Table 2. Alien species number comparison between different database and scientific references.

	GAVIIA, Dyer et al. (2017)	National Commission for the Knowledge and Use of Biodiversity of Mexico (2020)	Espinosa-García and Villaseñor (2017)	GloNAF, van Kleunen et al. (2019)	GRIIS, González-Martínez et al. (2020)	GISD (2021)	Álvarez-Romero et al. (2008)	This study
Vascular plants		1,044	700	2,376*	1,044	94		1,584
Algae		30			30	4		36 (only Macroalgae)
Crustaceans		65			65			89
Mollusks		65			65	11		82
Poliquets								28
Poriferans						1		14
Oligoquets								42
Insects and arachnids		105			105	23		304
Amphibians		5			5	5	5	8
Reptiles		19			19	7	11	32
Birds	29	14			14	11	29	79
Mammals		18			18	20	60	67
Fishes		67			67			299
Total		1,826	700	2,376*	1,326	250	95	2,664

* Including all plant species in North American region.

and many others that are not considered due to their scarce scientific evidence regarding their interactions with native biota and ecosystem or human activities. Contrary to this, our exhaustive review contemplated all that species that was introduced to a new environment different from where it is native regardless of whether it causes some type of impact and including species native to Mexico that have been translocated to other regions either for eating as pets, ornamental, food and accidentally supporting all the above with scientific evidence. For example, in the case of vascular plants, previous accounts reported many fewer vascular plant species for this country, 642 in total (Villaseñor and Espinosa-García 2004; Williams 2010), but the difference in the number of species is mainly due to these authors did not include many plant species that were native to Mexico and that translocated to new environments different to it natural distribution. This pattern occurs in a similar way with other taxonomic groups. In addition, many of the studies have focused on species such as the Indo-Pacific lionfish (*Pterois volitans*), the monk parakeet (*Myiopsitta monachus*), the armored catfish (*Pterygoplichthys* spp.), buffelgrass (*Pennisetum ciliare*), kalanchoes (*Kalanchoe* spp.), antelope grass (*Echinochloa pyramidalis*), Eurasian collared dove (*Streptopelia decaocto*) and the cactus moth (*Cactoblastis cactorum*) with more than 200 total references (Ramírez-Albores et al. 2019). Therefore, many alien species do not have a specific study that focuses on their natural history in the environment invaded in our country, but they simply appear in a checklist or in an occurrence record (Ramírez-Albores et al. 2019).

As for the significance of this study for the country, it should be noted that it includes all species that have been introduced from another region of the world as well as native species translocated. This is noteworthy

because many of them are not included in the national lists of alien species in Mexico (National Commission for the Knowledge and Use of Biodiversity of Mexico 2020) (see Table S2). This situation may be because these agencies and organizations only include species considered high-risk for native biota and ecosystems and/or socioeconomic human activities. A key area missing from national legislation is the management of movement of species native to Mexico to other regions of the country where they are not native. Discerning such movements requires an understanding of biogeographic discontinuities in species distributions but will be challenging due to the likelihood of a long history of plant and animal movements within Mexico. For example, the great-tailed grackle was likely introduced into the valley of Mexico from Veracruz where is native, by the Aztec Emperor Ahuitzotl in pre-Columbian times (Haemig 1978). The largest number of alien species was introduced were used for the provision of food for humans or animals in Mexico (Challenger 1998), beside plant species for forestry and ornamental use (Challenger 1998; Pacheco 2006). Finally, within this group are also many vertebrate species that have been introduced to Mexico for hunting and fishing (Challenger 1998; Álvarez-Romero et al. 2008). Species introduced unintentionally also constitute an important group (see Table S2), including species that constitute a high-risk to human health, such as the mosquito *Aedes aegypti*, which is a vector of diseases such as dengue, chikungunya and zika or others emerging infectious diseases (e.g., Peterson et al. 2002; Medley 2010; Cunze et al. 2018). Other species have been introduced into Mexico by research institutions related to agriculture, forestry, and aquaculture or as biocontrol agents for pest plant and insect species (see Table S2; e.g., Aguirre-Muñoz et al. 2009; Espinosa-García and Villaseñor 2017). These patterns in introduction pathways seem to reflect a consistent trend in biological invasions worldwide (Hulme et al. 2008; Saul et al. 2017). Finally, of the total of alien species in Mexico, 47 is listed in the "*100 of the World's Worst Invasive Alien Species*" (Lowe et al. 2000; see Table S2), but the lack of scientific studies on the impacts of these species in the invaded environment means that it is difficult to distinguish whether the species should be categorized as naturalized or invasive in Mexico. Therefore, it is necessary to know more about natural history as well as its ecology in particular, its interspecific relationships and its invasive capacity.

Most of the alien species of Mexico have their origin in the Old World (Africa, Asia, and Europe; Villaseñor and Espinosa-García 2004; Pacheco 2006; Álvarez-Romero et al. 2008; Espinosa-García and Villaseñor 2017). The above, agrees with what was mentioned with van Kleunen et al. (2015) over naturalized plant species clearly that shows that Asia-Temperate and Europe are the major donors. Mexico has not established as strong a cultural and commercial link with other regions as it has with Europe and Asia. Undoubtedly, the dominant presence of species from the Old World

has surely to be related to the lengthy colonization of the territory by the Spanish; for more than three centuries, they introduced their crops, cattle food, and technology, together with their weeds. In addition, for a long time the bulk of the commercial exchange was carried on with European countries (Challenger 1998; Pacheco 2006). For example, Di Castri (1989) suggests that the predominance of European plants in the alien floras of the world is due to the higher invasive potential of European weeds; however, they probably succeed because of their repeated introduction during the Spanish colonial activities (Crosby 1986; Heywood 1989). Other possible explanation for the maximum proportion of species from Old World can be the higher propagule pressure from different countries, such as India and China, to via historical trade routes through the human agencies of European colonisers and traders and matching of similar tropical climate (Wu et al. 2010; Xu et al. 2006; Khuroo et al. 2012). Today, in this age of globalization, Mexico serves as a strong export platform to its U.S. neighbor and the world. Mexico is a trading partner with more than 50 countries, with agreements reaching into Europe, South America, and Africa. Just for the period between 2000–2012 the Merchandise Trade US to Mexico grew up in 134%, increasing by a 94% of exports compared to other Latin American countries (Hornbeck 2014). Agronomists in search of new crop and fodder plants (Challenger 1998), and the globalization of markets starting during the past century, released a new upsurge of plant invaders (Driscoll et al. 2014). Our results indicate a proportion of 58% the alien plants were introduced in Mexico by ornamental and agricultural use (see Table S2). This date reflects the intensification of transcontinental transport of commercial goods and livestock, which dramatically increased the number of introduced species around the world.

Despite advances in government agencies and scientific and academic institutions in Mexico to determine which alien species are present in the country and which of them are invasive (i.e., National Strategy on Invasive Species in Mexico; Comité Asesor Nacional sobre Especies Invasoras 2010), this study indicates that the number of introduced species is underestimated, mainly for vascular plants and insects. Our results show that 37% are not included in the national current lists and 12.6% of the species have a different status. Similarly, although measures have been taken to prevent the entry of these species into the country, they remain isolated and specific cases (Aguirre-Muñoz et al. 2009). Finally, the scientific community must intensify actions towards inventorying and monitoring alien species distributions and impact assessments. Careful site-based monitoring is necessary for the early detection and management of newly established populations. This review will help fill instead some gaps in the knowledge about biological invasions in Mexico, where the list of species can serve as a scientific basis for future studies.

Acknowledgements

JERA thanks the doctoral grant CONACyT-169631, the mix-scholarship program CONACyT-290749, and thanks the CONACyT for supporting the postdoctoral stay at the Posgrado de Ciencias Biologicas in the Museo de Zoologia-Facultad de Ciencias-UNAM. We thank A. Gazda, C. Jarnevich and anonimouos reviewers on their useful comments and criticisms to this manuscript.

Funding declaration

This study was supported by Fondo Sectorial de Investigación Ambiental SEMARNAT-CONACYT, project FSSEMARNAT01-C-2018-1-A3-S-80837 to EIB.

Authors's contributions

JERA and EIB Conceived and designed the study; JERA did the data compilation and analyzed the data; JERA and EIB wrote the manuscript. The authors read and approved the final manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. Occurrence of alien species in Mexico: references and links database.
Table S2. Database of alien species present in Mexico.

This material is available as part of online article from:
http://www.reabic.net/journals/mbi/2021/Supplements/MBI_2021_Ramírez-Albores_Badano_SupplementaryMaterial.xlsx