



BIOCYT Biología, Ciencia y Tecnología, 14: 1029-1039, 2021.  
<http://revistas.unam.mx/index.php/biocyt>  
DOI: 10.22201/fesi.20072082e.2021.14.79878  
ISSN: 2007-2082 **Research Article**



Publicada en la Facultad de Estudios Superiores Iztacala, Universidad Nacional Autónoma de México

## A SYSTEMATIC REVIEW OF LITERATURE ON INVASIVE ALIEN SPECIES IN MEXICO

### UNA REVISIÓN SISTEMÁTICA DE LITERATURA SOBRE ESPECIES EXÓTICAS INVASORAS EN MÉXICO

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#### ABSTRACT

Invasive alien species (IAS) have been favored by rampant deforestation and degradation of natural habitats. The wide spreading of IAS worldwide has raised international concerns given their negative impact on ecosystems, native species displacement and local population extirpations resulting in loss of biodiversity. IAS have also become a social and economic problem for local and regional public sectors. Therefore, it is urgent to establish policies to help mitigate their negative impact. Here we conducted a systematic review of research on IAS to build a database platform and analyze their current knowledge in Mexico. We compiled the information available from widespread scientific internet search tools over the last 55 years into a database, using keywords related to IAS. It was found that the predominant type of reports were articles on faunistic groups published in peer-reviewed journals. The remaining reports were related to economic costs, social perception, and the legal framework. This is a first step to identify immediate actions, and establish research priorities and management programs nationwide.

**Keywords:** Biodiversity; biological invasion; conservation; fauna; flora; invasive alien species.

**Recibido el 04 de febrero de 2021.**

**Aceptado el 22 de mayo de 2021.**

**Publicado el 07 de julio de 2021.**

## RESUMEN

Las especies exóticas invasoras (EEI) se han visto favorecidas por la deforestación desenfadada y la degradación de los hábitats naturales. La amplia dispersión de las EEI en todo el mundo ha suscitado, preocupaciones internacionales debido a su impacto negativo en los ecosistemas, el desplazamiento de especies nativas y la extirpación de poblaciones nativas que provocan la pérdida de biodiversidad. Las EEI también se han convertido en un problema social y económico para los sectores públicos locales y regionales. Por ello, es urgente establecer políticas que ayuden a mitigar su impacto negativo. Se realizó una revisión sistemática de la investigación sobre EEI, para construir una plataforma de base de datos y analizar su conocimiento actual en México. Se recopiló la información disponible de las herramientas de búsqueda científica generalizadas, en internet, durante los últimos 55 años en una base de datos, utilizando palabras clave relacionadas con EEI. Se encontró que el tipo predominante de informes son artículos sobre grupos faunísticos publicados en revistas revisadas por pares. Los informes restantes se relacionaron con los costos económicos, la percepción social y el marco legal. Este es un primer paso para identificar acciones inmediatas y establecer prioridades de investigación y programas de gestión a nivel nacional.

**Palabras clave:** Biodiversidad; conservación; fauna; flora; invasión biológica; especies exóticas invasoras.

## INTRODUCTION

Invasive alien species (IAS), are defined as an exotic species whose introduction does, or is likely to, cause economic or environmental harm or harm to human health (Executive Order 1999; LGVS, 2018). Once an exotic species is introduced, established and dispersed, it is capable of causing multiple impacts. The impacts are derived from the absence of control measures that the species have naturally in the places where they are native, such as predators or climatic factors. In addition, the behavior and biological and ecological characteristics make them more efficient in the use of resources compared to native species. Impacts can be summarized as biodiversity/ecological, social, health, and economic (CONABIO, 2021a).

The factors usually promoting these impacts are land use change, exploitation, invasive species, climate change and pollution (IPBES, 2021). There are numerous factors that have been shown to facilitate the introduction of IAS into new habitats. For example, globalization of human transport and economic activities have facilitated the dispersal of IAS (Jesse *et al.*, 2017). Rapid changes in climatic conditions and rampant habitat degradation leading to loss of biodiversity also have contributed to the dispersal and establishment of IAS into new habitats (Sax and Brown, 2000; Mack and Lonsdale, 2001; McKinney, 2006; Kowarik, 2011).

Mexico is considered a megadiverse country holding 10% to 12% of the biodiversity worldwide (Jiménez-Sierra *et al.*, 2014). Given the potential threats of IAS on biodiversity and ecosystems degradation, it is a priority to conduct effective prevention, control, mitigation, and eradication programs. A first step is to produce a list of the potential species established as IAS nationwide (Sagoff, 2005). In recent years, there has been an increased interest in biological invasions, addressing different approaches and scopes. Most of the studies have been conducted in the United States, Eastern Europe, Eastern Australia, New Zealand, and Hawaii (Lowry *et al.*, 2013).

In Mexico, research on biological invasions is an emerging discipline that has grown in recent years (Born-Schmidt *et al.*, 2017). However, the scientific production is relatively low when compared to other Latin American countries and worldwide (Ramírez-Albores *et al.*, 2019). Here we conducted a comprehensive and systematic review of research on IAS over the last 55 years, complementing the approach by Ramírez-Albores *et al.* (2019), and analyzed the published information on their knowledge in Mexico. We also discuss research priorities, strategies to develop specific actions to address this problem, and the need to establish long-term monitoring, legislation, and management programs of IAS nationwide.

## MATERIALS AND METHODS

We compiled published information on IAS in Mexico over the last 55 years (1964 to 2019) into a database, based on a search conducted on reports related to flora that included land ferns, aquatic plants and land angiosperms; and fauna that included invertebrates, fishes, amphibians, reptiles, birds and mammals. A list of keywords was used related to IAS, such as **invasive**, **invasive plants**, **biological invasion**, **invasiveness**, **invader**, **naturalized**, **introduced** and **non-native**, including their Spanish translations, adding the word **Mexico** to each of these. The following internet search tools were used: Web of science, Science direct, Scopus, Google scholar, Redalyc, Scielo and Dialnet. In addition, the reports prepared by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO, 2021a, b) within the framework of the National Strategy on Invasive Alien Species were included in this search ([www.biodiversidad.gob.mx/especies/Invasoras](http://www.biodiversidad.gob.mx/especies/Invasoras)). We added and analyzed subsequent references to articles and scientific notes, summaries of conferences and workshops, divulgation material, reports from government institutions and NGOs, academic studies, plans, programs and protocols for prevention, control, and eradication.

The information was grouped by type of publication in:

- a) **Scientific articles.** Included scientific articles and notes, as well as taxonomic lists published in peer-reviewed journals.
- b) **Conferences and workshops.** Included all the information obtained from reports and/or summaries of workshops as well as national and international conferences.
- c) **Divulgation material.** Included species identification catalogues and guides, divulgation articles like books and brochures.
- d) **Technical reports.** Included all documents containing technical biological and ecological evaluations on IAS.
- e) **Plans and protocols.** Included all documents containing action plans and strategies for the mitigation, control and eradication of IAS.
- f) **Thesis.** Included all undergraduate and graduate theses directly related to the IAS.

The information was categorized on broad topics related to IAS:

- a) **Control and eradication.** Contains documents about techniques or strategies for the use, control or eradication, as well as strategies for preventing the entry or establishment of any IAS.
- b) **Analyses of available literature.** Contains reviews and analysis of literature related to IAS.
- c) **Impact generated.** Included reports addressing some type of economic, ecological, or socioeconomic impact caused by IAS.
- d) **Experimental work.** Included all type of experimental studies on IAS.
- e) **Natural history and distribution.** Included studies about geographical distribution and biological characteristics of IAS.
- f) **Restoration.** Included restoration of ecosystems damaged by any IAS.
- g) **Legal framework.** This category including all documents address or propose environmental laws in relation to species.
- h) **Social perception.** Included all studies about knowledge and the opinion's people on IAS conflicts.
- i) **Introduction records.** It included all first records reported for IAS.

The documents that presented more than one category were quantified as many times as necessary, according to the categories in which the topic was classified.

### Data analysis

We used a Spearman correlation coefficient to assess whether there was a relationship between the number studies of flora and fauna over time. A chi-square test was applied to evaluate differences between the number of studies on flora and fauna, and differences between the type of studies conducted on flora and fauna. A Kruskal-Wallis test was performed to determine if there were significant differences between the number of publications categorized in broad topics related to IAS. All tests were determined to be significant with  $p < 0.05$ . All statistical analyzes were performed with the Past software, version 2.17c

(Hammer et al. 2001).

## RESULTS

A total of 1036 reports were obtained on IAS in Mexico, of which 545 were on fauna, 284 were on flora, and 207 involved both groups. We observed an increasing trend of the cumulative number of reports over time. The number of reports were 13 in 2005 and peaked with 178 in 2017, and decreased with 105 in 2019. The publication rate increased correspondingly from 1.25 to 10.14 (Fig. 1). A significant correlation ( $r_s=0.850$ ,  $p<0.05$ ) was found between the number of flora and fauna studies over time. We found 393 scientific articles; 282 were on fauna, 106 on flora, and only five comprised both groups. A second group of documents comprised divulgation reports with 237; 119 records were on fauna, 46 on flora, and 72 on both groups. The group that comprised fewer records were thesis with 38; 23 on fauna, 11 on flora, and four on both groups (Fig. 2). We observed significant differences between the types of studies conducted on fauna and flora ( $\chi^2=38.033$ ;  $d.f. 5$ ;  $p<0.05$ ), between the different types of studies of fauna and both flora and fauna combined ( $\chi^2=202.16$ ;  $d.f. 5$ ;  $p<0.05$ ), and between flora and both flora and fauna combined ( $\chi^2=114.68$ ;  $d.f. 5$ ;  $p<0.05$ ), respectively.

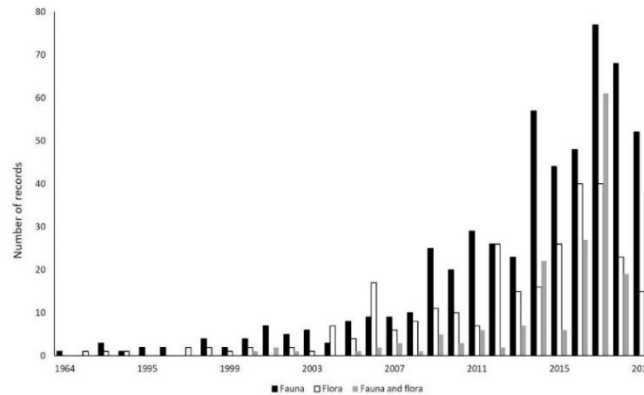


Fig. 1. Number of publications on invasive alien species of fauna (black bars), on flora (white bars), and both groups (grey bars) in Mexico over the last 55 y.

Further, the broad topics of **control and eradication** ranked highest with 510 references, of which 189 were on fauna, 130 on flora, and 191 for both groups. It was followed by **generated impact** with 300 records, of which 166 were on fauna, 65 on flora, and 69 on both groups, and by **introduction records** with 235, of which 159 were on fauna, 46 on flora, and 30 on both groups, respectively (Fig. 3). Regarding the types of publication, we found that technical reports had a higher number of records (161) with control and eradication topic, followed by **scientific articles** with 144 records, with the most frequent topic **introduction records**. The topic **divulgation material** had 134 records on the subject of **generated impact**. Overall, the topic of **control and eradication** ranked highest on different types of records (Fig. 3A). There were significant differences between studies conducted on fauna and flora ( $\chi^2=31.307$ ;  $d.f. 7$ ;  $p<0.05$ ), between fauna and both flora and fauna combined ( $\chi^2=176.43$ ;  $d.f. 7$ ;  $p<0.05$ ), and between flora and both flora and fauna combined ( $\chi^2=96.2$ ;  $d.f. 7$ ;  $p<0.05$ ). Invertebrates ranked top in number of records with 63 in the topic **control and eradication** and ranked second in the topic **introduction records** with 56. Fishes and mammals showed 53 and 43 records, respectively, on the topic **control and eradication**. Fishes had two records in social perception topic (Fig. 3A). On the other hand, land angiosperms showed more records with 97 in the topic **control and eradication**, 52 in **impact generated**, and 41 in **introduction records**. Aquatic plants also showed records although in fewer numbers (Fig. 3B). We observed no significant differences between the type of studies conducted in IAS between faunistic groups ( $H=8.634$ ;  $p=0.124$ ); a significant difference was observed between floristic groups ( $H=7.094$ ;  $p=0.028$ ).

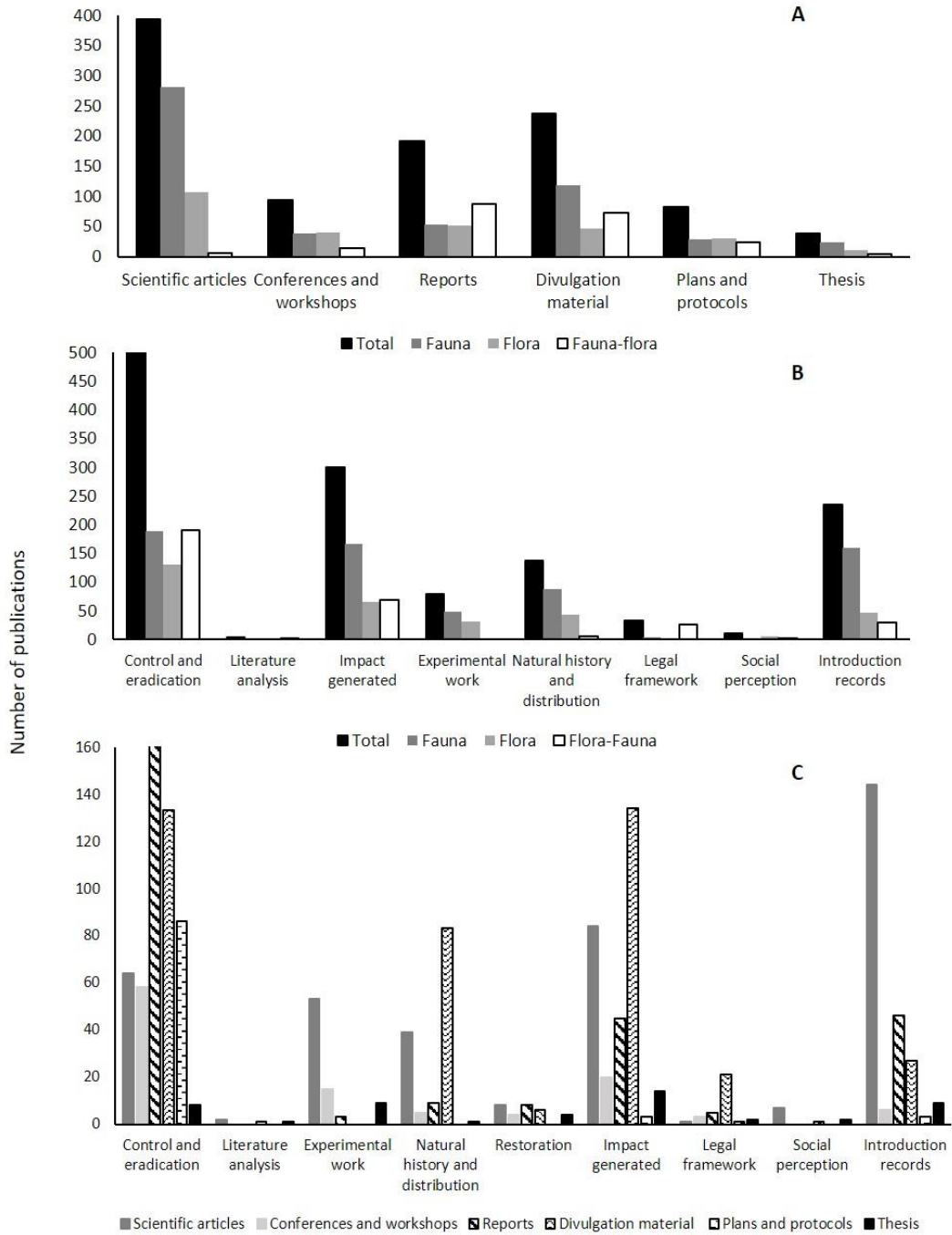


Fig. 2. Number of publications on invasive alien species in Mexico by (A) type of publications, (B) broad research topics, and (C) records of different kinds of publications. See methods for details.

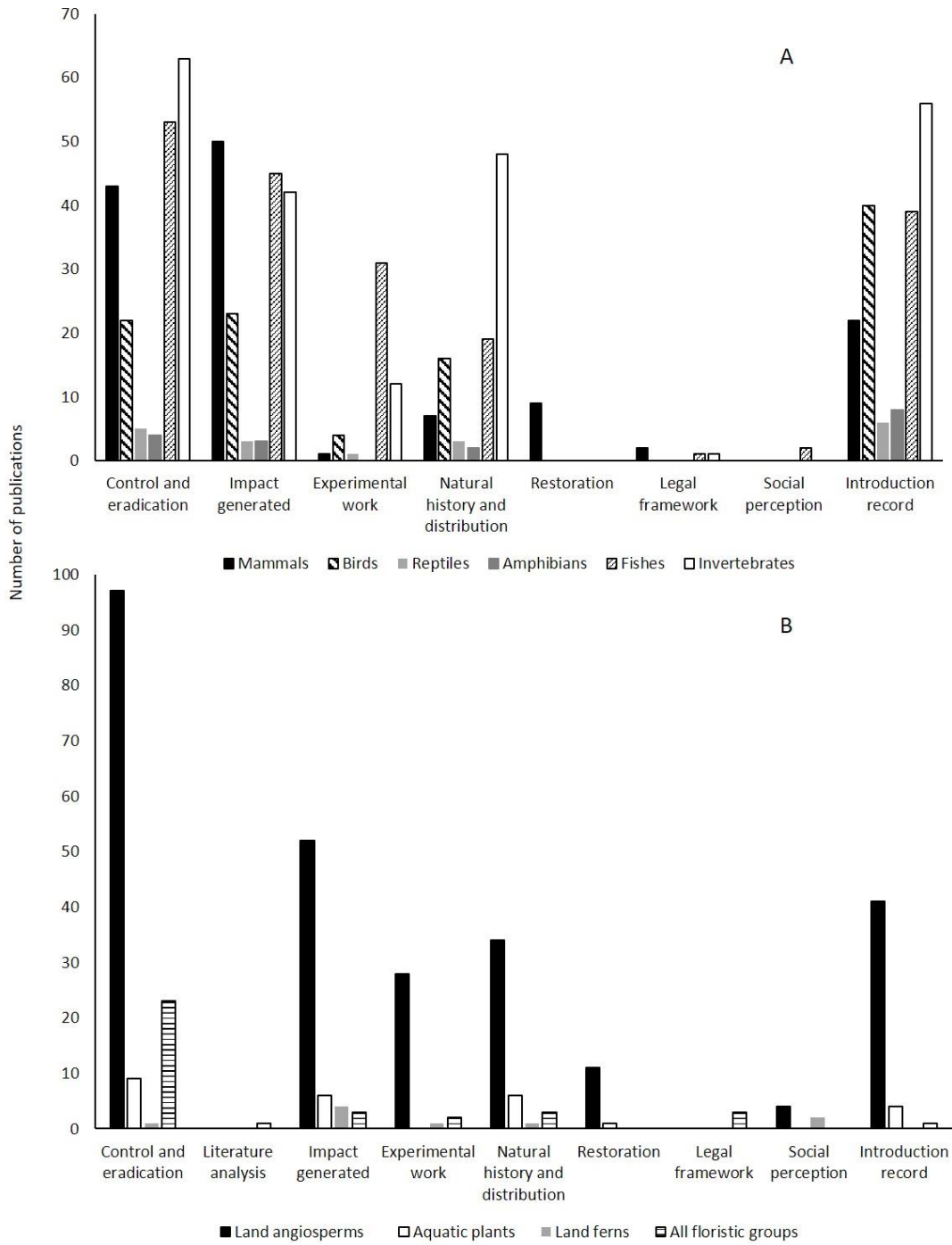


Fig. 3. Frequency of publications of invasive alien species in Mexico by broad research topics on different biological groups, including (A) faunistic groups, as mammals, birds, reptiles, amphibians, fishes, and invertebrates, and (B) floristic groups, as land angiosperms, aquatic plants and land ferns.



## DISCUSSION

We believe that our systematic research overview comprising over a thousand records on IAS in Mexico was adequate and contributed to complement previous works (Ramírez-Albores *et al.*, 2019). Overall, an increase in the published literature on IAS in Mexico was observed over the last 55 years (Fig. 1), the number of scientific articles ranked top indicating a growing research interest on IAS in Mexico. We found approximately 40% of scientific published papers, and 25% of divulgation documents (Fig. 2), indicating an interesting balance of producing basic research, as well as making specialized knowledge understandable, accessible, and available to the public (Briceño, 2012).

Conversely, undergraduate and graduate theses showed relatively low values with 0.3% of the publications found. In a previous study, Ramírez-Albores *et al.* (2019), registered 324 scientific articles, 261 conference summaries, 52 articles in popular science magazine, and 54 theses, which were similar to our findings. It has been argued that the most effective actions to avoid introductions of IAS, involve preventive measurements and complement expert knowledge based on scientific research and environmental public education (Tercero, 2016; Koleff, 2017).

Due to the efforts on research projects and divulgation on popular sciences magazines of the relevance of IAS, research interests emerged as a consequence of the problematic impacts that IAS are posing to our biodiversity and ecosystems degradation. It is important to establish an educational program in public universities and research centers nationwide to increase the number of undergraduate and graduate students interested in IAS. According to the Consejo Nacional de Ciencia y Tecnología (CONACYT, 2020), there were 4365 researchers registered in the areas of Biology and Chemistry in 2019. Mexico falls short by a factor between five and ten on the number of researches in these scientific disciplines compared with other countries holding similar economies (Franco, 2012).

Interestingly, we observed a continuous increase in the rate of publications since 2005 (Fig. 1). This trend demonstrates the interest of researchers to address IAS as a relevant research topic nationwide. Nonetheless, most of this research is not well articulated into a national policy, that includes concrete actions to be established by the federal and state governments (Espinosa-García and Villaseñor, 2017; Koleff, 2017). For example, only 83 (0.8% of total) reports were documents related to management plans and action protocols for IAS were recorded in our survey. Thus, a research priority should focus on increasing the number of studies pertinent to link basic information on IAS to management programs and local, regional and national policies (Koleff, 2017). Ramírez-Albores *et al.* (2019) analyzed the publications produced on IAS in Mexico for over a century (1910 to 2018), and included studies on algae, viruses, and bacteria, although these authors did not address the impact of their information on the challenges imposed by IAS in Mexico. We believe that our study complemented this information platform by posing research priorities, and the need to establish sound policies and management programs for IAS in Mexico (Born-Schmidt *et al.*, 2017).

Overall, the number of publications in fauna was significantly higher (545 records) than in flora (284 records), which is supported by previous work (Ramírez-Albores *et al.*, 2019). This trend can be associated with the fact that the ecological negative impact caused by faunistic groups appears higher. For example, in the case of mammals, 50 (10% of total) documents were related to the impact on ecosystems, and 43 (7% of total) were focused on its control and eradication. Furthermore, there were documents of invertebrates and fishes with a high number of publications related to control and eradication (see Fig. 3A). Despite that the three faunistic groups ranked top with the highest number of documents on the topic (keyword) **impact generated**, the total number of documents on faunistic groups fell short.

The topic **impact generated** is a research priority to be considered for an IAS given its negative impact on ecosystems and biodiversity (Pyšek *et al.*, 2008). There is a need to link basic research on

biological invasions and the urgent need to address the problems they generate (Hulme, 2003; Papeş *et al.*, 2011; Carwardine *et al.*, 2012).

Our study showed that scientists produce limited practical management policies for addressing IAS problems in Mexico. This represents a challenge in the development and implementation of policies focused on successfully mitigating the potential damage caused by IAS. Interestingly, in the case of floristic documents, a higher fraction was related to **control and eradication** research topics. Floristic documents included published scientific literature on land angiosperms; no record was found on gymnosperms. Although studies on aquatic plants were few, the documents that dealt with flora and fauna together were significantly less than the documents that dealt with floristic and faunistic studies separately (see Fig. 3B).

The topics with the highest literature records found included **control and eradication**, followed by **impact generated**, and **introduction records**; almost no records were found on the perception that people have about IAS. Ramírez-Albores *et al.* (2019), found that the two most studied topics were **natural history and distribution** (377 records) and **risk analysis** (203 records). We found significant differences in the type of studies conducted on plants, particularly on aquatic plants on topics related to **eradication and control**, and **impact generated**. This can be explained by the increasing interest to control plant invasions of superficial water bodies in Mexico, given the severe impacts including changes in chemical parameters of the water bodies, losses due to evapotranspiration, premature silting of reservoirs, limiting fishing and recreational activities, and obstructing irrigation channels (Koleff, 2017).

Further, the accumulation of large quantities of aquatic weeds causes water stagnation, which reduces dissolved oxygen and, consequently, the death of aquatic native plant and animal species (PNUD Mexico, 2019). This research priority should aim to establish sound management programs for eradicating aquatic weeds, and avoid an indiscriminate use of herbicides with drastic environmental consequences (PNUD Mexico, 2019). An exemplary action for improvement involved the participation of the academia, NGOs, and governmental agencies, and coordinated by the National Advisory Committee on Invasive Species (CONABIO). This workshop aimed to review the IAS from 2008 to 2010, identifying gaps and needs in terms of invasive species nationwide, as well as prioritizing specific actions to be conducted in the short- and long-terms (Born-Schmidt *et al.*, 2017; Koleff, 2017; CONABIO, 2021a, b).

On the other hand, Pyšek *et al.* (2008) argued that to improve knowledge and management of biological invasions, research on the economic costs infringed by IAS and their social perception should be emphasized. This will facilitate programs on prevention, control, and more effective IAS eradication strategies. By addressing the social perception on IAS allows identifying a general view of people's knowledge, and then develop education and divulgation programs accordingly to provide practical tools to recognize and report IAS (Espinosa-García and Villaseñor, 2017).

A main challenge of addressing economic studies of IAS is to disentangle the multi-dimensionality of the impacts of invasive species. For instance, we observed that most of the documents on floristic studies on IAS were related to **control and eradication**. Tisdell (1990) argued that such negative impacts have strong implications for human well-being, such as loss of crop production due to non-native weeds with a direct economic deficit, as a reduction of income in the agricultural sector. The loss of native species can also result in a decrease in water supply and biodiversity and implies indirect economic impacts (Wit *et al.*, 2001; Quiroz *et al.*, 2009; Ramírez-Albores *et al.*, 2019).

Even with incomplete assessments of all potential impacts that biological invasions cause, and considering only tangible values, the need to identify those invasive species causing great damage is obvious to reduce the problems IAS cause in Mexico (Koleff, 2017). In addition, conducting studies analyzing the legislation and its application on IAS policies will strengthen the design and implementation of a clear, explicit, and transparent legal framework change (Ochoa-Ochoa *et al.*, 2019) will likely increase the risk of IAS worldwide (Hulme, 2009; Lindgren and Darbyshire, 2011). The challenges related to IAS are



complex and require to be addressed in a multidisciplinary approach. The limited knowledge on most IAS requires to strengthen a national policy, with support of the academia, federal and local governments, NGOs, stakeholders, and producers (Espinosa-García *et al.*, 2009; Born-Schmidt *et al.*, 2017; Koleff, 2017; Ramírez-Albores *et al.*, 2019). Finally, our study showed an important increase in research interests on IAS in Mexico since 2000, as occurred worldwide (Hunter and Gibbs, 2006; Lowry *et al.*, 2013; Ramírez-Albores *et al.*, 2019).

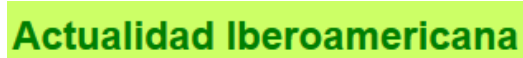
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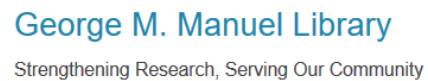


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