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Economic impact of invasive alien species in Argentina: a first national synthesis

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Abstract

Invasive alien species (IAS) affect natural ecosystems and services fundamental to human well-being, human health and economies. However, the economic costs associated with IAS have been less studied than other impacts. This information can be particularly important for developing countries such as Argentina, where monetary resources for invasion management are scarce and economic costs are more impactful. The present study provides the first analysis of the economic cost of IAS in Argentina at the national level, using the InvaCost database (expanded with new data sources in Spanish), the first global compilation of the reported economic costs of invasions. We analyzed the temporal development of invasions costs, distinguishing costs according to the method reliability (i.e. reproducibility of the estimation methodology) and describing the economic costs of invasions by invaded environment, cost type, activity sector affected and taxonomic group of IAS. The total economic cost of IAS in Argentina between 1995 and 2019 was estimated at US$ 6,908 mil-

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lion. All costs were incurred and 93% were highly reliable. The recorded costs were mainly related to terrestrial environments and the agricultural sector, with lack of costs in other sectors, making it difficult to discuss the actual distribution of invasion costs in Argentina. Nevertheless, the reported costs of IAS in this country are very high and yet likely much underestimated due to important data gaps and biases in the literature. Considering that Argentina has an underdeveloped economy, costs associated with biological invasions should be taken into consideration for preventing invasions, and to achieve a more effective use of available resources.

Abstract in Spanish

Impacto económico de las especies exóticas invasoras en Argentina: primera síntesis nacional. Las especies exóticas invasoras (EEI) afectan a la naturaleza y a servicios ecosistémicos fundamentales para el bienestar humano, la salud humana y las economías. Sin embargo, los costos económicos asociados a las EEI han sido menos estudiados en comparación con otros impactos. Esta información puede ser particularmente importante para países en vías de desarrollo como Argentina, donde los recursos económicos para el manejo de invasiones biológicas son escasos y los costos económicos son más impactantes. El presente estudio proporciona el primer análisis de los costos económicos de las EEI en Argentina a nivel nacional, utilizando la base de datos InvaCost (ampliada con nuevas fuentes de datos en español), la primera compilación global de los costos económicos registrados de las EEI. Analizamos el desarrollo temporal de los costos de las invasiones, distinguiendo los costos según la confiabilidad del método (es decir, reproducibilidad de la metodología de estimación) y describiendo los costos económicos de las invasiones por ambiente invadido, tipo de costo, sectores de actividad impactados y grupo taxonómico de las EEI. El costo económico total de las EEI en Argentina entre 1995 y 2019 se estimó en US$ 6,9 mil millones. Todos los costos económicos de las EEI fueron observados y el 93% fue altamente confiable. Los costos de las EEI se registraron principalmente en ambientes terrestres y en el sector agrícola, con pocos costos registrados en otros sectores, lo que dificulta discutir la distribución real de los costos de las invasiones en Argentina. No obstante, los costos económicos registrados de las EEI en este país son muy altos y probablemente estén muy subestimados debido a importantes lagunas de datos y sesgos en la literatura. Dado que Argentina tiene una economía en vías de desarrollo, los costos asociados a las invasiones biológicas deben considerarse para prevenir las invasiones y lograr un uso más efectivo de los recursos disponibles.

Abstract in Portuguese

Impacto econômico das espécies exóticas invasoras na Argentina: uma primeira síntese nacional. Espécies exóticas invasoras (EEI) afetam ecossistemas naturais e serviços ecossistêmicos fundamentais para o bem-estar humano, saúde humana e economia. No entanto, os custos econômicos associados com EEI é menos estudado que os outros impactos. Essa informação pode ser particularmente importante para países em desenvolvimento como Argentina, onde recursos financeiros para o manejo de invasões biológicas é escasso e os custos econômicos são mais impactantes. O presente estudo fornece a primeira análise dos custos econômicos de EEI na Argentina em nível nacional, utilizando a base de dados InvaCost (ampliada com novas fontes de dados em espanhol), o primeiro compilado global dos custos econômicos reportados de EEI. Nós analisamos a evolução temporal dos custos de invasãoes biológicas, diferenciamos os custos de acordo com a confiabilidade do método (isto é, facilidade de reprodução do método de estimativa) e descrevemos os custos econômicos das invasãoes biológicas pelo ambiente invadido, tipo de custo, setor de atividade afetado e grupo taxonômico de EEI. O custo total das EEI na Argentina entre 1995 e 2019 foi estimado em 6,908 milhões de dólares. Todo os custos foram observados e 93% deles são altamente confiáveis. Os custos reportados foram principalmente relacionados ao ambiente terrestre e ao setor de agricultura, com ausência de custos para outros setores, dificultando a discussão sobre a real distribuição de custos das EEI na Argentina. Ainda assim, os custos das EEI reportados no país são muito altos e, provavelmente, muito subestimados devido à falta de dados e viés na literatura. Considerando que a Argentina é uma economia em desenvolvimento, os custos associados com invasões biológicas devem ser levados em consideração para prevenir invasões e atingir um uso mais eficiente dos recursos disponíveis.

Abstract in French

Impact économique des espèces exotiques envahissantes en Argentine: première synthèse nationale. Les espèces exotiques envahissantes (EEE) affectent les écosystèmes naturels et les services écosystémiques essentiels au bien-être humain, à la santé humaine et aux économies. Cependant, les coûts économiques associés aux EEE ont été moins étudiés que les autres impacts. Cette information peut pourtant être particulièrement importante pour les pays en développement comme l'Argentine, où les ressources économiques pour la gestion des invasions sont rares et les coûts plus importants. Cette étude fournit la première analyse du coût économique des EEE en Argentine au niveau national, en utilisant la base de données InvaCost (étendue à d'autres sources de données), la première compilation mondiale des coûts économiques des invasions. Nous avons analysé l'évolution temporelle des coûts des invasions, distingué les coûts selon la forme d'implémentation (c.-à-d. observée empiriquement ou prévue) et décrit les coûts économiques des invasions selon l'environnement envahi, le type de coût, le secteur d'activité affecté et le groupe taxonomique des EEE. Le coût économique total des EEE en Argentine entre 1995 et 2019 a été estimé à 6,908 milliards de dollars américains. Tous les coûts ont été observés et 93% étaient hautement fiables. Les coûts enregistrés étaient principalement liés aux environnements terrestres et au secteur agricole, les autres coûts manquant de données, ce qui rend difficile la discussion de la répartition réelle des coûts d'invasion en Argentine. Néanmoins, les coûts déclarés des EEE dans ce pays sont très élevés, et probablement sous-estimés en raison d'importants lacunes et biais dans la littérature existante. Étant donné que l'Argentine a une économie sous-développée, les coûts associés aux invasions biologiques devraient être pris en considération pour prévenir les invasions et parvenir à une utilisation plus efficace des ressources disponibles.

Keywords

Damage costs, developing country, economic threat, InvaCost, management costs, non-native species

Introduction

Scientific literature provides robust and abundant evidence of negative impacts of invasive alien species (IAS) (e.g., Vilà et al. 2010, 2011; Pyšek et al. 2012; Castro-Díez et al. 2019). Notably, IAS threaten native biodiversity worldwide (Vilà et al. 2011; Pyšek et al. 2012; IPBES 2019) and burden human health, the production of food and other important goods, as well as ecosystem services that are fundamental for human well-being (Vilà et al. 2011; Simberloff et al. 2013; Shackleton et al. 2019). All these impacts on nature, health and production can also have important economic consequences. Although the problem of IAS is as much an economic as an ecological problem (Cuthbert et al. 2020), the economic costs associated with invasions have been relatively less studied (Pimentel et al. 2005; Bradshaw et al. 2016; Early et al. 2016; Cuthbert et al. 2020). For example, results of a meta-analysis on management of IAS showed that very few studies quantitatively evaluated the economic costs of invasive species control (Kettenring and Adams 2011). In addition, control costs were estimated in studies carried out at rather small spatial scales and over a considerably short period of time (Kettenring and Adams 2011), although quantifying damages and control costs at national levels is key to prioritizing management actions for IAS.

Research on IAS mostly focuses on developed countries (Pyšek et al. 2008), and this holds also for monetary impacts of invasions (Kettenring and Adams 2011). The scarce information on the monetary impact of IAS is especially true for areas where such information is desperately needed, as being unaware of these costs can limit the ability to timely respond (Leung et al. 2002). Research in developing countries is more focused on addressing basic aspects of invasions such as the distribution and ecology of IAS (Pauchard et al. 2011; Schwindt and Bortolus 2017). However, there is a great interest in the scientific community in addressing the issue of invasion costs in these areas (Pauchard et al. 2011; Schwindt and Bortolus 2017). Increasing such knowledge is important as prioritization and management of IAS in developing and developed countries may differ (Nuñez and Pauchard 2010). In this regard, developing countries such as Argentina present a flowering scientific community working on different socio-ecological aspects of biological invasions, which is reflected in the increasing number of publications in this field (e.g., Schwindt and Bortolus 2017; Kay et al. 2018; Nuñez and Paritsis 2018; Urcelay et al. 2019; Ballari et al. 2020; Fernandez et al. 2020; Huertas Herrera et al. 2020). In addition, in the last six years IAS became a priority of the Argentina government through a national strategy that aims to study, control and eradicate invasive species and to improve institutional capacities to manage biological invasions (MAyDS and FAO 2019). As an integral part of this strategy, the Argentine government seeks to promote the generation of public policies to minimize the impact of biological invasions on the national economy. For example, based on this strategy, the Argentine government approved risk analysis systems for the introduction of plants, fish and terrestrial vertebrates which are functioning and they elaborated an official list of IAS and, potentially, IAS in the country. However, to date, there is no public, open-access database that would facilitate collection and access to information on economic costs incurred by all IAS that could guide policy-makers. Moreover, very few studies report how much is actually spent on research or management of IAS (Fernandez et al. 2020, but see Zilio 2019). Consequently, there is a lack of consistent and complete information on the economic cost of biological invasions in Argentina.

Recently, the InvaCost database has been created to gather all the published data on the economic costs of invasive species (Diagne et al. 2020a, b). In the present study, we used this database to provide the first country-level synthesis of the economic cost of IAS in Argentina. More specifically, we analyzed how the reported costs of IAS evolved over time, distinguished costs according to the method reliability (i.e. reproducibility of the estimation methodology) and described their distribution by invaded environment, cost type, impacted sector and taxonomic group of IAS.

Methods

We retrieved economic costs data of IAS exclusively associated with Argentina that were collected in the frame of the InvaCost project (Diagne et al. 2020a), as of September 2020. Most of the original Invacost data was collected using traditional search engines, such as Web of Science and Google Scholar (Diagne et al. 2020b). However, these search engines provided extremely little information on the search topic for Argentina (only five references). To complete the dataset, we have added cost data collected from non-English sources (11 references), relying on both identical search strategies in existing repositories and more targeted collection through contacting experts and stakeholders (Angulo et al. 2021a). All cost entries were standardized to a common and up-to-date currency (US dollars exchange rate in 2017). Data were carefully checked to identify potential errors; all modifications to the original data were sent to updates@invacost.fr for further correction and consideration in the subsequent updated version(s) of the global database (latest version openly available at https://doi.org/10.6084/m9.figshare.12668570). Further details about the InvaCost database used here are provided by Diagne et al. (2020b).

From these 16 references (5 in English and 11 in Spanish), a total of 54 cost entries were selected for Argentina (Suppl. material 1). This dataset was expanded using the 'expandYearlyCosts' function of the R package "Invacost" (Leroy et al. 2020) considering the time period of each estimated cost entry using the database information (columns probable starting year adjusted and probable ending year adjusted, Suppl. material 1). Subsequently, this function multiplied the duration time (in years) by the cost per year to obtain the total cumulative cost along the defined period. When information was missing, we conservatively decided to consider the same year for both the starting and ending year if the cost was expected to occur over a single year, or used the publication year as a basis for calculating the duration if information was missing from both years. The reported annualized cost entries after costs were expanded totaled 68.

To investigate the temporal dynamics of the economic costs caused in Argentina by the IAS reported in the 68 annualized cost entries, we used the 'summarizeCosts' function implemented in the R package "invacost" (Leroy et al. 2020). With this method, we calculated the observed cumulative and average annual costs between 1995 and 2019, considering 5-year intervals for the mean costs. We also distinguished costs according to the implementation form and method reliability. The implementation form refers to whether the cost estimate was actually realized or incurred in the invaded habitat ("Observed") or whether it was a predicted or expected cost to be spent ("Potential"), (column implementation, Suppl. material 1). Method reliability refers to the perceived reliability of cost estimates based on the type of publication and method of estimation; "Low" vs. "High". Peer-reviewed or other official documents from the grey literature in which the original sources, assumptions and methods to estimate the cost were accessible and fully described were classified as "High" (column reliability, Suppl. material 1).

Finally, we described the distribution of costs by:

- **Invaded environment:** Aquatic, terrestrial, or semi-aquatic habitats (i.e. cost of IAS that spent part of their life in water) (column Environment, Suppl. material 1).
- **Cost type:** (a) "Damage-Loss", referring to damages or losses incurred by IAS, (b) "Management", comprising control-related expenditures (i.e., research, monitoring, prevention, management, eradication), and (c) "Mixed" costs, including undifferentiated damage and management costs (column Type_2 that we added based on information provided in the 'Type_of_cost' column, Suppl. material 1).

- **Impacted sector:** The activity, societal or market sector that was impacted by the cost of IAS (column "impacted_sector_2", Suppl. material 1). The sectors included were agriculture, authorities-stakeholders (briefly, institutions that manage IAS), environment (briefly, economic quantifications of impacts in ecosystem services, natural resources), fishery, forestry, health and public and social welfare (for the complete description of these categories see Suppl. material 2).
- **Taxonomic group of IAS** (columns "Class", "Order", "Family", "Genus" and "Species", Suppl. material 1).

Results

The total economic cost of invasive species reported in Argentina was estimated at US$ 6,908 million (AR$ 590,300 million, calculated considering the value of the dollar in 2017) over the entire period between 1995 and 2019, and the annual average was US$ 276 million (Fig. 1). The majority of the cost information (95%) was concentrated in the 2015–2019 period, concomitant with the majority of invasion cost records being published in 2016 (28 annualized cost entries out of 68). All costs were observed and 93% were highly reliable (i.e., costs were collected from peer-reviewed articles and official documents).

Economic costs by invaded environment

Economic costs of biological invasions differed according to the environment. Most of the costs associated with IAS were registered in the terrestrial environment (n = 52) with a total cost of US$ 6,816 million, while those associated with aquatic environments were much lower, amounting to US$ 87.91 million (n = 15). Only one record was found in a semi-aquatic environment, amounting to US$ 3.76 million (Fig. 2a).

Economic costs by cost type

The vast majority of the costs of IAS (98.9%) were related to damage-loss (US$ 6,835 million), while management costs represented 1.03% of the total (US$ 71.19 million). Costs belonging concomitantly to damage and management cost (Mixed costs; 0.03%) accumulated to US$ 1.69 million (Fig. 2a).

Economic costs by impacted sector

In general, the costs of invasive species were predominantly associated with agriculture (US$ 4,307 million). These costs were related with control or eradication actions or damages to crops of seven species; *Ceratitis capitata* (Mediterranean fruit fly), *Anthonomus grandis* (cotton boll weevil), *Anastrepha fraterculus* (fruit fly), *Cydia pomonella* (codling moth), *Castor canadensis* (beaver), *Sturnus vulgaris* (common starling) and

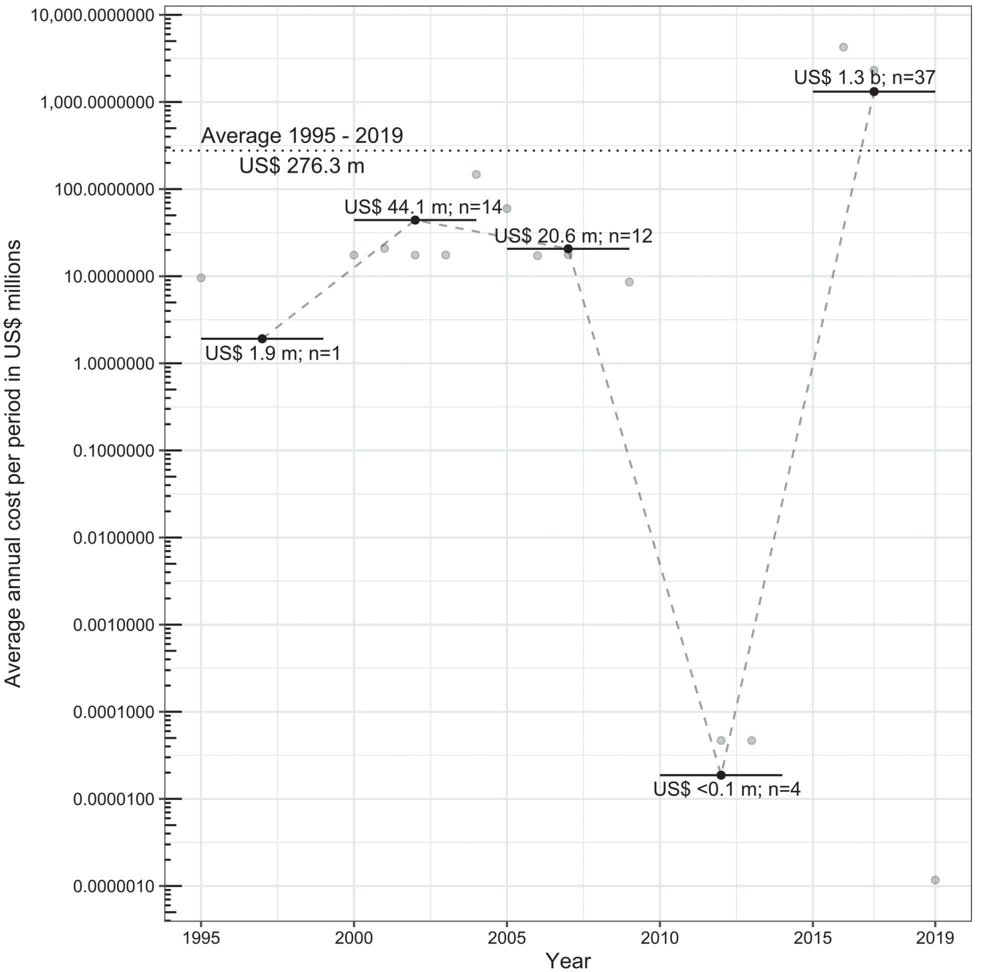

Figure 1. Cumulative economic costs of IAS in Argentina over time. Costs expanded between 1995 and 2019. Points are total annual costs for every year (i.e., all individual costs for a specific year are summed). Lines represent the average annual cost for 5 year intervals and the "n" in each line indicates the number of records in each period.

Tamarix sp. (saltcedar). The second most impacted sector was authorities-stakeholders (i.e., IAS management agencies/institutions, US$ 2,333 million). These costs impacting the authorities-stakeholders sector were associated with control, eradication, research, communication or damages caused by the species *C. capitata*, *Undaria pinnatifida* (Asian kelp), *Limnoperna fortunei* (golden mussels), *Ligustrum lucidum* (glossy privet), *C. canadensis* and *Sus scrofa* (wild boar). Particularly, the health costs were driven by the Insecta class (associated with medical care, direct medical costs, research, damage loss and control costs to *Aedes* mosquitoes transmitting dengue), fishery costs were driven by the algae *U. pinnatifida* and the public and social welfare costs were driven by *Tamarix* sp. (Fig. 2b).

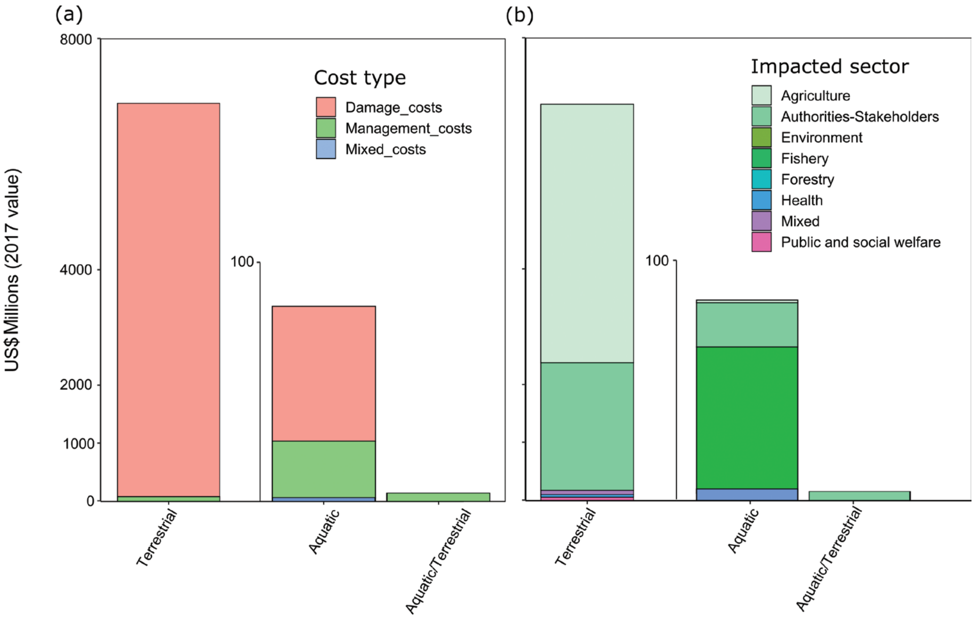

Figure 2. Economic cost of IAS in Argentina in each type of environment by **a** cost type and **b** impacted sectors.

Table 1. List of invasive species with reported economic costs for Argentina. Data sourced from the InvaCost database (Diagne et al. 2020b).

Class	Order	Family	Genus	Species	Cost $US	Database entries
Aves	Passeriformes	Sturnidae	Sturnus	Vulgaris	134,008,341.80	1
Bivalvia	Mytilida	Mytilidae	Limnoperna	fortunei	2,032,315	3
Insecta	Coleoptera	Curculionidae	Anthonomus	grandis	3,324,066.02	2
	Diptera	Culicidae	Aedes	aegypti	24,124,104.73	12
	Diptera	Culicidae	Aedes	aegypti/albopictus	155,807,802.40	10
	Diptera	Tephritidae	Anastrepha	fraterculus	38,242,382.17	2
	Diptera	Tephritidae	Ceratitis	capitata	129,773,008.00	2
	Hymenoptera	Siricidae	Sirex	noctilio	1,657,922.89	6
	Lepidoptera	Tortricidae	Cydia	pomonella	217,644.84	2
Magnoliopsida	Caryophyllales	Tamaricaceae	Tamarix	NA	4,035,079,013	6
	Lamiales	Oleaceae	Ligustrum	lucidum	94.74	6
Mammalia	Artiodactyla	Suidae	Sus	scrofa	2,293,673,994	5
	Rodentia	Castoridae	Castor	Canadensis	66,556,973	9
Phaeophyceae	Laminariales	Alariaceae	Undaria	pinnatifida	168,490	2
Pinopsida	Pinales	Pinaceae	Pinus	halepensis	78.15	1

Economic costs by taxonomic group of IAS

The majority of the 68 cost entries belonged to the Insecta class (n = 36), mainly of *Aedes Aegypti*. The second class with the highest number of cost entries was Mammalia (n = 14) represented by beavers and wild boars, and the third class was Magnoliopsida (n = 9) with the species glossy privet and saltcedar (Table 1). However, the Magnoliopsida class ("flowering plants") produced most of the costs, with US$ 4,035 million concentrated mainly in saltcedar; second were Mammalia with US$ 2,360 million (Table 1; Fig. 3).

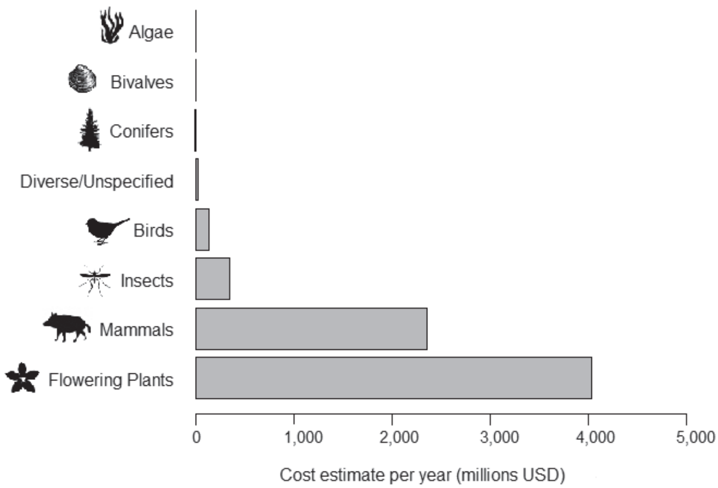

Figure 3. Economic costs of IAS in Argentina by taxonomic groups (Class).

Discussion

Our results show that the reported cost of IAS in Argentina accumulated to a total of US$ 6,908 million (AR$ 590,300 million) between 1995 and 2019. Despite the extensive search and the millions in costs observed, we consider that this value can be seen as highly conservative because the costs reported here were produced by just 15 species, which represent only 2% of the IAS registered for Argentina. Indeed, according to the National Invasive Exotic Species Information System, Argentina registers 654 IAS and 319 evidenced negative ecological impacts according to the global database of introduced and invasive alien species (Zalba et al. 2020). Although very problematic, this is not specific to Argentina, and similar knowledge gaps have been highlighted elsewhere, for example in economic assessments in Germany (Haubrock et al. 2021), France (Renault et al. 2021), United-Kingdom, (Cuthbert et al. 2021a), Asia (Liu et al. 2021) or Australia (Bradshaw et al. 2021). Furthermore, there are only very few entries in the database on economic costs for several sectors (e.g. forestry, fishery and health) of major importance in Argentina, which could still account for very large sums. For example, in the health sector, there are 12 entries about the high costs associated with direct medical costs, research, damage loss and control costs of invasive mosquitoes vectoring diseases like dengue, Zika and chikungunya fever, and all but one come from observed costs of only one year, 2016 (FAO FMAM Estrategia Nacional sobre Especies Invasoras; Ministerio de Medio Ambiente y Desarrollo Sostenible 2017). However, it is important to note that several dengue prevention and control actions were performed in Argentina, which implies high management expenditures, but these are not usually published (Vezzani and Carbajo 2008). Unsurprisingly, there is no record on monetized impacts of IAS on biodiversity and some ecosystem services (e.g. cultural services) because these are generally difficult to quantify (Vilà et al. 2010; Cerda et al. 2017; Diagne et al. 2020b). Yet, some countries invest more in biodiversity conservation and therefore have a higher percentage of management investment of

IAS, showing it is not a fate (e.g. Ecuador, Ballesteros-Mejia et al. 2021; Spain, Angulo et al. 2021b; Japan, Watari et al. 2021). More generally, the cost amounts shown here represent only a small part of the actual economic burden of IAS, as they are only based on the few documented costs that were collated in the InvaCost resource.

There is considerable variability in these reported economic costs of IAS in Argentina throughout the period analyzed, which is strongly linked with the publication effort. Most of the total costs are concentrated in the last 5 years of the period analyzed, because 50% of the studies on IAS costs are concentrated in that time. There is limited information about economic costs of IAS in Argentina and we noted that part of this may be related to the accessibility of information. Web search engines such as Web of Science, for example, that have been very useful in countries like the United Kingdom, proved to have really limited efficiency here, with less than 4% of the references analyzed coming from this tool. We believe that there may be technical reports on the impacts of invasive species in the agriculture, fishery, forestry and health sectors, but they are not available to the scientific community, and therefore not attainable through traditional search methods. As a result, some cost information could be missing in the InvaCost database despite having used a wide range of search terms in Spanish and English languages. This situation highlights clear gaps in the available data. In comparison, other Latin American countries like Brazil, Ecuador (mostly from Galapagos Islands), and Mexico, have respectively, two, six, and four times more entries than Argentina (174 entries in expanded database, Adelino et al. 2021; 464 entries in expanded database, Ballesteros-Mejia et al. 2021; 251 entries in expanded database, Rico-Sánchez et al. 2021). From there, scientists need to improve interactions with some official organisms to communicate the importance of increasing accessibility to this information. Given the standardization of the InvaCost database used, it would be interesting to have this type of analysis carried out in Argentina, Brazil, Ecuador and Mexico also applied to other Latin American countries.

In 2016, the year with the highest estimated costs, the total annual cost was US$ 4,260 million, which corresponds to 0.76% of the Argentina's Gross Domestic Product (GDP) of US$ 557,500 million in the same year, and is comparable to the health budget for the entire country of US$ 4,560 million for 2016 (Senado y Cámara de Diputados de la Nación Argentina 2016). This indicates that despite the limited information of the economic impact of IAS in Argentina, the costs are still high. In line with this idea, it is possible that other countries reported higher costs than in Argentina such as Brazil (US$ 105.53 billion, Adelino et al. 2021) and Mexico (US$ 10.77 billion, Rico-Sánchez et al. 2021) mainly because they have better data records (as mentioned above) and not because the IAS generated higher economic problems than in Argentina. Based on our conservative estimation and the clear missing data, the real cost of IAS in Argentina likely represents a significant problem for the developing economy of the country.

Our results also showed that there are important data biases. Indeed, the entire pattern of the costs reported was driven by one environment type (terrestrial), one sector (agriculture) and a single taxon (*Tamarix* sp.) of invasive species in Argentina. These costs based on data records to date do not represent the overwhelming majority of the real costs due to the prevalence of habitat, sector and taxonomic biases. Consequently, it is difficult to discuss the distribution patterns of invasion costs in this country. In fact, most of the cost records (76%) come from the terrestrial environment. This trend has been also observed in general for the InvaCost database, for which only 5% of reported costs were from aquatic species (Cuthbert et al. 2021b). This is not surprising given that, in general, invasion studies predominate in the terrestrial environment (e.g. Puth and Post 2005; Dana et al. 2014). Part of this disparity in invasion studies in aquatic and terrestrial environments may be related to a bias in social perception. In aquatic environments, IAS are perceived mostly by scientists who work in aquatic ecosystems or by fewer people who perform water-based recreational activities compared to activities in terrestrial environments (Eiswerth et al. 2011). There are several gaps in aquatic invasion research (Schwindt and Bortolus 2017) including economic impacts (Cuthbert et al. 2021b), which can be high considering that some invasive species can negatively affect numerous sectors. An important example of IAS in aquatic environments in Argentina is the mammalian *C. canadensis* (beavers). This species is an ecosystem engineer that produced large and dramatic ecological and economic impacts by invading forests, grasslands and peatlands in southern Argentina (Anderson et al. 2009; Zilio 2019). According to our records, the beavers' invasions affected forestry, agriculture, and environment sectors with an estimated cost of US$ 66.56 million (Table 1). Given the magnitude of its impacts both in aquatic and terrestrial ecosystems, it is likely that the real damage and management costs of this species are higher than those reported in this study. Another example of IAS in this environment with substantial impacts is the bivalve golden mussels. All costs of golden mussels accounted for US$ 0.007 billion and were registered in South America entirely (Haubrock et al. in prep). We know that in Argentina this species negatively affected several sectors that use water (e.g. nuclear and thermal power plants, food plants, commercial and tourist boats) (Boltovskoy et al. 2006), but these damage costs have not been estimated yet. The costs inferred to freshwater bivalves can be considerably higher. This is, for instance, indicated by the costs of another freshwater invasive macrofouling bivalve, *Dreissena polymorpha* (zebra mussel), in North America alone, totaling at US$ 24.8 billion (Haubrock et al., in prep).

We found an overwhelming predominance of reported costs related to damage or loss rather than to management of IAS. High damage-loss cost of invasions could be related to the incipient, and much needed, investment in prevention and control of IAS in Argentina. It is important to mention that the non-implementation of invasive species management and control strategies could increase the negative impact for both the national and private economies. Additionally, few control studies carried out in Argentina reported the costs of the different treatments evaluated, although these costs can easily be quantified since they are observable. Indeed, they are fundamental to evaluate the costs-benefits of applied management. This problem is not exclusive to Argentina, because in general studies on control of IAS do not report the costs associated with management actions of these species (Kettenring and Adams 2011; Dana et al. 2014). However, our results show a growing interest from the scientific community in considering this aspect of invasions, since the highest number of entries of invasions costs in Argentina were reported in the last 5 years.

Invasive species represent a threat to global agriculture, in particular for the economy of developing countries (Paini et al. 2016). Agriculture is an important economic sector for Argentina. This country is the second largest agricultural and food exporter in Latin America (US$ 35 billion in 2017; Food and Agriculture Organization of the UN, 2019) and it was the sector that registered the highest costs associated with invasions (more than 62%), even without including the costs of several exotic pests and weeds such as *Cirsium vulgare* (spear thistle), *Carduus acanthoides* (welted thistle) and *Vespula germanica* (German wasp) that also affect agriculture (Ziller et al. 2005; Masciocchi and Corley 2013; Renzi and Cantamutto 2013) but for which there is no economic cost evaluation associated. The invasive species also generated high costs on the authorities-stakeholders' sector (33% of the total), which includes all management policies of biological invasions, and the costs associated with research and management of IAS in protected areas. Given that invasive species represent a growing problem in protected areas in Argentina (e.g. Merino et al. 2009; Ballari et al. 2015) it is not surprising that the costs are high. Moreover, some sectors that may be much impacted by IAS in Argentina might be understudied there, and present an artificially low cost. For example, there was only one cost in Argentina for fisheries, and yet the costs for this activity sector could be very high; it was the most impacted sector in Mexico (US$ 5.96 billion, Rico-Sánchez et al. 2021).

Most of the total costs registered were produced by *Tamarix* sp., which has several negative ecological impacts and important social and economic impacts because it consumes large amounts of water and invades productive lands and subsistence agriculture areas (Natale et al. 2008; Natale et al. 2012; Zilio 2019). However, it is important to mention that the costs of this species registered in the invaCost database were estimated extrapolating the current areas invaded and the known cost for irrigation due to consumption of water in areas destined for agriculture on the large arid areas where it invades. Although *Tamarix* sp. was the species with the highest recorded economic costs in Argentina in our database, it is not certain if this is the one with the actual higher costs. This could be due to the lack of detailed studies on the economic cost of other important invasive species with very high impacts and with a larger number of reports such as *A. aegypti*, *S. scrofa* and *C. canadensis*. In Argentina, there are other invasive species such as *Pinus* spp, *L. lucidum*, *Bombus terrestris*, *Achatina fulica*, *Didymosphenia geminata*, *Neovison vison* and *Callosciurus erythraeus* whose negative ecological impacts are well known (e.g. Benitez et al. 2013; Valenzuela et al. 2013; Nuñez et al. 2017; Aizen et al. 2019; Fernandez et al. 2020), but lack economic impact assessments (or with a few, clearly underestimated costs). For example, the invasion of *B. terrestris* has caused a decrease in the populations of native bees and severe impacts on the natural and agricultural ecosystems of southern Argentina, but we lack information on the economic cost of these impacts (Aizen et al. 2019). Another problem is that several articles on the economic impacts of weeds do not differentiate whether the weeds are native species or not, which makes it difficult to estimate the impact of the latter. Having a biased sample of costs from a literature review is not something unexpected on an understudied topic, and we hope that our report will help reduce these biases. Additionally, studies are required to examine the costs caused by IAS for which there are no estimated costs in order to obtain a comprehensive database of the real economic costs of invasions at the national level. In this sense, future studies should evaluate the potential economic costs of IAS with the most negative impact in different sectors of the country considering the spatial scale of their distribution and the vulnerability of the invaded habitat.

One aspect that has been understudied is the positive economic benefits of invasions. We recognize that some IAS can be seen ambivalently, causing as they do both economic costs and benefits. For example, sport fisheries in Patagonia – based on nonnative salmonids – is a multimillion-dollar business that brings tourists from all over the world (Vigliano et al 2007). However, these reported economic benefits are in order of magnitude of millions of dollars rather than billions as we obtained here for economic costs of IAS. This suggests that the costs of IAS are notably higher than the benefits, but a case-by-case analysis is necessary for a deeper understanding of the impact of IAS on the local economies. Finally, considering the perceptions that different stakeholders have about IAS and their economic costs or benefits can contribute to estimating the cost-benefit ratio of IAS in the country.

Conclusions

The results of this study highlight the high economic burden of IAS for Argentina, which may be even more important given that the amounts presented are based only on the little documented cost information reported in the data resource considered here. They also underline a significant need to develop more research on the economic impacts of IAS as well as to improve the accessibility of that information in Argentina. The cost of IAS reported here is very high considering the low representation of taxa with cost estimates relative to the number of invasive taxa registered in Argentina, and the few data recorded of the taxa with cost information. Considering that Argentina has an underdeveloped economy, costs associated with biological invasions should be taken into consideration for prevention efforts of invasions and to achieve a more effective use of resources. The information about costs of IAS that we reported in the present study, could contribute to the objectives of the Argentine government which seeks to promote the development and implementation of public policies that minimize the impact of biological invasions on the economy (MAyDS and FAO 2019). Significantly, management (i.e., proactive costs) represented a very small fraction of the recorded costs, the rest being damages and losses (i.e., reactive costs). There is a need to improve the interaction with both market sectors and the government in order to develop an open access database on the economic costs associated with biological invasions (e.g. fumigation costs for prevention, and hospitalization cost related to *Aedes* mosquitoes). The development of collaboratively applied projects between decision makers and scientists could contribute to this objective. Further, we encourage researchers to report the quantity of public resources committed to evaluate the impacts of invasive species, and to report the economic costs of managing invasive species in the country in a thorough and standardized way (Diagne et al. 2020a). All this information could help to have a better picture of the real economic costs of IAS in Argentina and also may be useful to alert the public and policy-makers about the magnitude of the economic problem of biological invasions in this country.

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Supplementary material 1

Dataset of economic costs of IAS for Argentina, extracted from InvaCost Database

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Link: https://doi.org/10.3897/neobiota.67.63208.suppl1

Supplementary material 2

Description of the sectors considered in the InvaCost database

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