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Overview article

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Abstract

Biological invasions are a global challenge that has received insufficient attention. Recently available cost syntheses have provided policy and decision makers with reliable and up-to-date information on the economic impacts of invasive alien species, aiming to motivate effective management. The resultant InvaCost database is now publicly and freely accessible and enables rapid extraction of monetary cost information globally. This has facilitated knowledge sharing, developed a more integrated and multidisciplinary network of researchers, and forged multidisciplinary collaborations among diverse organisations and stakeholders. Over 50 scientific publications so far have used the database and provided detailed assessments of invasion costs across geographic, taxonomic, and spatio-temporal scales. These studies have been instrumental in guiding policy and legislative decisions, while attracting public and media attention. We provide an overview of the improved availability, reliability, and defragmentation of monetary costs, how this has enhanced invasion science as a discipline, and outline directions for future development.

1. Introduction

Globalisation of economies and societies has accelerated trade, travel, and connectivity, increasing the potential for exchanges of biological material between distant regions and eroding natural biogeographical barriers (Vander Zanden & Olden 2008; Duffy *et al.* 2017). Increased global trade and transport have concomitantly accelerated the translocation of alien species to unprecedented rates (Essl *et al.* 2011; Seebens *et al.* 2017). The intentional (e.g., for biocontrol or leisure activities) or unintentional (e.g., by 'hitchhiking') translocation of species by humans can result in the establishment of self-sustaining populations of alien species that consequently spread within their new environment (i.e., invasive alien species), with the potential to cause staggering ecological (Blackburn *et al.* 2011; Bellard *et al.* 2021), health (Zhang *et al.* 2022), socio- ((Bradshaw *et al.* 2016; Bacher *et al.* 2018; Diagne *et al.* 2021)), and economic damages (Bradshaw *et al.* 2016; Bacher *et al.* 2018; Diagne *et al.* 2021).

Invasive alien species are among the main drivers of (*i*) global biodiversity loss through their degradation of ecological communities and functions (Bellard *et al.* 2022), (*ii*) alteration of functional diversity (Milardi *et al.* 2019; Kaushik *et al.* 2022; Renault *et al.* 2022b), (*iii*) disruption of ecosystem services such as pollination, freshwater provisioning, nutrient cycling, and soil fertility (Pejchar & Mooney 2009; Vilà *et al.* 2010), and (*iv*) massive economic losses worldwide (Bradshaw *et al.* 2016; Diagne *et al.* 2021). This has propelled invasion biology as a major discipline in ecology, and a resulting increased awareness of their threats and rates of introduction highlights the need to prevent, control, and eradicate invasive alien species (Simberloff *et al.* 2013).

However, biological invasions have not yet been acknowledged to the extent the problems they impose deserve, by either the public or policy makers (Courchamp *et al.* 2017). This blindness to the importance and risks conveyed by invasions is further accentuated through doubt cast by works questioning the severity of the problem (Russell & Blackburn 2017). Additionally, challenges such as unclear definitions, lack of general rules, a multitude of impact- and risk-assessment scoring systems, inadequate funding, and inappropriate or absent legislation have reduced awareness and uptake of management approaches for biological invasions in conservation programs (Courchamp *et al.* 2017; Jarić *et al.* 2020). The resulting concepts, theories, threats, and laws have made it difficult to navigate the field and to disseminate novel findings, especially for decision makers. These challenges have led to insufficient efforts to mitigate biological invasions in tandem with other major global environmental changes (e.g., climate change), resulting in large impacts that potentially could have been circumvented if they had been addressed earlier (Ahmed *et al.* 2022).

Public health and monetary costs are salient metrics to communicate the effects of biological invasions with policy makers and the public (Diagne *et al.* 2021; Zhang *et al.* 2022), and economic impacts represent a familiar and readily standardised measure of impact across contexts. Reliable information on the costs of damage caused by biological invasions and the costs of managing them is also essential for setting priorities and developing effective management strategies (Dana *et al.* 2014; Booy *et al.* 2020). A limitation to overcome is the lack of openly available information on the monetary costs arising from invasive alien species. Overarching attempts to improve governance approaches for greater proactiveness towards invasions, for example by the European Commission (European Union 2014) or the US government (Reid *et al.* 2021; Meyerson *et al.* 2022), have successfully highlighted the importance of invasive alien species control and have formulated management prescriptions. However, such legislation often lacks a strong evidence base, which weakens operational effectiveness (Faulkner *et al.* 2020; Lukey & Hall 2020). The cornerstone of these regulations is the list of priority species at the territorial level, modelled on the list of the world's 100 worst invasive alien species (Lowe *et al.* 2000; Nentwig *et al.* 2018). However, although assessment methods on which these lists are based generally mention the costs caused by invasions, the lack of broad-scale cost information, and the flaws and untested assumptions of many local and regional cost studies (Bradshaw *et al.* 2016; Diagne *et al.* 2021) are major drawbacks.

While broad-scale economic cost estimates had been made previously, they are often based on unsupported extrapolations, unrealistic assumptions or undocumented sources (Pimentel *et al.* 2000, 2001, 2005; Kettunen *et al.* 2009; Pimentel 2011). Fortunately, structured and reproducible syntheses of monetary impacts from biological invasions have gained traction recently through the *InvaCost* database (Diagne *et al.* 2020; Leroy *et al.* 2022). These recent works have profoundly altered the focus of investigation into the monetary costs of alien species across regions and taxonomic scales (Zenni *et al.* 2021), and have demonstrated how effective control can benefit legislators and stakeholders (Ahmed *et al.* 2022; Cuthbert *et al.* 2022). InvaCost has established a sound socio-economic and political foundation for legislative change. Here, we synthesise the advances made through this extended approach, highlighting knowledge gaps and identifying future research avenues. Our main objective is to provide a comprehensive overview of this process, which necessarily includes a detailed description of InvaCost given its recent widespread uptake in the field of invasion costs.

2. Historical lack of accurate cost syntheses

Prior to InvaCost, most attempts to inventory the monetary costs of invasive species at broad scales were fraught with subjectivity, lack of empirical support, and/or speculation (see also Box 1). In many cases, cost estimates were given without citation, were obsolete, referred to untraceable sources such as personal communications with experts or unpublished data, or the sources cited — when cross-referenced — did not report the numbers claimed (see incidences provided in Lovell & Stone 2005; Oreska & Aldridge 2010; Goldstein 2011). Where citations were traceable and reliable, many estimates were crude, arising from overestimation, e.g., a total cost multiplied by the proportion of invasive species among many candidate species within the system; or extrapolations of case studies to the entire (often only suspected) distribution or population size of a particular invasive species. Additionally, many of these regional costs are based on extrapolations that draw from bioeconomic models that go beyond the intended contexts (e.g., Hoagland & Jin 2006; Yemshanov *et al.* 2009; Goldstein 2011; McDermott *et al.* 2013). Moreover, explanations for extrapolations, when provided, often had logical flaws or the multipliers used had no empirical basis (i.e., they were not measured quantitatively) (Goldstein 2011).

Box 1. Urban legends in invasion biology

Perpetuating citations of retracted papers in ecology spreads misinformation and retards research (Cosentino & Veríssimo 2016). An analogous phenomenon occurs in invasion biology, where citations of irreproducible estimates spread unreliable information (Section 2). However, irreproducible estimates can sometimes be concealed within convoluted citation chains.

For example, reviews of the Formosan termite *Coptotermes formosanus* in peer-reviewed journals suggest this species costs nearly US$40 billion year^{-1} globally (Rust & Su 2012; Ahmad *et al.* 2021); many studies cite these reviews to justify this estimate. However, the price tag was an unsubstantiated and unreferenced increase on a previous estimate of US$22 billion year^{-1} (Su 2002), but even that estimate was a dubious speculation extrapolated from a single value of US$1.5 billion year^{-1} for the USA (Su 1994). Digging deeper, it turns out that the USA-wide value came from another source (Su 1991), which was itself extrapolated from an unrefereed report in a symposium proceedings that only gave an unsubstantiated estimate of US$60 million for Hawai'i in 1985.

Therefore, an irreproducible local estimate of US$60 million in 1985 eventually mushroomed — without evidence — into a global value of US$40 billion year^{-1} by 2021, gaining the unwarranted endorsement of peer review in the process. Although this is an egregious example, it is unfortunately not an isolated case (Section 2). We urge invasion biologists to adopt best citation practices (e.g., Teixeira *et al.* 2013; Sanz-Martín *et al.* 2016) to avoid unsubstantiated statements and inflation. We therefore recommend (*i*) not citing a paper that is not itself the source of a monetary value, (*ii*) identifying when the original sources cannot be accessed/confirmed, (*iii*) highlighting uncertainties and inconsistencies in any dubious estimates, and (*iv*) avoiding updating or otherwise modifying previous estimates without providing detailed methods and justifications.

InvaCost has started a procedure to measure and report the reproducibility of each cost record; however, it is a laborious process for the more than 13,000 records currently reported in the database. The onus is therefore on cost reporters to be vigilant, detailed, and authentic.

To demonstrate these issues, consider the four major papers that provided cost estimates of invasive species at a global, national, or regional scale (Pimentel *et al.* 2000, 2001, 2005; Pimentel 2011) prior to the advent of the *InvaCost* database. These four sources, updated in succession, have consistently served as primary references in invasion cost-related studies, to date receiving several thousands of citations, underpinning other influential studies. Despite these acknowledged limitations, values from these publications are still cited today without recognition of the limitations embedded. Although the cost estimates formulated therein were arguably the best and the only available at that time and brought attention to the problem of invasions, in hindsight they all contained serious flaws.

For example, Sagoff (2008) outlined several flaws in the cost values presented, and Holmes *et al*. (2009) identified large biases in the estimates of damages arising from forest pests. Additionally, many values were not accompanied by any supporting citations or raw data, such as the value of 50,000 non-indigenous species having been introduced to the United States. The purported cost of zebra mussels at US$1 billion year^{-1} was not supported (U. S. Department of State 2009), although there were two credible sources citing the costs of this species, both substantially < US$1 billion year^{-1} (O'Neill 1997; U. S. Department of State 2009). Another example in Pimentel's 2011 book cited a cost of US$631 million for West Nile virus, but the corresponding table therein (Table 1) provides no citation, making it difficult for the reader to trace the source. Other references contained costs from non-peer-reviewed sources (e.g., Armstrong 1995) that were themselves based on unpublished reports that were difficult to source. Yet, other calculations were based on unsubstantiated costs, such as those given for rats (*Rattus* spp.) (without citation) as US$15 rat^{-1} year^{-1} and birds killed by cats (US$30 bird^{-1} year^{-1}) (critiqued by Goldstein 2011; Lamb 2013). Similarly, neither the data nor calculations were summarised in Pimentel *et al*. (2001) for the values of introduced mammals to Brazil (Mares *et al.* 1989). Other calculations were based on flawed logic — the total cost of dog bites was given as US$250 million year^{-1}, when most bites are from domestic (pet) dogs and not invasive (stray) dogs. Weeds were reported (U. S. Bureau of the Census 1998) to cause a 12% loss in yield, which translated to US$32 billion year^{-1}. However, this was based on the erroneous assumption that the damage by weed species to crops are distributed equally; a similar line of reasoning was applied to crop insect pests (US$14.4 billion year^{-1}), forest insect pests (US$2.1 billion year^{-1}), plant pathogens for crops (US$21.5 billion year^{-1}), and for forests (US$2.1 billion year^{-1}). Based on an unsubstantiated damage cost of US$200 pig^{-1} year^{-1}, they implicitly assumed that every single pig (*Sus scrofa*) attacks crops and therefore all entail this per-capita cost. This was the same approach taken to estimate the damage arising from starlings (*Sturnus* spp.) (US$800 million year^{-1}).

Perhaps the most egregious example of unsubstantiated estimates concerns the reported cost for fire ants (*Solenopsis* spp.) and Formosan termites (*Coptotermes formosanus*; see also Box 1). The *Solenopsis* estimates were derived from dubious sources (irretrievable: Vinson 1992; from a newspaper: Corn *et al.* 2002), and then simply multiplied by the number of U.S. states where the species were present, to arrive at a total value of US$1 billion year^{-1}. This figure has been cited many times since and continues to garner citations. Other estimates were grounded in ecological *non sequuntur* (Goldstein 2011). For example, if rats (that eat grain and other human commodities) are deemed to cost US$19 billion, and cats (that eat birds) are deemed to cost US$17 billion, but the beneficial impact of cats eating rats is ignored, these values are an overestimate. The papers also confused control and damage costs (Sagoff 2008) — the estimated control cost of one pigeon in a localised survey was multiplied by an unsubstantiated estimate of the total number of pigeons. The resulting value could be interpreted as the cost to control all pigeons (if such a program existed), but was instead claimed to be the cost of the total accrued damage caused by them.

Building on improving previous works that were methodologically flawed, yet widely needed and cited (Pimentel *et al.* 2000, 2005; Kettunen *et al.* 2009), assessments of economic damages due to invasions mostly focused on either few model taxa (Bradshaw *et al.* 2016), specific economic sectors (Paini *et al.* 2016) or ecosystems (Lovell *et al.* 2006), and limited spatial scales (Hoffmann & Broadhurst 2016). Despite their potential shortcomings, most published studies had the benefit of raising awareness on the consequences associated with the monetary burden of invasive alien species. Moreover, while being essential for the purpose of policy, management, and reporting, the lack of an accessible and broad inventory of the monetary costs of invasive alien species hindered improved understanding of the burden of invasions.

Due to the lack of precise cost estimates, flawed syntheses became widely cited and led to unsubstantiated values, which in turn provided ammunition for denialists to challenge the legitimacy of the field. Given this background and limitations in existing cost estimates, there was a clear need for improved calibration and synthesis of the economic costs of biological invasions worldwide, and most importantly including traceability of sources for costs. This need resulted in the creation of an interdisciplinary team of experts from ecology, economy and invasion sciences starting in 2014 (invacost.fr), who together contributed to the public release of the *InvaCost* database (Diagne *et al.* 2020).

3. History of InvaCost

3.1 Evolution of the *InvaCost* database

InvaCost is a global compilation of available estimates of the costs associated with invasive species and largely fills these gaps. Estimates in *InvaCost* are derived largely from peer-reviewed scientific articles and published grey literature, with particular attention paid to reproducibility and data descriptors. The original *InvaCost* database ('v0') only included data related to the damage and management costs incurred by invasive insects, containing 260 entries (i.e., rows of data, each including a cost estimate) at a global scale (Bradshaw *et al.* 2016). The first officially released version of *InvaCost* (v1.0) had grown to 2419 entries by September 2020 (doi:10.6084/m9.figshare.12668570.v1). The next publicly released version (v3.0) included 9823 entries and an associated complementary database consisting mainly of references not yet processed, as well as a database compiling data from 10 non-English languages (Angulo *et al.* 2021b). In June 2021, the number of entries increased to 13123 (v4.0), with the most-recent version (v4.1, January 2022) of *InvaCost* contains 13553 entries and compiles literature in 22 languages (Diagne *et al.* 2022; Kourantidou *et al.* 2022a). Moreover, the InvaCost project now includes a 'living figure' that uses the latest database version to represent the most up-to-date cost breakdowns across geographic and taxonomic contexts graphically (Diagne *et al.* 2021; Leroy *et al.* 2021).

The ongoing growth in cost information inevitably modified summaries of cost trends reported over time (Fig. 1), including number of database entries (Fig. 1a), number of species (Fig 1b), and annual costs (Fig. 1c). These trends each display a similar dynamic, characterised by a rapid accrual of the number of documents reporting costs, number of species reported as the cause, and the costs themselves, followed by an apparent decline in the most recent years. As with other aspects of invasion science, the incurring of economic costs is subject to pervasive time lags due to delays (Essl *et al.* 2011) in (*i*) the official reporting following species establishment, and (*ii*) the potential impacts post-establishment. These delays, particularly those pertaining to eventual publication of monetary cost estimates, explain the apparent decline over the most recent decades (Fig. 1). Several studies have accounted for these delays when summarising temporal trends in costs (Diagne *et al.* 2021; Haubrock *et al.* 2021) by removing or reweighting later ‘incomplete’ years based on the time delay between cost incurrence and reporting (Leroy *et al.* 2022). Nevertheless, excluding recent data or correcting for the lag in reporting as noted by Diagne *et al*. (2021) and Heringer *et al*. (2021), the analysis suggests that the rate and magnitude of invasion costs continue to rise.

3.2 Capturing the multi-faceted nature of invasion costs

There are large differences in how agencies assess the costs of biological invasions, reflecting differing, and sometimes competing, interests at local, regional, and national scales. The earlier attempts on reporting the costs of invasive species focused primarily on the United States (e.g., Pimentel *et al.* 2000, 2005; Pimentel 2011), whereas elsewhere, cost estimates were also provided for several other nations (including Australia, Brazil, India, South Africa, United Kingdom) (Pimentel *et al.* 2001) and European countries (Kettunen *et al.* 2009). These studies were constrained not only by geography, but also by taxonomic coverage, targeted sectors and habitats.

Recognising and addressing such limitations, 23 publications that have used the *InvaCost* database have provided cost assessments on national, regional or continental scales (Fig. 2). Of these, focus has been on nations (e.g., Spain: Angulo *et al.* 2021a; France: Renault *et al.* 2021), an important scale given its correspondence with relevant levels of governance and legal jurisdiction. Others focusing on regional scales (e.g., North America: Crystal-Ornelas *et al.* 2021; Europe: Haubrock *et al.* 2021; Mediterranean: Kourantidou *et al.* 2021) have provided useful comparisons between neighbouring locations or trading partners that face similar invasion threats. Global-scale assessments have provided comparisons of practice across areas with differing political geographies (Bodey *et al.* 2022a) or common management goals (Moodley *et al.* 2022)

In addition, 11 studies have focused on various taxonomic groups (Fig. 2). Taxonomic studies can be 'nested' at different scales, such as analyses of aquatic invaders as a whole (Cuthbert *et al.* 2021) followed by a detailed assessment for invasive fish (Haubrock *et al.* 2022), or a compilation of costs of terrestrial invertebrates (Renault *et al.* 2022a) followed by a specific assessment of ants (Angulo *et al.* 2022). Such distinctions are useful because, while a higher level of classification can reveal the general state of knowledge, different management strategies are often needed for specific taxonomic groups, and organisations/stakeholders can have particular taxonomic foci.

For a more holistic approach, cost assessments have also been provided for other thematic categories, such as habitats (e.g., costs incurred for island conservation) (Bodey *et al.* 2022a), sectoral (e.g., biosecurity and prevention) (Cuthbert *et al.* 2022), conceptual (e.g., additional expenditure due to delayed action or inaction) (Ahmed *et al.* 2022), and generic studies (e.g., increase in cost data by considering non-English sources) (Angulo *et al.* 2021b) (Fig. 2).

Assessments of invasion costs at more macro-scales are important because, without regional or national breakdowns of cost assessments, the motivation for national decision making is lacking. However, these studies have revealed research gaps, particularly for cost estimation in poorly investigated regions such as in many African nations. It is also essential to contextualise and summarise costs at more granular taxonomic, sectoral and geographically localised scales, because this information provides the detailed understanding of the impacts and costs associated with specific species or industries, and can help to prioritise resources and efficiently allocate funding at subnational scales. However, such finer-scale information is often lacking at the resolutions required for effectively targeting responses (Angulo *et al.* 2022; Soto *et al.* 2022). Yet, this additional detail in reporting of costs would provide a more comprehensive understanding of the impacts of biological invasions and, ultimately, contribute to a more effective response to the threat they pose.

3.3 Policy and communication impacts

3.3.1 Policy guidance

The study on environmental and economic costs in the United States by Pimentel *et al.* (2000) has been referred to in 21 policy documents, including a report by the National Research Council (2000) that explores the role of chemical pesticides to identify opportunities for increasing the benefits and reducing the risks of pesticide use, and a report on evidence-based and scientifically robust risk assessments for the prevention and management of the introduction and spread of invasive species (European Commission 2022). Subsequent updates and additions have been cited in 9 (Pimentel *et al.* 2001) and 21 policy documents (Pimentel *et al.* 2005). Pimentel's 2011 book has not appeared in policy documents, and Kettunen *et al.* (2009) is a technical report to guide European environmental policy, with the first full assessment on different environmental, social, and economic costs and benefits across Europe.

A focus of invasion biology research is to raise awareness about the economic costs of biological invasions and to compel policy makers to increase focus on these species. Since its conception in 2014, scientific publications based on the *InvaCost* database have been cited in several notable policy documents. To date, 10 InvaCost studies spanning 5 thematic categories have been cited in at least 8 policy documents or governmental reports. A few prominent examples are (see Supplementary Information Table S2 for sources): (*i*) *General*. A policy guide prepared by the Organisation for Economic Co-operation and Development (OECD) on aligning budgetary and fiscal policy with biodiversity goals for G7 and other countries (Organisation for Economic Co-operation and Development 2021) referred to Diagne *et al*. (2021). The report was designed to inform finance, economic, and environment ministries, emphasising the massive global economic costs of biological invasions, and outlining the transformative changes required to slow biodiversity loss. (*ii*) *Conceptual*. A report from the European Commission that reviewed pre-existing regulations on the prevention, management, and spread of invasive alien species highlighted the importance of timely management (European Commission 2014). The report revisited assumptions made in previous impact assessments and reaffirmed that the costs of inaction or delayed action outweigh the cost of early intervention (Ahmed *et al.* 2022). Also, a recent study demonstrated that the already massive economic costs of biological invasions in the European Union were previously underestimated (Henry *et al.* 2023). (*iii*) *Habitat*. A report by Partnerships in Environmental Management for the Seas of East Asia, which provides guidance to ministers and senior government officials from 11 partner countries (Partnerships in Environmental Management for the Seas of East Asia 2021), is focused on the regional state of oceans and coasts. That report stressed the severe economic impacts of aquatic invasive alien species on native fisheries, agricultural productivity, public utility operations, property values, tourism, and outdoor recreation, as well as the global expenditure of US$345 billion associated with their control (Cuthbert *et al.* 2021). (*iv*) *Geographical*. A scientific report compiled by the Australian Academy of Science highlighted the need for a unified national biosecurity data system, and that the timely and accurate identification of invasive alien species is critical for environmental protection (Australian Academy of Science 2022). The report emphasised that invasive alien species are a serious burden to Australia with ecological, health, and economic impacts, costing an estimated AU$24.5 billion year^{-1} — citing Bradshaw *et al*. (2021a).

There is an inevitable temporal lag between publication and impact of such studies through conversion into practical measures, so the aforementioned examples indicate promising progress in guiding policy and legislative decisions, and with the potential for more to come as more studies continue to reveal these costs.

3.3.2 Media attention

Another key objective of highlighting the economic costs of invasive species is to raise public awareness in a tangible way about the damage caused by biological invasions (Shackleton *et al.* 2019). As for climate change, which costs have been widely documented in successive IPCC reports, the costs of biological invasions are more likely to spark media interest and showcase the relevance and urgency of this issue to their readers. Societal awareness partly determines the level of support, commitment and effectiveness of public policy initiatives, as societies tend to protect only what they recognise as important (Akerlof *et al.* 2013). Yet, general awareness of this issue is still limited, for instance in comparison to climate change (Jarić *et al.* 2020). As such, large-scale research into the costs of biological invasions, and most importantly, frequent scientific publications on the topic, are expected to increase its salience and relevance to media organisations, change public perception of invasive species, and to improve collective support for their management (Novoa *et al.* 2017; Sosa *et al.* 2021).

The Altmetric tool has proved very useful to measure the media 'attention' received by scholarly articles, based on the volume, the importance of the sources, and the authors of media publications, blog and social network posts (see Supplementary Information Table S3 for details on each Invacost-related study). These descriptive statistics highlight the breadth of policy reports, media outlets and social network discussions that InvaCost studies have generated online, demonstrating a current momentum for putting biological invasions on the media agenda. Most importantly, some studies have been prominently featured in the media landscape: 8 studies got an Altmetric score > 100, which, when put in the context of the Altmetric performance of their respective journals, correspond to the top 2% of scientific publications tracked by Altmetric (Diagne *et al.* 2021, Soto *et al.* 2022, Bradshaw *et al.* 2016, Diagne *et al.* 2020, Bradshaw *et al.* 2021a, Cuthbert *et al.* 2022, Cuthbert *et al.* 2021 & Angulo *et al.* 2022). From the earlier works on economic costs of invasive species, the study by Pimentel *et al.* (2000) has an Altmetric score of < 100, but this value is not comparable because this can only be done for research outputs of a similar age or source (Elmore 2018).

Media outreach has also been achieved through the production of magazine articles aimed at scientists, politicians, and the public. Examples include an article on the economic costs of aquatic invasions in *Eco Magazine* (Eco 2021) and *World Fishing and Aquaculture* (World Fishing and Aquaculture 2021), features in *Science for Environment Policy* (European Commission, Directorate-General for Environment 2022) to inform management strategies, as well as *The Environment* (Cuthbert 2022) and *The Conversation* (Bernery *et al.* 2021; Bradshaw & Hoskins 2021; Bradshaw *et al.* 2021b; Courchamp 2021; Soto & Hudgins 2022). Such evidence underscores the importance, interest and applicability of assessing the costs of invasive species for end-users.

3.3.3 Scientific dissemination of socio-economic cost research

In addition to their influence on policy and media uptake, cost syntheses have opened dialogues among scientists from different disciplines in academic and nonacademic organisations and institutions through both scientific publications (Fig. 2) and invited presentations. For example, invited talks to international conferences (e.g., NeoBiota 2020, IUCN congress 2021, INTECOL 2022, International Conference on Aquatic Invasive Species 2022 plenaries, FAO-UN, Global Conference on Sustainable Plant Production) have had a focus on economic cost studies. Such discussion has also enhanced method development and built an increasing consortium of researchers. Invited talks have also been given at regional events (e.g., Alberta Invasive Species Council, Canada's Invasive Species Centre), helping disseminate results to stakeholders, citizens, and decision makers. These events are an immediate form of engagement that can influence future long-term policy changes and research directions.

Citizen science can be a powerful way to disseminate scientific knowledge and raise public awareness. It can be effective in achieving early detection and rapid response objectives (Howard *et al.* 2022), especially if public awareness of problematic invasive species is raised. Successful examples include the case of the network set-up to monitor the invasions of two hornet species causing problems for beekeepers and wildlife: the European hornet (*Vespa crabro*) in Sardinia (Pusceddu *et al.* 2019) and the yellow-legged hornet (*V. velutina*) in Europe (Lioy *et al.* 2019, 2022), the latter being the object of national and international projects that include public mobilisation and engagement (stopvelutina.it; vespavelutina.eu). Therefore, public engagement about the costliest species could improve their monitoring, reporting and allow for more effective management while reducing future potential costs.

4. Post-InvaCost: future directions

4.1 Further development of the *InvaCost* database, version 5.0

InvaCost is a dynamic database, and has therefore evolved over time as more cost entries are added or existing ones are corrected. The living figure provides the most up to date global value of the taxonomic and geographic costs of biological invasions based on the latest version 4.1 (at the time of writing; last updated 15 February 2022) (see Leroy *et al.* 2021). Here, we outline further developments that are currently in the process for the launch of *InvaCost* 5.0.

The maintenance of an up-to-date database ensures ongoing access to the most recent information, but also requires the development of assistance to the users so that they can appreciate the full content and diversity of data descriptors. Improved data accessibility can assist potential users and provide a baseline for environmental decision-making. By developing dashboards where data can be visualised interactively, users can obtain their desired information quickly without requiring programming skills. The development of open-source projects like *InvaCost* should ideally include tools facilitating data exploration such as `shiny`, an R package to build interactive web interfaces for data visualisation. *InvaCost* members are now developing such apps that will assist in creating a more interactive environment for non-experts.

At the same time, expertise from additional disciplines has been added to InvaCost. Previous versions of the *InvaCost* database were assembled primarily by natural scientists, but recently social scientists (e.g., resource economists) have been working to strengthen the economic dimensions associated with the cost data collected. These new efforts encompass a more detailed analysis of the methods used for the estimation of costs in every study, that will ultimately allow for an assessment of the methodology used. The need for a more granular analysis of the methods for every cost entry has arisen from the need to understand whether and to what degree the cited study is reproducible and/or reliable (Box 1). Because the sources of costs vary (e.g., in terms of quality, estimation methods, nature of costs estimated), this analysis will provide a qualitative indicator of each of the entries in the database and will help to better specify the evaluation methods used and the costs assessed. Beyond this, the *InvaCost* database will continuously be developed to standardise the methods of classification so that future contributors can identify these different cost characteristics for every study.

4.2 Improving communication with managers and policy makers

The management of invasive species can often instigate social conflicts, such that managers and policy makers can be mandated to find appropriate compromises that satisfy different groups of stakeholders (Crowley *et al.* 2017). Conjoint considerations of costs and benefits from biological invasions have promoted dialogue to resolve conflicts among stakeholders with different economic and environmental interests (Kourantidou *et al.* 2022a). Moreover, the language used plays a role in effectively communicating the risks and current/potential impacts caused by invasive species to all stakeholders (Copp *et al.* 2021). For example, including non-English cost entries revealed communication gaps between English-speaking scientists and local practitioners (Angulo *et al.* 2021b). However, while information in 21 languages has been added, there remain substantial gaps, particularly across large areas of Africa and Asia where future targeted searches would bolster outreach and the shared knowledge base. Both these language- and benefits-based initiatives could be further advanced to improve our socioeconomic understanding of costs and our ability to address how impacts affect and are distributed across stakeholders.

Future directions to improve communication among stakeholders could involve public, industry, and policy engagement events to raise awareness of the importance and relevance of costs and open-access databases such as *InvaCost*, as well as through implementing more streamlined processes to add data from different regions, cost types, and sources. For example, the French Invasive Alien Species Resource Centre (especes-exotiques-envahissantes.fr) provides a dynamic spatial mapping tool of management feedbacks, where targeted species, the managed area, and in some instances, the cost of management and its effectiveness, can be viewed. These approaches could, in turn, identify the most cost-effective species to manage, independent of their impact. A relevant analogue, *Conservation Evidence* (conservationevidence.com) distils science into decision support for managers to bolster conservation by summarising research, directing actions and providing synopses. Expansion of such initiatives would provide a more comprehensive picture at multiple geographic scales and facilitate the identification of knowledge gaps, thereby allowing policymakers and other stakeholders to improve and optimise strategies (e.g., ideal timing of intervention). Improved resources and better communications with decision makers (e.g., municipalities or ministries) could provide increased awareness for better future recording/classifications of costs, and more reliable cost estimates that could be incorporated in future versions of *InvaCost*. Engaging with affected industries could further catalyse actions by governments, given their operational impacts and policy influence.

Dynamic databases and the resources that flow from them allow for future corrections and updates, such as ensuring old and new taxonomy are aligned to facilitate ongoing regulatory efforts. Because invasive species require adaptive management strategies, such tools enable the assessment of the effectiveness of particular strategies across contexts (after a reasonable period that accounts for lags), and the need for refinement if conditions change (e.g., increased population sizes, ranges, or propagule pressure). This continuous calibration allows for taking proportionate actions while optimising intervention and public expenditure.

4.3 Linking *InvaCost* to other biodiversity databases

Biodiversity databases compile, collate, and standardise information on biological diversity, monitor compositional and functional changes across different levels of biological organisation, provide a basis for exploring relationships between species and their environments, and identify specific geographical, taxonomic, ecological, and other knowledge gaps related to biodiversity. Although challenging, correlating data from different sources is recommended (Hobern *et al.*

2019; König *et al.* 2019). Linking the *InvaCost* database with pre-existing biodiversity databases (e.g., on traits, niche, and genetic datasets) has the potential to provide invasion science with better tools to quantify the links between ecological mechanisms and invasion impacts, and establish relationships between costs, ecosystems composition, and invasion dynamics (Heger *et al.* 2021; Ricciardi *et al.* 2021; Daly *et al.* 2023). Integrating information on costs to a broader spectrum of biological groups (not solely invasive) and invaded socio-ecosystems can provide insights on (*i*) how invasive species impact non-native environments, (*ii*) areas where more resources might be needed (financial, technological, or research), and (*iii*) cost efficiency of current and alternative management options. In particular, this information will enable management efforts to be prioritised on economically vulnerable sites and on the most costly species.

Over the past decade, many online databases and repositories have been established, providing digital information in thousands of primary studies on taxonomic, temporal, and spatial information, allowing broad syntheses (Hardisty *et al.* 2013; Guralnick *et al.* 2016; Dornelas *et al.* 2018). Although the *InvaCost* database has many similarities to those pre-existing databases, it differs in that it serves rather specific purposes of standardising costs of invasive species and therefore has a different structure, content, and functionality. One database that has been used to augment several cost analyses so far is the *Standardising and Integrating Alien Species* workflow (Seebens *et al.* 2020), which includes information from five taxon-specific databases and two cross-taxon databases. This database leverages standardised biodiversity terminology (Darwin Core) to provide the most comprehensive distribution data for invasive species worldwide, with dates of first record wherever available, as well as evidence of impacts. Comparisons to *InvaCost* (Crystal-Ornelas *et al.* 2021) have provided estimates of missing data within the latter to test the predictiveness of first-record dates in invasion costs (Turbelin *et al.* 2023), and measure the total spending burden of invasive species (Cuthbert *et al.* 2022). Even when only considering species deemed impactful in the *Standardising and Integrating Alien Species* workflow — which itself has biases and data gaps — comparisons reveal widespread gaps, especially in taxonomic and geographic coverage. Merging such databases with extrapolations of the real, but unrecorded, cost of invasions will therefore provide a more comprehensive overview of the true economic impact of invasive species.

One of the greatest challenges of connecting biodiversity databases is the lack of standardisation (Feng *et al.* 2022), due to their particular objectives and different protocols for data acquisition and filtration, sometimes requiring specialised training (Maldonado *et al.* 2015). Another shortfall in integrating multiple datasets is the reliability of data entries (Harris 2003) or the lack of data to sustain evidence-based actions (Dickey *et al.* 2020). On the other hand, monetary loss is an international and defined proxy, capable of connecting and quantifying values arising from biodiversity losses. To stimulate the next stage of data integration between *InvaCost* and multiple existing and future derivative databases, automated tools such as machine learning and artificial intelligence should be developed to integrate and analyse these different but complementary data sources (Jeschke *et al.* 2021). Automation could facilitate comparisons to identify taxonomic, geographic, and other research gaps across datasets, thereby providing an evidence-based tool for decision-making within and outside invasion science. A connection with the *Global Biodiversity Information Facility* (gbif.org) could enable the identification of cost gaps at different geographic scales and social demand by integrating citizen science data. Merging existing databases of invasive species' distributions with the *Global Biodiversity Information Facility* could be further leveraged for this purpose (Seebens & Kaplan 2022). For example, understanding social-ecological networks can identify opportunities for cost-effective management and the potential benefits of invasive species (Hulme *et al.* 2017; McGeoch & Jetz 2019).

Within and outside the context of invasive species impacts, there are numerous opportunities for combining this quantitative measure for social and ecological losses to produce more comprehensive databases alongside other biodiversity threats such as climate change and habitat loss/exploitation (Seebens *et al.* 2018; Roxburgh *et al.* 2020; García-León *et al.* 2021).

4.4 Benefits alongside costs of biological invasions

Despite these recent advances in assessing the monetary costs of biological invasions at different spatial and temporal scales, the estimates are rather conservative and currently capture only a fraction of total costs. These knowledge gaps occur because there are many inaccessible, non-monetised, and missing costs, alongside costs from sources that are difficult to assess (e.g., grey literature such as internal reports) (Vaissière *et al.* 2022). The presence of benefits alongside costs has also been contested, given that *InvaCost* only focuses on assessing costs (Sagoff 2020; Boltovskoy *et al.* 2022; Sax *et al.* 2022). Part of this criticism relates to the fact that innocuous species, ancillary costs, and failed eradication programmes are potentially dominating and/or biassing cost analyses at present. Based on selected examples of species, it has also been argued that benefits of invasions might even outweigh costs — for example, the ecosystem services provided by exotic bivalves (Burlakova *et al.* 2022).

Currently, there is no comprehensive database that compiles the benefits of invasions in a way similar to what *InvaCost* does for costs. However, the argument that the presence of benefits lessens the importance or risks conveyed by invasive species does a disservice to natural resource managers and conservation practitioners, and conveys large risks to conservation programs and human wellbeing. This lack of knowledge about the magnitude, origin and distribution of benefits of invasive alien species has been inappropriately used to undermine or refute existing and synthesised estimates of costs (Boltovskoy *et al.* 2022; Sax *et al.* 2022). While it is important to quantify any simultaneous benefits alongside the costs of invasions (Kourantidou *et al.* 2022a), the presence of these benefits cannot be used to undermine the importance of negative impacts or costs. In fact, the presence of benefits from invasions is frequently a path-dependent outcome of the invasion itself. For example, a community might benefit today from a new species only because its introduction degrades a former native species in the region e.g., black wattle *Acacia mearnsii* (de Wit *et al.* 2001), Nile perch *Lates niloticus* (Aloo *et al.* 2017), pirarucu *Arapaima gigas* (Miranda-Chumacero *et al.* 2012), and other invasive fish in the Amazonia region (Doria *et al.* 2021). Even so, costs and benefits are often not directly comparable because they frequently do not impact the same stakeholders, and so likely need to be assessed case by case to avoid drawing incorrect conclusions.

4.5 Promoting cost reporting

InvaCost aims to increase the quantity and quality of cost reporting. Initially, this was done through the catalysing effect of high-profile studies synthesising estimates at different biological, spatial, and sectoral scales (Zenni *et al.* 2021). New scientific, stakeholder, and public awareness, coupled with extensive media coverage, encouraged further primary research to uncover additional costs, and for researchers, stakeholders, and other entities to make existing and emerging costs available for syntheses. Templates to enter cost information into the database, alongside associated explanatory files, examples, and an e-mail account for data submissions (updates@invacost.fr) have all improved cost reporting (Diagne *et al.* 2020). This infrastructure will continue to allow new and updated cost syntheses to be readily constructed, while raising project visibility and increasing international collaborations.

The research network has grown globally and across disciplines, and has enabled many new studies synthesising and analysing costs. The network has grown from a core group of around a dozen scientists in 2019, to over 145 active collaborators today (invacost.fr/en/consortium/experts), with the network also increasing rapidly via positive feedback loops from the pools of connections harnessed from new colleagues. With a wealth of expertise, perspectives, and technical knowledge, these diverse colleagues renew interests in capturing costs under particular contexts related to their core foci (taxonomic, sectoral, geographical), or employ new modelling techniques to extrapolate, and new descriptors to explain documented costs. Examples include studies with new geographic focus instigated by collaborations with scientists from India (Bang *et al.* 2022), New Zealand (Bodey *et al.* 2022b), and Nordic countries (Kourantidou *et al.* 2022b). Other examples are taxon-focussed, including assessments of costs of invasive plankton (Macêdo *et al.* 2022), mammals (Wang *et al.* 2023), and herpetofauna (Soto *et al.* 2022). Aside from leading the analyses and preparing scientific articles, such projects also targeted additional collections of cost data from relevant publications, stakeholders, and organisations. They were often permitted by a foundation of national knowledge and existing connections, as well as breaching language and access barriers.

New research to address missing data has been promoted by InvaCost projects. Because many studies identify gaps in costs, there is now an impetus to collect these missing data. In the past, research has been hampered by a lack of syntheses, meaning that cost assessments have been partly fuelled by positive feedback loops — costly species are well-publicised and continue to accrue scientific attention (and thus costs) (Cuthbert *et al.* 2021). This has contributed to poor coverage of cost assessments for most known invaders globally. Indeed, this is illustrated when comparing the total number of invasive alien species established per country (Fig. 3a) with the total costs reported in the *InvaCost* database (Fig. 3b), and the still low number of invasive alien species included therein (Fig. 3c). However, given the absence of costs and the disparity in values among countries (e.g., countries in Africa), the costs incurred by invasive alien species usually depend on the number of species with reported costs, with a few exceptions (Fig. 3d). A major strength in cost syntheses is therefore not only putting an aggregate monetary value on the negative impacts of biological invasions, but also highlighting knowledge gaps and future research needs.

5. Conclusions

The InvaCost project improves the quality and quantity of reported costs. This information can improve targeting and prioritising of resource investments and/or which species or pathways should be managed. To maximise their utility, we therefore recommend that future studies clearly specify the location(s), cost per species where possible, and the period when the costs occurred. Authors are welcome to adopt the nomenclature used in the *InvaCost* database (Diagne *et al.* 2020; Supplementary Table 4), and while not exhaustive, it is sufficient to encompass the main aspects of the potentially impacted sectors, and describe the type of cost and the management related to the time of introduction (Diagne *et al.* 2020). Promoting improved granularity and quality of cost reporting has therefore been another positive outcome, helping to direct efficient allocation of resources, foster method alignment, and detect overlaps in cost assessments. While InvaCost provides a solid foundation for estimating costs of invasive species, we acknowledge that the derived estimates are merely the tip of the cost iceberg, with the biodiversity and social impacts they entail in particular requiring much additional assessment.

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Statement of authorship

D.A.A., P.J.H., and R.N.C. led organising and writing the first draft, along with C.J.A.B. and F.C. R.N.C. and P.J.H. led Section 1. C.J.A.B. led Section 2. B.L. led writing Box 1. P.J.H., C.J.A.B., and I.S. led Section 3.1. D.A.A., P.J.H. and T.W.B. led Section 3.2. D.A.A. led Section 3.3.1. D.A.A., P.B., I.S., and P.C. led Section 3.3.2. R.N.C. and P.B. led Section 3.3.3. M.K. and D.R. led Section 4.1. R.N.C., F.J.O., D.R., and P.B. led Section 4.2. A.B., R.L.M., E.J.H and D.R. led Section 4.3. A.B., L.C., M.K. led Section 4.4. R.N.C. led Section 4.5. C.J.A.B. and F.J.O. made the figures. All authors contributed to all or most sections of the manuscript.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

Data accessibility statement

All data presented are available via the `invacost` R package. Related code and supplementary data available at github.com/cjabradshaw/InvaCostVersionTrends.

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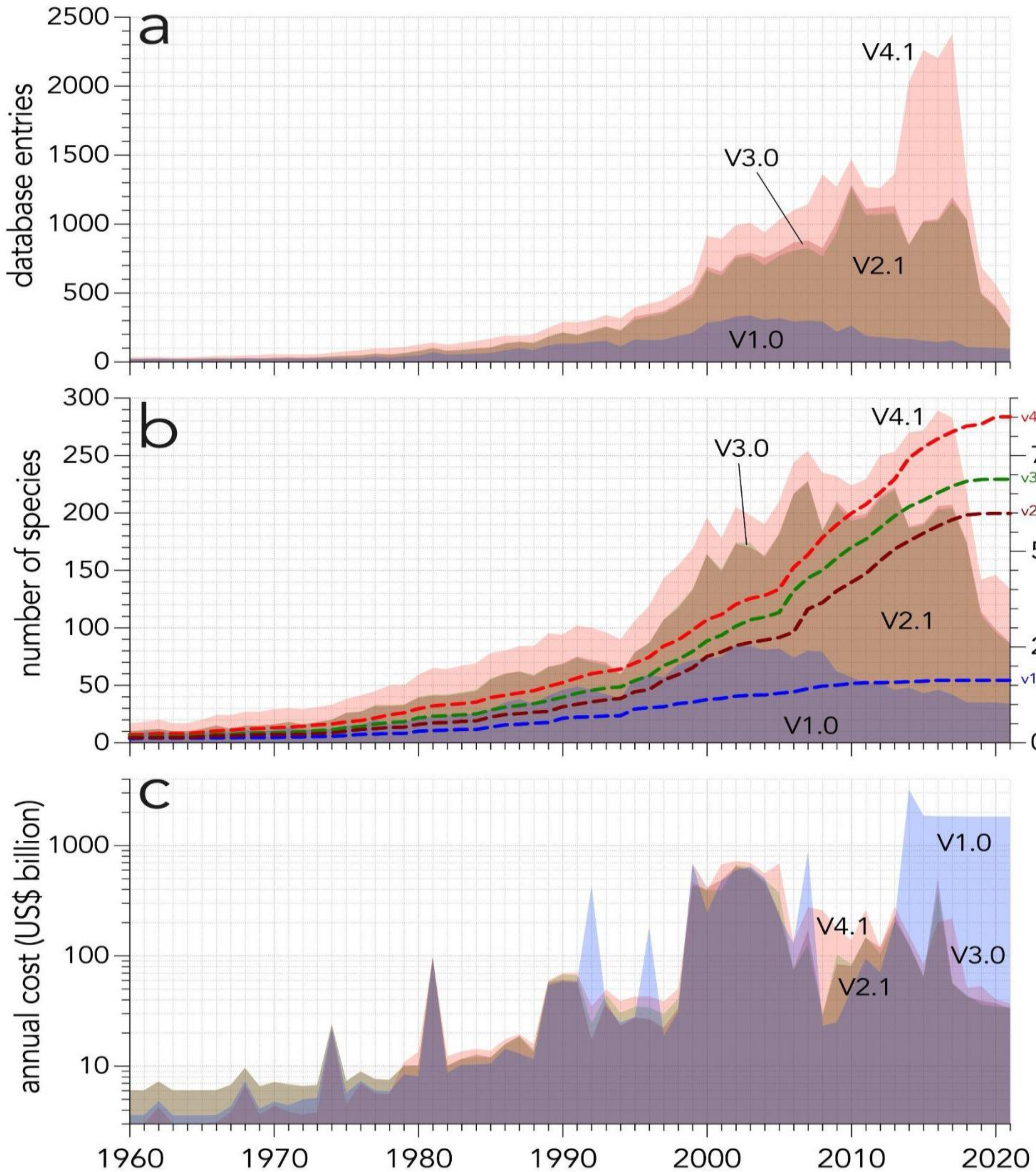
Figure captions

Figure 1 The growth of the living database *InvaCost* from 1960 to 2021, showing temporal trends in (a) recorded database entries, (b) recorded species, including cumulative curves of unique species (dashed lines, right *y* axis; v1.0 = blue; v2.1 = green; v3.0 = brown; v4.1 = red; unidentified/diverse species categories removed), and (c) total costs (without any filter, but *expanded*) among versions v1.0, v2.1, v3.0, and v4.1. The high costs associated with v1.0 in the latter years is due to refinement in subsequent versions and not filtering for cost reliability in the costs presented here. The apparent logistic form of the cumulative number of unique species might arise from the reporting lag in cost data, so should not be taken to indicate saturation. R code to generate the data for these plots available at github.com/cjabradshaw/InvaCostVersionTrends.

Figure 2 A total of 52 research works are based on the *InvaCost* database, with studies spanning several thematic categories: taxonomic (11 studies), conceptual (7), habitat (3), sectoral (3), general (5), and geographical (23). See supporting information S1 for references and the database version used in each study.

Figure 3 Global maps showing (a) number of established invasive alien species per country (based on Briski *et al*., unpublished data; $\log_{10}$ scale), (b) total costs of invasive alien species (US$ billion, 2017 value; $\log_{10}$ scale) per country, (c) number of invasive alien species reported in *InvaCost* per country, and (d) average cost (US$ billion 2017 value) per invasive alien species (sp) reported in *InvaCost* in each country. Blank countries indicate absence of data.

1103 **Figure 1**



1104

Figure 2

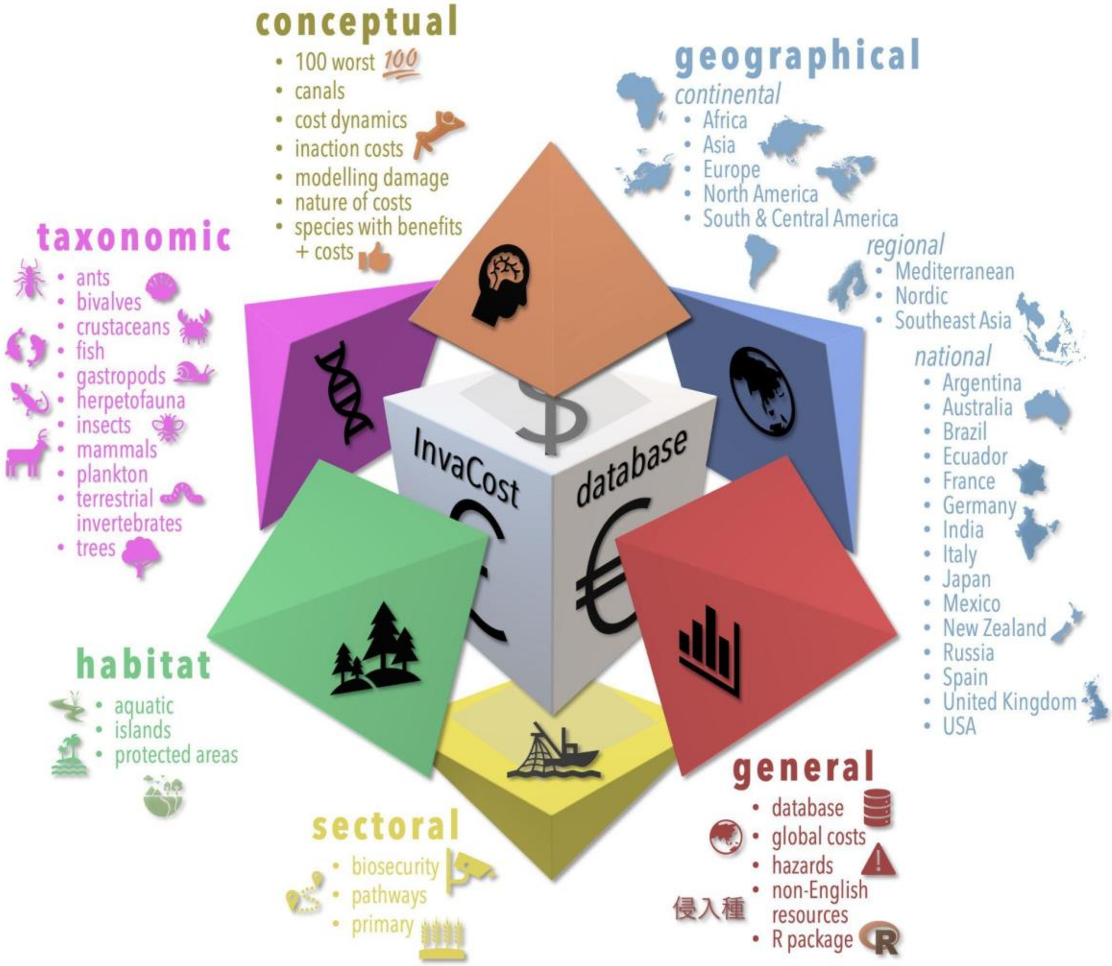
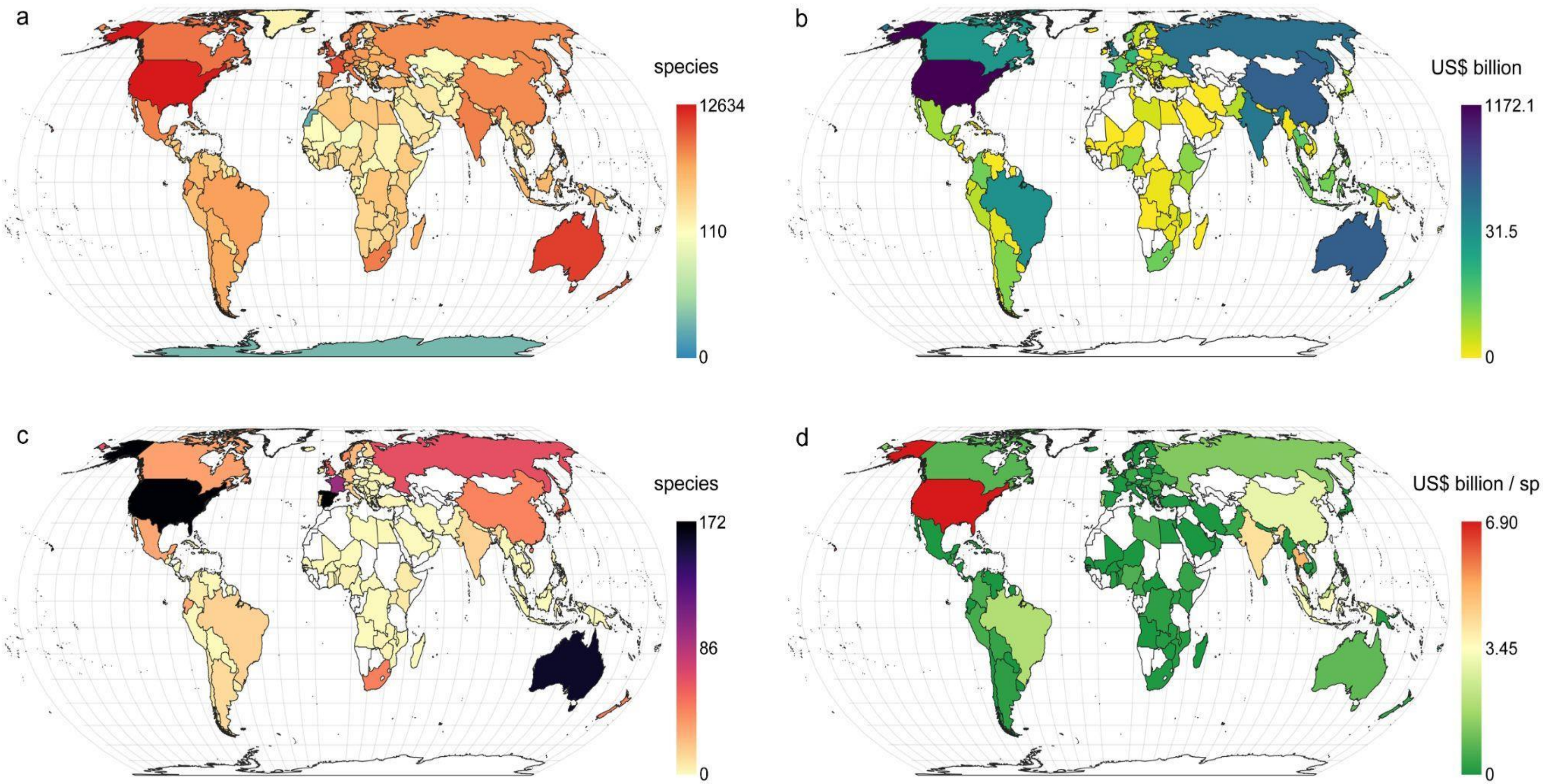

conceptual
100 worst
canals
cost dynamics
inaction costs
modelling damage
nature of costs
species with benefits + costs
geographical
continental
Africa
Asia
Europe
North America
South & Central America
regional
Mediterranean
Nordic
Southeast Asia
national
Argentina
Australia
Brazil
Ecuador
France
Germany
India
Italy
Japan
Mexico
New Zealand
Russia
Spain
United Kingdom
USA
taxonomic
ants
bivalves
crustaceans
fish
gastropods
herpetofauna
insects
mammals
plankton
terrestrial invertebrates
trees
habitat
aquatic
islands
protected areas
sectoral
biosecurity
pathways
primary
general
database
global costs
hazards
non-English resources
R package
侵入種
InvaCost
database

Figure 3


a
species
12634
110
0
b
US$ billion
1172.1
31.5
0
c
species
172
86
0
d
US$ billion / sp
6.90
3.45
0

Supporting Information for Recent advances in availability and synthesis of the economic costs of biological invasions

Ahmed DA, Haubrock PJ, Cuthbert RN, Bang A, Soto I, Balzani P, Tarkan AS, Macêdo RL, Carneiro L, Bodey TW, Oficialdegui FJ, Courtois P, Kourantidou M, Angulo E, Heringer G, Renault D, Turbelin AJ, Hudgins EJ, Liu C, Gojery SA, Arbieu U, Diagne C, Leroy B, Briski E, Bradshaw CJA, Courchamp F

Tables S1–S4 also available as .csv files at github.com/cjabradshaw/InvaCostVersionTrends

Updated on 9th March 2023

Table S1 InvaCost publications List of 52 peer-reviewed articles that have used the InvaCost database, categorised according to themes: taxonomic (11), conceptual (7), habitat (3), sectoral (3) and geographical (23; regional, continental and national). The studies, trees (Fernandez et al. 2022), primary (Turbelin et al. 2023b) are available in preprint repositories, and hazards (Turbelin et al. 2023a) is 'in press'. All other studies are published in journals.

taxonomic				
no.	**category**	**citation**	**reference**	**version**
1	ants	Angulo et al. (2022)	Angulo, E., Hoffmann, B.D., Ballesteros-Mejia, L., Taheri, A., Balzani, P., Bang, A., et al. (2022). Economic costs of invasive alien ants worldwide. Biol. Invasions, 24, 2041–2060 doi:10.1007/s10530-022-02791-w.	4
2	bivalves	Haubrock et al. (2022c)	Haubrock, P.J., Cuthbert, R.N., Ricciardi, A., Diagne, C. & Courchamp, F. (2022). Economic costs of invasive bivalves in freshwater ecosystems. Divers. Distrib., 28, 1010–1021 doi:10.1111/ddi.13501	4
3	crustaceans	Kouba et al. (2022)	Kouba, A., Oficialdegui, F.J., Cuthbert, R.N., Kourantidou, M., South, J., Tricarico, E., et al. (2022). Identifying economic costs and knowledge gaps of invasive aquatic crustaceans. Sci. Total Environ., 813, 152325 doi:10.1016/j.scitotenv.2021.152325	4
4	fish	Haubrock et al. (2022a)	Haubrock, P.J., Bernery, C., Cuthbert, R.N., Liu, C., Kourantidou, M., Leroy, B., et al. (2022). Knowledge gaps in economic costs of invasive alien fish worldwide. Sci. Total Environ., 803, 149875 doi:10.1016/j.scitotenv.2021.149875	4
5	gastropods	Jiang et al. (2022)	Jiang, X., Zheng, P., Soto, I., Haubrock, P.J., Chen, J. & Ji, L. (2022). Global economic costs and knowledge gaps of invasive gastropods. Ecol. Indic., 145, 109614 doi:10.1016/j.ecolind.2022.109614	4.1
6	herpetofauna	Soto et al. (2022)	Soto, I., Cuthbert, R.N., Kouba, A., Capinha, C., Turbelin, A., Hudgins, E.J., et al. (2022). Global economic costs of herpetofauna invasions. Sci. Rep., 12, 10829 doi:10.1038/s41598-022-15079-9	4

7	insects	Bradshaw et al. (2016)	Bradshaw, C.J.A., Leroy, B., Bellard, C., Roiz, D., Albert, C., Fournier, A., et al. (2016). Massive yet grossly underestimated global costs of invasive insects. Nat. Commun., 7, 12986 doi:10.1038/ncomms12986	0
8	mammals	Wang et al. (2023)	Wang, S., Deng, T., Zhang, J. & Li, Y. (2023). Global economic costs of mammal invasions. Sci. Total Environ., 857, 159479 doi:10.1016/j.scitotenv.2022.159479	4.1
9	plankton	Macêdo et al. (2022)	Macêdo, R.L., Franco, A.C.S., Kozlowsky-Suzuki, B., Mammola, S., Dalu, T. & Rocha, O. (2022). The global social-economic dimension of biological invasions by plankton: grossly underestimated costs but a rising concern for water quality benefits? Water Res., 222, 118918 doi:10.1016/j.watres.2022.118918	4
10	trees	Fernandez et al. (2022)	Fernandez, R.D., Haubrock, P.J., Cuthbert, R., Heringer, G., Kourantidou, M., Hudgins, E.J., et al. (2022). Underexplored and growing economic costs of invasive alien trees. SSRN doi:10.2139/ssrn.4196468	4.1
11	terrestrial invertebrates	Renault et al. (2022)	Renault, D., Angulo, E., Cuthbert, R.N., Haubrock, P.J., Capinha, C., Bang, A., et al. (2022). The magnitude, diversity, and distribution of the economic costs of invasive terrestrial invertebrates worldwide. Sci. Total Environ., 835, 155391 doi:10.1016/j.scitotenv.2022.155391	4.1

conceptual				
no.	**category**	**citation**	**reference**	**version**
1	100 worst	Cuthbert et al. (2022a)	Cuthbert, R.N., Diagne, C., Haubrock, P.J., Turbelin, A.J. & Courchamp, F. (2022). Are the “100 of the world’s worst” invasive species also the costliest? Biol. Invasions, 24, 1895–1904 doi:10.1007/s10530-021-02568-7	3
2	canals	Balzani et al. (2022)	Balzani, P., Cuthbert, R.N., Briski, E., Galil, B., Castellanos-Galindo, G.A., Kouba, A., et al. (2022). Knowledge needs in economic costs of invasive species facilitated by canalisation. NeoBiota, 78, 207–223 doi:10.3897/neobiota.78.95050	4.1
3	cost dynamics	Haubrock et al. (2022b)	Haubrock, P.J., Cuthbert, R.N., Hudgins, E.J., Crystal-Ornelas, R., Kourantidou, M., Moodley, D., et al. (2022). Geographic and taxonomic trends of rising biological invasion costs. Sci. Total Environ., 817, 152948 doi:10.1016/j.scitotenv.2022.152948	3
4	inaction costs	Ahmed et al. (2022b)	Ahmed, D.A., Hudgins, E.J., Cuthbert, R.N., Kourantidou, M., Diagne, C., Haubrock, P.J., et al. (2022). Managing biological invasions: the cost of inaction. Biol. Invasions, 24, 1927–1946 doi:10.1007/s10530-022-02755-0	4
5	modelling damage costs	Ahmed et al. (2022a)	Ahmed, D.A., Hudgins, E.J., Cuthbert, R.N., Haubrock, P.J., Renault, D., Bonnaud, E., et al. (2022). Modelling the damage costs of invasive alien species. Biol. Invasions, 24, 1949–1972 doi:10.1007/s10530-021-02586-5	1
6	nature of costs	Vaissière et al. (2022)	Vaissière, A.-C., Courtois, P., Courchamp, F., Kourantidou, M., Diagne, C., Essl, F., et al. (2022). The nature of economic costs of biological invasions. Biol. Invasions, 24, 2081–2101 doi:10.1007/s10530-022-02837-z	4

7	species with benefits + costs	Kourantidou et al. (2022a)	Kourantidou, M., Haubrock, P.J., Cuthbert, R.N., Bodey, T.W., Lenzner, B., Gozlan, R.E., et al. (2022). Invasive alien species as simultaneous benefits and burdens: trends, stakeholder perceptions and management. Biol. Invasions, 24, 1905–1926 doi:10.1007/s10530-021-02727-w	4

habitat				
no.	**category**	**citation**	**reference**	**version**
1	aquatic	Cuthbert et al. (2021b)	Cuthbert, R.N., Pattison, Z., Taylor, N.G., Verbrugge, L., Diagne, C., Ahmed, D.A., et al. (2021). Global economic costs of aquatic invasive alien species. Sci. Total Environ., 775, 145238 doi:10.1016/j.scitotenv.2021.145238	3
2	islands	Bodey et al. (2022a)	Bodey, T.W., Angulo, E., Bang, A., Bellard, C., Fantle-Lepczyk, J., Lenzner, B., et al. (2022). Economic costs of protecting islands from invasive alien species. Conserv. Biol., e14034 doi:10.1111/cobi.14034	4
3	protected areas	Moodley et al. (2022)	Moodley, D., Angulo, E., Cuthbert, R.N., Leung, B., Turbelin, A., Novoa, A., et al. (2022). Surprisingly high economic costs of biological invasions in protected areas. Biol. Invasions, 24, 1995–2016 doi:10.1007/s10530-022-02732-7	4

sectoral				
no.	**category**	**citation**	**reference**	**version**
1	biosecurity	Cuthbert et al. (2022b)	Cuthbert, R.N., Diagne, C., Hudgins, E.J., Turbelin, A., Ahmed, D.A., Albert, C., et al. (2022). Biological invasion costs reveal insufficient proactive management worldwide. Sci. Total Environ., 819, 153404 doi:10.1016/j.scitotenv.2022.153404	4

2	pathways	Turbelin et al. (2022)	Turbelin, A.J., Diagne, C., Hudgins, E.J., Moodley, D., Kourantidou, M., Novoa, A., et al. (2022). Introduction pathways of economically costly invasive alien species. Biol. Invasions, 24, 2061–2079 doi:10.1007/s10530-022-02796-5	4
3	primary	Turbelin et al. (2023b)	Turbelin, A.J., Hudgins, E.J., Catford, J.A., Cuthbert, R.N., Kourantidou, M., Roiz, D., et al. (2023). Biological invasions as burdens to primary economic sectors. Res. Sq. doi:10.21203/rs.3.rs-2444595/v1	4.1

general				
no.	**category**	**citation**	**reference**	**version**
1	database	Diagne et al. (2020)	Diagne, C., Leroy, B., Gozlan, R.E., Vaissière, A.-C., Assailly, C., Nuninger, L., et al. (2020). InvaCost, a public database of the economic costs of biological invasions worldwide. Sci. Data, 7, 277 doi:10.1038/s41597-020-00586-z	1
2	global costs	Diagne et al. (2021a)	Diagne, C., Leroy, B., Vaissière, A.-C., E. Gozlan, R., Roiz, D., Jarić, I., et al. (2021). High and rising economic costs of biological invasions worldwide. Nature, 592, 571–576 doi:10.1038/s41586-021-03405-6	1
3	hazards	Turbelin et al. (2023a)	Turbelin, A.J., Cuthbert, R.N., Essl, F., Haubrock, P.J., Ricciardi, A. & Courchamp, F. (2023a). Biological invasions are as costly as natural hazards. Perspect. Ecol. Conserv., in press	4.1
4	non-English sources	Angulo et al. (2021b)	Angulo, E., Diagne, C., Ballesteros-Mejia, L., Adamjy, T., Ahmed, D.A., Akulov, E., et al. (2021). Non-English languages enrich scientific knowledge: the example of economic costs of biological invasions. Sci. Total Environ., 775, 144441 doi:https://doi.org/10.1016/j.scitotenv.2020.144441	3

5	R package	Leroy et al. (2022)	Leroy, B., Kramer, A.M., Vaissière, A.-C., Kourantidou, M., Courchamp, F. & Diagne, C. (2022). Analysing economic costs of invasive alien species with the invacost R package. Methods Ecol. Evol., 13, 1930–1937 doi:10.1111/2041-210X.13929	4

geographical				
no.	**category**	**citation**	**reference**	**version**
continental				
1	Africa	Diagne et al. (2021b)	Diagne, C., Turbelin, A.J., Moodley, D., Novoa, A., Leroy, B., Angulo, E., et al. (2021). The economic costs of biological invasions in Africa: a growing but neglected threat? NeoBiota, 67, 11–51 doi:10.3897/neobiota.67.59132	3
2	Asia	Liu et al. (2021)	Liu, C., Diagne, C., Angulo, E., Banerjee, A.-K., Chen, Y., Cuthbert, R.N., et al. (2021). Economic costs of biological invasions in Asia. NeoBiota, 67, 53–78 doi:10.3897/neobiota.67.58147	1
3	Europe	Haubrock et al. (2021d)	Haubrock, P.J., Turbelin, A.J., Cuthbert, R.N., Novoa, A., Taylor, N.G., Angulo, E., et al. (2021). Economic costs of invasive alien species across Europe. NeoBiota, 67, 153–190 doi:10.3897/neobiota.67.58196	1
4	North America	Crystal-Ornelas et al. (2021)	Crystal-Ornelas, R., Hudgins, E.J., Cuthbert, R.N., Haubrock, P.J., Fantle-Lepczyk, J., Angulo, E., et al. (2021). Economic costs of biological invasions within North America. NeoBiota, 67, 485–510 doi:10.3897/neobiota.67.58038	3
5	South and Central America	Heringer et al. (2021)	Heringer, G., Angulo, E., Ballesteros-Mejia, L., Capinha, C., Courchamp, F., Diagne, C., et al. (2021). The economic costs of biological invasions in Central and South America: a first regional assessment. NeoBiota, 67, 401–426 doi:10.3897/neobiota.67.59193	3
regional				

6	Mediterranean	Kourantidou et al. (2021)	Kourantidou, M., Cuthbert, R.N., Haubrock, P.J., Novoa, A., Taylor, N.G., Leroy, B., et al. (2021). Economic costs of invasive alien species in the Mediterranean basin. NeoBiota, 67, 427–458 doi:10.3897/neobiota.67.58926	3
7	Nordic	Kourantidou et al. (2022b)	Kourantidou, M., Verbrugge, L.N.H., Haubrock, P.J., Cuthbert, R.N., Angulo, E., Ahonen, I., et al. (2022). The economic costs, management and regulation of biological invasions in the Nordic countries. J. Environ. Manage., 324, 116374 doi:10.1016/j.jenvman.2022.116374	4.1
8	Southeast Asia	Haubrock et al. (2021c)	Haubrock, P.J., Cuthbert, R.N., Yeo, D.C.J., Banerjee, A.K., Liu, C., Diagne, C., et al. (2021). Biological invasions in Singapore and Southeast Asia: data gaps fail to mask potentially massive economic costs. NeoBiota, 67, 131–152 doi:10.3897/neobiota.67.64560	3
national				
9	Argentina	Duboscq-Carra et al. (2021)	Duboscq-Carra, V.G., Fernandez, R.D., Haubrock, P.J., Dimarco, R.D., Angulo, E., Ballesteros-Mejia, L., et al. (2021). Economic impact of invasive alien species in Argentina: a first national synthesis. NeoBiota, 67, 329–348 doi:10.3897/neobiota.67.63208	3
10	Australia	Bradshaw et al. (2021)	Bradshaw, C.J.A., Hoskins, A.J., Haubrock, P.J., Cuthbert, R.N., Diagne, C., Leroy, B., et al. (2021). Detailed assessment of the reported economic costs of invasive species in Australia. NeoBiota, 67, 511–550 doi:10.3897/neobiota.67.58834	1
11	Brazil	Adelino et al. (2021)	Adelino, J.R.P., Heringer, G., Diagne, C., Courchamp, F., Faria, L.D.B. & Zenni, R.D. (2021). The economic costs of biological invasions in Brazil: a first assessment. NeoBiota, 67, 349–374 doi:10.3897/neobiota.67.59185	3

12	Ecuador	Ballesteros-Mejia et al. (2021)	Ballesteros-Mejia, L., Angulo, E., Diagne, C., Cooke, B., Nuñez, M.A. & Courchamp, F. (2021). Economic costs of biological invasions in Ecuador: the importance of the Galapagos Islands. NeoBiota, 67, 375–400 doi:10.3897/neobiota.67.59116	3
13	France	Renault et al. (2021)	Renault, D., Manfrini, E., Leroy, B., Diagne, C., Ballesteros-Mejia, L., Angulo, E., et al. (2021). Biological invasions in France: alarming costs and even more alarming knowledge gaps. NeoBiota, 67, 191–224 doi:10.3897/neobiota.67.59134	3
14	Germany	Haubrock et al. (2021a)	Haubrock, P.J., Cuthbert, R.N., Sundermann, A., Diagne, C., Golivets, M. & Courchamp, F. (2021). Economic costs of invasive species in Germany. NeoBiota, 67, 225–246 doi:10.3897/neobiota.67.59502	3
15	India	Bang et al. (2022)	Bang, A., Cuthbert, R.N., Haubrock, P.J., Fernandez, R.D., Moodley, D., Diagne, C., et al. (2022). Massive economic costs of biological invasions despite widespread knowledge gaps: a dual setback for India. Biol. Invasions, 24, 2017–2039 doi:10.1007/s10530-022-02780-z	3
16	Italy	Haubrock et al. (2021b)	Haubrock, P.J., Cuthbert, R.N., Tricarico, E., Diagne, C., Courchamp, F. & Gozlan, R.E. (2021). The recorded economic costs of alien invasive species in Italy. NeoBiota, 67, 247–266 doi:10.3897/neobiota.67.57747	3
17	Japan	Watari et al. (2021)	Watari, Y., Komine, H., Angulo, E., Diagne, C., Ballesteros-Mejia, L. & Courchamp, F. (2021). First synthesis of the economic costs of biological invasions in Japan. NeoBiota, 67, 79–101 doi:10.3897/neobiota.67.59186	3

18	Mexico	Rico-Sánchez et al. (2021)	Rico-Sánchez, A.E., Haubrock, P.J., Cuthbert, R.N., Angulo, E., Ballesteros-Mejia, L., López-López, E., et al. (2021). Economic costs of invasive alien species in Mexico. NeoBiota, 67, 459–483 doi:10.3897/neobiota.67.63846	3
19	New Zealand	Bodey et al. (2022b)	Bodey, T.W., Carter, Z.T., Haubrock, P.J., Cuthbert, R.N., Welsh, M.J., Diagne, C., et al. (2022). Building a synthesis of economic costs of biological invasions in New Zealand. PeerJ, 10, e13580 doi:10.7717/peerj.13580	4
20	Russia	Kirichenko et al. (2021)	Kirichenko, N., Haubrock, P.J., Cuthbert, R.N., Akulov, E., Karimova, E., Shneider, Y., et al. (2021). Economic costs of biological invasions in terrestrial ecosystems in Russia. NeoBiota, 67, 103–130 doi:10.3897/neobiota.67.58529	1
21	Spain	Angulo et al. (2021a)	Angulo, E., Ballesteros-Mejia, L., Novoa, A., Duboscq-Carra, V.G., Diagne, C. & Courchamp, F. (2021a). Economic costs of invasive alien species in Spain. NeoBiota, 67, 267–297 doi:10.3897/neobiota.67.59181	3
22	United Kingdom	Cuthbert et al. (2021a)	Cuthbert, R.N., Bartlett, A.C., Turbelin, A.J., Haubrock, P.J., Diagne, C., Pattison, Z., et al. (2021). Economic costs of biological invasions in the United Kingdom. NeoBiota, 67, 299–328 doi:10.3897/neobiota.67.59743	3
23	USA	Fantle-Lepczyk et al. (2022)	Fantle-Lepczyk, J.E., Haubrock, P.J., Kramer, A.M., Cuthbert, R.N., Turbelin, A.J., Crystal-Ornelas, R., et al. (2022). Economic costs of biological invasions in the United States. Sci. Total Environ., 806, 151318 doi:10.1016/j.scitotenv.2021.151318	3

Table S2 Compilation of policy documents that have referenced InvaCost studies. See also supporting information Table S1 for complete citation for each InvaCost study.

policy document (citation)	published date	link (DOI/URL)	InvaCost studies cited (citation)	thematic category
OECD (2021), "Biodiversity, natural capital and the economy: A policy guide for finance, economic and environment ministers", OECD Environment Policy Papers, No. 26, OECD Publishing, Paris.	May-21	doi:10.1787/1a1ae114-en	Diagne et al. (2021a), global	general
Australian Academy of Science (2022). Australia's data-enabled research future: Science.	Jun-22	science.org.au/supporting-science/science-policy-and-analysis/reports-and-publications/australias-data-enabled-research-future-science	Bradshaw et al. (2021), Australia	geographical
European Commission, Directorate-General for Environment, Nesbit, M., Whiteoak, K., Underwood, E., et al., Biodiversity financing and tracking : final report, Publications Office of the European Union, 2022.	May-22	doi:10.2779/950856	Haubrock et al. (2021d), Europe	geographical
IPPC Secretariat. 2022. Report on the analysis to support the transition to a sustainable Implementation Review and Support System (IRSS). Rome, FAO on behalf of the Secretariat of the International Plant Protection Convention.	Sep-22	doi:10.4060/cc0799en	Cuthbert et al. (2021b), aquatic	habitat

Report from the commission to the EU parliament and the council on the review of the application of Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species.	Oct-21	eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0628	Diagne et al. (2021a), global Cuthbert et al. (2021b), aquatic Ahmed et al. (2022b), inaction costs	general habitat conceptual
Regional State of Ocean and Coasts 2021: The East Asian Seas Region (Volume 1).	Jun-22	app.overton.io/document.php?policy_document_id=pemsea-30680e5825f82040e533f9a66eff2dd9	Cuthbert et al. (2021b), aquatic	habitat
European Commission, Directorate-General for Environment, Study on invasive alien species : development of risk assessments to tackle priority species and enhance prevention : final report, Publications Office of the European Union, 2022.	Dec-22	https://data.europa.eu/doi/10.2779/5726	Kouba et al. (2022), crustaceans Angulo et al. (2022), ants	taxonomic taxonomic

Table S3 News articles Altmetric scores, examples of news stories with associated outlets, and number of tweets. The examples provided are those captured either by Altmetric or PlumX and therefore the media coverage listed below is not exhaustive.

taxonomic							
no.	**category**	**citation**	**Altmetric (or PlumX)**	**news story examples**	**associated outlet(s)**	**news stories (outlets)**	**tweets (users)**
1	ants	Angulo et al. (2022)	101	Le formiche invasive sono una minaccia più grande del previsto	*National Geographic*	6 (5)	96 (86)
				Invasive ants are a bigger threat than we thought	*NewsBeezer*, *MSN*, *National Geographic*		
				Cuantifican los efectos de las hormigas invasoras	*Catalunya Avanguardista*		
				El coste económico provocado por el impacto de las hormigas invasoras alcanza los 46.000 millones de euros	*Dicyt*		
2	crustaceans	Kouba et al. (2022)	PlumX	The Signal Crayfish: The Cost of Invasion	*The Orkney News*	2 (2)	-
				Hohe wirtschaftliche Schäden durch invasive Krebstiere	*Wissenschaft.de*		
3	fish	Haubrock et al. (2022a)	PlumX	-	-	-	28
4	gastropods	Jiang et al. (2022)	PlumX	-	-	-	16
5	herpetofauna	Soto et al. (2022)	626	BEYOND LOCAL: Invasive species are causing billions of dollars in damages globally	*TimminsToday.com*	98 (76)	40 (35)
				Costs of amphibian and reptile invasions exceeded US$17 billion between 1986 and 2020	*Phys.org, Swift Telecast, Nature Asia, Whats new, Environewsbits*		
				Environment: Costs of amphibian and reptile invasions exceeded US$ 17 billion between 1986 and 2020	*EurekAlert!*		

no.	category	citation	Altmetric (or PlumX)	news story examples	associated outlet(s)	news stories (outlets)	tweets (users)
				Invasive reptiles have cost the global economy billions	*Earth*		
				Invasive species bullfrog and snake cost world $16bn - study	*BBC News*		
6	insects	Bradshaw et al. (2016)	622	Invasive insects cost the world billions per year	*Seed daily, Environment institute blog*	70 (57)	247 (209)
				Invasive insects—an underestimated cost to the world economy	*Phys.org*		
				Global costs of invasive insects	*DNA barcoding*		
				Flexible Reproduction 'Mite' Explain Invasion Success	*Entomology today*		
				Invasive tawny crazy ants have an intense craving for calcium – with implications for their spread in the US	*Environewsbits*		
7	mammals	Wang et al. (2023)	PlumX	李义明研究团队揭示外来哺乳动物入侵的全球货币成本	*ScienceNet.cn*	1 (1)	-
8	terrestrial invertebrates	Renault et al. (2022)	PlumX	-	-	-	18

conceptual							
no.	**category**	**citation**	**Altmetric (or PlumX)**	**news story examples**	**associated outlet(s)**	**news stories (outlets)**	**tweets (users)**
1	100 worst	Cuthbert et al. (2022a)	155	-	-	-	235 (215)
2	canals	Balzani et al. (2022)	6	-	-	-	10
3	cost dynamics	Haubrock et al. (2022b)	PlumX	Geographic and taxonomic trends of rising biological invasion costs	*DocWireNews*	1 (1)	1
4	inaction costs	Ahmed et al. (2022b)	20	-	-	-	42 (33)

5	modelling damage costs	Ahmed et al. (2022a)	12	-	-	-	22 (20)
6	nature of costs	Vaissière et al. (2022)	13	-	-	-	25 (21)
7	species with benefits + costs	Kourantidou et al. (2022a)	16	-	-	-	37 (28)

habitat

no.	category	citation	Altmetric (or PlumX)	news story examples	associated outlet(s)	news stories (outlets)	tweets (users)
1	aquatic	Cuthbert et al. (2021b)	PlumX	University Of Florida Scientist Helps Perfect Tool To Reduce Invasive Species Worldwide	*NewsBreak*	3	130
				Aquatic invasive species cause billions of dollars in damage	*Phys.org*		
				Aquatic invasive species cause damage worth billions of dollars	*EurekAlert!*		
2	protected areas	Moodley et al. (2022)	34	-	-	-	62 (54)

sectoral

no.	category	citation	Altmetric (or PlumX)	news story examples	associated outlet(s)	news stories (outlets)	tweets (users)
1	biosecurity	Cuthbert et al. (2022b)	PlumX	Invasive reptile and amphibian species are causing billions of dollars in damages globally	*Phys.org, The Conversation, NewsBreak*	4 (9)	63
				Invasive species prevention 'could save trillions'	*Eco-Business, SciDev.net, SciDev.Net: Asia & Pacific*		

				Rack of squirrel, anyone? The chefs putting invasive species on the menu	*MSN UK, The Guardian: Environment News,*		
				Capitol rioter who dressed as Jack Skellington on Jan. 6 will be donning prison garb for up to 8 years	*Raw Story*		
2	pathways	Turbelin et al. (2022)	9	-	-	-	18 (17)

general							
no.	**category**	**citation**	**Altmetric (or PlumX)**	**news story examples**	**associated outlet(s)**	**news stories (outlets)**	**tweets (users)**
1	database	Diagne et al. (2020)	296	BEYOND LOCAL: Invasive species are causing billions of dollars in damages globally	*TimminsToday.com*	32 (21)	217 (187)
				Invasive reptile and amphibian species are causing billions of dollars in damages globally	*Winnipeg free press, Futures tradingCharts.com, Phys.org, Foregin Affairs New Zealand, Phys.org, Newsbreak, The conversation*		
				Invasive species have cost UK at least £5bn since 1970s, study reveals	*Google News, Yahoo! News, Newsbreak, The Guardian*		
				Attack of the alien invaders	*COSMOS magazine, Newsbreak, The conversation*		
				Ecology: Global cost of biological invasions(Scientific Data)	*Nature Asia*		
2	global costs	Diagne et al. (2021a)	1033	Pests are destroying Canada's trees — and a warming climate threatens to send more insects north	*MorningNews*	72 (61)	869 (786)

				Invasive species are costing the world billions every year	*The Boar*		
				Pest plants and animals leave a frightening $1.7 trillion bill	*Brazil News.net, Newsbreak, The conversation*		
				Attack of the alien invaders: Pest plants and animals leave a $1.7 trillion bill	*Phys.org*		
				Invasive exotic species: how much are they costing us?	*MarketScreener*		
3	non-English sources	Angulo et al. (2021b)	PlumX	Pest plants and animals leave a frightening $1.7 trillion bill	South Africa Today	2 (3)	501
				Attack of the alien invaders: Pest plants and animals leave a $1.7 trillion bill	Phys.org, The Conversation		

geographical							
no.	**category**	**citation**	**Altmetric (or PlumX)**	**news story examples**	**associated outlet(s)**	**news stories (outlets)**	**tweets (users)**
continental							
1	Africa	Diagne et al. (2021b)	6	-	-	-	7 (7)
2	Asia	Liu et al. (2021)	9	-	-	-	14
3	Europe	Haubrock et al. (2021d)	64	Fremmede arter koster milliarder	*ABC Nyheter*	3 (3)	58 (44)
				La costosa invasione delle specie aliene in Europa	*Green Report (Italy)*		
				I danni delle specie invasive in Europa crescono di 10 volte ogni decennio	*Innovazione*		
4	North America	Crystal-Ornelas et al. (2021)	41	More Than 400 Invasive Fish Dumped From Aquariums Found in Texas River	*Smithsonian magazine*	1 (1)	48 (39)
5	South and Central America	Heringer et al. (2021)	11	-	-	-	22 (19)
regional							
6	Mediterranean	Kourantidou et al. (2021)	24	-	-	-	38 (30)

7	Nordic	Kourantidou et al. (2022b)	PlumX	-	-	-	2
8	Southeast Asia	Haubrock et al. (2021c)	10	-	-	-	19 (15)
national							
9	Argentina	Duboscq-Carra et al. (2021)	28	-	-	-	57 (43)
10	Australia	Bradshaw et al. (2021)	204	To lock out foot-and-mouth disease, Australia must help its neighbor countries bolster their biosecurity	*Phys.org, Futures TradingCharts.com, Yahoo! News, The conversation, Newsbreak*	27 (19)	133 (65)
				Rapid response team tackles invasive species	*Australian Greens, Mirage News*		
				Fish robots put a scare into invasive species	*COSMOS magazine*		
				Pest plants and animals cost Australia around $25 billion a year – and it will get worse	*Outlook India, Devdiscourse, Mirage news, Newsbreak*		
				Ryegrass, fire ants and feral cats: major Australian study identifies costliest pests in past 60 years	*MSN, The Guardian*		
11	Brazil	Adelino et al. (2021)	12	-	-	-	7 (7)
12	Ecuador	Ballesteros-Mejia et al. (2021)	6	-	-	-	10 (9)
13	France	Renault et al. (2021)	92	A new species of flatworm in our gardens that comes from Asia: Humbertium covidum	*Phys.org, Foregin affairs New Zealand, Global advisors, The conversation*	7 (6)	66 (55)
				Biodiversité : Pourquoi les « invasions biologiques » coûtent (vraiment) très cher à la France	*MSN*		
				News story from 20minutes on Wednesday 15 September 2021	*20minutes*		
				Les invasions biologiques, un fardeau économique pour la France	*The conversation*		

14	Germany	Haubrock et al. (2021a)	6	-	-	-	10 (9)
15	India	Bang et al. (2022)	47	Colonialism Changed the Way Plants Are Distributed Around the World: Study	*The Wire*	4 (4)	34 (23)
				Poorly planned plantation drives are helping invasive species bloom in India	*Moneycontrol.com*		
				भारत में घुसपैठ कर गए जीव-जंतुओं से हो रहा लाखों-करोड़ों का नुकसान	*Yourstory*		
				“Aliens” have cost the Indian economy $127 billion over 60 years	*Quartz*		
16	Italy	Haubrock et al. (2021b)	7	-	-	-	6 (6)
17	Japan	Watari et al. (2021)	34	-	-	-	56 (56)
18	Mexico	Rico-Sánchez et al. (2021)	5	-	-	-	9 (7)
19	New Zealand	Bodey et al. (2022b)	-	-	-	-	11
20	Russia	Kirichenko et al. (2021)	5	-	-	-	9 (7)
21	Spain	Angulo et al. (2021a)	28	-	-	-	43 (34)
22	United Kingdom	Cuthbert et al. (2021a)	110	European Colonialism Has Had A Lasting Legacy On How Plants Are Distributed Around The World	*Futures TradingCharts.com, Foreign affairs New Zealand, Yahoo! News, The conversation*	15 (10)	47 (35)
				Specieswatch: run rabbit – why they are disappearing from the countryside	*MSN, Newsbreak, Yahoo! News, The Guardian*		
				Fremmede arter koster milliarder	*ABC Nyheter*		
				Invasive species cost UK economy over £5 billion over past 40-50 years	*Envirotec Magazine, Google News, Yahoo! News, Newsbreak, The Guardian*		
23	USA	Fantle-Lepczyk et al. (2022)	PlumX	Noble false widows: The tiny spiders taking a big bite out of British and Irish wildlife	*Phys.org, The Conversation*	7	64
				the tiny spiders taking a big bite out of British and Irish wildlife	*United Kingdom KNews.MEDIA*		
				Rat killers in paradise: An eradication program remakes a tropical atoll	*Mongabay*		

				Auburn University researcher co-authors study determining economic impact of invasive species in US exceeds $1.2 trillion	*RocketNews, Agri Marketing*		
				Invasive Species Cost The US $21 Billion Per Year, Study Finds	*FocusOn Equipment Rentals*		

Table S4 Summary of the descriptors *Type of cost merged* and *Management type* used in *InvaCost* database. The complete summary of the descriptive columns of *InvaCost* is available at: github.com/Farewe/invacost/blob/master/data-raw.

Type of cost merged	**Categories of the Type of cost column reassigned**
Damage	Economic losses due to direct and/or indirect impacts of invaders, such as yield loss, health injury, land alteration, infrastructure damage, or income reduction.
Management	In a broad sense of management. When monetary resources are allocated to mitigate the spread or impacts of invaders, such as prevention, control, research, long-term management (*sensu stricto*), eradication.
Mixed	When costs included both 'damage' and 'management' components.
Unspecified	Every cost for which the nature of cost was not clearly defined.
Management type	**Management in a broad sense in relation to the moment of the invasive species introduction**
Pre-invasion management	Monetary investments for preventing successful invasions in an area — including quarantine or border inspection, risk analyses, biosecurity management, etc.
Post-invasion management	Money spent for species management in invaded areas - including control, eradication, containment.
Knowledge/funding	Money allocated to all actions and operations that could be of interest at all steps of management at pre- and post-invasion stages — including administration, communication, education, research, etc.
Mixed	When costs include at least (and without possibility to disentangle the specific proportion of) two of the previous categories.
Unspecified	Every cost for which the nature of cost was not clearly defined.
NA	Every entry that has partly or fully associated with damage costs was assigned.

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