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# Is the number of non-native species in the European Union saturating?

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## Abstract

**Background** Non-native species can have significant negative impacts on the environment, economies, and amongst others, also human well-being, among other factors. Globalisation and economic incentives have substantially facilitated the growth in the numbers of newly recorded non-native species in the European Union. The European Union's diversity in terms of political and socio-economic differences across member states may have contributed to the introduction of non-native species.

**Results** Data reported in the *Alien Species First Record Database*, however, suggests a decreasing trend in the number of non-native species recorded over the past three decades. *InvaCost*, a database of non-native species with economic impacts, similarly shows increasing numbers of reported non-native species with costs until the 2010s, which were, however, followed by a plateauing and ultimately decline. Although the recent trends in non-native species reports may be affected by a lag time in reporting and data allocation as well as possibly a disparity in research efforts, their impacts persist, leading to a growing ecological but also economic burden. We further identified substantial spatial differences as western European member states generally reported higher numbers of non-native species and non-native species with monetary impacts.

**Conclusions** Without improved actions, biological invasions and their associated impacts will continue to rise, degrading natural capital and hampering sustainable development and sustainability targets. Therefore, improved coordinated efforts across the European Union are necessary to improve reporting of non-native species and a centralized collation of data through accessible databases should be considered.

**Keywords** Ecological impact, Economic burden, Biological invasion, Sustainability, Biodiversity

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## Background

In recent years, the study of non-native species has become a prominent topic in ecology, as they can have major impacts on native communities and ecosystems [3, 31]. Long-term records of non-native species introductions have provided valuable information for studying temporal dynamics and processes of biological invasions as they present high-quality data on their distribution and demography, enabling quantitative assessments of impacts and potential risks [13, 15, 24, 46]. These records can also be used to assess the effectiveness of management strategies or to identify emerging threats from newly introduced non-native species [41], i.e., those that eventually become invasive. The importance of long-term non-native species records is particularly evident when considering the scale of species introductions, as large-scale introductions or spread can have major impacts on ecosystems or economy [4, 47]. Long-term data therefore present the unique ability to track these changes over time, being ultimately essential for understanding and mitigating the negative effects of biological invasions [23].

Despite the importance of long-term data for understanding the ecology, and most of all invasion history and dynamics of non-native species, there is a growing concern whether non-native species records are saturating over space and time [42]. Saturation occurs when new species introductions are unlikely to be detected due to the fact that all potential habitats and pathways have already been colonised or that no new non-native species is introduced. Whilst some studies suggest that non-native species records are reaching a point of saturation and that individual species may saturate in their local abundance, thereby limiting their ability and/or incentive to spread [47], new introductions may continue to occur and these records remain useful for monitoring changes in non-native species distributions over time [17]. Hence, the importance of understanding the saturation of non-native species records extends beyond simply understanding the spread of these species as it can also inform conservation strategies and management decisions [30]. For example, if records are saturating, it may be necessary to shift management efforts from preventing the introduction of new non-native species to rather focus on control and eradication efforts for those species already established. In addition, understanding patterns of non-native species records can inform the allocation of resources for monitoring and management, allowing for a more efficient use of limited resources and a reduction of the public expense. These decisions become increasingly important on larger scales, such as at the national or supra-national level, where the number of non-native species records can become overwhelming [14].

This is especially important at the level of political organisations like the European Union, which relies on transnational agreements and international regulations that must be received by each individual member state and translated into laws to tackle the threat of non-native species. The European Union regulates the matter of invasive species with the *Invasive Alien Species Regulation*, which aims to prevent and reduce the impacts of the introduction and spread of such species within the Union by requiring the member states to take action for the prevention and management of these species within their territories [10]. This regulation is accompanied by a series of regulations which list the species of Union concern and are regularly updated, currently listing 88 species [11] and it is being followed by also candidate countries like Turkey (<http://teriasturk.org/>). Here, we used the two most recent and complete databases on non-native species, the *Alien Species First Record Database* and *InvaCost*, to infer the number of non-native species over time in the European Union. We hypothesised that reports of non-native species introductions—albeit differing across taxonomic groups—are still increasing, far from saturating, resulting in a lagging but also increasing number of non-native species with detectable impacts.

## Methods

To determine whether the number of non-native species recorded in the European Union and its individual member states saturate over time, we used the two most recent and comprehensive databases for non-native species: the *Alien Species First Record Database* which details the first year a non-native species was first recorded in a given country [40] and *InvaCost*, the most up-to-date database on monetised impacts of non-native species [6]. Using the records within each database, we used saturation curves with the *specaccum* function of the *vegan* R package [26] to identify temporal patterns in the number of non-native species recorded after the year 1492 (by convention the year in which species introductions became relevant [8]), for the European Union, each of its member states, and individual taxonomic groups (mammals, birds, fishes, amphibians, reptiles, crustaceans, insects, arachnids, molluscs, vascular plants, algae, and fungi). In the former's case, we used only the first year of every non-native species recorded in the *Alien Species First Record Database* to avoid double-counting. We used cumulative non-native species richness as it will take on the shape of a logistic curve when saturating, as a decrease in newly described species (i.e., reaching an inflection point) will ultimately lead to a plateau [15]. Cumulative curves were considered to be plateauing if values of the recorded species were within  $\pm 0.5$  of the range of the asymptotic number of records

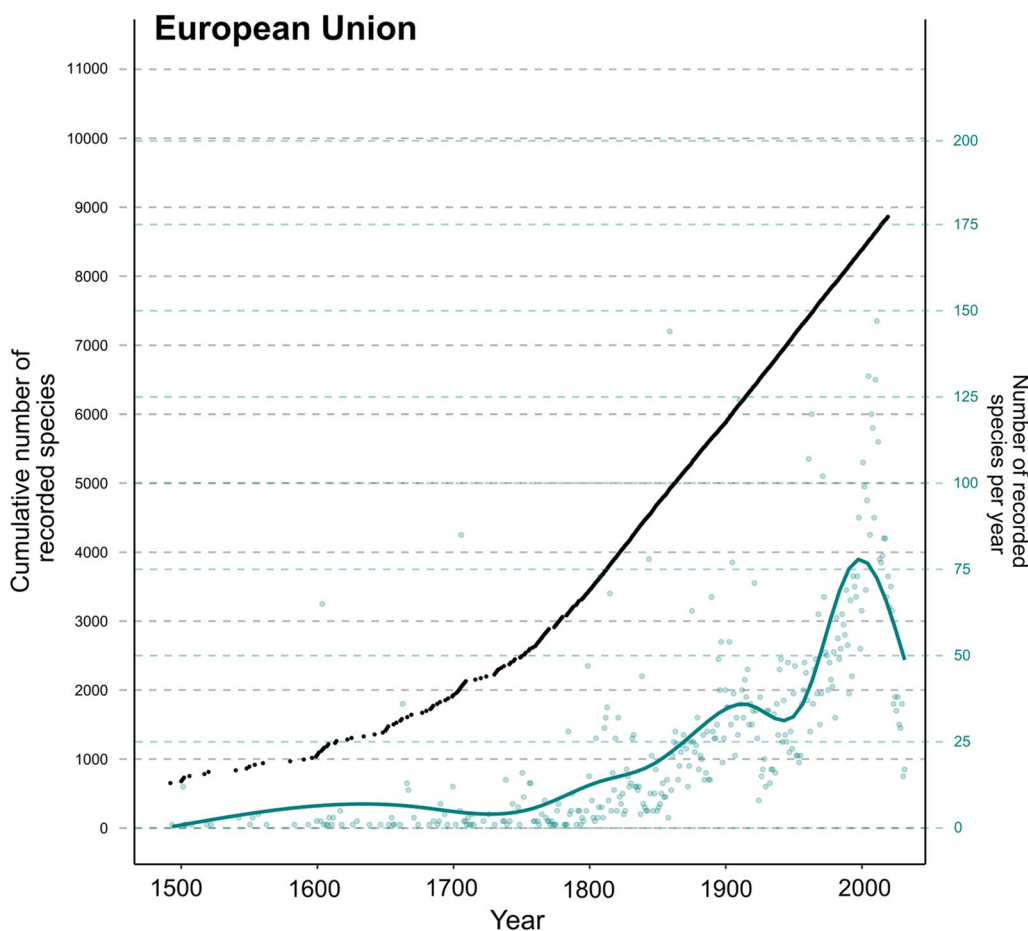
(see [27]). In addition, we plotted the number of non-native species recorded per decade to infer larger temporal trends. Finally, we investigated spatial patterns in the distribution of non-native species reported in the *Alien Species First Record Database* ([40], <https://doi.org/10.12761/sgn.2016.01.022>) and those with costs reported in *InvaCost* across European Union member states to identify if specific European regions are more prone to report non-native species. The results are discussed in the light of our findings.

**Results**

Focussing on the period post-1492, the first record of a non-native species in the European Union was the oriental red flea *Xenopsylla cheopis*, recorded in 1492. Since then, the number of non-native species has accumulated to a total of 9237 recorded non-native species. At the level of the European Union, the cumulative number of newly recorded non-native species as recorded in the *Alien Species First Record Database* showed no

sign of saturation (Fig. 1), albeit annual values of the 2000s ( $n=788$ ) and 2010s ( $n=336$ ) remaining substantially below the peak in the 1990s ( $n=1082$ ), indicating a decline in annually newly recorded non-native species per year since then. Across the different European Union member states, cumulative trends also showed no indication of reaching an inflection point or trend towards a plateau, whilst decadal trends across European Union member states differed substantially, as several countries did not show a steep incline in the last decades (Additional file 1). Several countries indicate consistent numbers of new species introduced in the last decades (see e.g., Belgium, France, or Greece; Additional file 1), whilst others showed clear signs of decreasing records of new non-native species (see e.g., Lithuania, Poland, or Romania; Additional file 1).

Across taxonomic groups, non-native vascular plants recorded in the European Union were the most numerous ( $n=5136$ ), followed by non-native insects ( $n=1595$ ), non-native birds, fish, crustaceans, molluscs, and algae



**Fig. 1** Cumulative number of non-native species recorded in the European Union (black) and new non-native species recorded per decade (blue) based on the *Alien Species First Record Database* [40]. Visualisation focussed on the period 1492 to 2021

(all  $n > 250$ ), non-native mammals, and fungi (both  $n > 75$ ), and finally non-native amphibians, arachnids, and reptiles (both  $n > 25$ ). Cumulative numbers of recorded non-native species increased almost linearly, whereas records per year decreased across all groups after the 1990s, and in the case of non-native vascular plants after the beginning of the twentieth century (Fig. 2).

Focussing on non-native species with monetised economic impacts recorded in *InvaCost* over time, we found the first species with monetised costs to be the Chinese mitten crab *Eriocheir sinensis* recorded in Germany in 1912. Plotting newly recorded non-native species over time indicated no saturation, suggesting that the number of new non-native species with monetisable costs was still growing. Whilst 2012 saw the highest number of new non-native species with costs ( $n=29$ ), the number of newly recorded non-native species declined afterwards. Annually recorded non-native species with costs increased over time in a similar way as newly recorded non-native species, reaching a peak with  $n=108$  species in 2013. After 2013, the number of non-native species with costs recorded per year remained constantly above  $n=90$  species per year, before declining after 2017 (Fig. 3).

Across European Union member states, we identified a clear pattern in the recording of new non-native species, being generally higher in Central and Western European member states, being contrasted by lower numbers of reported non-native species in Eastern European member states. The member state with the highest number of recorded non-native species was Belgium ( $n=3204$ ), whilst the member state with the lowest number of recorded non-native species was Luxembourg ( $n=34$ ; Fig. 4a; Additional file 2). A different spatial pattern was found for records of non-native species with reported monetary impacts in *InvaCost*. Member states with the most non-native species with costs recorded were solely in South-Western Europe (France and Spain, but not Portugal), whilst Eastern member states reported less records. The member state with the highest number of recorded non-native species with costs was Spain ( $n=204$ ), whereas the member states with the lowest number of reported species were Estonia, Lithuania, Luxembourg, and Malta (all  $n=1$ ; Fig. 4b). No species-specific costs were reported from Latvia.

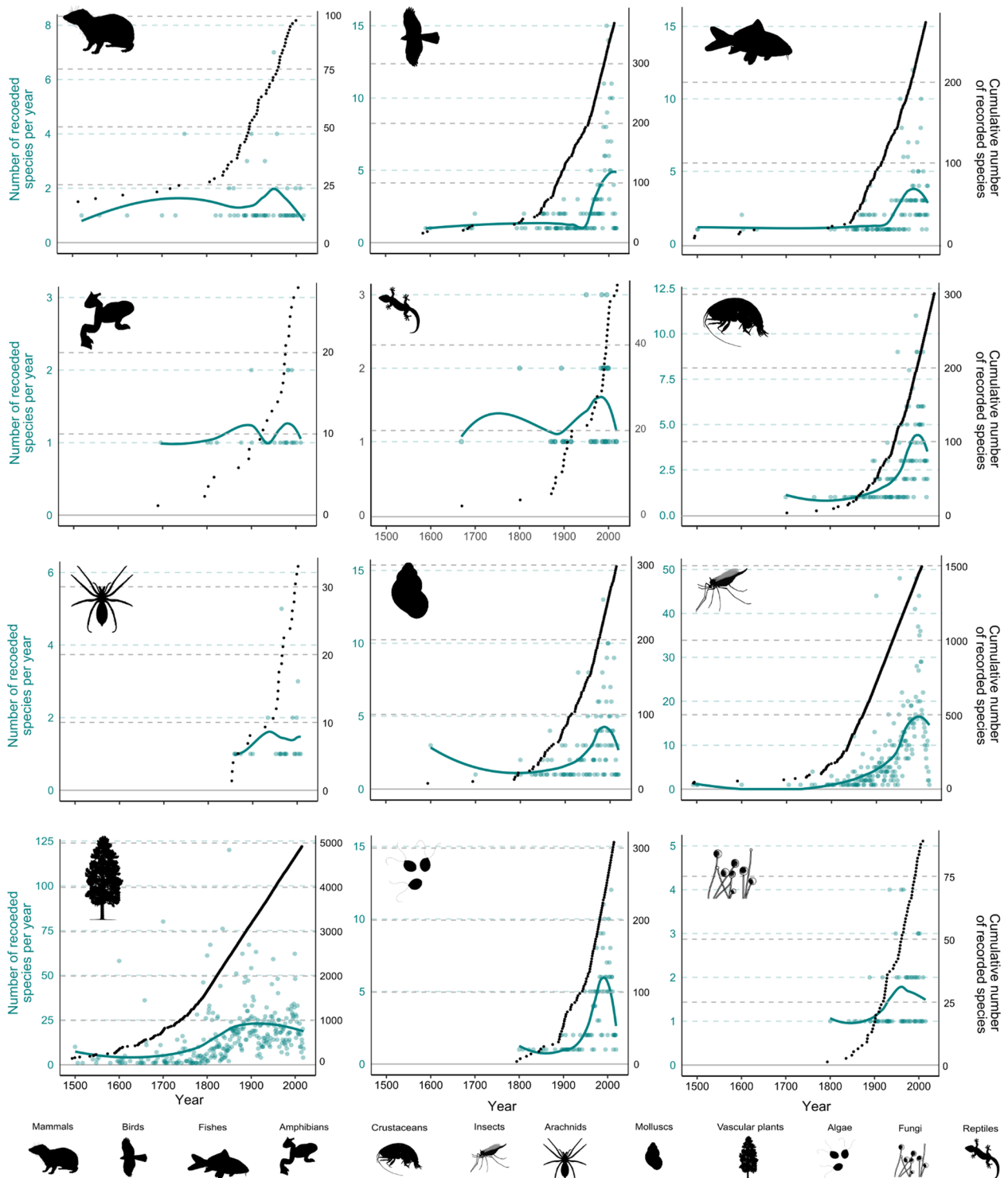
## Discussion

Non-native species can present a considerable economic or ecological burden, especially on the environment, the economy, or human health and well-being [45]. Continental Europe, and therefore the 27 member states of the European Union, has been a historic centre of trade, human migration, and tourism, being therefore

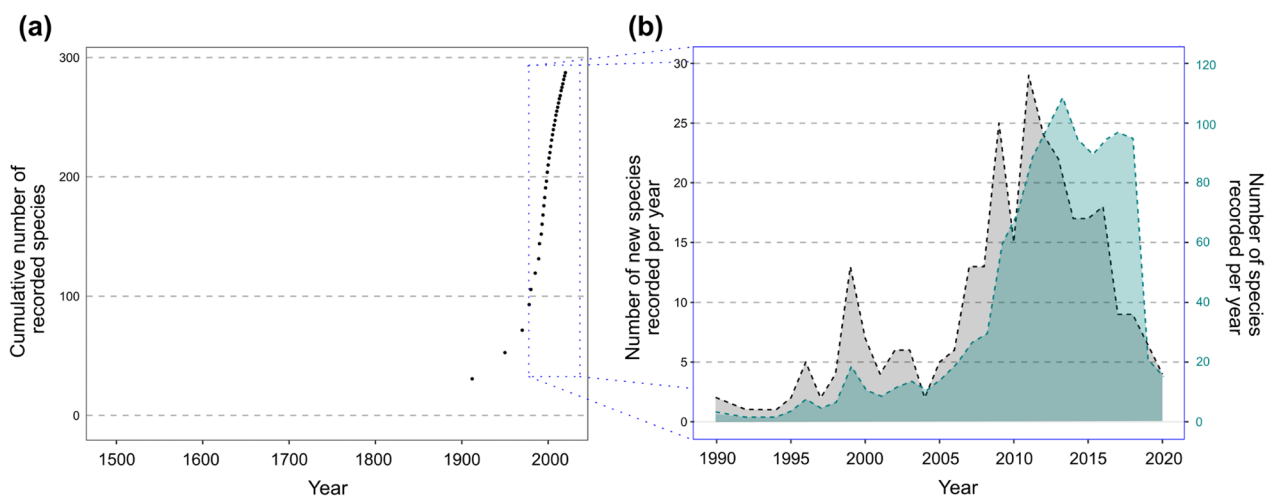
particularly susceptible to biological invasions [52]. Here, we found that whilst at the level of the European Union the cumulative number of newly recorded non-native species was increasing over the last 500 years, non-native species introductions declined in the last two decades. This was also true for recorded non-native species with a monetised impact, suggesting an overall recent amelioration in trends.

The *Alien Species First Record Database* describes the year a new non-native species is first recorded in a specific country. It does not follow up on the potential non-native species' success in establishing or spreading. Based purely on the number of first records, we found that the cumulative number of recorded non-native species across the European Union was increasing steeply. Yet, it is possible that several member states have—due to their individual history of trade and socio-economic development [20]—already reached an inflection point, trending towards a plateau which may not yet be visible. The number of non-native species recorded per year—for each taxonomic group and individual European Union member state—also revealed a decreasing trend over the past decades, contrasting recent findings that suggest increasing trends by 2050 [42]. Whilst cumulative trends can be misleading and falsely suggest growing introduction rates, annually recorded data on recorded species are more adequate in reflecting changes in introduction rates [25]. However, it should be highlighted that even decreasing annual reports of non-native species result in a net positive increase in the cumulative number. It is moreover possible that the steep incline at the level of the European Union itself can be the result of the (bio)-diverse nature and differences across member states, but also their socio-economic differences [48] contributing to the introduction of non-native species [20], which levelled off in recent decades. One particularly important driver of non-native species introductions in the past was globalisation [21]. Globalisation is however retreating, as not at last due to COVID-19 pandemic [43, 49] more and more countries reverted to more national-centred politics [1, 28, 37]. This will ultimately affect the number of non-native species introduced and those finally established, therefore causing measurable ecological or economic impacts.

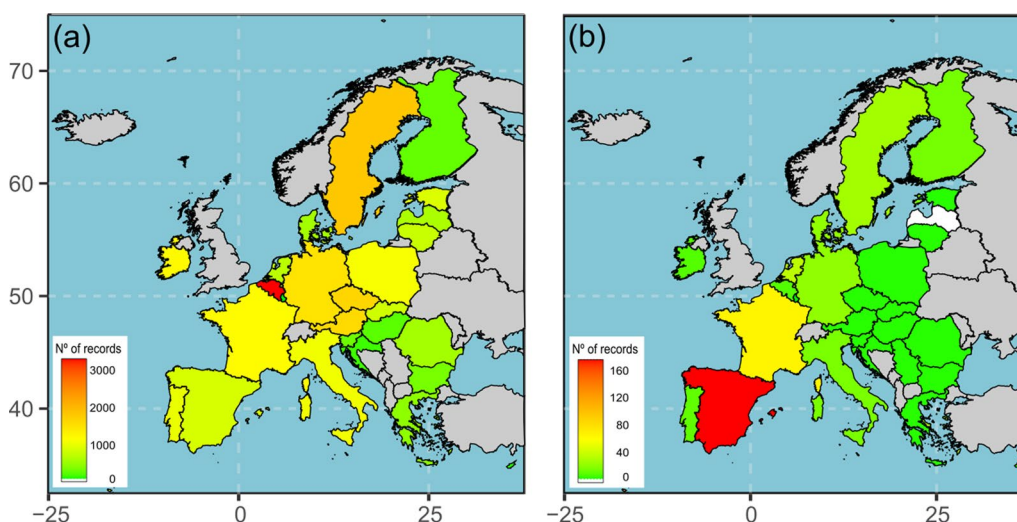
Without engulfing into the debate of how to define an invasive species or the ratio of non-native species ultimately becoming invasive [33, 35], the fact that many non-native species cause monetisable impacts cannot be neglected [6]. Using *InvaCost* to infer temporal trends in the number of non-native species causing economic damages in the European Union over time, we found increasing numbers of reported non-native species with costs until the 2010s, followed by a plateau and ultimately



**Fig. 2** Cumulative number of non-native species recorded in the European Union (black) and new non-native species recorded per decade (blue) based on the *Alien Species First Record Database* [40] broken down by taxonomic group. Visualisation focussed on the period 1492 to 2021



**Fig. 3** Cumulative number of non-native species recorded in the European Union based on the *Alien Species First Record Database* (a) and annually recorded non-native species with costs vs. the number of new non-native species with costs recorded per year based on *InvaCost* (b)



**Fig. 4** Number of recorded non-native species based on the *Alien Species First Record Database* (a) and number of non-native species with reported monetary impact in *InvaCost* (b) by European Union member states

a decline. Whilst it is possible that new introductions are actually slowing down, it is also possible that this final decline observed in both annually recorded non-native species and non-native species with costs are just an artefact resulting from a previously identified lag time in reporting [6], a temporal disparity in research efforts [16], and the periods for which literature was searched for [2]. The decline of new invader species in Western European countries may however also be influenced by reduced recording efforts due to financial constraints or delayed reporting, which could potentially skew the observed decline. Trends in reporting until the 2010s do indeed suggest growing numbers of new non-native species with

reported monetised impacts. However, it is possible that the recent transboundary legislation (i.e., the EASIN Catalogue, <https://easin.jrc.ec.europa.eu> or the Regulation EU 1143/2014 on invasive species, European Union, 2014) is succeeding in its aim to slow down the influx of non-native species and to minimise their impacts [36, 50]. Declining trends in recent years of newly recorded non-native species and those with costs do not necessarily mean that the manifold issues caused by non-native species are going to disappear. This is, as even stable or declining introduction rates of non-native species will still be net positive, therefore causing a continuous growth in the measurable impacts of non-native species

as a whole. Increasing impacts from non-native species, including a growing economic burden, could exacerbate an already difficult period of geopolitical tension [29], at the cost of natural resources and biodiversity. The identified growing socio-economic impacts of non-native species [6, 9] and the current persistent misallocation of strategic investment [18], mean that non-native species are altering many aspects of human life, and placing an additional burden on human and social well-being [31]. Rising resource losses and damages due to non-native species could ignite further political debates amongst European Union member states (i.e., on reparations for damages caused by certain species) and affect conservation and research budgets. This relative instability could weaken the European Union in the future following recent crises (e.g., COVID-19 pandemic, Brexit, Russian invasion of Ukraine [32, 39]), and result in reduced attention to environmental challenges, such as those of biological invasions. Considering these ongoing economic stressors within the European Union [32], our results warn against the pattern of reduced investment in environmental management [5, 12]. Without improved actions, the rates of biological invasions and associated impacts will continue to rise, degrading natural capital, and hampering industries, sustainable development, and sustainability targets [19]. In the light of increasing numbers of introduced non-native species, this ultimately underlines the need for a coordinated effort across the European Union to improve reporting of non-native species and centralise collation of data through accessible databases.

The numbers of non-native species with reported economic impacts were generally underreported when compared to the number of reported non-native species overall, ranging from 0.1% in Estonia (1 of 851 species) to 19.9% in Spain (162 of 813 species). Across the European Union, Belgium and Luxembourg were the two member states with the highest and respectively the lowest number of recorded non-natives species in the *Alien Species First Record Database*, and Spain and France the member states with the most non-native species with monetary impacts recorded in *InvaCost*. Differences amongst neighbouring countries like Belgium and Luxembourg may simply represent differences in size (as larger areas relate to more introduction events just by chance and thus, more species reported), albeit both countries being small in comparison to other European Union member states. However, it is impossible to discriminate the effect of the country size from e.g., their continental position, international trade and connectivity, and colonisation history [20]. In addition, we identified a considerable gradient between western European countries with tententially higher numbers and eastern

European countries with lower numbers of reported non-native species. Although socio-economic arguments that could explain this trend are manifold [7, 14, 38], historical differences in trade [20], and differences in research effort [16] arguably contributed considerably to the observed differences. These differences could also be due to a combination of different factors including the climate, type of ecosystems, history of introductions, level of knowledge (i.e. research beginning later and information being less available in eastern Europe) and drivers of use (e.g. more common angling activities in western part favouring the accidental introductions through a strong propagule pressure [51]). It is therefore possible that non-native species reported in either database are underreported or generally lower in eastern European member states. Concomitantly, it is possible that (i) the cumulative number of non-native species described here is far from saturating, as species present in eastern European member states can spread into central and western European member states (and vice versa), or (ii) reporting of non-native species in eastern European member states is lagging, but will overlap taxonomically with species already reported in other European countries, therefore underlining the saturation of non-native species reported in European Union member states.

## Conclusion

The impacts of non-native species can be manifold, negatively affecting a multitude of (environmental and socio-economic) dimensions [45]. If economic impacts, which are the focus of *InvaCost*, are to be seen as a proxy for other forms of negative impacts caused by non-native species [22, 44] whilst considering at the same time that non-native species can have a multitude of different impacts across a large spatio-temporal gradient and ultimately ignoring the lag time in reporting, negative impacts of non-native species are likely to grow exponentially. The European Union, with its 27 member states, already hosts several thousands of established non-native species, although the number of those species with assessed impacts is considerably lower. Renault et al. [34] for example found that from the minimum of 2621 non-native species established in France, only 98 (<4%) have reported economic impacts. Indeed, whilst not all non-native species will ultimately cause a monetisable damage or management expenditure, the identified disparity between non-native species richness and those with economic costs suggests that the actual economic, but also ecological burden on the economy of the European Union is much greater [14]. This disparity further underlines the urgent need for more detailed impact assessments for non-native species, but also indicates that in the foreseeable future, management efforts should be

redirected from predominantly biosecurity and prevention actions [31] to the eradication of established non-native species populations and the restoration of natural biodiverse ecosystems.

## Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12302-023-00752-1>.

**Additional file 1.** Country-specific plots breakdown in the cumulative number of non-native species recorded in the European Union and new non-native species recorded per decade based on the *Alien Species First Record Database* [40]. Visualisation focused on the period 1492 to 2021.

**Additional file 2.** Recorded non-native species reported in the *Alien Species First Record Database* [40] and the number of recorded non-native species with monetary impacts reported in InvaCost [6].

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## Author contributions

PJH, AST and RM analysed the data. PB and AST contributed to the writing of the first version of the manuscript. All authors contributed to the writing of the manuscript and the interpretation of results. All authors read and approved the final manuscript.

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## Availability of data and materials

All data generated or analysed during this study are openly available.

## Declarations

### Ethics approval and consent to participate

Not applicable.

### Consent for publication

Not applicable.

### Competing interests

The authors declare that they have no competing interests.

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