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PERSPECTIVES AND PARADIGMS

Discrepancies between non-native and invasive species classifications

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Abstract Biological invasions pose a growing threat to ecosystems, biodiversity, and socio-economic interests. In the European Union, the introduction of non-native species through trade, tourism, and other pathways has led to unintended consequences. Among these non-native species, a subset exhibits negative impacts and is commonly referred to as 'invasive'. However, the number of non-native species and the proportion considered invasive vary across different member states of the European Union. Classifications and definitions of invasive species also differ among countries potentially leading to an underrepresentation. Here, we use Germany as a case study to highlight gaps in invasive species classifications. The number of non-native species reported as invasive in Germany remains low (~14%) compared to other European Union member states (~22%), despite Germany's strong economy, significant research investments, and well-established trade networks. This disparities may be attributed to complex and multifaceted factors, encompassing

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differences in classifications, variations in research effort and focus, and diverse national priorities. We further propose that the impacts of non-native species on resources and biodiversity may be more likely to be overlooked, principally in large economies reliant on international trade, such as Germany. This oversight could negatively affect conservation efforts and funding for research aimed at improving understanding invasive species threats. We suggest that this underreporting may stem from a focus on maintaining economic growth, which might have taken precedence over addressing the potential ecological and economic impacts of invasive species.

Keywords Economic burden · Biodiversity · Biological invasion · Species conservation · European Union

Introduction

Non-native species are those intentionally or unintentionally introduced to an ecosystem or area where they do not naturally occur (Ruiz and Carlton 2003; Britton et al. 2011; Essl et al. 2018). A subset of these individuals can survive and establish self-sustaining populations. While some of these populations spread and become invasive (Soto et al., 2023), only a subset has known impacts in their new environment by negatively affecting native biodiversity (Cucherousset and Olden 2011), ecosystem functioning (Vilizzi et al. 2015), economies, and/or human well-being (Peyton et al. 2019; Diagne et al. 2020). Moreover, non-native species are often falsely classified as invasive due to having an impact (Soto et al., 2023), making differentiating between non-native and invasive species difficult, as definitions of invasive species vary among researchers, stakeholders, and policy makers (see e.g., Falk-Petersen et al. 2006; Ricciardi and Cohen 2007; Simberloff 2013; Pereyra 2016).

While the terminology and definition of 'invasive' are subject to much debate (Ricciardi and Cohen 2007; Blackburn et al. 2011) and to reporting failures and biases (Pyšek et al. 2008; Hulme et al. 2013), the conceptual framework for biological invasions proposed by Blackburn et al. (2011) considered impacts to fall outside the definition of invasive species and defined invasiveness as the ability of a non-native species to establish and spread. This framework implies that species can exert impacts and disrupt ecosystems along every step of the invasion process (Blackburn et al. 2011). The term invasive however is still associated with the impacts exerted, particularly in political and management context. An issue

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associated with impacts is that they usually grow once populations become successfully established and abundances increase (Haubrock et al. 2022). Yet, non-native populations can persist at low densities giving the impression of negligible impact until a populational outbreak due to abrupt shifts in e.g., environmental conditions (Spear et al. 2021). It is for that reason that the Convention on Biological Diversity (CBD) defines plants, animals, pathogens, and other organisms that are non-native to an ecosystem, and which *may* cause economic or environmental harm or adversely affect human health as invasive. Definitive issues also arise from the challenge of distinguishing between invasive species and those non-native species that may or may not have perceived benefits (Sax et al. 2023) or the debate surrounding the so-called 'neo-natives', i.e., native species which expand their range, often because of climate change (Essl et al. 2019; Rew et al. 2020; Wilson et al. 2020). Complexities further arise considering cases of non-native species introduced before 1492 that are often considered as naturalised (Callaway 2022), translocated species within the same country or continent (Sastrapawira et al. 2020; Balzani et al. 2022; Baquero et al. 2023), and those with a long history of beneficial uses (Hickley et al. 2015), including controversial initiatives aiming to 'naturalise by decree', which is arguably a political decision to favour the economy and associated activities without any scientific basis (Pelicice et al. 2014). The chaotic terminology in the field of invasion science, in particular for the classification of species as non-native or invasive, has resulted in a discrepancy in policy, research, and management of non-native species (Pysek et al., 2008; Turbelin et al. 2017).

A clear definition of the different terms used in the biological invasion literature, albeit not the focus of this paper (but see Iannone et al. 2020; Soto et al., 2023), is however crucially important for global biosecurity and for policy makers to prioritise management and to fully elucidate the range of impacts caused by populations of non-native species (Haubrock et al., 2019; Hudgins et al. 2023). With rising non-native species numbers, staggering impacts, and a lack of effective management strategies, research into non-native and invasive species' success, impact, and management has never been as urgent (Seebens et al. 2020; Tedeschi et al. 2022). This is especially pertinent in Europe, which has historically been a centre of exploration, colonisation, and later globalisation (Menozzi 2013; Kulman and Tamïr 2022), having led to the introduction of a vast number of non-native species to countless regions worldwide, as well as the introduction of numerous non-native species in continental Europe itself (Turbelin et al. 2017). Introductions have been facilitated through various pathways linked to globalisation, i.e., growing trade networks, urbanisation, travel, tourism, and—among others—the cultivation of animals and plants for aesthetic or economic purposes (Huamir et al. 2015; Hickley and Chare 2004). An example of the chronogeography of the invasion of hematophagous arthropods according to historical events, evidenced the crucial role Europe has played in the translocation of non-native species over the centuries, starting from exploration of the "new world", colonialism, up to more recent modern era of global change (Cuthbert et al. 2023). However, along with these introductions, several unintended consequences arose: some non-native species that escaped or were intentionally released (Mangiante et al. 2018) thrived in their new environments and began to negatively impact recipient ecosystems, human well-being (Pejchar and Mooney 2009), and/or economies (Gallardo et al. 2016), thus being labelled as invasive. There are, however, various ecological, economic, and social drivers that contribute to the introduction and spread of non-native species (Gallardo 2014; Saul et al. 2017), which oftentimes differ depending on the socio-economic characteristics and value systems of a given country (Hulme 2007; Haubrock et al. 2021a).

How should non-native species introduced for their economic, cultural or aesthetic benefits be considered and classified?

A challenging conflict of values arises when species are introduced for their economic, cultural, and/or aesthetic benefitsand but exhibit negative impacts. Labelling these species as invasive and implementing policies for curtailing their spread and population may threaten the goods and services they provide. The presence of benefits in such species has ultimately led to them becoming exempt from regulatory frameworks (EU Council Regulation 708/2007), revealing compromises between policy, economy, and science, but with the quagmire to deal with the problem of non-native species in certain economic sectors (Carpio et al. 2017). This includes several species introduced for hunting purposes, e.g., the New England cotton-tail *Sylvilagus transitionalis* or the Canada goose *Branta canadensis*, but also aquaculture species such as the invasive Manila clam *Lajonkairia lajonkairii* and the Pacific oyster *Magallana gigas*, which although harmful (Herbert et al. 2016; Carpio et al. 2017) have been used in aquaculture for extended periods of time. Based on the reasoning of 'no adverse effects' (Lehtiniemi et al. 2015), such species are exempt from the principles of the European Union invasive species regulation (1143/2014). Only if introduced for other purposes than aquaculture, they can fall under the Regulation. Another remarkable example is common carp *Cyprinus carpio*, a freshwater fish species with high economic value, as well as other species introduced for fishing purposes in many European countries (Gozlan 2008). Although *C. carpio* is non-native to some regions in Europe (native distribution covers mostly Eastern Europe), its management across countries where non-native populations have established differs significantly depending on how invasive it is perceived to be (e.g. Aksu et al. 2023). Regardless of the actual invasiveness (defined as the ability to establish and spread) in certain areas, *C. carpio* classifications vary across countries. Consistently, in Turkey where the species holds considerable economic importance, regulations on non-native aquatic species management do not include *C. carpio*, as the status of the species is not clearly defined as being native to some ecoregions of the country. Following translocation in its feral 'naturalised' form, it is seen as being ubiquitous across Anatolia especially (Gaygusuz et al. 2015). Contrastingly, in the United Kingdom, carp is valued by anglers and thus, carp management is governed by national policies on fish movements. This includes regulations on both native and non-native fish species, such as the Prohibition of Keeping or Release of Live Fish (Specified Species) (England) Order 2014 (Vilizzi and Copp 2017). In Italy, the species is non-native but highly valued among anglers and since it was likely introduced before 1500 (Roman times or Middle Ages; Hoffman 1995), it is assimilated to a native species for its management. Inaccurate species classifications can lead to insufficient management practices, as evidenced by these examples, potentially resulting in heterogeneous outcomes and policy approaches. In this example, carp may not be perceived as invasive in Turkey or Italy but in the United Kingdom it could be treated as highly invasive.

How can we deal with the differences of invasiveness across geographical scales?

Invasiveness can greatly vary according to the considered geographical dimensions. One example is the rainbow trout *Oncorhynchus mykiss*, which is listed among the worst invasive alien species in Europe (Lowe et al. 2000; van der Veer and Nentwig 2015). Risk assessments and invasiveness screenings have found mostly high-risk scores for different European countries (Koutsikos et al. 2019), which, together with dense stockings, poses an important ecological problem and threat (Stanković et al. 2015). Nevertheless, ecological impacts are mostly anecdotally reported, mainly originating from laboratory experiments, or inferred from non-European populations (Blanchet et al. 2007; Fausch et al. 2007). Differing potentials to establish, being e.g., relatively low in Mediterranean countries such as Greece (Koutsikos et al. 2019) or Spain (Doadrio 2001), but successful in Switzerland with potential to spread and negatively impact native trout species (Burkhardt-Holm et al. 2002), imply varying classifications across European countries. In Germany for instance, established populations of non-native fish species exist, although most populations rely on continuous stocking activities (Wolter and Röhr 2010). Although its presence clearly has a negative effect in all the aforementioned cases, it remains tolerated in most cases and is even stocked for angling. Indeed, it is the most important fish of Germany's commercial inland fisheries (Wolter and Röhr 2010), as economic benefits ultimately undermine stocking restrictions and management interventions targeting the invasion (Britton and Orsi 2012; Hickley et al. 2015).

The above case studies illustrate some of the striking discrepancies on the classification of species as non-native or invasive. In what follows, we take a closer look at the classification in the European Union and Germany as an example of a high gross domestic product (GDP) country.

Reported non-native and invasive species in the European Union and Germany

As a simple proxy for the extent of reporting and listing of non-native species as invasive, we relate the number of reported non-native species in a region to the number of reported invasive species of that region using a suite of EU-wide databases (Table 1). Despite acknowledging the spatial heterogeneity among European countries (Gerhards 2007; Bodor et al. 2014), we assumed that the fraction of non-native species that—depending on definition—are considered as invasive was independent of their recipient environments, and therefore, all other things constant, should be approximately consistent across contexts if reporting is consistent. If this holds, so that the percentage of non-native species that are invasive is approximately the same across different countries, then any national variation in the reported invasive species could indicate misclassification. It should be noted though that this assumption ignores other factors influencing invasion success, and was used here merely for the purpose of illustrating discrepancies in reporting of invasive species. The databases used are also imperfect, entailing biases in reporting of non-native and invasive species, driven by various factors such as the interests or capacity of the group compiling the data (i.e., scientists, managers, stakeholders).

Despite the significant number of non-native species documented for Europe, the share of non-native species listed as invasive in the European Union is low (Table 1). This disparity is further exacerbated by differences in research effort, political priorities, taxonomic groups (Roques et al. 2008; Vilizzi et al. 2021), ecosystems (Tarkan et al. 2021), definitions of invasiveness (i.e., biological stage-based vs. impact-based; see Richardson et al. 2000; Ricciardi and Cohen 2007; Iannone et al. 2020) and the presence of benefits (Sax et al. 2023). These discrepancies in classifications are problematic particularly for the policies they inform which are expected to fail at treating invasive populations in a consistent manner, therefore dampening resource allocation and jeopardising prioritisation of invasive species for management (Vilizzi et al. 2021b).

Our evaluation highlights that this discrepancy between non-native species and those listed as invasive is particularly prominent in Germany (Table 1). Germany's economy is the largest within the European Union (data.worldbank.org), with a GDP of EUR€ 3.86 trillion (2021 value), and a strong export sector that particularly draws from manufacturing (Stehrer and Stöllinger 2015). Indeed, Germany's manufacturing industry is the third world's largest exporter of goods (data.worldbank.org) and is largely driven by expertise in high-tech industries (Beier et al. 2017), with a net trade of goods and services of EUR€ 207.13 billion (2021). The significant investments in research and development (Pece et al. 2015) over time have resulted in Germany becoming a global hub for innovation and technological advancement (Schiederig et al. 2012). The country's geographical location in Central Europe also makes it a crucial transit point for trade and travel, with goods and people moving through the country from all corners of the continent (De Benedictis and Tajoli 2011), further facilitated by the Schengen agreement (Felbermayr et al. 2018). Indeed, Germany's ports and airports, as well as inland waterways, are among the busiest in Europe, which has contributed to the establishment of strong trade networks between Germany and other regions, providing numerous opportunities for the introduction of non-native species (Briski et al. 2012; Albero 2022). Additionally, Germany is a major hub for tourism and travel, with large numbers of people entering and leaving the country on a regular basis (Becken 2002; Šauer and Bobkova 2018).

Drawing from several sources (Table 1), we found on average 1080 (min-max: 262–2419) known non-native species in Germany, out of which only 10.7% were classified as invasive based on varying definitions (avg. 116; min-max: 29–196). The most recently compiled and most extensive databases on established non-native species, i.e., the *Established Alien Species in the European Union* (Henry et al. 2023) listing 2419 established non-native species, and the *Global Invasive Species Database* (GISD; Poorter and Brown 2005) listing 196 invasive species, suggest 8.1% of non-native species to be invasive in Germany (Table 1; Supplement 1), which is less than the expected 10% according to the 'tens rule' (Jeschke et al. 2012). We further note that Jeschke and Pyšek (2018) even suggested that the invasion '*tens rule*' should be replaced by the '*50% invasion rule*' for vertebrates and the '*25% invasion rule*' for e.g., plants and invertebrates. Using the *Global Register of Introduced and Invasive Species* which lists both non-native and invasive species, Germany reported 6.5%

Table 1 Records of non-native and invasive species based on the most common databases in Germany and the European Union overall

Database	Type of documentation	Germany		EU Member States (overall)		References
		Non-native	Invasive	Non-native	Invasive	
InvaCost v.4.1	Invasive species with reported monetary costs		22		367	Diagne et al. (2020)
Established Alien Species in the European Union	Known established non-native species in EU member states	2419		13,858		Henry et al. (2023)
Alien Species Regulation (Regulation 1143/2014)	Invasive alien species of Union concern		29		88	EU (2014), (2022)
Global Alien Species First Record Database	First national annual record of alien species	758		6,739		Seebens et al. (2017)
Global Invasive Species Database (GISD)	Alien invasive species that negatively impact biodiversity		196		430	http://www.iucngisd.org
European Alien Species Information Network (EASIN)	Alien and high-impact invasive species in the EU	2786	403	14,269	965	EASIN (2023)
Global Register of Introduced and Invasive Species (GRIIS)	Country-wide checklists of introduced (naturalised) and invasive species	1036	67	14,548	1,440	https://griis.org
Bestandsaufnahme und Bewertung von Neozoen in Deutschland	Assessment and evaluation of non-native species in Germany	1123 (262 established)				https://www.umweltbundesamt.de; https://neobiota.bfn.de/grundlagen/anzahl-gebietsfremder-arten.html
Bundesamt für Naturschutz	Assessment and evaluation of non-native species in Germany	927 established (+ 1,965 potentially)	104			Geiter et al. (2002)
BfN Schriften 352 (Neophyta)	Assessment and evaluation of non-native plant species in Germany	658 established (> 2,000 present)	38 (+ 42 potentially)			Nehring et al. (2013)
BfN Schriften 409 (vertebrates)	Assessment and evaluation of non-native vertebrate in Germany	46 (+ 100 potentially)	20 (+ 28 potentially)			Nehring et al. (2015)

of non-native species to be invasive. This is less than half compared to the average among other European Union member states (14.7 ± 20.7%) and ~3% less than the 9.8% reported at the level of the European Union, underlining a profound discrepancy in the number of non-native species listed as invasive across European Union member states.

Using the *European Alien Species Information Network* (EASIN 2023), the discrepancy was similar when comparing Germany (14.5% of non-native species being considered as high-impact invasive species) to the national average of European member states (21.5 ± 7.3%), but was found to be twice as high as at the level of the European Union (6.8%). Further, the proportion between the number of *invasive alien species of Union concern* (last update, EU 2022/1203) was 2.23% and between the number of *invasive alien species of Union concern* and those with documented monetary costs listed in *InvaCost* (v4.1; Diagne et al. 2020) out of all non-native species known to be established (Henry et al. 2023) only 0.91%. These shares were considerably lower for invasive species among the *invasive alien species of Union concern* reported for Germany (1.20%) but comparable for those reported in *InvaCost* for having a monetary impact (0.87%), further substantiating the classification discrepancy (Supplement 1).

Issues with a discrepancy in records

The drivers behind the discrepancy in non-native and invasive species listings across European Union member states, especially in the case of Germany that is used as an example here, are complex and multifaceted. Despite knowledge on the role of well-established trade networks, but also tourism, human travel, education and awareness, enforcement of regulations, and other factors facilitating species introductions in Germany, such as the strong presence of the pet and horticulture trade (Nunes et al. 2015), the number of recognized invasive species in the country remains relatively low (Table 1). This also is found to be true when compared to other European Union member states (Henry et al. 2023; Supplement 1). This could be due to several reasons: Germany's large research capacity allows for intensive monitoring of the spread of non-native species. Academics together with practitioners have thus contributed to implementing various measures to prevent and control invasive species. These include strict regulations on the import and transport of plant and animal products (EU Regulation 1143/2014; Essl et al. 2011; Nehring et al. 2013, 2015) and regional monitoring programs to detect and respond to biological invasions. Additionally, German research institutions have played a significant role in developing best practices for managing invasive species, particularly in aquatic systems (see e.g., Wolter and Röhr 2010). These efforts, combined with Germany's strong economy, high level of economic activity, and connectivity within Europe, would in theory be expected to result in proactive management approaches that lower the number of invasive species also compared to other European Union member states. Vice versa, Germany could also be considered as a reference point, suggesting that other European Union member states have a relatively higher share of species listed as invasive. This could be, because other countries (1) might be more affected by non-native species impacts or invader impacts are perceived as more damaging due to differently structured economies, thereby (2) resulting in more species being wrongly classified as invasive despite an impact not being a defining criterion for invasiveness; (3) spend less resources for the management and early detection efforts; or (4) have environmental differences which result in more non-native species spreading and thus, being classified as invasive. Another aspect that should be noted in this context is the difference in management purposes, as different entities might favour impact over spread focused management, where those species (rather than populations) that have been highlighted as impactful are managed over those that spread rapidly.

Previous studies have highlighted a significant link between economic output (GDP; GDP per capita) and the recorded impacts of invasive species (see e.g., Haubrock et al. 2021a). Hence, it could be argued that a strong economy can be expected to make more investments in academic research that succeeds in advancing understanding of invasions and documenting with higher accuracy those non-native species that have been classed as invasive. However, the strength of Germany's economy and the size and intensity of trade networks may have contributed to overshadowing the threat of invasions, while also limiting proactive management investments, along with public and governmental awareness on the risks posed by non-native and especially invasive species (Genovesi et al. 2015; Piria et al. 2017). Economic losses resulting from the impact of these species on resources and other environmental assets, such as loss and/or degradation of biodiversity and ecosystem services, may not be as immediately apparent in a strong economy where growth could be overshadowing conservation goals. This is, because losses in a nation's GDP due to the damages of invasive species can be absorbed by other economic sectors, despite absolute losses being higher when compared to weaker economies due to greater levels of economic activity and hence, more damageable assets. At the same time, it could be argued that economic interests may result in consciously disregarding known impacts in favour of their role as commercially valuable resources. This is the case for example with *O. mykiss* and *C. carpio* which are both of commercial importance for inland water fisheries, but also the case of the black locust tree *Robinia pseudoacacia*, which is highly invasive in Central Europe but important for, among other reasons, the production of honey (Vítková et al. 2017).

Furthermore, it is the authors' assertion that the prevailing expert focus, whether among researchers, policymakers, or stakeholders, appears to have drifted away from crucially needed basics to advance national understanding of invasions. This shift, not pinned to any specific group, potentially leaves the core comprehension of non-native species impacts—essential for invasive classification—underexplored. Acknowledging that intricate models overshadow basic invasion ecology, it is clear that emphasis on complex methodologies has hidden the importance of studying local-level effects. Without assigning blame, it is worth suggesting that realigning focus on these basics could yield new insights. Understanding local-level effects forms a sturdy base for informed management, bridging gaps in comprehension and strengthening tools to combat invasive species. In essence, a well-rounded perspective on invasive species and impacts, beyond advanced methods, can pave the way for holistic invasion management. This benefits the environment, economy, and society—a crucial stride forward. This is also despite government efforts to screen for potential non-native species that may or may not be invasive and present a threat (see Nehring et al. 2013, 2015). The focus on economic growth and maintaining Germany's position as a global leader in exports may therefore have taken precedence over the need to address the potential ecological and economic impacts of invasive species. As a result, there may be less pressure to prioritise invasive species management, even if the long-term impacts continue to accumulate and are known to exacerbate costs if not addressed in a timely manner (Ahmed et al. 2022; Haubrock et al. 2021b). Ultimately, a focus on short-term economic gains over long-term sustainability could be the reason for limited attention to potential environmental consequences of trade.

Incorporating scientific research and public education into decision-making processes and policy design is important to ensure the long-term sustainability of a country's economy and environment. The number of those non-native species listed as invasive differs among databases due to varying criteria and definitions of what an invasive species is, resulting in listing errors (McGeoch et al. 2012) and consequently, a high variability among European Union member states as well as between the national and the European Union level. This number is further often derived without regional or national invasiveness screenings or impact assessments, as non-native species with known impacts in one country are presumed to be invasive also in another (Vilizzi 2012). This, paired with limited or inadequate invasiveness screenings or impact assessments for most species in e.g. Germany (Nehring et al. 2013, 2015; Haubrock et al. 2021b; Vilizzi et al., 2022), suggests that the number of invasive species is likely substantially higher than the estimated 8% (but may vary substantially depending on definition). The number of invasive species recognized at the national level is therefore highly likely to increase with proper risk, invasiveness and impact assessments (e.g., Tarkan et al. 2022) that draw from the available lists of non-native species. To this end, unified classification as to what constitutes 'invasiveness' (see Soto et al. 2023), is expected to help, particularly when considering highly debated species such as the racoon *Procyon lotor*, the Egyptian goose *Alopochen aegyptiaca*, the rainbow trout *O. mykiss*, or carp *C. carpio* (Salgado 2018; Biermann and Geist 2019; Hohmann and Woog 2021), many of which have benefits and costs (Kourantidou et al. 2022).

The lack of consensus on the definition for what constitutes an invasive species (i.e., the evidence of a generated impact over the potential to spread; see e.g., Blackburn et al. 2011; Soto et al. 2023) hinders the effectiveness of management interventions, which are also limited by the availability of resources. Consensus on the definition for invasive species can aid with prioritisation, assessment of management feasibility and appropriate action based on the species' invasion stage (Estévez et al. 2015; Roberts et al. 2018; Haubrock et al. 2022). The lack of a standardised and generally accepted definition on invasive species (Falk-Peterson et al. 2006; Ricciardi and Cohen 2007), is exacerbated by varying degrees of research effort and different ecological, economic, and social drivers that pose a significant challenge for developing effective management strategies across interconnected ecosystems and landscapes in the European Union (Keller et al. 2011; Genovesi et al. 2015). Without a more unified approach to invasive species classification and management that also clearly distinguishes between non-native species and invasive non-native species, the European Union risks hindering its ability to coordinate management across space and prioritise its efforts towards mitigating impacts of the most detrimental non-native species. In light of the increasing conservation challenges posed by invasive species (Courchamp et al. 2017), it is more relevant than ever to develop a coordinated and sustained approach, at both national and European Union levels, to mitigate impacts on biodiversity, ecosystems, and human well-being, as well as prevent to the extent possible new introductions, from which a subset will become invasive.

A way forward

To establish effective management strategies, it is crucial that invasiveness is based on the same criteria and that a standardised definition is adopted by all institutions relevant to the European Union, stakeholders involved in invasion sciences, and managers of problematic invasive species. Additionally, a critical consideration is that invasiveness should not be assessed for an entire species, but rather at its population level, as the potential for invasiveness (defined as either the species' ability to spread or cause impacts) may vary significantly across different regions within the European Union. By recognizing these complexities and adopting a consistent approach, the European Union can more readily enhance its ability to effectively address the challenges posed by non-native and invasive species and develop better targeted and region-specific management strategies.

Specifically in Germany, as well as in other European Union member states, efforts should be cognisant to (*1.*) strengthen regulations on trade and transport and increase biosecurity measures. Given Germany's strong trade networks and the country's position as a major hub for travel and tourism in Europe (Selke 1936; Hau 2001), it is important to implement stronger regulations on the import and transport of non-native plant and animal products, as well as measures to prevent unintentional 'hitchhiking' of species. This can include more rigorous screening and monitoring of shipments and protocols for ballast water monitoring and sterilisation (David et al. 2015), as well as increased penalties for those found to be in violation of regulations. Similar measures could be implemented more thoroughly at the European Union level to help prevent the spread of invasive species across member states (Caffrey et al. 2014).

Furthermore, (*2.*) investments in public awareness, communication with stakeholders, and education should be increased (Patoka et al. 2018; Lipták et al. 2023) to raise awareness of the issue and the potential environmental and economic impacts of invasive species and bring invasions (and their successful management) to the forefront of conservation agendas and to increase community science engagement (Cooper et al. 2007). Communication and information campaigns should be also addressed to mitigate stakeholder conflict (e.g., conservationists vs. resource users etc.) on contentious species, leading to a good understanding of trade-offs present (Novoa et al. 2018; Kourantidou et al. 2022). Neglecting public education can lead to the failure of an initiative and inhibit community science engagement (Cooper et al. 2007). Additionally, decision makers should design policies with considerations in mind of conflicting stakeholder interests for certain invasive species (e.g., conservationists vs. resource users etc.) and a good understanding of trade-offs present (Novoa et al. 2018; Kourantidou et al. 2022). Inclusive processes and stakeholder consultations at early stages of management design are known to be key in creating successful policies that are also most likely to be accepted by those affected by and/or with direct interest in the invasion (Shackleton et al. 2019; Reid et al.

2021; Kourantidou et al. 2022). Furthermore, there is a need to critically analyse the designation of non-native species recognized as harmful by the International Union for Conservation of Nature's World's Worst Invasive Species list and species of concern in the European Union. Despite ongoing efforts for improving communication and management, these efforts are mostly limited to few non-native taxa, with a large number of species known to cause impacts to human health and biodiversity still largely neglected (European Commission 2022 ; Meriggi et al. 2022). Yet, the so-called 'worst invasive species' are not always the costliest (Cuthbert et al. 2022). More effort can therefore be invested in the future for developing comprehensive lists of species of regional concern that draw from known or expected impact, considering the relevant biogeographic context rather than political/national boundaries. Such boundaries may also be allowing for inconsistencies in management across space due to heterogeneous invasive species definitions. These efforts should be expanded to target relevant stakeholders but also the general public that may include for example tourists or those working in industries that may be particularly involved in the spread of invasive species.

Raising awareness can, in turn, (*3.*) encourage sustainable economic practices: while economic growth is undeniably important for both Germany and the European Union, it is crucial to maintain a balance with sustainability considerations (Kostetckaia and Hametner 2022). While significant momentum has been built in recent years, over carbon-clean practices and technologies, broader conservation and ecosystem disturbance considerations have received less attention. Sustainable practices should tackle environmental degradations and disturbances that can be pervasive factors that promote invasion success, and thus their regulation could help resist biological invasions (Ricciardi et al. 2021). Other measures include investing in research and development of new technologies and practices that can help prevent and control invasive species, as well as a the prioritisation of trade partners which are in closer proximity to reduce novel species introductions (Hudgins et al. 2023).

Finally, (*4.*) international cooperation and research in addressing the challenges posed by invasions should be fostered. The spread of invasive species is a global conservation issue that requires international cooperation to be effectively addressed. Despite the strong economy, investments into targeted research for biological invasions (i.e., horizon scanning or risk and impact assessments; González-Moreno et al. 2019; Roy et al. 2019; Bernardo-Madrid et al. 2022) remain limited in practice. Germany and the European Union could work with other countries and international organisations to develop efficient evidence-based strategies for identifying, preventing, and controlling the spread of invasive species. This can include sharing best practices, strengthening of research collaborations, and providing financial and technical support to and sharing research capacity with countries that may be more vulnerable to the impacts of invasive species. Most importantly, it is key to establish foundations for reaching consensus on shared strategies and definitions regarding invasive species, as this is key to forming shared policies that will help discourage new high-risk introductions and address existing ones. By taking these steps, Germany and other European Union member states can better protect their native biodiversity and ecosystems, promote sustainable economic development, and safeguard public health and well-being for future generations.

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Declarations

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