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Taming the terminological tempest in invasion science

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ABSTRACT

Standardised terminology in science is important for clarity of interpretation and communication. In invasion science – a dynamic and rapidly evolving discipline – the proliferation of technical terminology has lacked a standardised framework for its development. The result is a convoluted and inconsistent usage of terminology, with various discrepancies in descriptions of damage and interventions. A standardised framework is therefore needed for a clear, universally applicable, and consistent terminology to promote more effective communication across researchers, stakeholders, and policymakers. Inconsistencies in terminology stem from the exponential increase in scientific publications on the patterns and processes of biological invasions authored by experts from various disciplines and countries since the 1990s, as well as publications by legislators and policymakers focusing on practical applications, regulations, and management of resources. Aligning and standardising terminology across stakeholders remains a challenge in invasion science. Here, we review and evaluate the multiple terms used in invasion science (e.g. 'non-native', 'alien', 'invasive' or 'invader', 'exotic', 'non-indigenous', 'naturalised', 'pest') to propose a more simplified and standardised terminology. The streamlined framework we propose and translate into 28 other languages is based on the terms (*i*) 'non-native', denoting species transported beyond their natural biogeographic range, (*ii*) 'established non-native', i.e. those non-native species that have established self-sustaining populations in their new location(s) in the wild, and (*iii*) 'invasive non-native' – populations of established non-native species that have recently spread or are spreading rapidly in their invaded range actively or passively with or without human mediation. We also highlight the importance of conceptualising 'spread' for classifying invasiveness and 'impact' for management. Finally, we propose a protocol for classifying populations based on (*i*) dispersal mechanism, (*ii*) species origin, (*iii*) population status, and (*iv*) impact. Collectively and without introducing new terminology, the framework that we present aims to facilitate effective communication and collaboration in invasion science and management of non-native species.

Key words: biological invasion, classification, communication, non-English language, non-native, polysemy, synonymy.

CONTENTS

I. INTRODUCTION

Scientific disciplines often grapple with lexical and semantic ambiguities and inconsistencies that can confuse, misinterpret, and create barriers to effective interdisciplinary collaboration among scientists, as well as hinder engagement with practitioners, policymakers, educators, stakeholders, and society (Metzger & Zare, 1999; Regan, Colyvan & Burgman, 2002). This problem spans many fields, from ecology and taxonomy to physics, computer science, and social science (Boucher, 1985; Herrando-Pérez *et al.*, 2012; Stroud *et al.*, 2015; Kirk *et al.*, 2018; Amador-Cruz *et al.*, 2021; Roth *et al.*, 2021; Bortolus & Schwindt, 2022; Macêdo *et al.*, 2023). Over time, each discipline develops a unique technical lexicon (jargon) with the common challenge of establishing a clear, universally accepted terminology that enables accurate communication within its community and with other scientific or public domains (Montgomery, 1989; Hirst, 2003). While Hodges (2008, p. 35) argued that '… [u]seful lexical reviews should focus on the development of [ecological] knowledge that is signalled by a wealth of terms and meanings, rather than critiquing the terms employed', relying on jargon can be detrimental to effective communication, especially among researchers from different backgrounds and disciplines (Orwell, 1968; Plavén-Sigray *et al.*, 2017; Bullock *et al.*, 2019, Martínez & Mammola, 2021). Judicious use of specialised terms permits effective and precise communication of ideas and concepts not available in the common language, but this is best achieved when jargon is unambiguous and agreed by most scientists in a given field (Hirst, 2003).

Invasion science is a swiftly evolving discipline that encompasses a wide range of specialised fields. Despite its relative youth, the jargon of invasion science has many inconsistent definitions that hinder research progress, effective management, alignment with global-change science, and standardised communication (Colautti & MacIsaac, 2004; Ricciardi & Cohen, 2007; Lockwood, Hoopes & Marchetti, 2013). For example, Castro *et al.* (2023) found that ambiguous terminology in the field of invasion science hampers effective reporting of non-native taxa for regional checklists. Terms associated with the stages and impacts of biological invasions in particular are often polysemous (i.e. many meanings for a word, phrase, or concept), leading to potential misunderstanding and limitations in scientific exchange and conservation practice (Colautti & MacIsaac, 2004), as well as hindering bidirectional translations between English and other languages (Copp *et al.*, 2021).

Biological invasions are generally defined as directed, human-mediated processes whereby organisms are transported and subsequently released by humans either intentionally or unintentionally beyond their native biogeographical boundaries from which they can potentially spread (Simberloff, 2013; Pyšek *et al.*, 2020). We also acknowledge that terms such as 'invasion' and 'native' can hold separate cultural meanings for stewardship approaches, including some perspectives by Indigenous Peoples (Wehi *et al.*, 2023). To standardise the terminology in this paper and beyond, we first define the 'native' (i.e. natural) range of a species as the biogeographical area where its occurrence has been determined solely by natural evolutionary processes, without any direct or indirect human intervention, such as transporting species, altering their boundaries, and/or breaching natural barriers to their dispersal. This definition implies that a species' 'non-native' range is the area where the species is present due to human intervention, whether intentional or unintentional, and where it has not naturally evolved (McNeill, 2003). This definition remains applicable regardless of the duration of the species' presence in the area or whether it has undergone evolutionary adaptations in response to the novel environment. However, non-native ranges also include human-assisted expansions due to other phenomena like the removal of biogeographic or climatic barriers caused by anthropogenic activities (Essl *et al.*, 2019).

The process of an initial invasion can be conceptualised as a series of stages – for example: (*i*) non-native species intentionally or unintentionally transported (including those classified as 'hitchhikers') to a new area through human activities, or naturally dispersing after a barrier is removed or made permeable through human action; (*ii*) escape or introduction of individuals from captivity or cultivation into (evolutionarily) novel locations; (*iii*) establishment of a viable (i.e. self-sustaining) population; and (*iv*) spread (when individuals of non-native species disperse spatially from the initial release area). While the latter two stages occur with or without direct human assistance, the quality, quantity, and frequency of introductions (i.e. generally termed 'propagule pressure') are relevant at all stages (e.g. Lockwood, Cassey & Blackburn, 2005).

In light of the multifaceted and largely negative effects that non-native species introductions can have on both nature (Blackburn *et al.*, 2011; Bellard, Marino & Courchamp, 2022; Rilov, Canning-Clode & Guy-Haim, 2024) and society (Vilà *et al.*, 2010; Bacher *et al.*, 2018; Diagne *et al.*, 2021; Zhang *et al.*, 2022), research on biological invasions lies at the crossroads of natural and social sciences (Vaz *et al.*, 2017; Heger, Jeschke & Kollmann, 2021; Bortolus & Schwindt, 2022). While a species' native range is identified by a historical range (Fig. 1A) that reflects its evolutionary history, dispersal capacity, and biotic and abiotic constraints, historical records (Fig. 1B) have sometimes been used controversially to justify local reintroductions (Fig. 1C, D), as in the example of rewilding (Seddon *et al.*, 2014). Past ecosystems are generally different from those in the present because ecosystems and their components are not static; therefore, even if historical records confirm the past presence of a species, these do not necessarily imply that species reintroductions will restore previous ecological conditions or positively affect contemporary ecological processes, particularly if the individuals being introduced originate from a population that is genetically distinct from the previous historical population (Davis, 2006; Richardson & Pyšek, 2008; Guerisoli *et al.*, 2023). Multi- and interdisciplinarity have allowed the implementation of innovative approaches to understand and manage biological invasions, but they have also introduced many related, and not always synonymous, terms and contrasting conceptualizations (Lockwood *et al.*, 2005). Further complication derives from the growing scientific attention being asynchronous across habitats, phyla, and geographic regions (Puth & Post, 2005; MacIsaac, Tedla & Ricciardi, 2011; Watkins *et al.*, 2021; Carvalho *et al.*, 2023), which has led to the establishment of multiple 'invasion science' communities that develop their own standards and often do not interact (Ojaveer *et al.*, 2015;

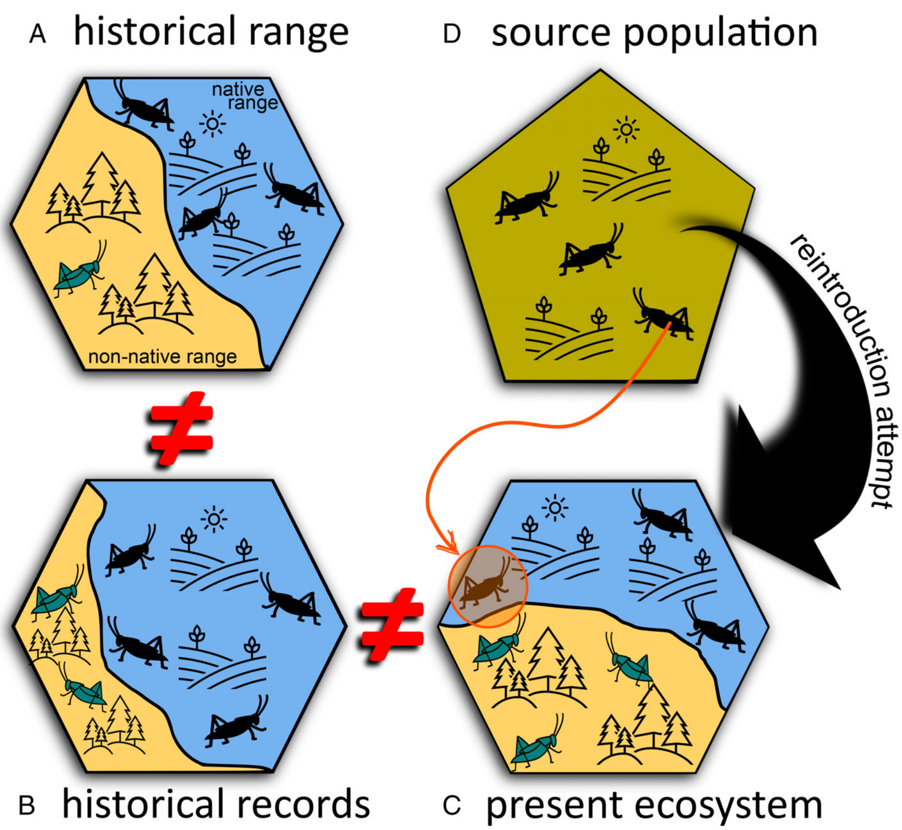

Fig. 1. Relationships between the historical range (A), known historical records (B), and the species current distribution in an ecosystem (C), which are used to justify reintroduction attempts using potentially genetically different source populations (D).

Latombe *et al.*, 2019). The resulting mix of terms and contexts (e.g. political, aesthetic, environmental) within and across disciplines has clouded universal comprehension, in turn impeding effective interventions (Padial *et al.*, 2017; Shackleton *et al.*, 2019; Heger *et al.*, 2021).

II. TERMINOLOGICAL EXPANSION

The rate at which flora and fauna began to be redistributed widely as a consequence of human endeavour (e.g. the migration of Austronesians; during European colonialism and the so-called 'Columbian exchange') has since been fuelled by expanding transportation networks during the age of industrialisation and rapid global change (Crosby, 1986; Amano *et al.*, 2021; Elton, 2020; Lenzner *et al.*, 2022). The ecological effects of these introductions were so evident, pervasive, and manifold that they were noted by naturalists and others, including Indigenous Peoples, as early as the 19th century (De Candolle, 1855; Darwin, 1859; Te Wehi, 1874; Berg, 1877), and more cogently in the first half of the 20th century (Ritchie, 1920; Oliver, 1930; Madsen, 1937; King, 1942; Oosting, 1948; Leopold, 1949). However, following the publication of Charles S. Elton's seminal book *The Ecology of Invasions by Animals and Plants* in 1958, concerns have emerged about these phenomena (Cadotte, 2006), which Elton (1942) presciently described as 'ecological pandemonium'. For the first time, Elton described invasions as a process distinct from the colonisations that occur during ecological succession and that drove the breakdown of Wallace's biogeographic realms (Elton, 2020). Later, Baker & Stebbins (1965) took a more neutral stance, describing biological invasions as 'probes' into the evolution and the inner workings of nature. Subsequently, invasion science, as with many other modern disciplines, grew out of a variety of older research fields, including agriculture, botany, ecology, entomology, forestry, mycology, human and animal pathology, and zoology, which often worked in isolation (Cadotte, 2006; Lockwood *et al.*, 2013). This rapid growth proceeded without a generalising framework to standardise and manage the proliferation of technical terminology employed in the field to describe similar phenomena. The international Scientific Committee on Problems of the Environment (SCOPE) programme of the 1980s focused on the integration of scientific knowledge in policy and decision-making related to prominent environmental challenges. It then finally initiated modern invasion science and triggered an explosion of publications (Simberloff, 2011), after setting an agenda for the study of biological invasions by posing three main questions: (*i*) what factors determine whether a species becomes invasive; (*ii*) what attributes determine if an ecosystem is resilient or susceptible to invasion; and (*iii*) how should invasions be managed, given knowledge addressing questions 1 and 2?

The continuous growth of and advances in invasion science are reflected in the increasing number of scientific publications on this topic, with >8000 scientific papers published by 2019 (see Stevenson *et al*., 2023). This rapid increase partially reflects the extensive impact of biological invasions on various sectors, including the environment, socio-economy, and human well-being. The increasing interdisciplinarity of invasion science, and the diversity of community voices that were previously ignored in conservation science, underline the need to reconsider widely accepted definitions and concepts (Vaz *et al*., 2017). However, this trend also highlights the need to tighten the connections between invasion and conservation sciences, and between invasion science and policy, that could otherwise weaken over time (Copp *et al*., 2005; Stevenson *et al*., 2023).

To address these challenges already highlighted by Carlton (2002), interdisciplinary research is needed to bridge the gaps among fields (Fachinello, Romero & de Castro, 2022), while simultaneously mitigating the proliferation of and reliance on disparate and convoluted terminology (Simberloff *et al*., 2013). The surging emphasis on frameworks (Wilson *et al*., 2020), theories, and hypotheses (Jeschke & Heger, 2018) has exposed certain concepts and ideas as potentially outdated and superfluous (Daly *et al*., 2023) or requiring amendment (Strayer *et al*., 2017; Soto *et al*., 2023*a*), while also identifying innovative paths such as moving beyond the 'linear' conceptualization of invasion dynamics (i.e. transport, introduction, establishment, spread; Blackburn *et al*., 2011). The first of four stages involves the movement of a species from its native range to a new location. This can be intentional, such as through trade or planting, or accidental, such as stowaways in shipping containers. In the second stage, the transported species is released into the new environment. It can be deliberate, such as when a species is introduced for pest control, or unintentional, such as escapees from aquaria, gardens, or ponds. Establishment refers to the successful reproduction and survival of a non-native species such that the new population becomes self-sustaining in its new environment. In the last stage, the established non-native species expands its range within the new environment. Contemporary perspectives acknowledge the many context dependencies mediating invasions and challenge the simplistic view that invasions are isolated occurrences or linear processes, with invasions potentially better understood as part of an 'adaptive network'. This considers that spread and impact of non-native species are not simply determined by their intrinsic characteristics, but rather shaped by the broader ecological and socio-economic context (Hui & Richardson, 2019).

(1) Scale mismatches

Researchers focusing on specific aspects of invasion science across different disciplines have tended to favour nuanced terminology, which has resulted in polysemies evolving independently in each discipline. Another possible reason behind the many definitions that created ambiguity is the mismatch in spatial scale between measurement and inference of impact. Often, a species' impacts are evaluated at a local scale (e.g. within a specific lake or a forest patch), whereas broader large-scale impacts are inferred by extrapolating local-scale measurements of ecological effects and/or invader abundance across regions or even broader spatial scales, thereby ignoring the spatial variation in the type and severity of impacts that is expected to increase with spatial scale (Haubrock *et al*., 2022; Ahmed *et al*., 2023; Soto *et al*., 2023*b*). Furthermore, designating a species as 'non-native' is commonly reported at the national scale (the typical spatial entity for which regulations are established) depending on the perspective of each jurisdiction, but in reality, nativeness is determined at the biogeographic scale, thereby de-emphasising sub-national or regional differences and biogeographic boundaries. Furthermore, variation in national perspectives or definitions such as invasiveness being defined based on political boundaries, which might not always correspond with ecological or biogeographic realities (e.g. European Union Regulation 1143/2014) (Vilizzi *et al*., 2022*b*), can generate inconsistent terminology among European countries (Haubrock *et al*., 2024). This is because distributions of non-native species frequently span many countries, while other species can be native to one part of a country and non-native to another (Baquero *et al*., 2023; Nelufule *et al*., 2023), exhibiting negative impacts only in the introduced parts of its range (Carey *et al*., 2012). This can lead to regional variation in approaches, terminology, and priorities within the same country (Vitule *et al*., 2019). One example is the pirarucu *Arapaima gigas* in Brazil, native to the Lower River Madeira basin in the Amazon. This species has been translocated to adjacent basins where it is not found naturally, resulting in detrimental effects on native species. While *A. gigas* is legally protected and threatened in its native range, the focus of local governments on farming this species generates a demand for more introductions into other basins (Doria *et al*., 2021).

Another profound example is the hundreds of non-native species crossing from the Red Sea to the Mediterranean Sea directly through the Suez Canal (Galil, 2006; Zenetos *et al*., 2012; Galil *et al*., 2021). In Israel, such species can be protected by law along the Red Sea coast, while they can be highly invasive in Mediterranean coastal ecosystems; e.g. rabittfish (*Siganus rivulatus* and *S. luridus*) or the lionfish *Pterois miles* (Sala *et al*., 2011; Yeruham *et al*., 2019; Stern *et al*., 2018; Ulman *et al*., 2020). These species might therefore require different legislative approaches, like targeted fishing in marine protected areas. The introduction of such species within specific regions or countries has posed challenges in measuring the extent of a species' native range (Pereyra, 2020).

The inconsistent use of terminology has also led to some native species being wrongly designated as 'non-native' (Valéry *et al*., 2009). This issue is amplified in large countries such as Russia, Canada, China, Australia, South Africa, and

Brazil, which have a diversity of biomes, basins and ecoregions, illustrating the complexity and nuances of species distribution within diverse environments (Yan *et al.*, 2001; Spear & Chown, 2009; Maslyakov & Izhevsky, 2011; Dgebuadze, 2014; Ellender & Weyl, 2014; Nelufule *et al.*, 2022). Furthermore, in countries spanning more than one biogeographical region, species can be both native in one part and non-native in another (e.g. largemouth bass *Micropterus salmoides* in Mexico; Wang *et al.*, 2019). In countries with both continental and insular regions the problem can be exacerbated, such as for some non-native species in Galápagos Islands native to continental Ecuador (e.g. Urquía *et al.*, 2019), or others in Robinson Crusoe Island native to continental Chile (Correa *et al.*, 2008).

The perceived status of a species can also shift from 'native' to 'non-native', requiring risk evaluation relative to other, already assessed non-native species [e.g. the disputed status of crucian carp *Carassius carassius* in Great Britain (Clavero *et al.*, 2016; Vilizzi *et al.*, 2022*a*)]. Because the relative abundance of a non-native species within a community is often used to classify its degree of invasiveness (Catford *et al.*, 2016; Haubrock *et al.*, 2022), it can be difficult to separate species expanding their range from those that do not spread without considering the area of reference. Locally established populations of non-native species can exhibit invasive characteristics (i.e. through observed spread, a rapid increase in relative abundance, and/or impacts) in one location, but not in another due to differences in *inter alia* source populations, residence time, habitat invasibility, and environmental (including climatic) conditions of the newly occupied area (Schaffner, 2005).

From a legislative perspective, applying a uniform definition and management approach based solely on national boundaries overlooks the diverse ecological and social contexts, and potential impacts, that might exist within different regions of the same country (Matsuzaki, Sasaki & Akasaka, 2013; Weyl *et al.*, 2016; Sommerwerk *et al.*, 2017). Therefore, spatially explicit information on distribution and status within a biogeographic region and understanding socio-economic and cultural contexts and values are important for effective management. However, policy and management strategies are generally framed within specific organisational scopes, such as at the country scale. In many cases, even categorising a species as 'native' or 'non-native' itself at such scales shapes perception and subsequent actions, but there are exceptions. For example, the European Union Regulation on Invasive Alien Species 1143/2014 takes into account three spatial scales: European (i.e. encompassing all Member States), regional, and national. This multi-scale approach allows for a more nuanced consideration of species categorisation and corresponding policies within the European Union.

(2) Lack of consensus

Despite more than four decades of modern invasion science and the recognised need for a consistent approach, there is still a lack of consensus over the meaning and usefulness of the terminologies currently in use (Colautti & MacIsaac, 2004; Valéry *et al.*, 2008; Shackleton *et al.*, 2022). The lack of a clear terminology has been exploited in ongoing criticism from those who aim to undermine the value and fundamental goals of invasion science (see Richardson & Ricciardi, 2013), which has further impeded clear communication of the issues associated with biological invasions. In turn, ambiguity can (*i*) reduce people's understanding and willingness to support actions to avoid or manage biological invasions (e.g. Dunn *et al.*, 2018; Cerri *et al.*, 2020), (*ii*) be used for ideological or political manipulation of controversial topics arising from non-native species, (*iii*) shift liability and responsibility for management away from certain stakeholders or even nations that are otherwise bound to prevent and eliminate biological invasions based on prior commitments (e.g. parties to the *Convention on Biological Diversity*, cbd.int), and ultimately (*iv*) hinder control and management in ways that increase risks of higher costs or even irreversible damage (Ahmed *et al.*, 2022).

Our aims herein are to (*i*) review regularly used terms in invasion science and to break down the core definitions of the relevant terminology to identify any associated ideological interpretation; (*ii*) explore recently proposed approaches by the Darwin Core terms ['degree of establishment' (http://rs.tdwg.org/dwcdoe/values) and 'means' (http://dwc.tdwg.org/em); see Groom *et al.*, 2019], the *Convention on Biological Diversity*, and by Blackburn *et al.* (2011) to identify their strengths and commonalities; (*iii*) propose a simplified terminology to collapse synonymies to produce a harmonised set of terms for standardisation; and (*iv*) propose an objective classification protocol for non-native species considering four components: (*i*) dispersal mechanism, (*ii*) origin, (*iii*) status, and (*iv*) impact. Building on the extensive knowledge gained from previous research and tackling the entanglement of the ongoing discussion, our review attempts to mitigate these concerns by suggesting a consolidated, streamlined, and comprehensive terminology. This framework aims to clarify the lexicon of invasion science. While striving for a consensus definition is beneficial, we concede that it might not always be attainable, particularly when dealing with pluralism and complex concepts like biodiversity, species, and life (Pascual *et al.*, 2021). We therefore acknowledge that even among ourselves, there remains disagreement about how some terms should be defined, reflecting the diversity of opinions within our evolving field and demonstrating the importance of international and multidisciplinary discussions on how to clarify terminology.

III. TERMINOLOGICAL TEMPEST

The language of invasion science is a complex network of terms that are often used interchangeably, yet each of these terms carries specific implications for understanding the nature, origins, and impacts of the organisms. The meaning of these terms can also vary among scholars in various disciplines, by culture and education, and among policymakers and the public (see Ricciardi & Cohen, 2007). In August 2023, we did a comprehensive search of the literature to identify relevant terms used to describe 'non-native' species (Table 1). We initially reviewed Colautti & MacIsaac (2004), Falk-Petersen, Böhn & Sandlund (2006), and Lockwood *et al.* (2013), which we subsequently expanded with suggestions by co-authors and checked the resulting terms in the *Web of Science* for relevance.

We identified a total of 59 terms used to describe or classify non-native species, which exceeds those identified by Colautti & MacIsaac (2004), Falk-Petersen *et al.* (2006), and Lockwood *et al.* (2013) more than a decade ago (they identified 25, 30, and 27 terms, respectively). Based on a comprehensive scoping review, employing platforms such as *Web of Science* and *Google Scholar*, as well as opportunistic searches to explore both scientific and grey literature, we then counted the number of papers that employed those 59 terms based on the specific search for each term (e.g. 'invasive' species; Table 1), while excluding unrelated fields such as medicine or psychology. We focused on literature published in English, but with the exponential growth in the number of potentially relevant papers in non-English languages (Chowdhury *et al.*, 2023), we assume a similar boom in terminology also could be expected in many other languages. We recognise that integrating literature from other languages enriches many scientific disciplines (Angulo *et al.*, 2021; Zenni *et al.*, 2023); however, it could also introduce socio-political complexities that are not central to our primary objective – a concise terminology in invasion science. As non-English languages gain prominence in scientific discourse, the need to propose unified terminologies becomes even more pressing to ensure a global consensus on knowledge and best practice.

Increasing scientific interest resulting in more published articles has introduced more terms to the lexicon (Fig. 2), which seems to be a source of confusion and potential driving force of ambiguity in identifying non-native species, prioritising management, determining appropriate control measures, and allocating resources adequately and effectively (Ricciardi & Cohen, 2007; Lockwood *et al.*, 2013; Iannone III *et al.*, 2020). This issue is compounded by the use of acronyms and initialisms for terminology. An example is the initialism IAS used by some for 'invasive alien species', whereas others have used it to mean 'invasive animal species' (Carlon & Dominoni, 2023). Similarly, South Africa's regulations on biological invasions refer to 'alien and invasive species', often shortened to AIS and then confused with the narrower grouping of 'alien invasive species' (also AIS, a synonym of IAS). Others have preferred the initialism A&IS to resolve this confusion, although yet another initialism still constitutes specialist jargon (Zengeya & Wilson, 2020). The initialism AIS also has been used to indicate 'aquatic invasive species' e.g. in the documentations and website of the Great Lakes Commission (Canada, USA; glc.org/work/ais), adding to the terminological confusion. Another example is the use of the term 'non-indigenous species' (and initialism NIS) (synonym: non-native species) in some peer-reviewed papers (Colautti, Grigorovich & MacIsaac, 2006; Colautti & Richardson, 2009; Ojaveer *et al.*, 2015; Riera *et al.*, 2018), while the same abbreviation has been used to indicate a 'nuisance invasive species' (Pereyra, Rossini & Darrigran, 2012). Adding to the confusion, initialisms for the same term differ among nations and regions – adapted to their own language – such as the governmental initiatives in Argentina and Brazil called 'National Strategy on Invasive Exotic Species' [NSIES, or ENEEI in Portuguese or Spanish (Faria *et al.*, 2022; Schwindt *et al.*, 2022)].

Among the terms we found in the identified literature, the most frequent was 'invasive', appearing in 37.1% of the 70,188 publications (Fig. 2), followed by terms such as 'alien', 'non-native', 'exotic', and, *inter alia*, 'introduced'. However, the relative dominance of terms varied when we used the adjective without 'species', albeit painting a comparable picture (see online Supporting Information, Fig. S1). The use of these terms often varied according to the scientific discipline. For example, 'weed' is commonly used in botanical studies focusing on plant invasion. By contrast, 'invasive' is a more universal term applicable to all taxa, which likely explains its widespread uptake across many disciplines. The term 'invasive' itself has a convoluted origin. A terminological shift occurred in the 1990s as 'invasive' began replacing terms like 'introduced' (sometimes used to refer to those at the arrival stage and/or those established) and 'non-indigenous'. At a national scale, this shift was deliberately implemented in US legislation, specifically when the *Non-Indigenous Aquatic Nuisance Prevention and Control Act 1990* was renewed in 1995 and renamed the *National Invasive Species Act*. The two main elements influencing this revision were that: (*i*) the term 'invasive' carried a more impactful and compelling implication compared to the milder 'non-indigenous' (Carlton, 2002), and (*ii*) the 1990 act lacked an easily pronounceable acronym, leading to alternative names such as the *Ballast Water Act* or *Zebra Mussel Act*. The definition of 'invasive' was further obscured with Executive Order 13112 by U.S. President Bill Clinton in 1999, which specifically included 'impact' and 'economic harm'. 'Invasive alien species' is currently used by the European Commission in its regulations (http://environment.ec.europa.eu//topics/nature-and-biodiversity/invasive-alien-species_en), which is also the term most widely used by the Convention on Biological Diversity (in English, but not in other languages), the United Nations Sustainable Development Goals, and International Union for Conservation of Nature (IUCN).

Several papers and book chapters subsequently explored and discussed the term 'invasive' (Sax, Stachowicz & Gaines, 2005; Lockwood *et al.*, 2013). In general, terminological pitfalls have been avoided by providing definitions for selected terminology (e.g. Rilov & Crooks, 2009). However, 'invasive' is often used without a precise description of its implications, such as the extent of spread observed (for spread-based definitions) or impact caused (for harm-based definitions), which are themselves ambiguous. One type of impact is denoted 'species replacement', which has been ambiguously described as 'displacement', 'elimination', 'eradication',

Table 1. Definitions of the English terms most often used in invasion science for classifying species. The terms highlighted in italics and bold in the 'Definition' column indicate cases where particular terms are themselves used as definitions. Numbers in parentheses in the first column indicate the number of identified papers for that specific term. 'Related terms' refers to synonyms and associated terms.

Term	Definition	Example references	Related terms
acclimatised (**8**)	Presence despite being able to fulfil a portion or most of its life cycle in a ***foreign*** environment or climate, unable to reproduce or maintain a viable population without human intervention	Scalera & Zaghi (2004)	*adventive*, *casual*, *newcomer*, *non-resident*, *transient*
adventive (**162**)	In an early stage of ***invasion*** and not yet spread 'extensively' [undefined] beyond the point of introduction	Morris (1992); Binggeli (1994); Lawrence (2000); Klimaszewski *et al.* (2013)	*acclimatised*, *casual*, *newcomer*, *non-resident*, *transient*
alien (**8080**)	***Introduced*** to an area in which it does not occur naturally	Crawley *et al.* (1999), Pyšek *et al.* (2020)	*allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
allochthonous (**130**)	***Introduced*** into a new area outside the native range (in which it is autochthonous)	Corsini-Foka & Economidis (2007)	*alien*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
anthropochore (**96**)	Actively disperses seeds or propagules through direct or indirect human intervention	James & Hendrix (2004)	*alien*, *allochthonous*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
archaeophyte (**230**)	Plants that became ***naturalised*** in a specific region or area before 1492 (pre-'Columbian exchange')	La Sorte & Pyšek (2009)	*neophyte*
bioinvader (**35**)	***Non-native introduced*** to new environments that causes ecological and socio-economic damage	Pérez *et al.* (2008)	*biopollution*, *invasive/invader*, *noxious*, *nuisance*, *pest*, *unwanted*, *vermin*, *weed*
biopollution (**30**)	Have harmful or disruptive effects on native ecosystems, often due to ***invasive*** nature or aggressive behaviours	Occhipinti-Ambrogi (2021)	*bioinvader*, *invasive/invader*, *noxious*, *nuisance*, *pest*, *unwanted*, *vermin*, *weed*
casual (**40**)	Incapable of persisting in a novel environment, despite capacity for reproduction there; persistence depends on regular re-***introductions*** to rescue otherwise moribund populations	Wu *et al.* (2004)	*acclimatised*, *adventive*, *newcomer*, *non-resident*, *transient*
coloniser/colonist (**5954**)	Capable of ***establishing*** in a new area, often through a combination of high reproductive rates, efficient dispersal, and adaptive traits enabling it to tolerate or exploit the new environment; individuals in a founding population reproduce, increase in abundance, and form a self-perpetuating population	Davis & Thompson (2000); Davis (2009)	*established*, *invasive/invader*, *naturalised*, *transformer*
cryptogenic (**162**)	When there is uncertainty about the native range, and native/***non-native*** status in an area	Carlton (1996)	*questionable*
domestic (invasive, exotic, alien) (**8**)	Introduced to internal units from within the national border	Guo & Ricklefs (2010); Kamada *et al.* (2013)	*extralimital*, *translocated*, *intra-country established alien*
escaped (**9**)	Escaped captivity (e.g. pet stores, aquaculture facilities, herbaria, zoos, garden plants), and ***established*** populations in the wild	Padilla & Williams (2004)	*feral*, *released*
established (**817**)	Self-sustaining population(s) in a new area; phenomenon experienced by an	Keller *et al.* (2011); Gormley *et al.* (2011)	*coloniser/colonist*, *invasive/invader*, *naturalised*, *transformer*

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Table 1. *(Cont.)*

Term	Definition	Example references	Related terms
	alien after ***introduction*** resulting in an independent ***established*** population in natural habitats		
exotic (**6883**)	***Introduced*** into a new area outside the native range	Green (1997); Myers *et al.* (2000)	*alien*, *allochthonous*, *anthropochore*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
extralimital (**56**)	Native range falls within the political boundaries of a country, but presence in another part of the same country attributable to human transport across biogeographical barriers	Robinson *et al.* (2016)	*intra-country established alien*, *transferred*, *translocated*, *tramp*, *vagrant*, *waif*
feral (**53**)	Organisms or their descendants domesticated, confined (animals) or cultivated (plants) and subsequently released or ***escaped*** into the natural environment	Liu & Li (2009)	*escaped*, *released*
foreign (**162**)	***Non-native*** or ***non-indigenous*** to a particular region or country; ***translocated*** beyond its native range to another country across an international boundary	Richardson & Pyšek (2008)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
immigrant (**64**)	Moved from the native range to a new area where not previously occurring naturally	De Meester *et al.* (2007)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
imported (**53**)	***Translocated*** into a new area from the native range	Holzapfel & Vinebrooke (2005); Williamson & Fitter (1996)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
intra-country established alien (**1**)	Successful ***introductions*** and ***establishment*** among regions or in a novel region within the same country	Vitule *et al.* (2019)	*extralimital*, *native-alien populations*, *transferred*, *translocated*, *tramp*, *vagrant*, *waif*
introduced (**5443**)	***Translocated*** by humans to a new geographic location where did not occur naturally; intentional or unintentional (accidental) ***introduction*** and/or release by humans, either directly or indirectly, into natural or anthropogenically altered (e.g. urban) environments or locations, in geographical areas where (species, subspecies, race, or variety) is not found naturally	Simberloff *et al.* (2005)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
invader (**9978**) **/** *invasive* (**26030**)	***Non-natives introduced*** to a new environment with ability to spread and cause ecological and socio-economic damage; either native or ***alien*** that can spread and ***establish*** in natural or semi-natural habitats, either with or without human assistance; can encompass spread and/or impact	Simberloff (2010)	*coloniser/colonist*, *established*, *naturalised*, *transformer*
invasive alien (**2402**)	Introduction and/or spread outside natural past or present distribution threatens biological diversity	CBD (2020); Pyšek *et al.* (2020)	*invasive non-native*, *invasive super dominant*, *neonative*, *new non-native*
invasive non-native (**242**)	***Introduced*** by humans (intentionally or accidentally) into areas where does not occur naturally without recognisable negative impact	Vitule *et al.* (2021); CBD (2020)	*invasive alien*, *invasive super dominant*, *neonative*, *new non-native*
invasive super dominant (**1**)	Not only successfully **established** in a new ecosystem, but also becomes	Pivello *et al.* (2018)	*invasive alien*, *invasive non-native*, *neonative*, *new non-native*, *transformer*

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Table 1. *(Cont.)*

Term	Definition	Example references	Related terms
	dominant, having substantive influence on the ecosystem's structure or function		
migrant (**444**)	Moved from its native habitats to new geographic areas; can be natural (e.g. birds migrating between continents), or facilitated by humans	Ibanez *et al.* (2008)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *neobiota*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
naturalised (**379**)	***Non-native*** successfully ***established*** self-sustaining populations in a new environment without human intervention; ***non-native*** after being ***introduced*** successfully ***established*** self-sustaining populations in the wild; must be present long enough to be perceived as an integral [undefined] part of the resident community of organisms	Wu *et al.* (2004)	*coloniser/colonist*, *established*, *invasive/invader*, *transformer*
neobiota (**40**)	***Introduced*** into new habitats or regions, typically due to human activities; can have ecological impacts and include **invasives**	Schittko *et al.* (2020)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *non-indigenous*, *non-native*, *transported*, *xenobiota*
neophyte (**766**)	***Introduced*** to a new habitat or region after 1492; often not fully integrated into new ecosystems and can still be in the process of spreading and establishing	Kühn *et al.* (2017)	*archaeophyte*
new non-native (**28**)	Fills similar role(s) to an extinct native that is not closely related (no more closely related than order)	Blackman *et al.* (2017)	*Invasive alien*, *invasive non-native*, *invasive super dominants*, *neonative*
neonative (**5**)	Expanded geographically beyond the native range and ***established*** populations driven by human-induced environmental change without human assistance	Essl *et al.* (2019, 2021*b*); Wallingford *et al.* (2020)	*invasive alien*, *invasive non-native*, *new non-native*
newcomer (**6**)	Recently ***established*** in a particular ecosystem or geographical area, often due to natural or human-mediated ***introductions***	Evans *et al.* (2020)	*acclimatized*, *adventive*, *casual*, *non-resident*, *transient*
non-indigenous (**2349**)	Not found naturally in a particular geographic location or ecosystem	Ojaveer *et al.* (2015)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-native*, *transported*, *xenobiota*
non-native (**5341**)	***Introduced*** to an area outside of natural range	Jeschke *et al.* (2014)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *transported*, *xenobiota*
non-resident (**46**)	No recent evolutionary history in focal ecological network and not familiar with species in that network (*cf.* 'resident')	Eckstein *et al.* (2012); Saul & Jeschke (2015)	*acclimatised*, *adventive*, *casual*, *newcomer*, *transient*
noxious (**65**)	Harmful or dangerous to human health, agriculture, or environment	Andreu *et al.* (2009)	*bioinvader*, *biopollution*, *invasive/invader*, *nuisance*, *pest*, *unwanted*, *vermin*, *weed*
nuisance (**256**)	Annoying or inconveniencing humans; typically not harmful or dangerous; can be ***non-native*** or native	Barrett *et al.* (2019)	*bioinvader*, *biopollution*, *invasive/invader*, *noxious*, *pest*, *unwanted*, *vermin*, *weed*
pest (**2702**)	Harmful or destructive to humans, crops, livestock, or property; can be ***non-native*** or native	Worner & Gevrey (2006)	*bioinvader*, *biopollution*, *invasive/invader*, *noxious*, *nuisance*, *unwanted*, *vermin*, *weed*
pseudo-indigenous (**7**)	***Introduced*** species mistakenly identified as native	Carlton (2009)	

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Table 1. *(Cont.)*

Term	Definition	Example references	Related terms
questionable (**28**)	Status as native or ***non-native*** (***alien/ invasive***) uncertain or disputed	Zenetos *et al.* (2010)	*cryptogenic*
range-expanding (**65**)	Extends geographical distribution beyond previously known or ***established*** range, often due to climate change, habitat modification, or dispersal abilities	Essl *et al.* (2019)	*coloniser/colonist*, *established*, *invasive/invader*, *naturalised*, *transformer*
released (**58**)	Deliberately or accidentally ***introduced*** into an environment outside of native range by humans	Blumenthal (2006)	*escaped*, *feral*
restocked (**1**)	Re-***introduced*** or replenished in a specific area through deliberate human intervention, often aimed at restoring or increasing population sizes, not specifically of same species	Roll *et al.* (2007)	*transplanted*
tramp (**48**)	Ability to colonise and spread rapidly across new habitats, often facilitated by humans; (***non-native***) disturbance specialist, closely associated with humans	Passera (2021)	*extralimital*, *intra-country established alien*, *transferred*, *translocated*, *vagrant*, *waif*
transferred (**80**)	Moved across a national border to a country within natural range	McGlynn (1999)	*extralimital*, *intra-country established alien*, *translocated*, *tramp*, *vagrant*, *waif*
transformer (**24**)	Alters the character, condition, form, or nature of an ecosystem over a broad area	Richardson *et al.* (2000); Protopopova *et al.* (2015)	*coloniser/colonist*, *established*, *invasive/invader*, *invasive super dominants*, *naturalised*
transient (**496**)	Occurs in a particular location only temporarily or sporadically	Snell Taylor *et al.* (2018)	*acclimatised*, *adventive*, *casual*, *newcomer*, *non-resident*
translocated (**98**)	Moved from the native range to a new location by humans; ***intra-country*** translocation is ***introduction*** from one region or political entity (country) within the same country where native to another region and where not found naturally; moved by humans for conservation (e.g. assisted migration/ colonisation); see also ***intra-country established alien***	Vitule *et al.* (2019); Doria *et al.* (2021); Essl *et al.* (2021*b*)	*extralimital*, *intra-country established alien*, *transferred*, *tramp*, *vagrant*, *waif*
transplanted (**58**)	***Introduced*** outside the native range, usually for ecological restoration or commerce/recreation; can be either ***non-native*** or native to area of transplantation	Hargreaves *et al.* (2014)	*restocked*
transported (**94**)	Moved outside the native range, can be either ***non-native*** or native to area of transport	Gross & Pharr (1982)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *xenobiota*
unwanted (**97**)	Undesirable for humans, crops, aquaculture, or property; can be ***non-native*** or native	Iuell (2002); Naylor *et al.* (2001); Caley & Kuhnert (2006); Nagy & Johnson II (2013)	*bioinvader*, *biopollution*, *noxious*, *nuisance*, *pest*, *vermin*, *weed*
vagrant (**61**)	Occur outside typical or expected range or habitat, often individual or fine-scale occurrences	Luiz *et al.* (2013)	*extralimital*, *intra-country established alien*, *transferred*, *translocated*, *tramp*, *waif*
vermin (**147**)	Undesirable due to detrimental impacts on agriculture, horticulture, or enemies to game preservation	Smout (2003)	*bioinvader*, *biopollution*, *noxious*, *nuisance*, *pest*, *unwanted*, *weed*
waif (**74**)	Found outside the normal geographic range, usually far from the native	Christy *et al.* (2009)	*extralimital*, *intra-country established alien*, *transferred*, *translocated*, *tramp*, *vagrant*

(Continues on next page)

Table 1. *(Cont.)*

Term	Definition	Example references	Related terms
	habitat, often without clear evidence of human-mediated transport		
weed (**6146**)	Plants considered undesirable or unwanted in a particular setting, typically due to competitive nature, rapid growth, and ability to spread quickly	Ogg & Dawson (1984)	*bioinvader*, *biopollution*, *noxious*, *nuisance*, *pest*, *unwanted*, *vermin*
xenobiota (**1**)	***Introduced*** or ***non-native*** to a particular ecosystem or geographic region, often originating from a different ecosystem or geographic area	Tsadok *et al.* (2015)	*alien*, *allochthonous*, *anthropochore*, *exotic*, *foreign*, *imported*, *immigrant*, *introduced*, *migrant*, *neobiota*, *non-indigenous*, *non-native*, *transported*

'exclusion', 'extirpation', 'extinction', and 'supplanted'. 'Invasive' can also have several meanings; for example, it can refer to species that have successfully established and spread to new areas, regardless of their impacts (Richardson *et al.*, 2000; Blackburn *et al.*, 2011), or those causing ecological or socio-economic harm in their new environment regardless of the stage of the invasion process (Leung *et al.*, 2002; Lockwood *et al.*, 2013). 'Invasive' has also been applied to weedy species such as *Phragmites australis* in Europe and Asia, where it is native but can become dominant due to human

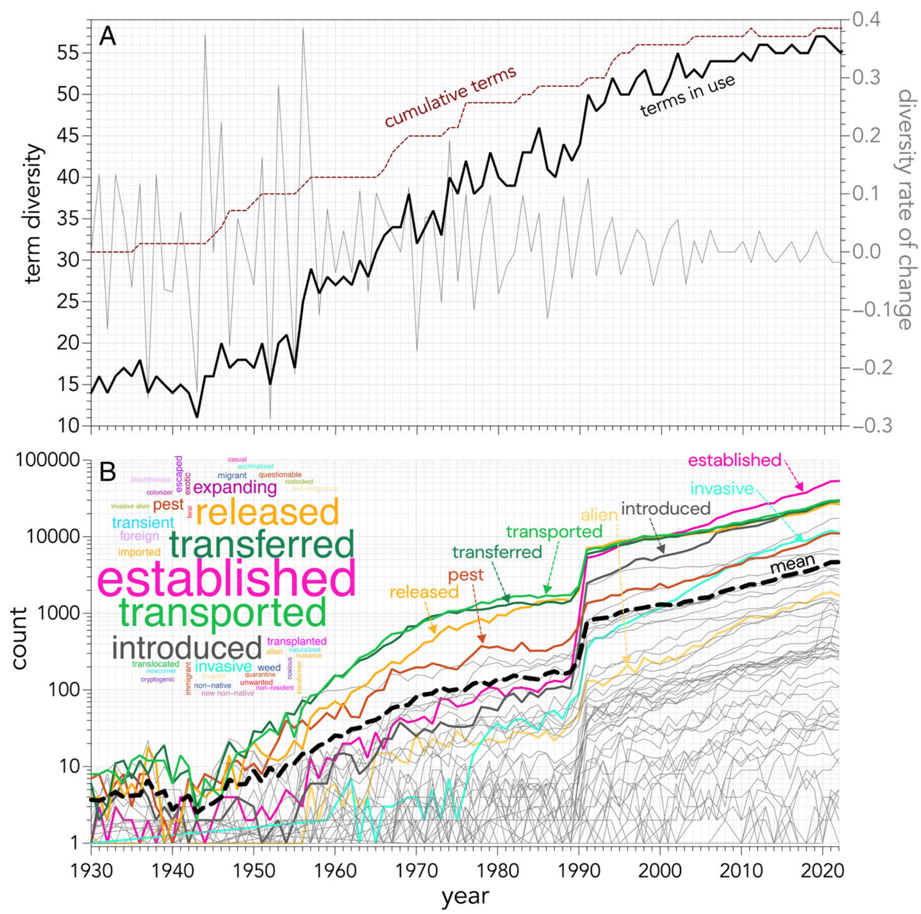

Fig. 2. (A) Total term diversity (i.e. number of different terms used in each particular year) over time, cumulative term diversity, and the instantaneous rate of change of diversity of terms. (B) Count timeline ($\log_{10}$ scale) lines reflecting the trend for each individual term identified in Table 1 (some popular terms are highlighted with colours). Wordcloud (inset) shows the total frequency use of each term (size of text is proportional to the total number of uses – only 40 different terms are shown). All terms here were used as adjectives with 'species' in the search string (e.g. 'invasive species'). Data and R code to reproduce trends and word cloud available from http://github.com/IsmaSA/Invasion-science-terminology.

disturbance (Lambert, Dudley & Saltonstall, 2010). 'Invasive' has even been applied to ecologically dominant native species undergoing a demographic explosion (Valéry *et al.*, 2009; Packer *et al.*, 2017), possibly a legacy of early plant scientists using 'invading' synonymously with 'spreading'.

Amid this etymological complexity, the nuanced interpretations of several terms used by invasion scientists to describe species such as 'invasive', 'invader', 'introduced', 'naturalised', 'non-indigenous', and 'exotic' cannot be overlooked. These terms are often used interchangeably, even within a single study (to avoid word repetitions), raising several concerns about their potential misinterpretation and misapplication, including the politicisation of non-native species (Ricciardi & Cohen, 2007; Russell & Blackburn, 2017). Each of these terms can have a unique, nuanced interpretation that relates to a specific aspect of population spread and the perceived negative impacts it can cause (Lockwood *et al.*, 2013). As such, labelling a species 'invasive' implies that its populations pose some harm or threat according to some frequently adopted definitions, such as those used by the Convention on Biological Diversity (Leung *et al.*, 2002; Lockwood *et al.*, 2013), but other definitions do not invoke harm or impact in general (Falk-Petersen *et al.*, 2006; Ricciardi & Cohen, 2007). Other terms such as 'exotic', 'alien', and 'non-indigenous' do not inherently imply harm to ecological or socio-economic systems (see also Falk-Petersen *et al.*, 2006; Stoett, 2010; Fachinello *et al.*, 2022).

(1) Previous attempts to tame the 'terminological tempest'

Despite multiple attempts to address the complex terminology in invasion science (Table 2), confusion nevertheless persists (Occhipinti-Ambrogi & Galil, 2004; Courchamp *et al.*, 2017; Colautti & Richardson, 2009). This has led to proposed protocols to identify the most appropriate terms for classifying species based on their stage of invasion (Colautti & Richardson, 2009; Colautti *et al.*, 2014). The Convention on Biological Diversity followed a simple and practical approach by defining 'invasive' as non-native plants, animals, pathogens, and other organisms that are introduced or that spread outside their natural habitats if they pose a threat to native biodiversity, otherwise cause environmental harm, impose negative economic consequences, or adversely affect human health (CBD, 2020). This definition emphasises measurable, negative impact (itself time-dependent, and might occur without notice or measure) and the potential for spread, with these two phenomena not necessarily linked. However, the ability or potential to spread is, like introduction, often aided by humans. But all established non-native species, because they interact with the local environment, will have some type of ecological effect – positive, negative, or mixed – along a continuum from negligible to enormous (Ricciardi *et al.*, 2013). Indeed, widely cited estimates of the proportion of invasions that have impacts are likely underestimated (Simberloff *et al.*, 2013).

Determining what constitutes an 'invasive' species can be difficult because of the demographic dimensions of invasiveness (Colautti & MacIsaac, 2004) and the underlying mechanisms involved (Gurevitch *et al.*, 2011; Rejmanek, 2011). Blackburn *et al.* (2011) proposed a highly cited and useful framework for biological invasions, where various terminologies for non-native species are associated throughout the different stages of an invasion. Therein, invasion state and impact are independent, because different populations can have measurable impacts at varying stages, acknowledging that all introduced species use resources and occupy space, thereby imposing some form of negative impact. While 'invasive' should be defined based on a population's stage of an invasion and spread patterns, the exerted impact should be considered a separate dimension pertaining to a specific invading population. However, various populations can exert differing magnitudes of impact at different stages of an invasion over time, which depend on the type of impact and the specific features of the invaded ecosystem (Gallardo *et al.*, 2016). Inferences of impact can also depend on perceptions and socio-economic evaluations (Falk-Petersen *et al.*, 2006).

Yet, defining a non-native species' invasiveness based exclusively on its ability to spread would imply that countless species qualify as 'invasive' as global (e.g. climate) change proceeds. Meanwhile, the focus on an identified impact could impede managers and stakeholders from acting until a negative impact is measured, such as for non-native species not currently spreading, but that cause local harm (Balzani *et al.*, 2022). This *modus operandi* would, however, reinforce the current predominance of reactive management strategies for biological invasions, rather than proactive actions that could avoid later harm (Cuthbert *et al.*, 2022). Proactive actions in managing biological invasions primarily encompass preventative approaches as well as early detection and rapid-response systems that are necessary for effectively mitigating potential impacts of non-native species (Cuthbert *et al.*, 2022). Because all non-native species might have an impact at some point during the invasion process, such as by consuming resources or simply occupying space, the magnitude of impact can change unpredictably.

But measures of impact do not necessarily determine if a species is invasive, even though they are useful for assessing the risk of an invasion and are therefore commonly applied in risk analyses. To identify the invasion risk or the invasiveness of non-native species based on their observed or predicted impacts, various methods such as the Australian Weed Risk Assessment scheme (Pheloung, Williams & Halloy, 1999), the European and Mediterranean Plant Protection Organisation Platform on Pest Risk Analysis (Soliman *et al.*, 2010), and related decision-support tools (Copp *et al.*, 2016; Vilizzi *et al.*, 2022*b*, 2024) have been developed. However, current risk-screening tools generally lack fully quantitative foundations, often incorporating qualitative information such as expert assessments due to limited tangible data or information on impacts (Roy *et al.*, 2014, 2018). A knowledge gap arises from biassed impact research

Table 2. Published articles and books (arranged chronologically, without claiming completeness) that have highlighted the ongoing debate and confusion over terminology in invasion science, many of which aimed to standardise the invasion science lexicon.

Year	Authors	Article type
1995	Pyšek	On the terminology used in plant invasion studies
1997	Shigesada & Kawasaki	Biological invasions: theory and practice
1999	Lonsdale	Global patterns of plant invasions and the concept of invasibility
2000	Davis & Thompson	Eight ways to be a coloniser; two ways to be an invader: a proposed nomenclature scheme for invasion ecology
2000	Richardson *et al.*	Naturalisation and invasion of alien plants: concepts and definitions
2002	Carlton	Bioinvasion ecology: assessing invasion impact and scale
2004	Colautti & MacIsaac	A neutral terminology to define 'invasive' species
2004	Brown & Sax	An essay on some topics concerning invasive species
2004	Pyšek *et al.*	Alien plants in checklists and floras: towards better communication between taxonomists and ecologists
2005	Copp *et al.*	To be, or not to be, a non-native freshwater fish?
2005	Helmreich	How scientists think; about 'natives', for example. A problem of taxonomy among biologists of alien species in Hawaii
2006	Falk-Petersen *et al.*	On the numerous concepts in invasion biology
2007	Warren	Perspectives on the 'alien' versus 'native' species debate: A critique of concepts, language and practice.
2007	Ricciardi & Cohen	The invasiveness of an introduced species does not predict its impact.
2007	Larson	An alien approach to invasive species: objectivity and society in invasion biology.
2008	Valéry *et al.*	In search of a real definition of the biological invasion phenomenon itself.
2009	Colautti & Richardson	Subjectivity and flexibility in invasion terminology: too much of a good thing?
2009	Wilson *et al.*	Biogeographic concepts define invasion biology.
2009	Wilson *et al.*	Something in the way you move: dispersal pathways affect invasion success.
2011	Richardson *et al.*	A compendium of essential concepts and terminology in invasion ecology.
2011	Gurevitch *et al.*	Emergent insights from the synthesis of conceptual frameworks for biological invasions.
2013	Shackelford *et al.*	Finding a middle-ground: the native/non-native debate.
2013	Lockwood *et al.*	Invasion Ecology
2013	Heger *et al.*	What biological invasions 'are' is a matter of perspective.
2013	Richardson & Ricciardi	Misleading criticisms of invasion science: a field guide.
2013	Simberloff *et al.*	Impacts of biological invasions: what's what and the way forward.
2016	Robinson *et al.*	Lost in translation? Standardising the terminology used in marine invasion biology and updating South African alien species lists
2018	Essl *et al.*	Which taxa are alien? Criteria, applications, and uncertainties.
2019	Essl *et al.*	A conceptual framework for range-expanding species that track human-induced environmental change.
2019	Kapitza *et al.*	Research on the social perception of invasive species: A systematic literature review.
2019	Latombe *et al.*	A four-component classification of uncertainties in biological invasions: implications for management.
2020	Cassini	A review of the critics of invasion biology.
2020	Iannone *et al.*	Invasive species terminology: Standardising for stakeholder education.
2021	Essl *et al.*	Neonatives and translocated species: different terms are needed for different species categories in conservation policies.
2022	Lepczyk	Time to retire 'alien' from the invasion ecology lexicon.
2022	Shackleton *et al.*	Consensus and controversy in the discipline of invasion science.
2022	Golebie *et al.*	Words matter: a systematic review of communication in non-native aquatic species literature.

targeting specific taxa, regions, or values, further complicated by context-dependent and time-lagged effects. Unfortunately, the formal and reliable information required for accurate and objective assessments is frequently lacking and/or is (spatially) incomplete for many non-native species, resulting in discrepancies among inadequate spatial risk and impact assessments (González-Moreno *et al.*, 2019).

(2) Language as a source of ambiguity

The circulation of many English terms and their translations can introduce ambiguity and hinder public engagement with diverse audiences. For instance, describing a species as 'exotic' can be perceived differently and carry positive connotations in several languages (like English, Portuguese, Italian, Czech or Spanish), such as 'extravagant', 'fancy', and/or 'unique'. On the other hand, the dominance of English in scientific publishing implies that the meaning of terms with different connotations (often with no direct translation) in other languages will inevitably be unclear, while it can concomitantly impede effective transfer of information and create knowledge gaps [e.g. regarding the impacts of invasive species (Bortolus, 2012; Angulo *et al*., 2021; Nuñez *et al*., 2022)]. For instance, many of the current debates about disciplinary denialism, the misleading xenophobic formulation of analogies with international human migration, and the impact of using emotive language, are likely exacerbated by culture and translation (Copp *et al*., 2021; Bortolus & Schwindt, 2022). Indeed, many issues of terminological ambiguity and epistemic injustice arise from the pervasive 'diffusion of English' approach in scientific research and terminology being published, reviewed, and accepted almost exclusively in English. This was recently addressed with an application of the 'ecology of language' paradigm to the development of a multilingual decision-support tool for communicating the risks of invasive species to decision-makers and stakeholders in their native language (Copp *et al*., 2021). In this complex multicultural and multi-linguistic scenario, one must accept that (*i*) consensus concepts published in English might not be ideal in other languages, philosophical frameworks, and cultures, and (*ii*) the aim is to achieve consensus of conceptual definition rather than on terms *per se*. Reviewing, comparing, and reaching agreements on definitions, as well as establishing precise regulations for translating technical terminology into various languages worldwide, constitutes an essential, but not easy, step.

'Exotic' and 'alien' denote species that have been introduced to a region outside their native ranges (Florencio, Lobo & Bini, 2019). However, using 'alien' in public discourse is potentially confusing because it: (*i*) is sometimes synonymous with 'extraterrestrial', therefore potentially confusing (Lepczyk, 2022); (*ii*) has socio-political connotations and legal implications in human immigration policies; and (*iii*) can limit the application of Indigenous People's frameworks and management and impede biodiversity protection (Wehi *et al*., 2023). This occurs because of the dichotomous portrayal of 'aliens' and 'natives' that echoes detrimental historical narratives and marginalises Indigenous stewardship, posing a barrier to protection of biodiversity (Warren, 2007; Wehi *et al*., 2023). 'Non-indigenous' should not be considered a synonym of 'alien' species (Kolar & Lodge, 2001) because 'non-indigenous' also has a socio-political interpretation, particularly in light of the growing recognition and awareness of Indigenous rights (Wehi *et al*., 2023), political correctness, and the increasing popularity of the diversity, equity, and inclusion agenda within academia. Even terms like 'colonise' to describe processes of pre-colonial human movements are falling out of favour in disciplines such as anthropology and archaeology given their association with colonial injustices.

A possible alternative would be 'allochthonous' (*contra* 'autochthonous'), an established term in freshwater ecology. 'Allochthonous' is not (yet) politically charged; it is derived from the Greek *allos* (*ἄλλος*, meaning 'other' or 'different') and *chthon* (*χθών*, meaning 'Earth' or 'land'), and is commonly used in geology and ecology to describe something that originates or is formed in a location different from where it is currently found (displaced). However, this term is not in common usage and difficult to pronounce in or translate to non-Romance languages, and is therefore unlikely to become part of the public discourse, even though it is well-established among experts in some countries (e.g. France, Serbia, Spain, Italy).

Other terms focus on the capacity of a species to spread, such as 'escaped' (Table 1) and 'introduced', which strictly address the act of intentional or unintentional introduction of an organism by humans into an environment where it did not occur naturally (Simberloff, Parker & Windle, 2005). 'Naturalised', favoured by the 'naturalisation and acclimatisation' societies of the 19th and 20th centuries, not only mixes concepts related to the ability to spread and establish, but also how long a given species has been present in the new environment such that people perceive it as part of the native community – e.g. dingo *Canis dingo* in Australia (Smith *et al*., 2019), North American ash-leaved maple *Acer negundo* in Russia (Vinogradova, 2006), and the smooth cordgrass *Spartina alterniflora* in South America (Bortolus, Carlton & Schwindt, 2015). 'Naturalised' describes a non-native species that has successfully established self-sustaining populations in the wild following introduction (Falk-Petersen *et al*., 2006), yet despite still being non-native, it sometimes attracts the same legal protection as native species (e.g. fallow deer *Dama dama* in the UK; Manchester & Bullock, 2000). However, other definitions have been applied to describe the naturalisation phenomenon: (*i*) species that are non-native and reproduce in environments aided by human cultivation; (*ii*) a group of non-native species that propagate in natural or semi-natural environments; (*iii*) species that exist outside their native regions, with their reproductive success varying; or (*iv*) non-native species that have broadened their geographic distribution (see Richardson *et al*., 2000). Carlton (2009) disapproved of the terms 'naturalised' and 'resident', asserting that these do not constitute distinct categories within the realms of biogeography, ecology, environment, history, or evolutionary status, arguing instead that identifiable species should be categorised as either 'native', 'introduced', or 'cryptogenic'.

Terms applied less frequently but subjected to linguistic ambiguity include 'noxious' to refer to species that are harmful or dangerous to humans (Andreu, Vilà & Hulme, 2009), 'foreign' to denote species originating from a different geographical location (Iannone III *et al.*, 2020), 'adventive' to refer to species that have been introduced to a new area but have not yet become invasive (Frank & McCoy, 1990; Klimaszewski, Bourdon & Pelletier, 2013), and the cultural terms 'pest' or 'weed' not necessarily related only to non-native species (Richardson *et al.*, 2011), but often used for native insects, rodents, or widespread plant species with a negative impact on agricultural production, forestry, or urban ecosystems (Worner & Gevrey, 2006).

IV. SEPARATING IDEOLOGY FROM TERMINOLOGY

The emergence of novel terminology deviating from established definitions, as well as certain terms that broadly promote 'political correctness' (Klotz, 1999; Wagner, 2005; Pace & Severance, 2016), denotes linguistic change. Such terms can have negative connotations and are therefore criticised (Colautti & MacIsaac, 2004; Lieurance *et al.*, 2022). This has been argued for terms like 'alien' (Lockwood *et al.*, 2013), and even 'invasive', which have been misused by populists and politicians (Schlaepfer, Sax & Olden, 2011; Sax, Schlaepfer & Olden, 2022) to advance ideologically based policies (Larson, 2005). The term 'invasive' itself is defined as '... (especially of diseases within the body) spreading very quickly and difficult to stop' (Oxford English Dictionary Online, 2023). According to Cambridge English Dictionary Online (2023), '... an invasive organism is one that has arrived in a place from somewhere else and has a harmful effect on that place'. Concomitantly, it is also connected to hostile (e.g. military) actions or directly from Medieval Latin *invasivus* meaning 'tending to invade, aggressive' (Weekley, 1921). 'Invasive' has been used in pathology (since the 1920s) and medicine (since the 1970s), and refers to both (*i*) propagation and (*ii*) harmfulness (Oxford English Dictionary Online, 2023). 'Invasive', when used by invasion scientists to describe non-native species, can create confusion because it might be interpreted as pertaining only to spread, or incorrectly associated with negative impacts, or both.

While the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) uses the terms 'alien' and 'invasive' in its reports (aligning with the terminology used in the Convention on Biological Diversity), some scientific journals are already banning terms such as 'alien' due to its value-laden nature. It is therefore unfortunate that some international bodies still actively promote such terms, because they can obfuscate discourse, fuel divisiveness, and undermine the principles of constructive dialogue and understanding. Rather than fostering healthy debates, such terminology serves only to entrench biases, deepen resentment, and polarise communities, nor does it align with principles fostering a balanced and informed discourse. While top-down initiatives echo recent calls to steer away from such concepts and terms in ecology (Ellwood *et al.*, 2023), creating language rules and enforcing verbal hygiene can be disadvantageous by hindering open dialogue, stifling diverse perspectives, and impeding the advancement of knowledge (Cameron, 2012). In his 2022 address to the Convention on Biological Diversity–Global Biodiversity Facility negotiations in Montreal, the Secretary-General of the United Nations António Guterres used the term 'invasive non-native species'. The negative connotations of several terms used by invasion scientists possibly also take root from using 'invasive species' for the taxon as a whole, instead of 'invasive population', for example. No species is invasive *per se* (i.e. being native in their original range and not necessarily invasive everywhere where they are introduced; Colautti & MacIsaac, 2004) and notable impacts within populations can be triggered by environmental changes or trait evolution (Cuthbert *et al.*, 2023).

(1) Avoiding problematic terminology

Different languages can employ different terms, and the translation between English and other languages can cause confusion (see Section III.2). This creates challenges when addressing non-native species, such as geographical and historical differences in the use of terminology (Richardson *et al.*, 2011). To foster clarity and progress while enhancing communication and comprehension, we propose avoiding historically problematic, redundant, and/or confusing terminologies especially, but not only, when non-native species are listed in different categories for management (Table 3). While clarifying the meaning of terms used in studies on biological invasions, we suggest avoiding 'Lessepsian migration' (Por, 1971) in view of the controversial history of Viscount Ferdinand Marie de Lesseps. As one of the founders of the 'Compagnie Universelle du Canal maritime de Suez', Lesseps was responsible for wide-scale exploitation of unpaid forced labour (Brown, 1994; Farouk, 2019; Ortiz-Serrano & Forero-Laverde, 2020). 'Lessepsian' glorifies the person and his actions, thereby perpetuating a legacy of European imperialism and corruption. A replacement term could be 'Suezian non-native migration'. Our proposed terminology attempts to overcome problematic terms, but also redundancies and ambiguities, and these terms classifying species in categories should be limited or eliminated entirely in invasion science, especially when using them to describe the invasiveness of a non-native species. Specifically, we propose to avoid the terms listed in Table 3 (especially when presented without context; e.g. Latombe *et al.*, 2019) to classify a non-native species, or to consider their use carefully and contextualise appropriately.

(2) Conundrum of nativeness and non-nativeness

The dichotomy of 'non-native' and 'native' species can often be applied effectively at broader scales (e.g. continental) where clear biogeographical units are considered, while evolutionary boundaries are sub-continental for many taxa (especially in fresh waters) and are therefore more complex to delimit due to ecological, genetic, or taphonomic variation (Lockwood *et al.*, 2013; Stigall, 2019; Lemoine &

Table 3. Terminology used by invasion scientists to describe non-native species that we suggest should be avoided because of the likelihood it will perpetuate confusion or offend. Otherwise, authors should carefully consider their use and explain appropriately the specific context to avoid misunderstandings, confusion, and controversy.

Term(s)	Reason
alien, *foreign*, *non-indigenous*, *exotic*	Often used interchangeably, and synonymous with ***non-native***, leading to potential confusion and ideological or political misuse
alien (including *invasive alien*), *extralimital*, *immigrant*, *migrant*, *unwanted*	Politicised with socio-political connotations often used in context of human migration; ***alien*** can also be confused with 'extraterrestrial being' in public discourse
acclimatised, *adventive*, *anthropochore*, *established alien*, *intra-country*, *non-resident*, *transformer*, *bioinvader*, *biopollution*, *coloniser*, *tramp*, *vagrant*, *waif*, *xenobiota*	Also used in other contexts, creating ambiguity
casual, *escaped*, *imported*, *neobiota*, *released*, *translocated*, *transferred*, *transported*, *transplanted*, *transient*, *vagrant*, *vermin*, *waif*	Do not indicate the invasive potential or establishment of the species
established, *naturalised*, *questionable*, *transient*	Without context, remain too open to interpretation (subjective); note difference to ***established non-native*** proposed herein (see Table 4)
noxious, *nuisance*, *pest*, *weed*	(Legal) terms often used to describe harmful or destructive species; as not all ***non-native*** species are designated ***noxious***, its use requires context
neonative, *new non-native*, *newcomer*, *non-resident*, *restocked*	Impractical, because human-caused climate disruption drives species distributional shifts, including species that are ecologically and phylogenetically distinct from resident native species; some of these species will become disruptive to ecosystems for the same reasons that cause ***invasive non-native*** species to do so; poorly linked and often conflicting with science, policy, and management

Note: Italics refer to terms identified in this paper as problematic (e.g., redundant).

Svenning, 2022). Furthermore, classification becomes more complex at finer scales where the boundaries between native and non-native ranges are more difficult to delineate (Lockwood *et al*., 2013; Brodie *et al*., 2021). However, the fact that a species' native range might be challenging to observe from a human perspective does not imply that nativeness must possess a gradation terminology beyond an inherently binary state – either it is native or it is not. While it is generally advantageous to define the native range of a species as temporally and spatially static (Pereyra, 2020), the concept of 'nativeness' should be interpreted as an eco-evolutionary continuum. This implies that an unambiguous categorisation of a species as native or non-native might not always be feasible due to varying ecological and evolutionary factors. This complexity arises, for instance, when species expand their native ranges within the same country or region due to human modification of the environment and/or climate change (Clements & Ditommaso, 2011; Saikkonen *et al*., 2012), possibly tracking their historical niches when the rates of environmental alteration exceed adaptation to those changes (Thomas, 2010), or when the biogeography of so-called 'cosmopolitan' species (distributed in most or all regions of the globe) is not well-resolved (Cerca, Purschke & Struck, 2018; *cf*. Darling & Carlton, 2018). Nevertheless, addressing these classification issues could not be resolved with a broad range of naming conventions for these organisms as a way to offset the limited understanding of the human role in their distribution. For practical applications, we therefore support a dichotomous categorisation ('native' or 'non-native') while still acknowledging the inherent ambiguities.

The newest term debated in the invasion lexicon is 'neonative' – referring to species that move on their own beyond their present natural range due to human-induced environmental changes (Wilson, 2020; Essl *et al*., 2019, 2020, 2021*b*). 'Neonative' was proposed to distinguish species moved through human agency (i.e. 'non-native') and range-expanding native species responding to human-caused environmental (local) and climate (global) changes (Essl *et al*., 2019; Urban, 2020). However, it is often challenging to distinguish between the observation and status of species moving naturally from those shifted passively or actively by human endeavour (i.e. as a result of human-assisted pathways; Essl *et al*., 2019). This differs from the proposed approach of Gilroy, Avery & Lockwood (2017), who did not deal with the issue of intermediate populations (i.e. 'stepping stones'; Floerl *et al*., 2009), but defined all species transported outside their native ranges by direct transport as 'non-native', leaving species moving *via* unassisted dispersal as 'natives'.

If we consider species as 'non-native' based on their evolutionary lineage and native habitat, disregarding the mechanism of their dispersal, invasions resulting from establishment after a long-range dispersal, akin to anthropogenically facilitated extinctions and climate change, have been a persistent aspect throughout the history of life on Earth (Stigall, 2019). Just as human activities affect current rates of extinction and climate change, they also influence the rate, scale, and impact of biological invasions (Ricciardi, 2007).

By viewing 'non-native' species in terms of evolutionary history, invasions can be understood as species settling populations outside their conventional biogeographic and evolutionary limits. Consequently, not every occurrence of range expansion can be classified as an invasion because all species experience natural range variation given enough time (Wilson, 1961). Yet, regardless of the reasons or processes involved, all invasions are indeed a form of range expansion (Ricciardi, 2007; Beest *et al.*, 2013). 'Neonative' is therefore impractical and weakly linked to policy and management [Wilson (2020), *cf.* Lenoir *et al.* (2020) for debate].

We recommend that 'neonative' should be used only to label native taxa undergoing climate-induced range extensions. But it should not be used to classify non-native species spreading *via* human-made pathways after an environmental barrier is removed, because this would overlook rapid, contemporary climate change driving some invasions and the erosion of biogeographic barriers *via* human influence. Assuming that the defining characteristic of 'non-native' is solely from direct, human-mediated dispersal, we would have to treat those species moving autonomously in response to shifting environmental conditions along human-made pathways like canals as natives, irrespective of human involvement in climate change. Endorsing this argument would require categorising all species independently moving through canals as 'native'. While the movement of 'neonatives' might be necessary to avoid extinctions [e.g. 'assisted migration' (*cf.* Hällfors *et al.*, 2014; Pereyra, 2020)], these populations can cause ecological disruptions once established (Forgione, Bacher & Vimercati, 2022), but might simultaneously require protection given threats in their native ranges (Essl *et al.*, 2021*b*; Forgione *et al.*, 2022). The conundrum arises from the origin of environmental or climatic changes, which might also be considered anthropogenic, thereby blurring the distinction between 'neonative' and 'non-native'.

Terminological complications are exacerbated by the complexity of reintroductions of non-native populations of historically native species translocated for conservation (Essl *et al.*, 2021*b*). Stocking practices in recreational and commercial fisheries (Tarkan *et al.*, 2017), or rewilding (Corlett, 2016) produce similar and recurring terminological problems. Such species fall under the definition of 'non-native', as in the case of the wild boar *Sus scrofa* in Ireland introduced into a new area by direct human action. For conservation and management purposes, they are however often misleadingly classified as Archeobiota (Essl, Glaser & Schertler, 2021*a*) rather than 'non-native' because they naturally inhabited Ireland in the past (before the 12th century). Inversely, the white-clawed crayfish *Austropotamobius pallipes* is considered native and threatened in Ireland, but was introduced from France in the Middle Ages (Gouin *et al.*, 2001).

'Native invaders', 'invasive natives', 'native super-dominants' (Carey *et al.*, 2012; Pivello *et al.*, 2018), and 'new natives' (Lemoine & Svenning, 2022) describing native species that have expanded their ranges due to human-mediated dispersal or environmental changes are problematic because they blur the distinction between naturally evolving ecosystems and those impacted by humans (even those that happened hundreds or thousands of years ago; Bucher & Aramburú, 2014). Conflating natural range shifts with invasive behaviours by ignoring the species' respective evolutionary history could compromise conservation management. Native species can expand their ranges in response to shifting environmental conditions, and such movements do not necessarily imply negative impacts on ecosystems.

V. PROPOSAL FOR A SIMPLIFIED TERMINOLOGY

All aforementioned initiatives and frameworks emphasised the need for more openness, neutrality, and consistency in invasion science, because no scientific discipline should continuously commiserate over the lack of clear definitions without constructive progress. By revitalising the approach of Colautti & MacIsaac (2004), we attempt to avoid redundant and potentially offensive terms in invasion science and provide clear and standardised definitions of invasion terms. While we acknowledge that our proposed updates will not necessarily replace the existing lexicon, our primary aim is to improve the consistency and definitive base for future terminology, while advocating the acceptance of pluralism as long as definitions are clear. This does not mean that a population of a 'non-native' species cannot be described as 'naturalised' or 'pest' (for example) in a given region or country to mean that is has achieved a self-sustaining population or report its socio-economic impact (as in the case for the ring-necked pheasant *Phasianus colchicus* in North America; Taylor, 2023), but that the species should not be labelled 'naturalised' or 'pest', thereby blurring an otherwise clear terminology.

We therefore encourage the use of a restricted and controlled terminology (Table 4) to reduce confusion and avoid superfluous terms such as 'unwanted', and 'imported' species (Table 3), because they are synonymous with more commonplace but politicised terms (such as 'alien'). To simplify and streamline the terminology, especially when communicating with the public, stakeholders, policy makers, or other officials, we recommend adopting an acceptable, clear, and concise framework for journal editors, stakeholders, and scientists alike, which could be linked to existing biodiversity standards, particularly the Darwin Core terms (Groom *et al.*, 2019). Invasion scientists often need to communicate the outcomes of their findings in a clear, detailed, and educational way to decision-makers and the public in languages other than English. In these cases, adopting the minimalist set of terms we propose will facilitate translation from the original English (see Table S1) and avoid the ambiguities that result from politically and/or culturally laden terms not available in those languages (see Copp *et al.*, 2021).

We propose that 'non-native' should focus primarily on describing the evolutionary relationship of a species to the biogeographic area in which it originally did not evolve,

Table 4. Proposed basic terminology for classifying populations of non-native species. These terms are hierarchical – a subset of all *non-native* species will become *established non-native* species, and a subset of those will become *invasive non-native species*. The terms highlighted in italics and bold indicate cases where particular terms are themselves used as definitions. For proposed translations of the terminology suggested here, see Table S1.

Term	Definition	Reason/application
non-native	Present in or arriving to an area to which it is not native (has no evolutionary history there) either by (*i*) being introduced through direct human activities, or (*ii*) 'natural' dispersal after a biogeographic barrier is removed, or across a created pathway after an artificial environmental gradient is removed following human intervention	Useful because it specifies a step in the invasion process – the introduction of a species outside its native range. It is used when an individual or population is first reported and its status is undetermined (e.g. found in only one collection, year, location), hence lacking evidence for establishment.
established non-native	A ***non-native*** species that reproduces ($\geq n$ generations) in an area to which it is not native (has no evolutionary history there), but is currently not spreading or spread is unknown	Differentiates populations of non-native species that have arrived in a new environment and are confined to a location or area from those that reproduce and sustain populations over continuous life cycles (depending on the species, e.g. in several collections in separate years in the same location) without direct intervention by humans.
invasive non-native*	An ***established non-native*** species that spreads (actively or passively), resulting in the establishment of successive populations beyond the introduction point(s)	Underscores the ability of a population of a non-native species to colonise, establish, and spread. While any population of a non-native species can be introduced into a new environment, not all will be able to survive and reproduce successfully in the new area. It is the species that establish self-sustaining populations and spread further from the introduction point that become invasive.

Note: Impact can occur at any of the stages during the process of biological invasion and is not confined to the 'invasive' stage. Impacts can vary due to a change in the abundance and spread of the 'invasive' species. However, definitions of 'invasive' have often only considered impact, which can obfuscate the full scope of the biological invasion process. An established or invasive non-native species might not always be immediately or obviously harmful, because non-native species can cause more damage as environmental conditions change or as adaptations occur. At the same time, it is possible that a non-native species remains confined to one locality, where it has a severe impact on its recipient ecosystem, without being classifiable as 'invasive'.
*'Invasive non-native species' is used for clarity and specificity; however, where context permits, the term can be abbreviated to 'invasive species'.

concomitantly acknowledging the importance of human-mediated dispersal for modern invasions. The term 'invasiveness' should denote a population's ability to colonise, establish, and spread, possibly encompassing the criterion of 'superabundance' (i.e. a species that has exceeded its normal carrying capacity due to favourable conditions, resulting in potential ecological imbalances; Ricciardi & Cohen, 2007; Aizen *et al.*, 2014).

This produces the following terms when classifying populations, which should not be abbreviated as acronyms or initialisms because they confuse and provide no additional value: *non-native*, referring to species that have been actively or passively translocated and released through human action beyond their known historical and natural range without the necessity of establishing in the new environment; *established non-native* to signify a non-native species that has successfully established in the area where it was introduced, evidenced by the presence of a self-sustaining population; and *invasive non-native*, representing those populations of established non-native species that are currently spreading or have recently spread (see Section V.1 for the concept of spread) in their invaded range (Table 4). The 'invasive' condition varies temporally as well as spatially; i.e. a non-native population that has long maintained low abundance or remained largely confined to a specific region can suddenly undergo explosive growth (e.g. Witte *et al.*, 2010) or expand well beyond its historical range (e.g. *Ficus* spp. following the arrival of their coevolved pollinator chalcidoid fig wasps; Nadel, Frank & Knight, 1992). Initially non-invasive, or even considered benign, these populations can become invasive later due to triggering factors (Spear *et al.*, 2021). Similarly, a population that has demonstrated invasiveness for an extended period can later stop spreading or diminish in abundance – for instance, following the introduction of an effective control agent or after encountering physical or ecological constraints. Such populations could become invasive once more if constraints are removed (e.g. sea lamprey *Petromyzon marinus* in the Great Lakes after control was suspended during the COVID-19 pandemic) (Sullivan *et al.*, 2021).

If a non-native species' invasiveness is solely defined by its ability to spread, 'invasive non-native' could be replaced with 'spreading non-native'. However, 'spreading non-native' is redundant because almost all 'established non-native' species eventually spread, albeit at variable rates, within the geographical and ecophysiological limits imposed by their new environment. If defined exclusively by the process of invasion (Ricciardi & Cohen, 2007), 'invasive' can be used to distinguish (and even rank) those species that have higher rates of establishment than others, or populations that have higher rates of spread than others. 'Invasive' could also be used to describe a non-native population that has suddenly begun to expand rapidly or become superabundant within a region after having remained at low densities prior to being triggered to increase following environmental (Spear *et al.*, 2021) or anthropogenic changes (Bortolus, 2006). The absence of consensus among invasion scientists on objective, quantitative definitions for 'impact' and 'spread' has hindered progress in the conceptual understanding of populations being 'invasive'. The continuum of both 'spread' and 'impact' has lacked clearly definitive boundaries, mediated by many context dependencies. Defining 'invasive' based solely on 'spread' would include many non-native species with potentially negligible effects on human society and biota, while defining it solely on 'impact' would yield similar outcomes because all non-native species eventually cause impacts by occupying space or using resources, albeit possibly perceived as inconsequential to humans. Combining the two debated concepts would not resolve, but exacerbate, these challenges because some species spread and establish faster than others, while some exert larger or more observable impacts than others regardless of their dispersal ability. While the concepts of 'spread' and 'impact' are impossible to disentangle, the invasiveness of a species can best be defined as an ability to colonise, establish, and spread, which are integral components of the invasion process (Blackburn *et al.*, 2011). Further, Ricciardi & Cohen (2007) found no relationship between characteristics of invasiveness (establishment success and rate of spread) and impact on biodiversity. They concluded that non-native species that spread and establish quickly are not necessarily the ones causing measurable ecological changes, although they could have larger cumulative impacts over broader spatial or temporal scales. Constructing a comprehensive table of definitions and terminology using both spread and impact is therefore infeasible. Instead, spread is more suitable for objective measurement in the context of biological invasions, with impact being a separate dimension that is not as well studied (acknowledging that all non-native species can exert a negative impact at some point).

While acknowledging the existence of sub-categories of invasions, such as 'failed' invasions (Zenni & Nuñez, 2013), or knowledge gaps where the establishment status or point of introduction is unknown, only a small proportion of the many introduced 'non-native' species eventually establishes and becomes invasive. This subset varies among ecosystems, regions, and other relevant contexts and is influenced by modes of introduction that affect propagule pressure and repeat inoculation events (Williamson & Fitter, 1996). Other than in some special cases (e.g. in isolated and altered microhabitats such as thermal springs or artificially heated outflows; Aksu *et al.*, 2021), establishment results in the spread of the non-native species, and hence, potential invasiveness. This suggests that populations of 'established non-native' species that remain in this category are rare in reality because most populations of such species spread to some extent at some point after their arrival. Rare examples to the contrary include populations of warm-water species that were originally used as ornamental species and that established in thermally polluted waters [e.g. power plant discharge (Yanygina, Kirillov & Zarnbina, 2010; Klotz *et al.*, 2013; Castañeda *et al.*, 2018)], but are restricted to the artificially heated environments or eventually went extinct (Castañeda *et al.*, 2018). The mosquitofish *Gambusia* spp. introduced to a canal in Liverpool (UK) due to the closure of a pet shop, failed to spread beyond the introduction site (Vale Gordon H. Copp, personal communication). Another example is the golden clam *Corbicula fluminea* that invaded a section of the Saint Lawrence River immediately downstream of a nuclear power plant, established, but was extirpated after the plant shut down (Castañeda *et al.*, 2018). Besides thermally polluted environments, an array of other examples of populations of 'established non-native' species are found in natural thermal springs (Yanygina *et al.*, 2010; Bláha *et al.*, 2022). The status as 'established non-native' is however profoundly influenced by its context and location. For instance, the red-eared slider *Trachemys scripta* (Ryan *et al.*, 2008) or the eastern mudminnow *Umbra pygmaea* (Haubrock *et al.*, 2023), often found established in isolated ponds, present a different scenario compared to many non-native fish species established within entire freshwater ecosystems. This contrast highlights the importance of perspective (i.e. local *versus* regional establishment) when classifying non-native species. Yet, cases satisfying the 'established non-native' criteria might disappear over time because self-sustaining populations do not establish under limited conditions (e.g. limited space), thereby being classified as a 'failed invasion'. Alternatively, an 'established non-native' species can adapt to less-favourable environments, and potentially become an 'invasive' population (Vandepitte *et al.*, 2014; Weiperth *et al.*, 2019), while potentially (even if only temporarily) returning to the 'established non-native' status once reaching a constraint or barrier. Most island introductions would qualify as 'invasive' species, having spread within, around, and on a given island.

(1) Conceptualising invasive species and spread

The concept of 'spread' in invasion ecology is important because it refers to the movement and dispersal of a non-native species beyond its original point of introduction (Wilson *et al.*, 2009*a*; Hui & Richardson, 2017), forming the basis for the classifications of 'non-native' populations as 'invasive'. Therefore, invasions must first be considered a population-level phenomenon, and then a context-dependent, species-level phenomenon. While it appears intuitive that a species' spread within biogeographical and administrative boundaries (and not its impact) constitutes the final stage of the invasion process biologically, and thus merits the classification 'invasive', quantifying the parameters and thresholds that define spread lacks resolution and likely differs among habitats, taxa, regions, and other contexts (Shigesada & Kawasaki, 1997; Suarez, Holway & Case, 2001; With, 2002). Furthermore, an ill-defined conceptualisation of 'spread', and possibly multiple introductions, make it challenging to measure spread rates (Hengeveld, 1992). Estimates of spread rate are however essential to validate and advance theoretical models predicting spatial patterns that arise from invasions (Hastings, 1996; Lewis, Petrovskii & Potts, 2016).

While spread can be defined as the dispersal of a species beyond its introduction point or natural range, the identification of the latter is challenging for many species. This is especially the case in aquatic or terrestrial ecosystems in developing countries where non-native species are often detected when they are already abundant and widespread. When the location and date of introduction are unknown or anecdotal, an alternative is to default to the earliest recorded instance of the species as a proxy (e.g. Vargas *et al.*, 2022). This information, coupled with ecological investigations that elucidate the species' dispersal capabilities, could potentially shed light on whether it has spread outward from its point of introduction. The introduction point requires context-specific interpretation due to its relative nature. In some cases there could be several points of introduction (Sax *et al.*, 2005) arising from separating primary (initial human-mediated introduction of a non-native species) and secondary spread (subsequent dispersal within the new environment or to neighbouring environments). Determining the dispersal mechanism – specifically the importance of 'jump' dispersal *versus* 'diffusive' range extension (Borcherding *et al.*, 2011; Reynolds, 2012; Liebhold *et al.*, 2017) – is needed to disentangle issues associated with primary and secondary spread (Bartumeus *et al.*, 2005; Viswanathan *et al.*, 2011).

For terrestrial invasive non-native species, spread is commonly quantified as the distance from the introduction point (Renault, 2020). However, the relationship between spread and invasive species becomes more complex in the aquatic realm. For a bay or stream, the definition of spread is often subjective; not only are points of introduction poorly resolved, there is also no consensus on the criteria for designating a species as 'invasive' based on spread within these environments. In freshwater environments, spread can occur within and among water bodies, both qualifying as criteria for invasiveness. For ponds and lakes, the same principle applies as for islands within an archipelago, because spread includes dispersal between insular ecosystems such as lakes and islands and homogeneous diffusion within them (e.g. American bullfrog *Lithobates catesbeianus* in Uruguay; Laufer *et al.*, 2023).

A comprehensive and accepted definition of spread that accounts for its nuances among different life forms, realms, habitats, and biomes is needed to ensure clarity in the classification of invasive species. Without a clear definition of spread and knowledge of an invasive species' rate of spread per unit time (Richardson *et al.*, 2000, 2020), 'invasive' can be subjective and ambiguous. Spread is ultimately limited by geographical and ecophysiological boundaries, but also depends on species-specific dispersal. The rate of spread per unit time can differ depending on traits such as size, means of locomotion, or life stage. Neither is spread necessarily continuous, for it can fluctuate over time. To avoid ambiguity, we suggest that when a species or population is reported as 'invasive' (especially for the first time), the reporting authority should state the evidence for and scale of spread (Gago *et al.*, 2016; Gkenas *et al.*, 2024).

(2) Conceptualising invader impacts and the importance for management

While the descriptor 'invasive' is based on a population's stage of invasion, different populations can be in different stages of the invasion process (Blackburn *et al.*, 2011; Essl *et al.*, 2011; Spear *et al.*, 2021), leading to conflicting perceptions about their impacts (e.g. 'double-edge' invasive non-native species; Kourantidou *et al.*, 2022). Prior to introduction (and dispersal), management should focus on prevention, but once a population is established, management should shift to eradication, or at least to density reduction and containment if substantial spread has already occurred. Both population growth and spread indicate a species' abundance (which can modulate a population's impact sigmoidally; see Fig. 3; Soto *et al.*, 2023*a*) and geographical expansion, but they do not necessarily determine impacts that are instead dictated more by the characteristics of the invaded ecosystem and how societies perceive and evaluate impacts economically (Falk-Petersen *et al.*, 2006; Gallardo *et al.*, 2016).

While the 'invasive' label should primarily refer to the spread stage of a non-native population, the real or perceived impact of that invasive population represents a second dimension. Evaluating a species' impact can be subjective (Turbé *et al.*, 2017) because (*i*) impact assessments are usually done at a local scale by targeting populations, and focus on specific areas where spread is confined by the boundaries of the ecosystem unless anthropogenically facilitated (Turner, 1996; Echeverría *et al.*, 2006), and (*ii*) total impacts are often inferred by extrapolating local-scale measurements of ecological effects and invader abundances to larger regions, neglecting potential spatial variation (Howard *et al.*, 2018; Haubrock *et al.*, 2022; Ahmed *et al.*, 2023; Soto *et al.*, 2023*b*), as well as non-linear impact–abundance relationships (Sofaer, Jarnevich & Pearse, 2018). Schemes such as the *Environmental Impact Classification for Alien Taxa* [EICAT (Hawkins *et al.*, 2015); EICAT+ (Vimercati *et al.*, 2022)] and the *Socio-Economic Impact Classification of Alien Taxa* (SEICAT; Bacher *et al.*, 2018) have fortunately advanced the complex task of quantifying the impacts of invasions.

Management decisions often rely on perceived and subjective impacts, indicating that the goal of management has shifted from limiting spread to curtailing damage, particularly where limited resources necessitate efficient prioritisation among many species and populations (Kueffer & Daehler, 2009; García-Díaz *et al.*, 2021). Impacts can be

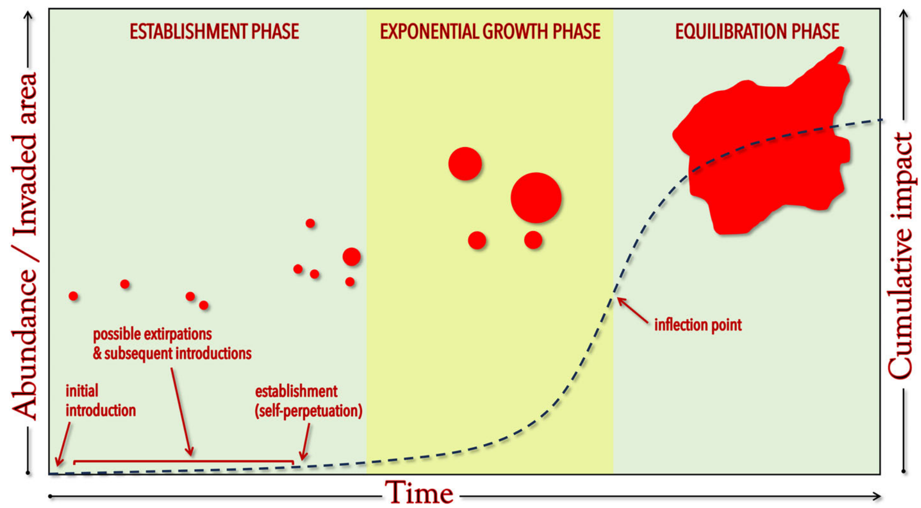

Fig. 3. Invasion (impact) curve conceptually illustrating the abundance or invaded area as well as cumulative impact over time as a sigmoidal function. We divide the invasion curve into three phases: establishment, exponential growth, and equilibration. The red areas indicate the hypothetical population-level distribution/impact of these phases. Adapted from Haubrock *et al.* (2022).

context-dependent, time-lagged, and co-mingled with other stressors, but as long as a species' invasiveness is contingent on its impact or quantified risk, management is handicapped. The spread-based term 'invasive' might therefore lose relevance in management, particularly when directed towards populations perceived as highly impactful. The issue of spread-based decisions in the management of 'invasive' species (Epanchin-Niell & Hastings, 2010) is further complicated because the concept of spread itself is ambiguous among scales and environments.

An alternative is to assume that all established non-native species have negative impacts, and management interventions should be considered for those populations that are spreading, unless evidence demonstrates that their spread does not cause negative impacts. However, determining the potential impacts of all established non-native species during their spread can be complex and resource intensive. Meanwhile, possible pre-invasion 'deny list' (lists of species prohibited for import) approaches to management following invasion might become impractical when applied over broad spatial scales (e.g. political entities like the European Union or USA), because assessment outcomes might vary among ecosystems, biogeographic regions, and value systems (Rilov *et al.*, 2024). This issue is exacerbated by benefits perceived from invasive species due to human interest in some socio-economic sectors (e.g. fisheries or ornamental trade), as well as in climate-change hotspots where thermally sensitive native species are extirpated and thermophilic invaders with similar traits take their place, or where native species are the minority (Rodríguez-Barreras *et al.*, 2020). Perceived and real benefits can obfuscate the negative effects at the expense of environmental degradation and community well-being (Mwangi & Swallow, 2008), presenting another challenge for management (Shackleton *et al.*, 2019; Wehi *et al.*, 2023) and creating difficulties in establishing universal criteria for management decisions that should be based on the species' invasion potential and any ecological and socio-economic impacts (Sandvik *et al.*, 2019).

Adopting a unified approach assuming that all established populations of non-native species will ultimately have a negative impact would lead to ineffective resource allocation and hinder the prioritisation of 'high-risk invaders' – non-native species that spread rapidly, thrive in new environments, and exert large negative impacts. The primary aim should therefore be the prevention of both species-specific vectors and pathways. Emphasising shifts in invasion pathways and vectors over time, along with their associated species, is important because problematic species likely entered through historical routes that might be less relevant today. Managers, stakeholders, and scientists should subsequently base decisions on changes in population size, the population's potential to spread, and their *per capita* impacts, even in early invasion stages and, whenever possible, prioritise preventive measures. Quantifying *per capita* impacts is possible for example by estimating consumer functional responses (Dick *et al.*, 2014; Faria *et al.*, 2023). At later invasion stages, the *per capita* effects of a species are nevertheless modulated by the numerical response at the population level (Solomon, 1949; Dick *et al.*, 2017). These *per capita* impacts can fluctuate across space and time (Gallardo *et al.*, 2016); hence, management interventions should aim to reduce population size and growth, because abundance dictates the extent and magnitude of impacts (Dick *et al.*, 2017; Ahmed *et al.*, 2022).

VI. PROPOSED CLASSIFICATION PROTOCOL

After having identified unclear terms and recommended an acceptable, clear, and concise terminology moving forward, we also propose an objective approach to classify different populations of 'non-native' species for scientific discourse.

This is needed because the term 'invasive' itself lacks clear and objective boundaries given the complexities of measuring 'spread' across varying scales (i.e. local *versus* regional spread). While both impactful and spreading species are often wrongly referred to as 'invasive', and although useful to assist in focusing management resources and a wider discourse, assessments and classification are often bereft of quantitative boundaries and are subjective. Even if value-laden, concern regarding those 'invasive' (spreading) species with impacts (*cf.* those with few impacts) is based on human values and thus is relevant for the distribution of limited management resources. We therefore recommend an alternative quantitative (binomial) assessment we deem unambiguous and ideal to classify populations of non-native species. The DOSI scheme is based on four main components that the current lexicon captures: (*i*) DISPERSAL mechanism, defining how a population arrived at a new locality; (*ii*) ORIGIN, defining the origin (native region) of a species; (*iii*) STATUS, describing if the population is expanding, stationary, or shrinking (either in terms of abundance or range) to describe 'invasiveness'; and (*iv*) IMPACT, defining the real or perceived impact of the population as harmful or benign and which can be split into: (*i*) economic (defined as alteration to the financial budget of a geographic region *via* loss of resources caused by non-native species or from expenditure allocated for management of non-native species), (*ii*) ecological (defined as alteration to ecological interactions shaped *via* pre-industrial – non-anthropogenic – evolution, which can include biodiversity loss, ecosystem alteration, predation and disease spread, competition, hybridisation, etc.), (*iii*) cultural (defined as changes in landscape and heritage, impact on traditional practices, recreational activities, etc.), or (*iv*) health (defined as consequences from the spread of pathogens or parasites that cause diseases) (Fig. 4).

On the far right in Fig. 4, we provide the dependencies for each component, including how we should define 'here' and how we assess 'status' and 'impact', drawing inspiration from the IUCN *Red List of Threatened Species* (IUCN, 2023).

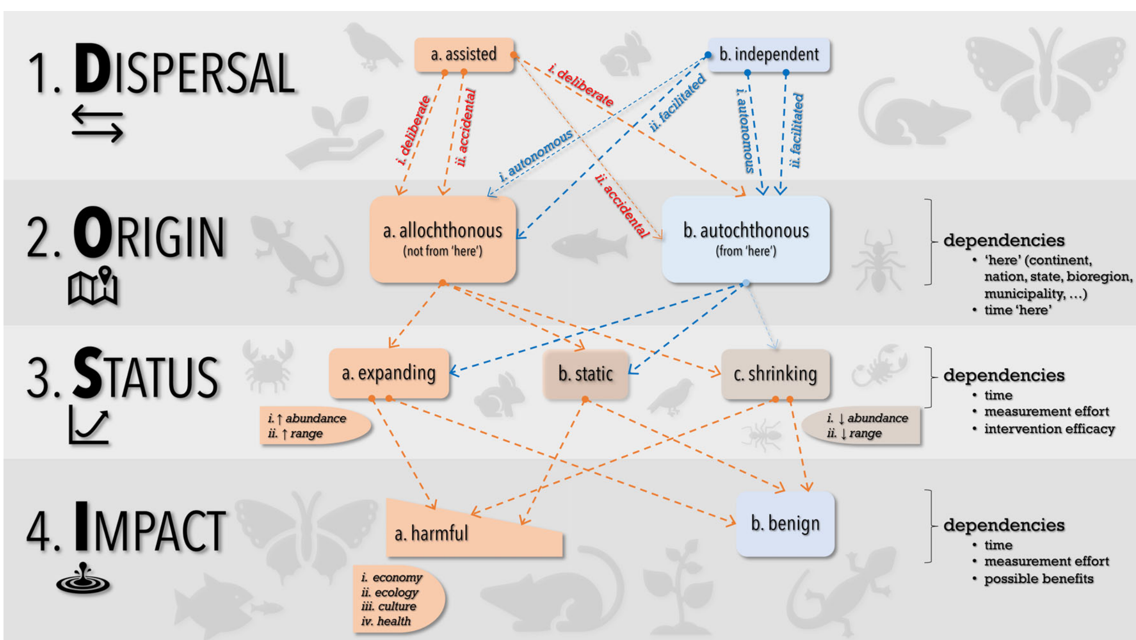

Fig. 4. Flow diagram for the proposed classification scheme for species/populations moving into a novel environment. A species' DISPERSAL mechanism can be assisted from its place of origin either *deliberately* (**D**a$_{i}$) or *accidentally* (**D**a$_{ii}$), or it can migrate *independently* of direct human intervention (**D**b$_{i}$) or by being *facilitated* (**D**b$_{ii}$) by exploiting a human-driven change to the environment (e.g. canals). The ORIGIN of a species that has its distribution shifted according to the mechanisms described under DISPERSAL can either be *allochthonous* (**O**a) (not from 'here', where the definition of 'here' depends on the spatial scale of interest), or *autochthonous* (**O**b) (from 'here', as in the case of local species moving within the region of focus). The definition of allochthonous or autochthonous can also depend on how much time has elapsed since the species arrived (e.g. events in geological time, ancient introductions, etc.). STATUS refers to the state of the population(s) of the species, defined either/both in terms of *abundance* or/and *range* size (*expanding*, *static*, or *shrinking*) – these assessments depend on the time that the species has been present, how much measurement effort has been applied to assess population change, and whether interventions (if any) have been effective. The IMPACT category assesses whether the species causes harm to one or more sectors (economy, ecology, culture, health – such an assessment can cover a gradient from little to extensive harm), or if it is benign (no effect) – this assessment also depends on the time since appearance, measurement effort to investigate impact, and any possible benefits along a temporal or stakeholder gradient that modify harm intensity. While we acknowledge that impacts can also be 'beneficial', negative impacts (e.g. by damaging local ecology) outweigh those perceived as positive (e.g. monetary gain) in magnitude and ecological consequences, and are therefore not considered in the context of classifying populations of species in this scheme.

For instance, consider the European mink *Mustela lutreola*, listed as 'Critically Endangered' on the IUCN *Red List*. The decline in its population is due primarily to habitat loss and competition with the non-native American mink *Neogale vison*. We provide a few examples based on our proposed classification protocol. Example 1 is a species that is deliberately introduced into a new country, its population expands both in abundance and range, resulting in economic and ecological harm. In our scheme, its classification would be $\mathbf{D}\mathrm{a}_{i}\mathbf{O}\mathrm{a}\mathbf{S}\mathrm{a}_{i,ii}\mathbf{I}\mathrm{a}_{i,ii}$. Example 2 is a species that is accidentally transported by humans from one part of its range to another. Although it remains static without an increase in range or abundance, it causes cultural harm locally: it is classified as $\mathbf{D}\mathrm{a}_{ii}\mathbf{O}\mathrm{b}\mathbf{S}\mathrm{b}\mathbf{I}\mathrm{a}_{iii}$. Example 3 is a species that establishes itself in a new range following a human modification to its environment (e.g. building a canal connecting two previously isolated bodies of water), subsequently increasing its range and causing ecological problems: it is classified as $\mathbf{D}\mathrm{b}_{ii}\mathbf{O}\mathrm{a}\mathbf{S}\mathrm{a}_{ii}\mathbf{I}\mathrm{a}_{ii}$.

To facilitate analyses of the drivers of different states and classifications, this descriptive classification scheme can be illustrated using a binomial matrix, wherein each component and subcomponent are depicted as columns, and species/populations as rows. We provide an example in Table S2. This classification scheme avoids the use of terminology with a negative connotation and focuses on objective categorisations based on scientific and empirical grounds, while also considering impact, which can be value-laden but relevant for prioritising management. The scheme acknowledges that categorisations vary across time, space, and measurement intensity. Consequently, politically charged terms like 'invasive' or colonial terms such as 'non-indigenous', 'naturalised', or 'colonised' can be circumvented. While we recognise that this classification scheme might not replace common language, it would promote objectivity and consensus among invasion scientists, particularly in the peer-reviewed literature.

Some countries, especially low- and middle-income nations, often have insufficient data covering all four proposed components that are necessary for classifying non-native populations. This difficulty also applies to some taxa, such as fungi and phytoplankton for which many biogeographic and taxonomic uncertainties persist. Nonetheless, we anticipate that our protocol will identify the types of information required. This could in turn enable such nations to prioritise resources towards the generation of this indispensable information for non-native species management.

VII. CONCLUSIONS

(1) Invasion science is constantly growing and confronting existing terminological inconsistencies, often leading to misunderstanding and confusion that can come at the cost of conservation. Our review sheds light on the issue of lexical inconsistency pervading multiple scientific disciplines, here shown in the case of invasion science, underlining its potential to obstruct scientific progress, policy design, and effective communication.

(2) We recommend reducing redundancy and propose a unified suite of terms in an attempt to increase the clarity and consistency in invasion science. Any deviation from the proposed terms outlined in Table 4 (i.e. 'non-native' species, 'established non-native' species and 'invasive non-native' species) and their translations in Table S1 should be justified by defining terms appropriately and aligning with the definitions outlined in Table 4. The successful implementation of this consensus will require collaboration among scientists, policy makers, and stakeholders to facilitate interdisciplinary dialogue and exchange of knowledge.

(3) Reaching consensus and implementing measures to achieve consistency in the terminology used across various platforms (i.e. from science to policy, as well as public communication outlets) will not be easy or fast. Efforts by journals, editorial boards, or professional societies and organisations can be an avenue for identifying ways to recognise the challenge and ways to address it. The more simplistic and clearer terminology for broader audiences we propose herein will be helpful to enhance communication and comprehension among scientists, decision-makers, and the public.

(4) We hope that such a unified and standardised language can promote more effective management strategies, better policies, and public engagement in citizen-science initiatives to address the threats of non-native species. By bridging the gap between scientific understanding and practical action, we can improve conservation aiming to protect ecosystems and human health while also minimising economic losses.

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IX. DATA ACCESSIBILITY

Data and R code to reproduce trends and word cloud are available from http://github.com/IsmaSA/Invasion-science-terminology.

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XI. SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Fig. S1. Similar plot to Fig. 2 but considering terms as independent adjectives (i.e. without 'species' in the search string).
Table S1. Proposed translations of the English terminology suggested in Table 4.
Table S2. Classification of real examples using the Dispersal–Origin–Status–Impact (DOSI) classification scheme.

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