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Perspective

Nativeness is a binary concept —Invasiveness and its management are not

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ABSTRACT

In interdisciplinary fields such as biodiversity conservation or invasion science —where multiple perspectives from diverse disciplines often need to converge for effective environmental management, it is crucial to minimise terminological confusion in order to understand and transmit concepts accurately. The diversity of perspectives can exert a substantial influence on defining key terms in those interdisciplinary fields, potentially resulting in confusion. A lively topic within invasion science concerns the definitions of nativeness, non-nativeness, and invasiveness. While some academics dismiss the nativeness concept because it cannot be objectively defined, others advocate for its categorization, and a third perspective posits it as a binary term. Here we argue the inherent binary nature of nativeness, even when our capacity to observe is challenging. Nativeness (and consequently, non-nativeness) is an intrinsic and binary property of a species (i.e. the set of populations of a species) in a place, which should remain a central piece of information in biodiversity conservation and ecosystem restoration. In contrast, invasiveness, which relies on quantitative metrics (including abundance, spread, or impacts), should not be defined on binary terms. This underscores the importance of offering diverse, context-specific management strategies to deal with it. We illustrate the consistency of nativeness' binary nature and the need to rely on diverse management options to address different invasion scenarios with the example of the freshwater crayfish in the Iberian Peninsula.

1. Background

Terminology plays a pivotal role in understanding concepts across scientific disciplines. Invasion science has witnessed an intricate usage of terminology to refer to the same concept, which complicates comprehension and communication among stakeholders (Soto et al., in press). Nativeness is a fundamental concept for invasion science and a relevant one for several other disciplines within the natural sciences (Gilroy et al., 2017; Essl et al., 2018). Yet, this concept has sparked significant controversy (Head and Muir, 2004; Warren, 2007; but see Richardson et al., 2008) and has recently garnered considerable attention (Pereyra, 2020; Warren, 2023; but see Courchamp et al., 2020). The diverse range of ways in which nativeness is defined and interpreted holds substantial implications for the regulation of biological invasions and, more broadly, for environmental management (Gilroy et al., 2017; Guiaşu and Labib, 2021). For example, nativeness has been delineated based on geographical (physical barriers such as mountain ranges or rivers), ecological (species interactions with environment), evolutionary (patterns of coexistence), or even political (human-defined borders such as nations) definitions (Pyšek et al., 2004; Berthon et al., 2021). The confusion regarding the definition of nativeness is connected to the cultural influences on the various ways in which humans perceive and interpret the biogeographic status of taxa (Kaplan et al., 2022). For instance, the classification of species' nativeness into categories has been developed for decades, driven by the perceived improvement in nature conservation practices (see Scottish Natural Heritage, recently rebranded to NatureScot; Usher, 2000). Recently, Lemoine and Svenning (2022) argued that the challenges in identifying the native status of taxa and translating it into management targets preclude the idea of the binary nature of nativeness (i.e., native vs non-native). To overcome these difficulties, Lemoine and Svenning (2022) proposed a 10-step nativeness gradient, wherein organisms are classified into distinct

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categories based on their histories, origins and impacts, with each category linked to different management options. While acknowledging the value of the gradation of management actions, we think that their approach is misguided due to an erroneous use of the nativeness concept, which in our view is inherently binary. In contrast, we do see invasiveness as a non-binary concept, and incorporating a gradation in its management is both reasonable and desirable, due to several context-dependencies.

In the literature, three main perspectives on the nativeness construct are still under discussion: species nativeness does not exist, it exists but is not binary, and it is a binary concept. Hereafter, we emphasize the term's inherent binary nature, focusing solely on ecological and biogeographical aspects. We avoid delving into criticisms of xenophobic and ethical elements, as they extend beyond our focal point, even though they are often used to justify the denial of the construct. We intend to clarify and simplify the concepts of nativeness, non-nativeness and invasiveness in order to overcome the confusion that artificially complex definitions may introduce in invasion science and biodiversity management.

2. Nativeness and non-nativeness as complementary binary concepts

Nativeness refers to the property of a taxon occurring within its natural distribution range, where it has evolved and its presence, whether present or past, is not a result of direct human intervention (Pyšek et al., 2004). Complementarily an organism is considered non-native in a particular area if its presence there is human-mediated (Essl et al., 2018; Gilroy et al., 2017). A source of uncertainty in these complementary concepts can arise from the spatio-temporal dynamics of species ranges (Warren, 2007; Pereyra, 2020), which can be expedited by rapid global change (Webber and Scott, 2012; see *neonative* term coined by Essl et al., 2019). In certain cases, due to spatial patterns, it is more straightforward to discern (e.g., an African freshwater species

Fig. 1. Examples illustrating that nativeness is a binary concept, even though describing it may present challenges. From left to right and top to bottom: the Iberian magpie *Cyanopica cooki*, native to the Iberian Peninsula; the carob tree *Ceratonia siliqua*, native to the Western Mediterranean; the crucian carp *Carassius carassius*, non-native to the UK; the tench *Tinca tinca*, non-native to the Iberian Peninsula; the spur-thighed tortoise *Testudo graeca*, probably non-native to the Iberian Peninsula; the common periwinkle *Littorina littorea*, non-native to North America; the Mediterranean tree frog *Hyla meridionalis*, probably non-native to Europe; the dingo *Canis familiaris dingo*, non-native to Australia; and the common reed *Phragmites australis*, both native and non-native to North America. For further explanations, scientific literature and photo credits, see Appendix A.

introduced in North America), while other instances may be more challenging (broad species distributions, lack of research in less-studied taxa). Cryptogenic species exemplify the challenges that may arise regarding uncertainties about the knowledge of species' native distribution (Jarić et al., 2019). However, scientific advances are usually able to overcome these difficulties, often providing surprising results (e.g., proving the native status of species thought to have been introduced or vice versa; Fig. 1 and Appendix A). In any case, the convolutedness lies in our own capacity to observe and describe nativeness, not in the concept of nativeness itself, which is binary by definition. Indeed, non-nativeness also inherently implies a binary status —a taxon has either historically evolved in a particular area, or it has not. This is the crux of invasion science.

Similarly, the temporal framework, coupled with establishing the timing of human influence, has hindered the assignment of nativeness to a species. As clarified by Cuthbert et al. (2020), the use of human agency by invasion scientists to define non-native species does not imply that humans are outside the realm of evolution or other biological laws; thus, this idea is not anchored in any ontological dualism. Humans have moved thousands of taxa across biogeographical barriers for millennia, sometimes on purpose (e.g., colonial supplementation), sometimes accidentally through obscure pathways/vectors (e.g., hitchhiker species). Thus, challenges, if any, may arise for identifying the human footprint of a species' presence in a given area (Essl et al., 2018). Nonetheless, these shortcomings do not alter the fundamental binary nature of both terms, i.e. nativeness and non-nativeness. Whether a species was introduced by humans 2000 years ago, 500 years ago, or just recently holds no relevance in the context of nativeness. Temporal distinctions are essentially human constructs that give rise to arbitrariness in determining when species are deemed to have been introduced by humans or not. Indeed, in the term 'native species', the concept of nativeness itself is the least prone to uncertainty. Discerning whether a set of populations constitutes a species or not remains one of the core contentious issues in biology, with no immediate resolution in sight (Hey et al., 2003). Despite this uncertainty, the use of 'species' in biological sciences for knowledge generation, biodiversity quantification and environmental management has persisted. Consequently, far less important uncertainties should not undermine the native versus non-native status of any given species in a particular area.

3. Non-binary invasiveness and management

In contrast to the binary nature of nativeness and non-nativeness, the invasive character of a non-native species (i.e. invasiveness) in a place can be hardly defined through binary delineations. Unlike the clear-cut binary nature of nativeness and non-nativeness concepts, invasiveness involves human evaluations based on ecological contexts, but also social norms and perceptions. Independently of the definition used for invasiveness, e.g. widespread introduced species and/or normative impact judgements, this can be defined in relation to quantitative human-chosen metrics, which may encompass population abundance, geographical spread and ecological or socioeconomic impacts (Blackburn et al., 2014). These components, less so their combinations, do not easily lend themselves to simple yes/no answers. Abundance, spread, impacts or other population-level features largely vary across space, time, and perception in non-natives areas. Ultimately, it is the gradient of invasiveness that predominantly drives environmental management decisions, influenced by public perceptions and socioeconomic policy constraints.

Environmental management aimed at addressing biological invasions predominantly focuses on metrics of invasiveness, which is modulated by cultural contexts and societal knowledge and perceptions. While this is the general trend, some native species can also cause undesired impacts and require management (e.g., native dominant plants, Hejda et al., 2021), just as some non-native species may not require such determined actions (see below). Given the non-binary nature of invasiveness, effective management responses should also adopt a non-binary approach, encompassing various nuances and context-dependent distinctions and metrics of impacts (García-Díaz et al., 2021; Oficialdegui et al., 2021). Some examples of how to quantify the magnitude of impacts with metrics include those for detrimental environmental impacts, e.g., EICAT (Blackburn et al., 2014; Hawkins et al., 2015), negative socio-economic impacts, e.g., SEICAT (Bacher et al., 2018), or positive environmental impacts, e.g., EICAT+ (Vimercati et al., 2022). The multifaceted and variable nature of invasiveness, alongside the technical and social feasibility of managing non-native populations and their impacts therefore necessitates the avoidance of one-size-fits-all binary approaches for effectively dealing with biological invasions (Oficialdegui et al., 2020a). Confounding the binary nature of nativeness with the non-binary one of invasiveness and their associated management actions introduces confusion in invasion science and potentially hinders effective communication with policymakers, stakeholder engagement, and society at large (Courchamp et al., 2017).

Nativeness is a highly regarded attribute in conservation biology due to its role in shaping the spatial variation of biotic communities (referred to as β diversity), which is vital for the preservation of regional and global biodiversity (Socolar et al., 2016). However, environmental management cannot solely aim at promoting all native species while strictly forbidding, controlling, or eradicating all non-natives. This perspective, and not the binary nature of nativeness, is the true oversimplification that ought to be overcome in invasion science. In fact, the conservation of native biodiversity is prioritised through threat assessments and rankings, such as those provided by the International Union for Conservation of Nature (IUCN) Red List (https://www.iucnredlist.org/), as well as through systematic planning procedures (Adams et al., 2019). Similarly, the management of non-native species can, and does, move beyond naïve dichotomies, by prioritising those at high risk of invasion (Oficialdegui et al., 2023), considering threat classifications (Blackburn et al., 2014), and including the possibility of recognising their positive effects (Vimercati et al., 2022). Regardless of the approach adopted, it is increasingly recognized that the management of biological invasions must take into consideration the human component of invasions (Shackleton et al., 2019), introducing further nuances that preclude binary responses.

4. Crayfish in Iberia as a case study

To elucidate the inconsistencies and challenges associated with the nativeness construct and the diverse management actions that a set of equally non-native species might require, we here present the case of freshwater crayfish in the Iberian Peninsula. Crayfish have multiple threatened species susceptible to environmental drivers and diseases (Richman et al., 2015), with several other species used for human consumption or as a fishing resource and also as pets, resulting in multiple introductions across all continents (Lodge et al., 2012).

The Italian crayfish (*Austropotamobius fulcisianus*) was thought to be native to the Iberian Peninsula until an interdisciplinary study solved the cryptogenic status of this species and concluded that there are no native freshwater crayfish in Iberia (Clavero et al., 2016). Therefore, all ten recorded crayfish species introduced so far (not necessarily present today) are equally non-native (Table 1). However, a gradation terminology of nativeness (see classification proposed by Lemoine and Svenning, 2022) would identify different categories of nativeness, with some species being hardly assignable to a single category. For example, in Iberia there would be a *New Native* species, i.e. *Historical Introduction*, because the Italian crayfish was introduced nearly 500 years ago (in 1588, Clavero et al., 2016). After its population collapse in Spain (from the 1970s), the Italian crayfish is managed in the country as a conservation priority, a debatable approach given its non-native status (Clavero, 2014). However, given the endangered status of *Austropotamobius* species, coordination between Spain and Italy would be crucial for collaborative management initiatives aimed at promoting the

Table 1
Crayfish species introduced in Iberia. A comparison of a binary classification with a graduated terminology concerning nativeness. Scientific name, year of first introduction in Iberia, current status, graduated categories of nativeness (according to Lemoine and Svenning, 2022) and proposed management actions accordingly (if the species is absent/present in the territory) is shown. The graduated categories of nativeness are assigned based on the current understanding of the species, not what was known at the time of their introduction, which could potentially result in a different category assignment (see further explanation about this 'temporal issue' in the main text).

Crayfish species	Year	Status in Iberia	Graduated categories	Lemoine & Svenning's proposed management actions	Own proposed management actions
Austropotamobius fulcisianus	1588	Strong decline	Historic introduction	Reintroduction/Recognition	None but coordination with native range
Astacus astacus	1962	Absent	Substitute introduction	Replacement/Recognition	Prevention
Procambarus clarkii	1973	Very widespread	Invasive introduction	Prevention/Control-Elimination	Local control & eradication
Procambarus zonangulus	1974	Absent	Neutral introduction	None/None	Prevention
Pacifastacus leniusculus	1974	Widespread	Invasive introduction	Prevention/Control-Elimination	Local control & eradication
Pontastacus leptodactylus	1975	Absent	Substitute introduction	Replacement/Recognition	Prevention
Cherax destructor	1983	Eradicated	Neutral introduction	None/None	Prevention
Faxonius limosus	2010	Localised	Invasive introduction	Prevention/Control-Elimination	Eradication
Cherax quadricarinatus	2013	Localised	Neutral introduction	None/None	Eradication
Procambarus virginalis	2022	Localised	Invasive introduction	Prevention/Control-Elimination	Eradication

conservation of the species within its Italian native range. In this sense, the introduction of the Italian crayfish in Iberia almost five centuries ago could be seen as an unintended conservation introduction (Seddon, 2010).

Other crayfish species introduced around the 1970s in Iberia as replacement species after the decline of the Italian crayfish, including European (*Astacus astacus*, *Pontastacus leptodactylus*) and North American crayfish (*Pacifastacus leniusculus*), would fit into the *Substitute Introduction* category, for being similar phylogenetically (Family Astacidae) and ecologically (except that *P. leniusculus* is a carrier of the crayfish plague). The concept of functional nativeness argues that confamilial species could be acceptable substitute species if the niche is demonstrably similar and beneficial to biodiversity (Lemoine and Svenning, 2022). However, functional equivalency, or putative ecological benefits, have nothing to do with nativeness and should not be linked to it. For example, no one would nowadays think of introducing the North American *P. leniusculus* with known impacts on ecosystem services (Lodge et al., 2012) as a *Substitute Introduction* (similar ecological niche, Viana et al. [2023]) of a declining European native crayfish species, as was done in the past (see in Gutiérrez-Yurrita et al., 1999).

Analogously, the introduction of other species from the Cambaridae family originating from North America (such as *Procambarus zonangulus* or *Procambarus clarkii*), which were introduced to serve similar functions (more commercial than ecological) as the Italian crayfish but belong to a different family, could be regarded as a *Surrogate Introduction*. Yet, as in the case of *P. leniusculus*, the non-native and the now-known impacts of *P. clarkii* would classify them as an *Invasive Introduction* today, but not so fifty years ago when they were legally introduced (Oficialdegui et al., 2020b).

Other crayfish species introduced to Iberia would have been considered *Neutral Introductions*. These include the two Australian species in the genus *Cherax*, as they are not native to Iberia and their ecological effects there are so far unknown (regardless of potential severity). According to Lemoine and Svenning (2022), no strategic actions would be taken against them at the time of introduction (Table 1). This is against widely accepted management frameworks, which favour rapid response and decided actions in early invasion stages for efficient management (Simberloff et al., 2013).

Crayfish species such as *P. leniusculus* and *P. clarkii* should now be regarded as *Invasive introduction* due to their well-documented impacts on biodiversity and ecosystem functioning (Souty-Grosset et al., 2016). However, at the time of their introduction, this knowledge was absent, leading to be classified as *Substitute* and *Surrogate introductions*. This 'temporal' issue tends to give rise to additional complications within the framework of a graduated classification of nativeness, further accentuating the inconsistencies and counterproductive application thereof.

5. Concluding remarks

We stress the importance of avoiding unnecessary confusion in the terminology in conservation biology and invasion science, particularly around the concept of nativeness. Did the uncertainty surrounding the native status of the Italian crayfish imply that the native species' status does not exist and that, in this specific case, a native range cannot be attributed to the crayfish species? No, it did not. It simply calls for further research to define the species' native and non-native ranges (Clavero et al., 2016). Knowing the native range of a species can range from straightforward to intricate, and in some cases, may even remain unattainable from a human standpoint (Courchamp et al., 2020). However, these technical difficulties do not imply that any gradation is introduced in the inherently binary concept of nativeness.

We stress the need to interpret nativeness and non-nativeness as binary concepts, and to avoid binary management responses to biological invasions. While nativeness merely informs about the role of humans in the occurrence of a species in a specific location, invasions are intricate processes influenced by considerable environmental and social context-specificities and their management must be flexible enough to deal with these complexities effectively.

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Francisco J. Oficialdegui: Writing – review & editing, Writing – original draft, Investigation, Conceptualization. **Josie South:** Writing – review & editing, Conceptualization. **Franck Courchamp:** Writing – review & editing, Conceptualization. **Miguel Clavero:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

No data were used in writing this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2024.110631.

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