Cultural inception of invasive species

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Abstract

1. Many invasive alien species gradually become embedded within local cultures. Such species can increasingly be perceived by society as familiar and native elements of the social-ecological system and as integral parts of local cultures.
2. Here, we explore this phenomenon and define it as *cultural inception*. Cultural inception can greatly hinder our ability to successfully manage invasive alien species, by reducing public support to their management and contributing to secondary introductions.
3. Furthermore, cultural inception can affect societal values and cultural identities, and lead to erosion and homogenization of cultural diversity. Cultural inception can also modify or displace the cultural uses and values of native species, and even lead to their societal extinction.
4. We present the main mechanisms of cultural inception, its drivers and major implications, and provide key recommendations for the management and conservation of biological and cultural diversity.

Keywords: Alien species; Biological invasions; cultural niche; non-native species; societal extinction.

Introduction

Biological invasions are a major threat to global biodiversity, leading to profound ecological and socioeconomic impacts (Pyšek et al., 2020; Diagne et al., 2021; IPBES, 2023). After their introduction and establishment, invasive alien species (IAS) often also become embedded within local cultures through various forms of interaction with people (Nuñez et al., 2012; Soga & Gaston, 2020). Over time, these species may become increasingly familiar and ultimately be perceived by people as native elements of the environment, and/or as an integral part of local culture (Pfeiffer & Voeks, 2008; Lambertucci & Speziale, 2011; Lindemann-Matthies, 2016).

Changes in the perception of IAS are driven both by social and ecological processes and can strongly affect societal support for IAS management. Here, we suggest the term *cultural inception* for the gradual process in which IAS become embedded in cultures and societies through collective memory, attention, knowledge, representations, uses, and cultural products. Cultural inception provides an umbrella term to include previously used notions, such as assimilation, incorporation, integration, adoption, and percolation of IAS (Pfeiffer & Voeks, 2008; Kull et al., 2011; Nuñez et al., 2018; Simberloff, 2018; Pissolito et al., 2020; Bortolus & Schwindt, 2022; Sax et al., 2022). The process of cultural inception can generate serious challenges in the sustainable management of IAS. It may affect peoples' interactions with nature, their values, identities, and sense of place, motivate instrumental and relational conflicts, and modify or displace the cultural presence and identity of native species (Nuñez & Simberloff, 2005; Weeks & Packard, 2009; Kull et al., 2011; Shackleton, Richardson et al., 2019).

Research on social dimensions of inception lags behind the ecological work on biological invasions, partly because the sociocultural impacts of IAS are inherently complex, context-dependent at multiple levels, elusive and hardly quantifiable (Pfeiffer & Voeks, 2008; Pejchar & Mooney, 2009; Srithi et al., 2017; Souza et al., 2018). Sociological research on IAS has primarily focused on individual knowledge and perceptions of such species, their impacts on people's livelihoods, stakeholder engagement, and management dimensions (Kull et al., 2011; Nuñez et al., 2018; Shackleton, Richardson et al., 2019; Shackleton, Shackleton et al., 2019). Better defining and unpacking the process of cultural inception can deliver a coherent and inclusive research framework for IAS, and help identify and address the culturally appropriate and relevant aspects of sustainable IAS management.

Here, we present the concept of cultural inception of IAS, its main mechanisms and drivers, discuss the importance of understanding and tracking cultural inception, and illustrate it with examples of IAS that are already embedded in local cultures or in the process of becoming so. It is important to note that cultural inception may occur in any alien species, and not exclusively in those that are invasive. Nevertheless, we focus here on IAS because the consequences of their cultural inception are particularly relevant. We also address the major implications of cultural inception and provide key recommendations to implement biocultural approaches to the sustainable management and conservation of biological and cultural diversity.

Characteristics and mechanisms of cultural inception

The process of cultural inception, as a cultural phenomenon, is a population-level aggregate of individual interactions with IAS (Acerbi, 2016). It emerges from societal exposure to a species, through human-nature interactions, which may lead to affective attachments and the acceptance of the species, followed by a gradual loss of collective memory about its origin and status (Humair et al., 2014). The mere exposure to a certain species can lead to familiarity and potentially to developing more positive attitudes towards that species (Kueffer & Kull, 2017; Hooykaas et al., 2019). The presence of people and an IAS in the same physical or virtual space further allows various forms of human-nature interactions to occur, which can additionally strengthen the societal salience of a species (Soga & Gaston, 2020). Finally, repeated or prolonged exposure to and interactions with IAS can lead to the establishment of emotional connections, referred to as 'affective attachments' (Crowley et al., 2019), as well as relational values such as sense of place, responsibility and care, social bonding, and spiritual or religious associations (Mattijssen et al., 2020).

Over time, IAS can undergo a deeper integration within cultural, community, and individual identities (Fig. 1A; Box 1; Crowley et al., 2018, 2019; Jarić et al., 2020). Such species can be appreciated aesthetically, incorporated into cultural practices and products, used as a source of food, medicine, or other products (Fig. 1B; Nuñez & Simberloff, 2005; Nuñez et al., 2012; Dickie et al., 2014; Lovich & Yamamoto, 2016). This process potentially allows the species to inhabit an existing or novel cultural niche (see Glossary in Supplementary material) within the cultural space (Fig. 2; Garibaldi & Turner, 2004), regardless of their alien status. Perceptions of what is native or alien are, to a large extent, the result of social constructions and can be fluid and highly dynamic, being defined not only by species ecology but also by mental representations and socio-economic contexts (García-Llorente et al., 2008; Estévez et al., 2015; Backstrom et al., 2018). Species that gradually acquire a 'culturally native' status are disjoined from their biogeographic status (Bhattacharyya & Larson, 2014). Over time, IAS can even become cultural icons, identified with their host, place or location, personal histories, community identities, and cultural symbolism, as has happened, for example, with monk parakeets (*Myiopsitta monachus*) in many parts of their introduced range (Crowley et al., 2019).

Exposure to IAS can either be direct, or manifest through indirect, vicarious experiences based on virtual exposure to various physical or digital records from the literature, arts, and especially through the media (Jarić et al., 2022). Vicarious experiences (i.e., those based on virtual exposure, without direct sensory contact with the species; Jarić et al., 2022) are often based on highly stylized or homogenized species representations (Truong & Clayton, 2020), which can be especially effective in influencing people's attitudes towards IAS, for example by presenting species as endearing or charismatic (Jarić et al., 2020). In addition, such mediated experiences can occur regardless of a species' local presence and status, so they can sensitize individuals to the species and initiate cultural inception before it is even introduced, and thus before direct, personal experience occurs. The process of cultural inception can also be actively initiated or facilitated, for example, by promoting the value of IAS (e.g., the campaign by the Illinois Department of Natural Resources to rebrand the invasive Asian carp species as 'Copi', to make them more appealing and motivate the public to eat them).

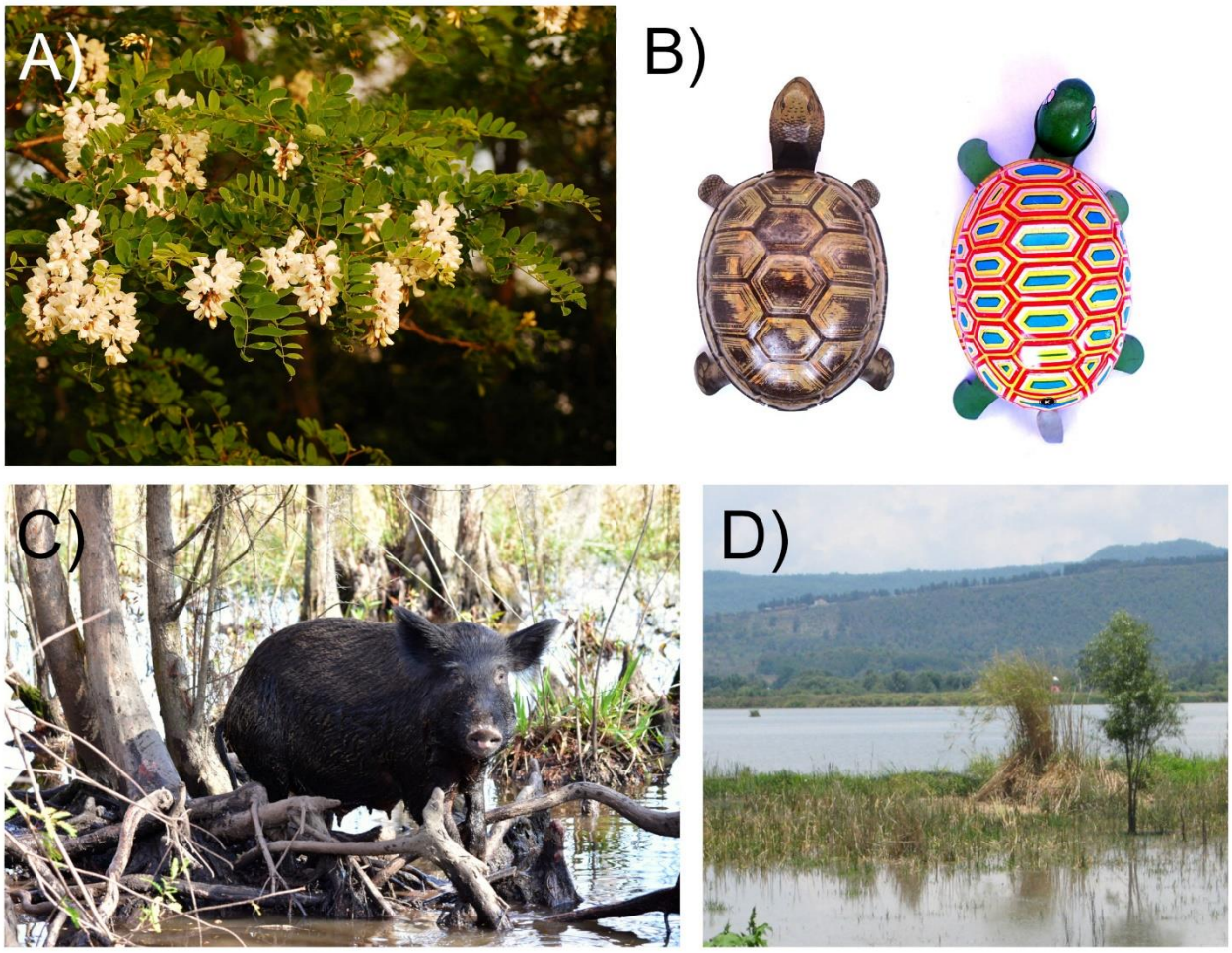

Fig. 1. *Case examples of cultural inception of invasive alien species. A) black locust (*Robinia pseudoacacia*), an invasive alien species in Hungary that causes conservation problems and is managed in protected areas, is widely perceived as one of the most traditional Hungarian trees (Box 1; Photo: Zsolt Molnár); B) Japanese tin toy turtles have experienced a notable shift over time from colors dominated by brown and black (left) to those dominated by red, yellow and green (right), which was potentially driven by the dominance of the invasive red-eared slider (*Trachemys scripta elegans*) over native turtle species, and their respective coloration (Lovich & Yamamoto, 2016); C) many feral animals, such as feral pigs (*Sus scrofa*) in the USA (Weeks & Packard, 2009), have been incorporated in local culture and economy (Photo: Pedrik); D) once cattail (*Typha domingensis*) became commodified as a popular resource for handicrafts, local communities in Mexico started to intentionally facilitate its invasion, which is negatively affecting the native California bulrush (*Schoenoplectus californicus*), another culturally valuable wetland plant (Photo: Steven J. Hall; Hall, 2009).*

The process of cultural inception can be facilitated and intensified by, but also contribute to, the shifting baseline phenomenon, i.e., a gradual change in the accepted norms and expectations of what people consider to be a 'normal' or desirable state of the environment. This can happen due to a lack of experience, memory, or knowledge about past conditions (Soga & Gaston, 2018). Consequently, IAS that are present over a long time period may no longer be perceived by people as invasive or alien, but as an intrinsic, original, or even desirable part of local fauna, flora, and culture (Lovich & Yamamoto, 2016; Nuñez et al., 2018; Beever et al., 2019; Jarić et al., 2020). Considering the past and ongoing rates of invasions, it is possible that this process has over time already substantially altered perceptions of nature and historical memory (Shackleton, Richardson et al.,

2019; Bortolus & Schwindt, 2022). For example, many North American Indigenous communities believe that they had always had horses (*Equus ferus*) and associated horse cultures, even though they were, in fact, reintroduced in the 16th century by European colonizers (Zomorodi & Walker, 2019).

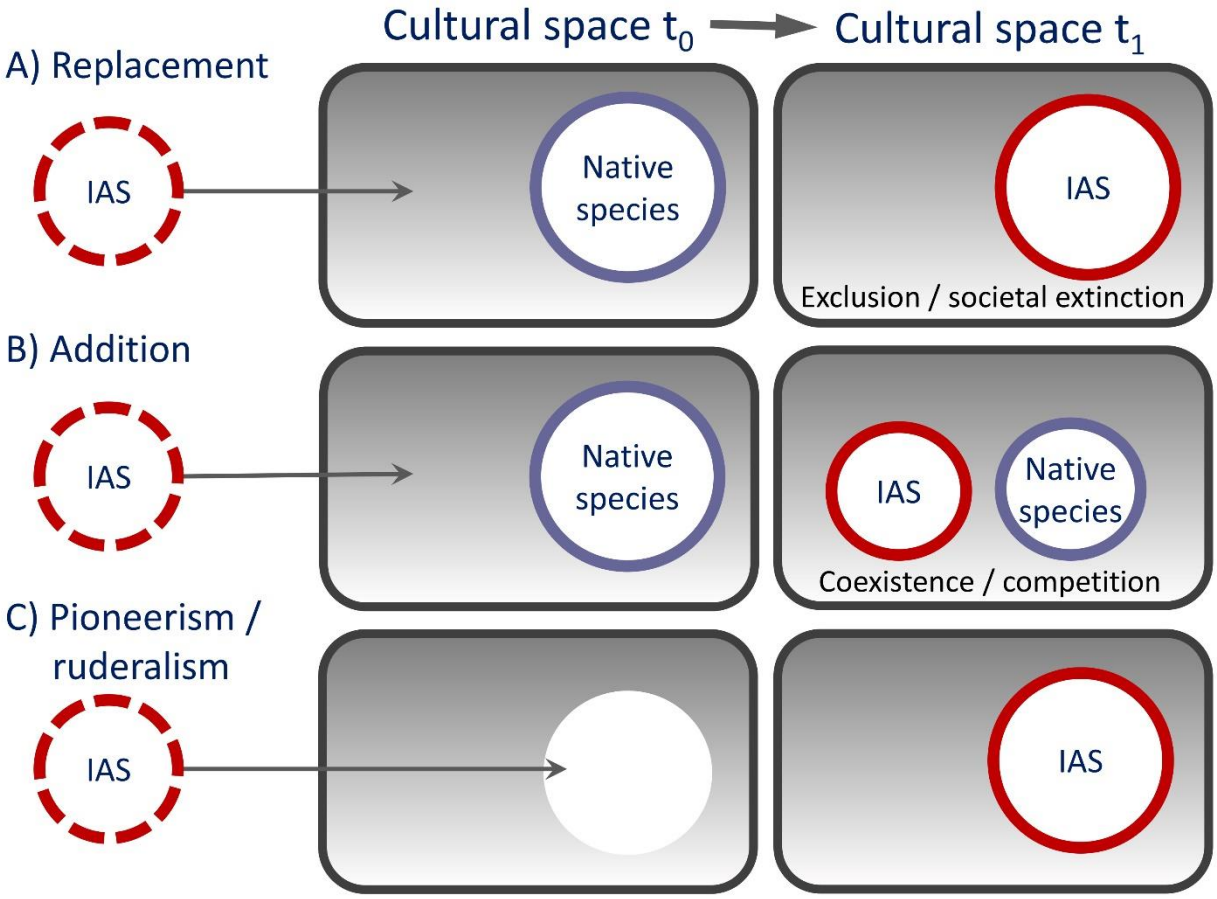

Fig. 2. *Potential scenarios for interactions of a culturally incepted invasive alien species (IAS) with native species in the cultural sphere. A) Replacement of the affected native species within the cultural sphere, with the exclusion and/or societal extinction (Jarić et al., 2022) of the native species, and IAS taking over its roles in livelihoods, customs, and sense of place and identity; B) addition of IAS in the cultural space, leading to coexistence of IAS and the affected native species, but a reduction of the occupied cultural space by the native species due to competition; C) IAS occupying cultural space that was previously vacant, either through establishment of novel human-nature interactions and cultural practices (pioneerism) or by occupying space of a previously extirpated species (ruderalism). The three archetypes represent only the main types of outcomes, and there are many other possible alternative scenarios and their combinations.*

Cultural inception can occur within a single human generation (Lovich & Yamamoto, 2016; Kueffer & Kull, 2017; Nuñez et al., 2018). Once incepted, IAS can have their cultural status modified and strengthened over time, as well as become iconic and embody cultural, spiritual, or symbolic values (Nuñez & Simberloff, 2005; Estévez et al., 2015; Bortolus & Schwindt, 2022). They can even become symbols of national identity and acquire the status of city emblems or state plants or animals, such as the red clover (*Trifolium pratense*), the state flower of Vermont, and the common pheasant (*Phasianus colchicus*), the state bird of South Dakota (Pfeiffer & Voeks, 2008; Bortolus & Schwindt, 2022). Such species can ultimately become cultural keystone species (Garibaldi & Turner, 2004), deeply embedded in cultural traditions, narratives, discourse, and sense of place (Duenn et al., 2017; Winter et al., 2020). On the other hand, many IAS never become societally and culturally present.

This is typically the case for uncharismatic, small, cryptic, or inaccessible species, such as invertebrates (particularly those living underwater or belowground), fungi, and microorganisms (Jarić et al., 2019), or those with well-known negative social-ecological impacts. For example, it is unlikely that the Asian tiger mosquito (*Aedes albopictus*), the most invasive vector species worldwide (Bonizzoni et al., 2013), will experience cultural inception.

Once an IAS enters the human culture in its introduced range, it may start interacting with the cultural niche of native species. This may either lead to the exclusion and replacement of certain native species from the cultural niche, or their coexistence, although IAS can also occupy cultural niches that were previously vacant (Fig. 2). Through partial or full cultural replacement of native species, IAS can become 'cultural substitutes' for people's livelihoods, customs, and sense of place and identity (Pfeiffer & Voeks, 2008). Interactions between IAS and native species in the human culture are often complex and multidimensional. For example, an IAS can affect or replace a native species in one type of use or interaction with a particular subset of humans but not in another one.

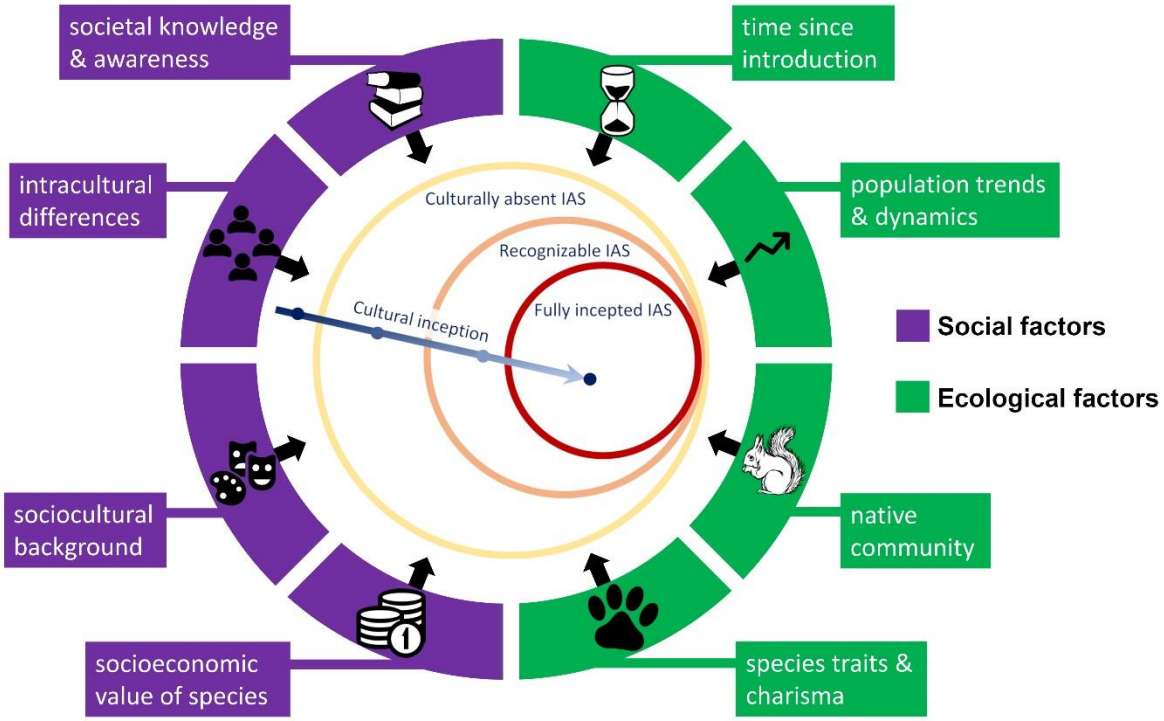

Fig. 3. *The process and key factors affecting cultural inception of invasive alien species. Following its introduction, an invasive alien species can either remain culturally absent or enter the cultural sphere, where it can over time become fully incepted and perceived as being native, and an integral or even essential part of culture. Fields surrounding the central diagram present the key factors affecting the cultural inception process.*

Factors affecting the process of cultural inception of invasive species

Various factors can influence the process of cultural inception of IAS. These include time since introduction, species' origin, abundance, rate and magnitude of spread, local knowledge, awareness and attitudes, perceived ecological and cultural impacts, cultural uses, benefits, and values, characteristics and charisma of IAS, the vulnerability of local communities, and local livelihood practices (Fig. 3; Kull et al., 2011; Nuñez et al., 2018; Shackleton, Richardson et al., 2019; Jarić et al., 2020). Cultural inception can vary spatially and temporally, across and within societies, and be

strongly affected by societal, cultural and economic dynamics, as well as by species ecology and demography (Kull et al., 2011; Nuñez et al., 2018; Shackleton, Richardson et al., 2019).

Time since introduction

There is likely a strong relationship between the time since an IAS was introduced to a new region and the stage of cultural inception. People's ability to identify species as alien or invasive decreases with time, as species introduced in the distant past had more time to become embedded in the local culture and memory (García-Llorente et al., 2008; Nuñez et al., 2018; Shackleton, Richardson et al., 2019). For example, bluegrass (*Poa pratensis*) and tumbleweed (*Kali tragus*), introduced to the USA from Eurasia, have come to be seen as natural and iconic landscape elements in the 'Bluegrass region' and the American West, respectively, with very few people being aware of their alien origin (Lovich & Yamamoto, 2016; Sax et al., 2022). The process is often also associated with changes in the names of introduced species. For example, following its introduction to the USA in 1852, the invasive house sparrow (*Passer domesticus*) was given the name 'English sparrow'. However, as the sparrow became normalized in society, people gradually ceased to refer to it as 'English' (Fig. 4).

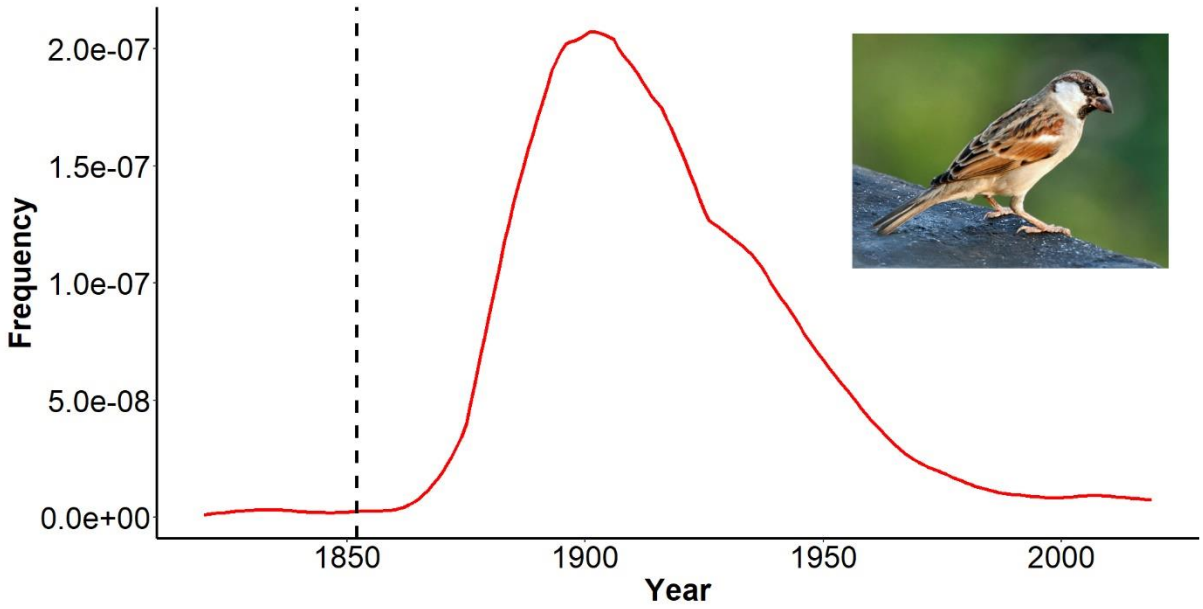

Fig. 4. *Cultural inception of the house sparrow (*Passer domesticus*) in North America. Following its introduction to the USA in 1852 (dashed line), its initially given name of 'English sparrow' gradually dropped from use, as people ceased to refer to it as 'English' (Photo: J. M. Garg). The time series shows the frequency of the term 'English sparrow' in printed sources published between 1820 and 2019 based on Google Books Ngram Viewer data, which were fitted with LOESS smoothing (f = 0.1).*

Population status, abundance, dynamics and spread

Population status, abundance, and spread of IAS may strongly affect the cultural inception process. Overall, cultural salience tends to be higher for more abundant species with wider geographic ranges that are also more closely overlapping with human populations (Ladle et al., 2019; Jarić et al., 2022). This leads to greater visibility of such species and provides greater opportunity for interactions with humans and the formation of affective attachments (Box 1; Humair et al., 2014; Crowley et al., 2019). Abundant and widespread IAS, and those more closely associated with urban areas, generally have a higher chance of becoming culturally incepted. The process of inception can also be affected

by changes in the IAS ecology, population structure, or dynamics that may affect its salience, appeal, or perceived value.

Box 1. The cultural inception of black locust in Hungary: A highly controversial, culturally native and beloved, invasive alien tree species

„*Why you don't like this traditional akác?*" – an old woman asked a local conservationist.

Black locust (*Robinia pseudoacacia*), native to North America, was introduced to Hungary in 1710, and became widespread by 1895 after large-scale promotion of the species. Black locust filled an almost empty niche in the treeless lowlands of Hungary. It became an important source of the economy, with half of the EU plantations located in the country. The species was declared as harmful to biodiversity and invasive in 2009. Pushed by foresters and beekeepers, and widely supported by the public, the tree and its honey attained the status of 'Hungarikum', as elements of unique value for the country, and thus entered the political arena and public discourse in 2014. A '*Robinia* Coalition' was founded to lobby for black locust in Hungary and in the EU, to prevent its inclusion in the EU invasive species list. A representative survey in the 1990s showed that it is widely considered as '*the most Hungarian tree species*' (Vítková et al., 2017; Ispánovics Csapó, 2019).

Black locust is useful for many people, with 12 identified positive and three negative impacts associated with the species. A fifth of the Hungarian forests consists of black locust, but it is also common among arable fields, along roads, and in small woods around farms. This quickly growing hardwood tree provides high quality timber, honey (provides half of all honey produced in Hungary), excellent firewood, improves soil, prevents erosion, fixes sand dunes, and is also used for medicinal purposes and as a fodder. Black locust is considered 'environmentally friendly', because no chemical treatment is needed for its outdoor use (e.g., as street furniture) due to its resistance to insects and fungi (Vítková et al., 2017; Ispánovics Csapó, 2019).

There is a high level of awareness and knowledge of black locust in Hungary, with widespread personal connections and positive attitudes. It has become a cultural keystone species and attained local symbolic value, and is often mentioned in poems and songs. Black locust is regarded as native by most local villagers, even by the traditional knowledge holders, because "*it was already widespread in their childhood*". Even those people who know that it is non-native regard it as an intrinsic, and desirable part of local landscapes. Black locust is generally regarded as 'nativized', especially by foresters who even feel a responsibility towards it and cultivate it, with many cultivars selected. Some forest types, marginal arable lands and abandoned pastures were often reforested with black locust in hilly areas and lowlands, which is a missed opportunity for increasing forest cover with native trees. On the flip side, black locust is regarded as a harmful invasive species by ecologists and conservationists. Black locust can survive in naturally non-forested habitats and replaces native vegetation and associated biodiversity. As a result of the benefits and despite the impacts of the tree, there is a strong public opposition to invasion control, particularly as local people have limited understanding about the harms black locust causes to native biodiversity (Vítková et al., 2017; Ispánovics Csapó, 2019).

Box 1 – continued

Without black locust, the Great Hungarian plain would be 'characterless' – many people argue (Vítková et al., 2017; Ispánovics Csapó, 2019). This view shows that black locust covers the pre-industrial knowledge of the landscape, as a manifestation of a shifting baseline syndrome. Black locust may have contributed to the erosion of local, traditional knowledge, but possibly of only particular tree species and only in some regions where it became the almost mono-dominant wood source (e.g. Nyírség), because other species became less needed, and thus less known. There may be intergenerational differences in the perception of black locust, as the understanding of its invasiveness is increasing (Vítková et al., 2017; Ispánovics Csapó, 2019).

Fig. 5. *Traditional farm in the Hungarian Great Plain in 1930s, with a stand of black locust (*Robinia pseudoacacia*) visible in the background.*

Species traits, life history, and charisma

Certain IAS traits can facilitate their cultural inception, namely those that drive their perceived appeal or charisma (Jarić et al., 2020). Charismatic IAS often become culturally significant or iconic even if their alien and invasive status is still widely recognized, such as feral hippopotamuses (*Hippopotamus amphibius*) in Colombia, Chinese windmill palm (*Trachycarpus fortunei*) in Switzerland, and Jacaranda trees (*Jacaranda mimosifolia*) in South Africa, which became a symbol of the city of Pretoria (Nuñez et al., 2018; Jarić et al., 2020; Tonellotto et al., 2022). IAS exhibiting unique or exotic features, such as large trees and conspicuous flowers, tend to be highly valued by people, irrespective of their origin (Gobster, 2011; Dickie et al., 2014; Kueffer & Kull, 2017). Overall,

species that can build or strongly affect their invaded ecosystems, such as foundation species and ecosystem engineers, may become more quickly associated with the new environment and landscapes. For example, the groves formed by *Eucalyptus* species introduced to California in the 19th century came to be appreciated as a characteristic feature of the state's landscapes (Nuñez & Simberloff, 2005).

Native community and the landscape context

The morphological similarity of IAS to native species can facilitate their cultural inception. At the same time, similarity among species may lead to a stronger overlap of their respective cultural niches and often to stronger cultural competition and cultural replacement of native species (Fig. 2). Such processes can be strengthened by their biological interactions, for example, if IAS also drive population or range reduction of native species, replacing them both biologically and culturally (Lovich & Yamamoto, 2016). For instance, the replacement of native turtle species in Japan by the invasive red-eared slider (*Trachemys scripta* subsp. *elegans*) may have contributed to shifting baselines in people's awareness and knowledge, with such changes consequently manifested in cultural products such as toys (Fig. 1B; Lovich & Yamamoto, 2016). On the other hand, IAS without an analogous, morphologically similar native species, can also become easily incepted, for example, by novelty contributing to the perceived uniqueness or charisma of a species (Jarić et al., 2020). IAS can also fill an empty ecological niche in the ecosystem, which may make them more readily accepted by local communities.

The cultural identity of IAS can be transferred from native, extant, or extirpated species. Such a process can occur unconsciously and often through taxonomic misidentification, for example, if the two species are not easily distinguishable at the morphological level, as is the case for native and alien subspecies of common reed (*Phragmites australis*) in North America, represented by a complex mixture of their populations, as well as their hybrids (Pyšek et al., 2018). This is especially common in the case of cryptic species, i.e., those that are not yet described or identified in their introduced range (Jarić et al., 2019).

Societal knowledge and awareness

Lack of local knowledge about IAS, the invasion phenomenon, and its impacts can facilitate cultural inception (Pissolito et al., 2020; Bortolus & Schwindt, 2022; Chaudhary et al., 2022). Additionally, a lack of knowledge about native species and ecosystems can hamper the ability of people to recognize species as alien or invasive and make such species more readily accepted and incorporated into local culture (Nuñez et al., 2018; Simberloff, 2018). For example, a survey among communities in the sub-Antarctic Magellanic ecoregion showed that their awareness of the surrounding flora was not dominated by native plants but by alien, cosmopolitan ornamental species, likely driven by media and their everyday encounters with these species in urban areas (Rozzi, 2013). On the other hand, high awareness of IAS negative impacts, such as threats to human health, can potentially hinder the inception process. Attitudes towards IAS can also change and switch between positive and negative over time, translating into changes in general societal knowledge and awareness. On the other hand, even negatively perceived IAS can become culturally incepted in some cases, such as the invasive cane toad (*Rhinella marina*) in Australia, which became for some a symbol of resilience, adaptability, and transformation (Trigger et al., 2008).

Species cultural uses, benefits, and values

Cultural inception is more likely if IAS are considered beneficial for local livelihoods or the economy (dos Santos et al., 2014; Hart et al., 2017; Jarić et al., 2020). Such benefits can include all regulating (e.g., pollination or energy), material (e.g., medicine or raw material), and non-material (e.g., recreation or learning) Nature's Contributions to People (Pfeiffer & Voeks, 2008; Kull et al., 2011; Jarić et al., 2020; Bortolus & Schwindt, 2022). The use of IAS as a food source is a powerful

driver of cultural inception (Nuñez et al., 2012). For example, following their introduction worldwide for food and hunting, feral pigs (*Sus scrofa*) have become strongly associated with local cultures, including traditional, subsistence, and recreational hunting, as well as traditional cuisine (Fig. 1C; Weeks & Packard, 2009; Estévez et al., 2015). Economic value is also affected by other factors, such as the abundance, availability and traits of an IAS (i.e., those that contribute to higher yields, faster growth, better taste; Palmer, 2004; Kull et al., 2011). Economic value represents one of the main drivers of intentional introductions (Nuñez & Simberloff, 2005). Furthermore, management programs based on utilization, i.e., creating a market for IAS, can contribute to their cultural inception by enhancing their economic value and through marketing efforts (Nuñez et al., 2012).

Sociocultural background

People's relationship with and access to nature, existing value systems, general perceptions of biodiversity and the environment, and the level of cultural insularity, globalization, and urbanization are among the main sociocultural factors that can affect the process of cultural inception (Nuñez et al., 2018; Kueffer & Kull, 2017; Shackleton, Richardson et al., 2019; Höbart et al., 2020). Cultural inception can also be affected by sociocultural changes in society, including current trends in people's growing disconnection from nature (Soga & Gaston, 2018), the ongoing erosion of Indigenous and local knowledge (Fernández-Llamazares et al., 2021), and the rise of biophobia (fear of nature; Beery et al., 2023; Soga et al., 2023).

In areas with a high prominence of transnational human communities, cultural inception can be affected and driven by people's origins or their displacement (Nuñez et al., 2018). In human migrations, both historic and contemporary, newcomers often perceive their new environment as normal or natural, which can make them more open to accepting already present IAS. They may additionally be more receptive to introductions of species they have known as native in their previous environment, or they may bring such species. For example, immigrants from Europe and Asia settling in the Americas and the Pacific were deliberately introducing alien species that were considered culturally and socioeconomically relevant at their place of origin (Nuñez & Simberloff, 2005; Dickie et al., 2014). This was even organized in so-called acclimatization societies. It was mainly done for aesthetic or economic reasons, as well as for psychological support, by attempting to recreate a familiar environment and regain a sense of place and continuity for colonial or immigrant communities (Nuñez & Simberloff, 2005; Dickie et al., 2014; Estévez et al., 2015; Srithi et al., 2017; Shackleton, Richardson et al., 2019), with IAS acting as 'culturally facilitating' species (Pfeiffer & Voeks, 2008).

Intercultural, intracultural and individual differences

Perceptions and attitudes towards IAS vary across cultural groups, social sectors, stakeholders, and individuals (García-Llorente et al., 2008; Estévez et al., 2015; Shackleton, Richardson et al., 2019). For example, *Echium plantagineum* is called 'salvation Jane' in South Australia and 'Patterson's curse' in other regions of that continent and in the USA, reflecting different perceptions of this invasive plant species (Kueffer & Kull, 2017). Similarly, invasive fish species can be simultaneously perceived as a promising opportunity by some recreational fishers but negatively by others (Sbragaglia et al., 2022). Perceptions can also be affected by differing religious norms and ethical value systems within different cultural groups (Shackleton, Richardson et al., 2019), or a species can be highly relevant for a group of people while remaining completely unknown to the rest of society (Turner, 1988). Such differences within a society can make the speed and outcome of the cultural inception process highly complex and partly unpredictable (Pfeiffer & Voeks, 2008; Nuñez et al., 2018).

Individual perceptions of nature, such as a 'sense of place', are shaped by personal identities, values, education, histories, experiences, and knowledge, as well as by emotional and psychological factors (Nuñez et al., 2018; Shackleton, Richardson et al., 2019; Pissolito et al., 2020; Reyes-García

et al., 2023). In turn, these perceptions shape individual interactions with nature. Consequently, individual perceptions of IAS and their cultural inception may differ considerably. As the cultural inception phenomenon operates at the societal level, the complexity of individual-level interactions from which it is derived makes it highly unpredictable and dynamic.

Implications and impacts of cultural inception

Impacts on management

While being fully incorporated into cultures and livelihoods, IAS can, at the same time, cause large-scale ecological impacts and negatively affect human well-being (Kull et al., 2011; Crowley et al., 2017). The process of inception can lead to public opposition to management, generate unanticipated social conflicts (where some actors may benefit, while others are harmed by the species), and result in management failure and reduced public trust and support (Estévez et al., 2015; Crowley et al., 2017). For example, the public is typically less supportive of harsher management actions, such as lethal measures, for species perceived as native or desirable, especially if they are considered charismatic or iconic (Verbrugge et al., 2013; Jarić et al., 2020; Straka et al., 2022; Tonellotto et al., 2022).

IAS that have acquired sociocultural or economic value that exceeds its perceived negative impacts might paradoxically even be subjected to protection or restoration measures (Nuñez et al., 2012; Jarić et al., 2020; Sax et al., 2022). Moreover, in cases where IAS become more valued than native species, such measures may even run in parallel with the control of native species to mitigate their competition with the IAS and promote the invasion process. Examples of such paradoxical scenarios include the poisoning of native guanacos (*Lama guanicoe*) in Patagonia to reduce competition with invasive red deer (*Cervus elaphus*) and livestock (Lambertucci & Speziale, 2011), promotion of the invasion of the cattail (*Typha domingensis*) by local communities in Mexico at the expense of the native California bulrush (*Schoenoplectus californicus*; Fig. 1D; Hall, 2009), and the active spread of the culturally valuable but highly invasive Nypa tree (*Nypa fruticans*) in Nigeria (Moudingo et al., 2015). Cultural inception can also stimulate intentional IAS introductions and thus contribute to secondary introductions and further spread.

Effects on human culture

Cultural inception of IAS can affect people's perceptions of their environment, their values, traditions, and customs, modify collective memory, and even alter historical knowledge and understanding (Nuñez & Simberloff, 2005; Kueffer & Kull, 2017; Bortolus & Schwindt, 2022). Consequently, cultural inception can lead to fundamental societal changes. For example, the inception of invasive prickly pear cactus species (*Opuntia* spp.) in Madagascar contributed to a shift within local communities from mobile pastoralism to settled agricultural practices (Shackleton, Shackleton et al., 2019).

Just as biological invasions lead to the impoverishment and homogenization of biological diversity, they can have the same effect on cultural diversity (but see discussion below about potential positive effects). Through this process, also termed biocultural homogenization (Rozzi, 2013), the cultural presence of invasive IAS can push and suppress the cultural presence and identities of native species and their associated cultural services, and ultimately lead to their societal extinction (Pfeiffer & Voeks, 2008; Pejchar & Mooney, 2009; Simberloff, 2018; Jarić et al., 2022).

When the process of inception affects culturally important native species that play key roles in supporting cultural identity and social cohesion (Reyes-García et al., 2023), it can lead to the restructuring of sociocultural systems or the establishment of distinct, novel social-ecological systems (Pfeiffer & Voeks, 2008; Simberloff, 2018; Mooij et al., 2019). Such changes can be gradual, but they may ultimately lead to social-ecological tipping points (Milkoreit et al., 2018) and potentially irreversible changes in social systems, affecting societal resilience to other ecological impacts (e.g., health quality from a changing climate), socioeconomic changes (e.g., job maintenance and revenues)

and further invasions. This, for example, happened with biological invasions in Lake Victoria, where impacts of IAS such as water hyacinth (*Eichhornia crassipes*) and Nile perch (*Lates niloticus*) led to massive ecosystem transformations and strong shifts in social-ecological systems, with complex effects on job opportunities, industry, infrastructure, and land uses in the wider watershed (Mooij et al., 2019).

Indigenous Peoples, small-holders and traditional knowledge holders

Indigenous Peoples, small-holders and traditional knowledge holders are disproportionally affected by social and environmental changes (Fernández-Llamazares et al., 2021; Molnár et al., 2023), which can make them particularly susceptible to the impacts of biological invasions. Furthermore, species that are highly prominent within Indigenous Peoples' cultures are often inordinately threatened (Ladle et al., 2023; Reyes-García et al., 2023). The process of cultural inception of IAS may additionally impact culturally important species and consequently negatively affect societies and knowledge systems dependent on them. Many Indigenous Peoples have already experienced such changes, with widespread shifts from using native species to IAS in their livelihoods and traditions (Robinson et al., 2005; Reo et al., 2017; Shackleton, Richardson et al., 2019). Over time, this may lead to potentially irreversible negative changes and exacerbate existing pressures on traditional ecological knowledge and cultural heritage associated with native species and communities (Ticktin et al., 2006; Fernández-Llamazares et al., 2021).

On the other hand, there is often a high level of awareness among Indigenous Peoples and other traditional communities of IAS and their potential impacts (Robinson et al., 2005; Reo et al., 2017; Black et al., 2021; Theys et al., 2023). Moreover, peoples' responses to IAS may strongly differ among and within communities, with some people embracing such species and others actively controlling them, and with their attitudes based on lived experience typically differing from native/non-native binary perceptions that commonly characterize science and management (Black et al., 2021; Wehi et al., 2023). Several Indigenous scholars argue that IAS management should apply a biocultural lens to align more closely with Indigenous land-based stewardship (Reo et al., 2017; Nxele et al., 2019; IPBES, 2020). Indeed, biocultural thinking is becoming a major trend in applied ecology, ethnobiology, and related disciplines, and is gaining traction as an effective and just model for IAS management (Alexander et al., 2017; Wehi et al., 2023).

Positive societal effects of cultural inception

The consequences of cultural inception are not exclusively negative. It can also lead to a wide range of positive effects, for example, by strengthening attachments to nature, strengthening or developing new human-nature interactions, providing important resources for people, promoting food security and reducing the vulnerability of people, and enriching local cultures. IAS can enrich cultures through their positive role in livelihoods, traditions, spirituality, and inspiration, and can reinforce local cultural identities by becoming cultural symbols (Pfeiffer & Voeks, 2008; Pejchar & Mooney, 2009; Bortolus & Schwindt, 2022; Sax et al., 2022). For example, horses have been deeply integrated with Indigenous Peoples' cultures in North America, enriching their livelihoods and customs, and acquiring a strong role in cultural identity and heritage (Bhattacharyya & Larson, 2014; Beever et al., 2019). Similarly, some local communities in Australia have established spiritual associations with IAS, such as dromedary (*Camelus dromedarius*; Estévez et al., 2015). Many alien species have come to play an important role in national identities and traditions, such as Arabic coffee (*Coffea arabica*) in Colombia and cannabis (*Cannabis sativa*) within Rastafari culture in Jamaica (Nuñez & Simberloff, 2005). IAS are more likely to become 'culturally enriching' (Pfeiffer & Voeks, 2008) when they occupy a cultural space that was previously vacant (Fig. 2).

Human cultures are inherently dynamic and change through time. Shifts in species' cultural uses and identities are part of these changes (Tareau et al., 2020; Odonne et al., 2021). Efforts to preserve traditional knowledge and culture often aim to fix and revert changes in space and time,

overlooking the importance of changes for the long-term resilience of human cultures (Fernández-Llamazares et al., 2021).

Broad sustainability implications

The cultural inception of IAS brings forth both challenges and opportunities to achieve sustainability goals. It can act as a barrier to sustainability transitions, for example by negatively affecting social justice and intergenerational equity through impoverishment and homogenization of cultural and biological diversity. It can obstruct the long-term stability of social-ecological systems by influencing and modifying place-based human-nature relationships that have supported them (Reyes-García et al., 2023). Such impacts might particularly threaten Indigenous Peoples by impairing their knowledge systems and livelihoods, which represent the backbone of their identity and survival (Magni, 2017). On the other hand, cultural inception can help promote the resilience of social-ecological systems by, for example, improving food sovereignty and security.

Acknowledging the cultural inception of IAS can improve our understanding of the societal aspects of biological invasions, as well as the social and cultural dimensions of sustainability transitions. However, addressing cultural inception within sustainability science and practice will require full recognition of the complexity of this process through adequate changes in management measures and policies. For example, considering that social systems and cultures tend to adapt to biological invasions at different rates than ecosystems (Beever et al., 2019), management plans need to be designed to work across a wide range of temporal and spatial scales (Bortolus & Schwindt, 2022). Furthermore, the diversity of perceptions within society can only be adequately incorporated in sustainability management through participatory governance in the context of the Sustainable Development Goals.

Mitigation and adaptation strategies

The consequences of the cultural inception of IAS need to be addressed in research, education, decision-making, policy, and management, with adequate involvement of all sectors of society and relevant stakeholders. IAS management and decision-making need to be science-based, socially inclusive, and participatory to the largest extent possible (Zomorodi & Walker, 2019), with open and fair involvement to ensure diverse perspectives and strengthen trust in and societal support for the process (Estévez et al., 2015; Shackleton, Shackleton et al., 2019; Meinard et al., 2022). Potential conflicts can be mitigated by involving stakeholders and rights holders early in the management phase, gathering their first-hand knowledge and perspectives, and seeking solutions based on compromise among environmental, social, and economic priorities (Hall, 2009; Crowley et al., 2017; Backstrom et al., 2018; Novoa et al., 2018). Timely involvement in management is especially relevant because IAS often get accepted without adequate knowledge and awareness of the threats they may pose to social-ecological systems.

Invasion science, management, and policy recently started to shift from a dominantly biological focus to a transdisciplinary perspective (Vaz et al., 2017). Such shifts will benefit from expertise and insights of a wide range of disciplines and stakeholders and allow for capturing the complexity of sociocultural processes associated with biological invasions (Pfeiffer & Voeks, 2008; Estévez et al., 2015; Shackleton, Richardson et al., 2019). Yet, implementing a truly holistic perspective of social-ecological systems will require closer involvement of social sciences and humanities (Kapitza et al., 2019; Shackleton, Richardson et al., 2019; Bortolus & Schwindt, 2022), as well as perspectives outside of academia (Reed et al., 2023). The cases reviewed in this article exemplify many of the different ways in which biocultural relations shape people's understandings of their roles within, and responsibilities towards their environment, including IAS (IPBES, 2020). Biocultural approaches should therefore be recognized as an essential prism for looking at the interwoven relationships between people and IAS from culturally grounded perspectives (Alexander et al., 2017; Wehi et al., 2023).

Cultural inception can be managed either by controlling IAS presence or by addressing their relationship with the cultural sphere, for example, through education and awareness raising. Such efforts can be directed to improve species literacy regarding IAS (Hooykaas et al., 2019), including knowledge and recognition of the invasion process and impacts (Nuñez & Simberloff, 2005; Nuñez et al., 2018). Management should simultaneously improve knowledge of affected native species – their threat status, and ecological and sociocultural importance. Such a process can further strengthen the 'sense of place' and human-nature interactions, and stimulate interest in biodiversity and sustainability (Hooykaas et al., 2019). Additionally, various economic incentives and disincentives could be considered to promote this (Pejchar & Mooney, 2009), as well as a wide range of behavioural interventions (Byerly et al., 2018).

However, obstructing or reversing the process of cultural inception may not always be appropriate or advisable. IAS removal can sometimes lead to considerable and unforeseen negative biological effects (D'Antonio & Meyerson, 2002; Doody et al., 2017), while the disruption of their sociocultural embeddedness can lead to a wide range of impacts on culture, livelihoods, and the economy (Weeks & Packard, 2009; Shackleton, Shackleton et al., 2019). Biological invasions have played an important role throughout history in shaping and enriching human culture (Estévez et al., 2015; Bortolus & Schwindt, 2022). Past reference conditions are not always viable or even desirable restoration goals in systems that have undergone dramatic environmental, social, and cultural changes. Any potential action to hinder or reverse the process of cultural inception should thus carefully evaluate biological, socioeconomic, and cultural costs and benefits through a participatory approach.

As opposed to the cultural inception of IAS, such a process is not only desirable but even necessary for some management issues, such as managed relocation efforts (Serota et al., 2023), for example, as a climate-change mitigation measure (McDonald-Madden et al., 2011), or in the case of the ongoing, unmanaged distributional range shifts due to climate change ('species on the move'; Pecl et al., 2023). They are also important in the case of reintroductions or rewilding with substitute species (Griffiths et al., 2011), particularly for those species that were never culturally present or have been lost from collective memory (Jarić et al., 2022). For example, the reintroduction of the Eurasian beaver (*Castor fiber*) in Central Europe has been met with conflicts with local communities, mainly because many such communities often perceive it as a pest rather than a natural element of the environment (Ulicsni et al., 2020). Improved understanding of the cultural inception process can also help to promote native species that are less appreciated, especially in the case of threatened species that lack conservation support.

The process of cultural inception of IAS and its effects, both positive and negative, should be recognized and incorporated into existing frameworks, such as the values-based decision framework (Backstrom et al., 2018), the mitigation hierarchy (Arlidge et al., 2018), and other promising concepts such as invasion syndromes (Novoa et al., 2020). However, a major challenge will be to find a way to assess the complexity of societal values related to the process of cultural inception of IAS. One potential approach in this respect could be Turner's multidimensional index of the cultural significance of a species, based on the estimates of the quality, intensity, and exclusivity of species use (Turner, 1988).

To ensure the long-term sustainability of social-ecological systems, ongoing biocultural changes will need to be addressed through transdisciplinary research and participatory governance and management, based on inclusion, equity, justice, and open, responsive communication (Crowley et al., 2017; Harris et al., 2023). Ultimately, future research and management efforts focusing on the cultural inception of IAS will have to fully recognize that biological invasions are as much a sociocultural phenomenon as they are a biological one.

Acknowledgements

We thank Tina Heger for valuable suggestions on an earlier version of the manuscript, as well as Jeffrey E. Lovich, Katsuya Yamamoto, and Steven J. Hall for providing the photographs. This work was supported by grant no. 23-07278S to I. J., A. N., and P. P. from the Czech Science Foundation. F. E. appreciates funding from Austrian Science Foundation FWF (Global Plant Invasions, grant no. I 5825-B). R. A. C. acknowledges funding from the Research Council of Finland (grant #348352) and the KONE Foundation (grant #202101976). VS acknowledges funding from Spanish Ministry of Science and Innovation with a "Ramón y Cajal" research fellowship (RYC2021-033065-I). ZM was supported by the National Laboratory for Health Security (NKFIH, RRF-2.3.1-21-2022-00006). ASV acknowledges support from FCT - Portuguese Foundation for Science and Technology through the program Stimulus for Scientific Employment – Individual Support 2020.01175.CEECIND/CP1601/CT0009.

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Table 1. Glossary

Term	Definition
Alien species	A species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans), including any part, gametes or propagule of such species that might survive and subsequently reproduce. Also known as non-native, non-indigenous, foreign, or exotic species (IPBES).
Behavioural interventions	Behaviour modification measures aimed at encouraging societally valued behaviour change (Balmford et al., 2021).
Biophobia	Fear of nature, negative feelings or responses to certain natural stimuli (Soga et al., 2023).
Cultural identity	Subjective identification with a particular cultural group (Usborne & De La Sablonnière, 2014).
Cultural inception	A process where alien species gradually become embedded within the local culture, becoming perceived by the public as familiar, native elements of the environment, and/or as an integral part of local culture.
Cultural keystone species	Culturally salient species that strongly shape the cultural identity of people, as reflected in the fundamental roles these species have in diet, materials, medicine, and/or spiritual practices (Garibaldi & Turner, 2004).
Cultural niche	Those parts of the human cultural environment that a species occupies (Schuetz & Johnston, 2021).
Cultural product	Tangible and intangible creations of a particular culture.
Invasive alien species	Alien species that becomes established in natural or semi-natural ecosystems or habitat, are agents of change, and threaten native biological diversity (IPBES).
Nature	All living organisms and ecosystems, excluding those that are not self-sustained (Soga & Gaston, 2022).

Ruderal species	Species that are first to colonize disturbed lands, i.e. lands laid bare by natural events, such as wildfires, or human action, such as construction or agriculture.
Shifting baseline syndrome	A gradual change in the accepted norms for the condition of the natural environment due to lack of past information or lack of experience of past conditions (Soga & Gaston, 2018).
Societal extinction of species	Loss of societal attention and collective memory of a species (Jarić et al., 2022).
Societal salience of a species	Cultural profile and visibility, or public popularity of a species.
Species on the move	Species whose distributions are shifting in response to climate change (Pecl et al., 2023).
Vicarious experiences	Indirect, disembodied experiences, based on virtual exposure to species, through various physical or digital records from the literature, arts, oral traditions, or media (Gaston & Soga, 2020).

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IPBES. Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem. https://www.ipbes.net/glossary

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