

Biological invasions and human dimensions: We still need to work hard on our social perspectives

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ABSTRACT. In this article, we analyze and challenge a long-held paradigm that reduces the field of biological invasions to its ecological components. We explore thirteen case studies grouped within three major human dimensions (values, traditions, and quality of life) to show how biological invasions interwove and interact with them. The group of human dimensions we explore in this work, although small, exposes a rich spectrum of interdisciplinary synergies between natural and social sciences that should receive more attention to make the field of biological invasions more sound and socially integrated.

[Keywords: natural sciences, social sciences, interdisciplinary, humanistic studies, values, traditions, quality of life]

RESUMEN. *Invasiones biológicas y dimensiones humanas: Aún necesitamos trabajar duro en nuestras perspectivas sociales.* En este artículo analizamos y desafiamos el paradigma que reduce el campo de las invasiones biológicas a sus componentes ecológicos. Para esto, revisamos trece casos de estudio agrupados dentro de tres dimensiones humanas principales (valores, tradiciones y calidad de vida) para mostrar cómo las invasiones biológicas se entretajan e interactúan con ellas. El grupo de dimensiones humanas que exploramos en este trabajo, aunque pequeño, expone un rico espectro de sinergias interdisciplinarias entre las ciencias naturales y sociales que deberían recibir más atención para hacer que el campo de las invasiones biológicas sea más sólido y socialmente integrado.

[Palabras clave: ciencias naturales, ciencias sociales, interdisciplinario, estudios humanísticos, valores, tradiciones, calidad de vida]

INTRODUCTION

Naturalists from around the world were historically intrigued about the human-assisted introduction and dispersal of species worldwide. In Argentina, for instance, Carlos Berg made early records of an impressive number of non-native species of plants he called 'transmarine' because they arrived from Europe through the port of Buenos Aires, from where they were rapidly transported by carts inadvertently mixed with the cargo and goods along 2000 km and become established and widespread across the southernmost end of Patagonia (Berg 1877). Berg, among others, was dazed by the idea that non-native species could reshape these remote landscapes before any scientist could get to know them as they originally were, which would lead to long lasting misperception of what was native there (Bortolus et al. 2015). Over the following century, observations like Berg's had accumulated around the globe, eventually leading to the emergence of a new scientific field encompassing the study of biological invasions, for which experts consider the

book *The Ecology of Invasions by Animals and Plants*, by Charles Elton (1958), its cornerstone (Richardson 2011; Simberloff 2011a). Since the publication of Elton's book, the pioneering role of biologists and ecologists, combined with their overwhelming rate of publication, have made of ecology the dominating field creating the concepts, hypotheses, and theoretical frameworks that shaped the language, storyscapes, and procedures concerning the study of biological invasions worldwide (Anderson 2009; Vaz et al. 2017; Kapitzka et al. 2019). This predominance has been sustained over time not only in terms of the number of books, book chapters, and research articles published, but also in terms of the number of publishing journals fully devoted to the topic, the number of editorial staff members in specialized journals, and the number of scientific meetings, conferences, and workshops organized to specifically debate about biological invasion problems. However, since the relevance and the impacts of the biological invasions are culturally shaped and interpreted by using different

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human perceptions and perspectives (Tassin and Kull 2015), they require insight from other disciplines, specifically from the social sciences.

The term 'human dimensions' covers a broad set of ideas and practices, including not only social values, traditions, and quality of life, but also economic values, individual and social behavior, public involvement in management decision making, and communication, among others (Decker et al. 2001). Here we explore a set of thirteen case studies grouped within three major human dimensions (values, traditions, and quality of life) shared by cultures and societies worldwide, to show how biological invasions interwove and interact with them. The human dimensions we explore in this work, expose a rich spectrum of interdisciplinary synergies between natural and social sciences that will help to expand the field of biological invasions and make it more socially integrated.

Values: Six case studies related to individual and collective human values

Empowerment and international influence. The ancestral fascination for non-native flora and fauna has historically led humans to look for them and use them as symbols of domination and power. Human history shows that non-native species have often been a source of power and influence. Emperors and kings from Europe to Asia proudly showed their panthers, lions, elephants and polar bears in their palaces, personal zoos, parades and parties, while their royal gardens and greenhouses were full of stunning plant specimens collected in their newest and most remote domains (Hughes 2003). These non-native animals and plants became a symbol of power and wealth (Figure 1a). The farther and more inaccessible their provenance was, the greater the power associated with its possessor. For centuries, early rulers sent many thousands of professional hunters and trappers to scout distant lands and bring non-native creatures for them to show privately and in public as a display of power (Hughes 2003; Martín-Forés 2017). Even characters like the infamous criminal Pablo Escobar understood the importance of displaying non-native species. Escobar, once considered the third richest person on Earth, illegally introduced non-native animals in Colombia to be displayed in a private zoo in order to strengthen his reputation as a great smuggler

(Jaramillo 2017). Also, museums and academic institutions commonly increase their prestige by growing their scientific collections of living and dead animals and plants from remote places and ages (Novacek and Goldberg 2013). Currently, the number of non-native species that managed to escape from these institutions and became invasive across non-native regions remains uncertain. However, having non-native species from remote regions is commonly perceived as a badge of quality not only for museums and educational institutions but also for pet and aquarium stores. Indeed, the psychological fundamentals of this ancient human fascination for non-local flora and fauna might be the key to understanding the transcultural nature of the biological invasions problem.

Urban art and social communication. While art can influence people's ideas, social perception and actions, biological invasions can influence artists' work. In fact, over the past few decades, the problem of biological invasions has impregnated urban cultures and countercultures across the world. For instance, in 2004, researchers found non-native barnacles colonizing different traffic signs and the walls and roof of an old building in Puerto Madryn (Patagonia, Argentina). This unusual event was the work of a young street artist making a dramatic representation of the sea influence in the everyday life of Patagonian coastal cities. For this urban intervention, the artist collected thousands of intertidal barnacles of the species *Balanus glandula*, native to the Pacific coast of North America and first detected in Southern South America circa 1970. This species is currently expanding its distribution across the region where it forms small reefs on top of native mussels and marsh plants, showing a fascinating display of ecological plasticity never recorded before (Orensanz et al. 2002; Schwindt et al. 2009, 2018). Aware of the positive impact the artistic intervention had on local people and visitors, local scientists started using it as an outreach tool to engage society concerning biological invasions. In a similar vein, music has also been used to communicate and influence people's ideas, perceptions and actions. Environmental communication specialist Bret Shaw (University of Wisconsin-Madison), worked with a group of singers and songwriters to explore how music can help to prevent the spread of aquatic invasive species. In association with the Wisconsin Lakes Partnership and the University of Wisconsin

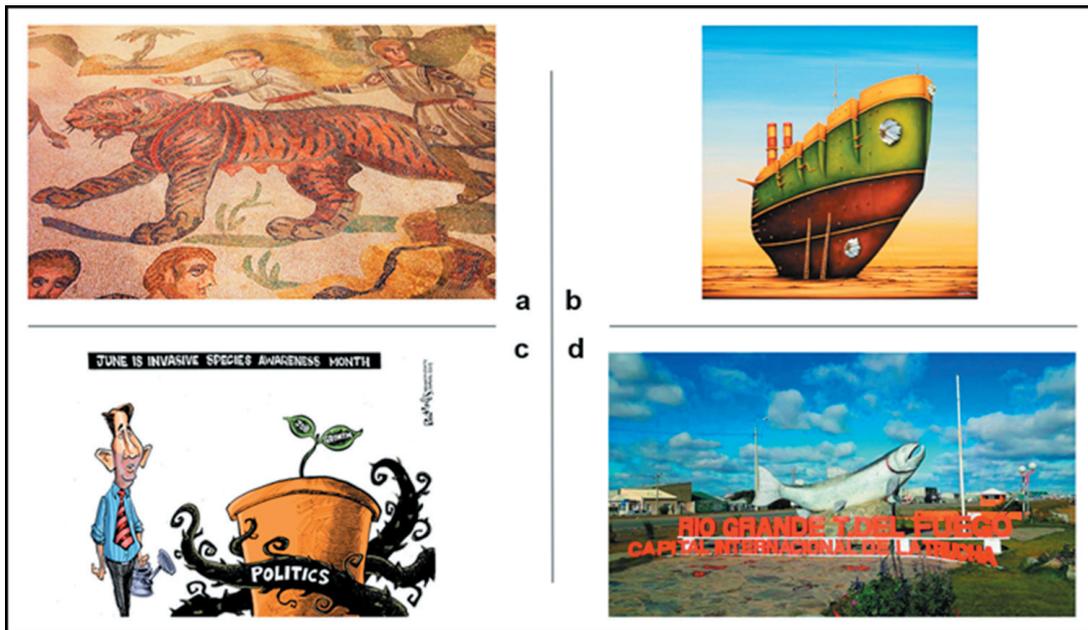


Figure 1. Examples of the cultural and social importance of non-native species worldwide and across human history. a) The mosaics of Casale, Italy, symbolize the power of the Roman empire by depicting scenes of the hunt, capture and transport of non-native animals from several continents to the Roman ports from where caged beasts were later distributed to different palaces, circuses and public *venationes* (Pensabene and Gallochio 2011; Venturo 2020; image credit: wikiwand.com/en/Villa_Romana_del_Casale). b) The renowned artist Yagui depicts a cargo ship grounded in the middle of a Patagonia desert with invasive acorn barnacles *Balanus glandula* to symbolize the links between marine and continental life. c) The problem of biological invasions becomes a friendly heuristic tool for many social communicators trying to call people’s attention on a variety of crucial social issues (cartoon credit: Phil Hands 2013 for the Wisconsin State Journal). d) Non-native species are commonly depicted in monuments and emblematic of many cities worldwide to encourage tourist affluence and boost commercial activities. The monument in this photo celebrates Río Grande city, in Tierra del Fuego, as “the international capital of trout”, more than a century after the introduction of this non-native fish.

Figura 1. Ejemplos de la relevancia cultural y social de las especies no nativas en el mundo y a través de la historia. a) Los mosaicos de Casale, Italia, simbolizan el poder del Imperio Romano con escenas de caza, captura y transporte de animales no nativos desde todos los continentes a los puertos de Roma, desde donde los animales enjaulados eran llevados a diferentes lugares del imperio. (Pensabene and Gallochio 2011; Venturo 2020; crédito de la imagen: wikiwand.com/en/Villa_Romana_del_Casale). b) Cuadro del artista plástico Yagui muestra un barco de carga encallado en el desierto patagónico con cirrípedos de la especie invasora *Balanus glandula* originaria de las costas de Norte América simbolizando la relación entre ambientes marinos y continentales. c) El problema de las invasiones biológicas es utilizado como una herramienta de comunicación social para referirse a diversos temas dentro y fuera de la biología (créditos de la caricatura: Phil Hands 2013 para el Wisconsin State Journal). d) Las especies no nativas son comúnmente representadas en monumentos y emblemas icónicos de diferentes ciudades en el mundo entero para alentar la actividad turística e incentivar el comercio local. La foto muestra un monumento celebrando a la ciudad de Río Grande, Tierra del Fuego como la “capital internacional de la trucha”, donde estos animales fueron introducidos hace más de un siglo.

Extension, Shaw’s project (erc.cals.wisc.edu/music) engaged local singers and songwriters (Scott Gatzke, Ella Shaw, Andrew Isham and James T. Spartz) to compose folk songs that remind listeners about the importance of cleaning boats when moving among bodies of water to keep Wisconsin’s waters free of invasive species. These songs are currently posted on social networks for people to enjoy while learning about invasive species. Similarly, marine biological invasions had inspired the Patagonian painter Yagui (Instagram: @Yaguiart) to join efforts with expert scientists to hold a Sci-Art exhibition

at the Patagonian Museum of Modern Art that integrated paintings and storytelling sections strengthening the outreach initiatives organized around the Xth International Conference on Marine Bioinvasions (Bortolus and Schwindt 2018) (Figure 1b). Since many art forms are devoid of any written or spoken language, they have tremendous potential to convey scientific ideas free from the drawbacks associated with the use of one particular working language (see Bortolus 2012). This potential for alternative communications, however, remains considerably unattended and underutilized.

Ethics and moral. Dealing with the problem of biological invasions requires the existence of solid well-coordinated ethics protocols, especially when international teams from societies with different backgrounds and socioeconomic realities are involved. The study of biological invasions often posits ethical dilemmas (Fall 2017; Simberloff 2003; Tassin and Kull 2015), including those originated in the misconception that humans are an invasive species, to name one (Simberloff 2011b; Alyokhin 2011; Lerdau and Wickham 2011; Simberloff et al. 2011). For instance, many societies have experienced some degree of internal conflict and social turmoil triggered by the potential implementation of management strategies that include the mass killing of animal and plants by poisoning, shooting and/or causing them lethal stress (Goldson et al. 2015; Olszańska et al. 2016). The implementation of these strategies tends to revive the biophilic emotions humans have toward other living organisms (Wilson 1984).

Although most people respond positively or indifferently to the killing of small insects, rats and weeds, there is strong resistance to targeting large organisms like cats, dogs, beavers, rabbits or birds to name a few (Horvath et al. 2013; Drinkwater et al. 2019). The aversion against this sort of killing strategy increases even more when the killing method is perceived as cruel, from an anthropocentric point of view and, in turn, decreases people's support for decision-makers and for the policies they intend to enforce (Jarić et al. 2020). Another controversial method, from the ethical point of view, implies the introduction of non-native species as biological control with the specific purpose of selectively killing, preying upon or somehow exterminating another non-native species targeted as invasive, dangerous, or noxious in any way (Delfosse 2005; Messing and Wright 2006; Hajek et al. 2016). Although strategies involving the biological control of invasive plants might be perceived as safe, cost-effective and environmentally benign (Clewley et al. 2012; Hinz et al. 2020), the lack of sound studies focusing on different invasive plants and animals in freshwater and marine ecosystems, and the potentiality for negative impacts there have often led experts to discourage this practice and to advocate for the design of well-coordinated regulatory frameworks before any biological control is considered (Messing and Wright 2006). In

a different vein, some of the methods and strategies used to control invasive species may transgress basic human rights, for example, when children from poor and racial minorities are found to experience disproportionately higher exposure than any other demographic group to toxic herbicides during invasive plants sprayings in rural areas (Norgaard 2007; Vales 2008). The issues in this section highlight the importance of having ethical protocols that help scientists to address the problem more properly, and decision-makers to better serve stakeholders and their societies.

Public perception and community-building capacity. When invasive species are perceived as a threat, they often inspire a valued sense of union and collaboration among the people trying to solve the problem (Shackleton et al. 2019). This social reaction to adversity has fueled the creation of groups of volunteers worldwide devoted, for instance, to uproot invasive species like the pampas grass in Spain, or the honeysuckle shrubs and *Phragmites* grass from local wetlands in Michigan (USA), etc. It also facilitates initiatives like the Invasive Paper Project led by artist educator Megan Heeres (bit.ly/2ZLLs3q), which encouraged people to transform the increasing pile of unwanted invasive shrubs and grasses collected by volunteers into colorful artisanal paper. Learning the paper-making process strengthens the bonds among people in the community and makes them revalue natural resources and their possible uses, including the invasive species. Initiatives like Invasive Paper Project not only take advantage of new abundant free resources, but it teaches people how to think positively and how to adapt when facing irreversible environmental problems (Howard 2019). Other initiatives, like Play Clean Go (playcleango.org), Clean Drain Dry (bit.ly/3Cz5dWA), Mares Sin Exóticas (bit.ly/3277192), Habitattitude (habitattitude.net), among others, thrive worldwide as effective strategies not only to prevent unwanted environmental deterioration but also to inspire and build a positive community spirit of social cooperation and adaptation to adversity.

Gender and society. The environmental changes caused by biological invasions can deepen social inequalities and social injustice. There are unsuspected links between gender roles in society and the study of invasive species (Terefe et al. 2020 and citations therein), especially in countries experiencing strong gender inequality (Lambrecht et al. 2018). For instance, in Ethiopia, since the

thorny bush *Prosopis juliflora* (native to Mexico) was introduced in 1999, it started replacing native pastures people used to feed their cattle, as well as some native trees used for house construction (Terefe et al. 2020). This ecological change has direct repercussions on the low-income population, but specifically on women. The sharp *Prosopis* thorns cause injuries to local women who are traditionally engaged in collecting fuelwood, while the displacement of native trees increases their work burden by forcing them to travel greater distances to collect building materials, which is also one of the traditional women's responsibilities. In addition, the decline in pasture negatively impacts the production and sale of milk and butter, which are under the exclusive control of women while men get exclusive benefits from selling charcoal made with the *Prosopis* collected by women. Although gender inequity precedes the introduction of *Prosopis*, it has worsened considerably by interacting with the new ecological scenario. The South American shrub *Parthenium hysterophorus* was also accidentally introduced to Ethiopia circa 1980 through aid shipments and, given that it is highly allergenic, it causes severe respiratory and dermatological reactions in humans and animals. Research showed that since women are responsible for weeding activities, they are more exposed to this sort of health problem than men (Terefe et al. 2020). In addition, livestock feeding on *Parthenium* plants produces tainted milk, which has a direct negative impact on women's profits. There are many cases where the effects of invasive species are perceived and experienced differently by women and men, and where the design of gender-sensitive approaches focused on traditional gender roles will help solve profound social problems along with the management of invasive species (e.g., Kleitou et al. 2019). Nevertheless, the links between gender and biological invasions remain as intriguing and complex as poorly understood.

Religious and spiritual practices. Religion and science are major social forces that do not segregate each other *per se* as commonly believed (see Dobzhansky 1973; Wilson 1998), and they often interact synergistically to solve a variety of problems that afflict modern societies. For example, for many years Buddhists and Taoists have practiced the 'prayer animal release' tradition during which captive wildlife is released as a demonstration of compassion and kindness. Originally,

this practice used to involve only common farm/house animals. However, the current increasing number of believers worldwide has favored the growth of a very specific kind of social scenario in which thousands of birds, fish, monkeys, reptiles, frogs and insects are purchased in pet markets to be then released into the wild, turning the 'prayer animal release' practice into a potential pathway to introduce species in their non-native environments (Severinghaus and Chi 1999; Everard et al. 2019). That was the case of the red-eared Brazil turtle (*Trachemys scripta*), which is now one of the most abundant invasive turtles in Taiwan; and also, the American bullfrog (*Lithobates catesbeianus*), listed among the 100 worst invasive species, which has become invasive after repeated introductions in water bodies of the Yunnan province of China through this religious practice (Awoyemi et al. 2016). However, the strong desire of Buddhists to do no harm led to the acceptance of new scientific knowledge that prevents believers from creating environmental pollution and ecological disruptions associated with invasive species (Liu et al. 2013). Efforts are currently directed to increase environmental responsibility and to reinforce the education about invasive species within religious groups willing to adapt their spiritual practices to current environmental concerns. Similar cooperation between scientists and religious groups occurs worldwide. In South Africa, for instance, religious organizations created an innovative project in which people manufacture affordable coffins made of invasive tree species in coordination with the growth of indigenous plants used for the restoration of invaded sites (Awoyemi et al. 2012). Examples like these show how biological invasions provide unexpected scenarios where religion and science meet, assist each other, and co-evolve. A better understanding of these interactions is not only interesting but socially unifying and constructive.

Traditions: Three case studies related to cultural development and identity

Flavors and taste. While people's culinary preferences are conditioned by their cultural heritage and customs, biological invasions can work as a driver for cultural change. Many of the species collected during the European exploration of the Americas were used for medicinal purposes long before they started being assimilated into everyday culinary tastes across Europe and Asia (Sharma 2012).

However, changing local traditions is usually a slow process. It took centuries, for instance, until the potato was finally accepted and embraced as one of the most common foods outside the Americas. Nevertheless, as the transport and introduction of non-native species worldwide increase (Seebens et al. 2017; Bailey et al. 2020), the speed at which the associated traditions will change is also likely to increase. Currently, chefs of the 'haute cuisine', and their restaurants, attract their customers with sophisticated menus planned to make people feel they are not only enjoying new flavors but also 'saving nature' by fighting back against invasive species. Within this context, every time customers eat Indo-Pacific lionfish (*Pterois* spp.) in the Caribbean, Japanese oysters (*Crassostrea* [= *Magallana*] *gigas*) in France, European red deer (*Cervus elaphus*) in Patagonia, Pacific salmon (*Oncorhynchus tshawytscha*) along the Atlantic coast or the Wakame algae (*Undaria pinnatifida*), pretty much anywhere worldwide, they feel like they are winning an environmentalist battle, regardless of the true origin of the specimens they eat (wild or farmed) or if this 'invasivory' is even a successful method to control invasive species or not (Snyder 2017). The pioneer initiative Eat The Invaders (eattheinvaders.org) is widely known through its social networks and scholarly publications and has inspired the Reef Environmental Education Foundation to publish a cookbook encouraging people to have non-native lionfish as a convenient option for dinner (Ferguson and Akins 2010). Despite the fact that experts have often suggested that the practice of 'invasivory' will not control biological invasions (Núñez et al. 2012; Pasko and Goldberg 2014), non-native species continue to be served as culinary delicacies in many countries. Although invalid as a management tool, the 'invasivory' seems a valuable initiative to help raise awareness by providing a creative environment where people are encouraged to reflect about biological invasions and invasive species.

Human dispersal history and cultural development. Invasive species are traces of past human presence, and the study of biological invasions has changed the way we understand the global dispersal of humans and their cultures (Anderson 2009; Hofman and Rick 2018). In the mid-19th century, pioneer botanists of Argentina were able to identify the geographic origin of the immigrants around the harbor of Buenos Aires by watching what

species they grew in their gardens. Currently, it is widely accepted that by studying the historical ecology and introduction pathways of different species, archeologists and anthropologists can reconstruct the human behavior, migration routes and trade networks operating in ancient civilizations (Hofman and Rick 2018 and citations therein). For instance, the presence of non-native domesticated plants and animals and their commensal species (including invertebrates and infectious microorganisms) marked the arrival of cultivators to Mediterranean islands some 10600 years ago along the North Atlantic, from Scandinavia to North America, during the Viking Age (Vigne et al. 2012; McGovern et al. 2007) and across Polynesia circa 3000 years before European contact (Matisoo-Smith 2009; Prebble and Wilmshurst 2009). By understanding the movements of commensal species associated with prehistoric human migrations, it is possible to distinguish the intentional from the unintentional introduction of species (Matisoo-Smith 2009), which in turns helps to understand how humans' power to transform the environment interacts with cultural development worldwide.

Tradition and cultural identity. Many aspects of what people perceive and treasure as their national identity are actually built upon, or based on, elements originated in distant regions and foreign cultures. Often, animal and plant species widely considered traditional symbols of national identity may not even be native. One example is the tea plant *Camellia sinensis* native to Southeast Asia, where it has been an important feature of China cultural identity for millennia (Sigley 2015). After centuries of massive importation to the UK, the tea became an iconic symbol of British customs and cultural identity (Rose 2010). By 1999, the first tea plants were introduced and farmed in England (The Guardian 2013), in part due to "publicity campaigns [...] intended to show that tea [...] was not foreign, but also British" (Sharma 2012). There are other cases that show non-native species being inadvertently assimilated by distant cultures. For instance, in Southern South America, the presence of non-native cardoons like *Cynara cardunculus* has caught the attention of famous naturalists for centuries. Charles Darwin wrote "I doubt whether any case is on record of an invasion on so grand a scale of one plant over the aborigines" (Darwin 1878, p. 119). However, even today, few local people know these plants were introduced by early European

travelers, before they became adopted by native people, Spaniards, and Argentinians as food and a source of medicine (Gutiérrez et al. 2020). Currently, the spiny flowers of these cardoons are so blended into local culture that they appear represented in traditional folkloric clothing including gaucho 'rastras' buckles, and other identity-defining ornaments. Also, traditional pieces of music and poetry have been dedicated to cardoon species, specifically to symbolize the resilient endurance of the early Argentinian people. The importance of these species in building local identity is such that many towns, estancias, commercial establishments and companies are currently named after them, while several governmental shields, flags and even important presidential symbols like the presidential baton, depict their flowers as a proud symbol of national identity. Other examples include the Pacific salmon along the Atlantic coast of Tierra del Fuego, the European red deer and the wild boar in northern Patagonia, as non-native species adopted as a symbol of local identity. However, while these species contributed to the consolidation of local cultural identities, some invasive species have done the opposite. This is the case of some invasive species of salmon negatively affecting native species that were deeply associated with the religion and cultural identity of several tribes in North America (Pfeiffer and Voeks 2008). In a similar vein, the invasive alga *Undaria pinnatifida* modified coastal ecosystems that were historically tied to the Maori cultural identity (Pfeiffer and Voeks 2008). In cases like these, managing biological invasions might imply redefining the traditions and cultural identities of entire nations. Although there are many commercial, political, and aesthetic reasons why a non-native species becomes assimilated into local cultures (Figure 1a-d) (e.g., Lambertucci and Speziale 2011; Núñez et al. 2018), the consequences of such assimilation remain largely unattended.

Quality of life: Four case studies related to people's perception of reality, subsistence and biosecurity

Perception of reality. The capacity to perceive reality in concordance with the rest of society is among the most treasured attributes of a healthy person. However, the perception that something, ranging from a species to a landscape is native, will be critically conditioned by the extent of our knowledge about it and its historical records. Led by

intuition, people from different cultures and regions worldwide tend to believe they are capable of recognizing, or somehow detecting any new (i.e., non-native) species appearing in the landscapes they live in (Campbell et al. 2017). However, biological invasions constantly challenge our ability to perceive Nature. The Ecological Mirage Hypothesis proposes that even landscapes deeply associated with our life, our cultural identity, our religion, or our history, might not be as pristine as we were led to perceive and/or believe (Bortolus et al. 2015). For instance, the unnoticed introduction of the cordgrass *Spartina alterniflora* is believed to have driven radical ecosystem shifts from mudflats to salt marshes and coastal grasslands along the Atlantic coast of South America (Bortolus et al. 2015; Bortolus et al. 2019). Over a period of approximately 200 years, this invasive cordgrass seems to have created what is currently considered one of the more emblematic and protected native landscapes in the Americas. In a similar vein, many cases of cryptic invasions worldwide have changed our perception of nature (Morais and Reichard 2018), including, for instance, the incorporation of non-native species in prestigious native species lists (see Gerlach et al. 2009). Charles Darwin (1878) elucidated how native South American landscapes might have transformed over time after the introduction of non-native species by Europeans, altering the very perception of what later was considered native: "... since the year 1535 [...] countless herds of horses, cattle, and sheep, not only have altered the whole aspect of the vegetation, but they have almost banished the guanaco, deer, and ostrich. Numberless other changes must likewise have taken place; the wild pig in some parts probably replaces the peccari; packs of wild dogs may be heard howling on the wooded banks of the less frequented streams; and the common cat, altered into a large and fierce animal, inhabits rocky hills. As M. d'Orbigny has remarked, the increase in numbers of the carrion vulture, since the introduction of the domestic animals, must have been infinitely great; and we have given reasons for believing that they have extended their southern range. No doubt many plants, besides the cardoon and fennel, are naturalized; thus the islands near the mouth of the Parana, are thickly clothed with peach and orange trees, springing from seeds carried there by the waters of the river." [sic] (Darwin 1878; p. 120). Indeed, it is unclear how much biological invasions have

altered our perception of reality, and how the new perceptions have interacted with modern societies, our values, customs and actions.

Subsistence. Throughout history, humans have always transported species across immense distances to ensure their subsistence during migrations. For thousands of years, during forced migrations (e.g., fleeing from ethnic/religious persecution/annihilation, starvation, wars or epidemics), people commonly transported items from their homelands, including seeds and all sorts of propagules of plants and animals to sustain not only their physical needs but also the spiritual (Heinsohn 2003). For instance, it was imperative for these people to bring everything necessary to make the unguents, oils, paints and drinks they needed to perform religious rituals. Some of these essential seeds, animals and plants were, in turn, associated with fungi, micro and macro parasites, predators, commensal and symbionts sharing their geographic origin (Matisoo-Smith 2009; Santini et al. 2018). Apart from their physical and spiritual needs, humans have also shown a historical impulse to pursue economic improvement by transporting species to grow them and exploit them commercially during their journey. However, these initiatives often had counterproductive consequences. In the 15th century, for instance, European rabbits introduced with commercial purposes drove places like the Porto Santo island and Australia, from a “virgin” [sic] state to one where “men could sow nothing that was not destroyed by them” and where they “ate not only the crops but just about everything gnawable”, often bringing native species to extinction (see Crosby 2009). Besides migration and commercial greed, the trading of flora and fauna is highly valued as a component of subsistence economies intended to help small social groups worldwide in overcoming difficult economic periods (Carrete and Tella 2008; García-Díaz et al. 2015; Lockwood et al. 2019; Westphal et al. 2008). Nevertheless, the benefits of practicing a subsistence economy in one region may turn negative for the recipient societies, especially when the exchange is made among regions with strongly asymmetric development of legal environmental regulations (Patoka et al. 2018; Peres et al. 2018).

Biosecurity and homeland security. Bioterrorism implies the dispersal of deadly organisms, including non-native pathogens, with the

purpose of creating a dramatic impact on major water sources (like glaciers, underground basins, rivers, lakes and water reservoirs) or the agricultural economy of food-producing countries (Chomel and Sun 2010). Over the last century alone, there were more than a dozen records involving the intentional introduction of microbiological agents into livestock and other animal populations, leading to millionaire losses and directly threatening human welfare (Chomel and Sun 2010). Even the COVID-19 pandemic was a matter of suspiciousness concerning the origin of the SARS-CoV-2 virus and its potential use as a biological weapon (Wikipedia review accessed 8/19/20: bit.ly/3gc3ZVs). However, although there is vast evidence that venomous and poisonous species threatening human health are being transported and introduced worldwide (Bédry et al. 2021), we know little about the potential involvement of most of them in planned biosecurity issues. Moreover, as long as collectors and enthusiasts worldwide keep financing the illegal collection, smuggling and trading of non-native species, independently of their conservation status or their invasive habits, complex criminal networks will continue to grow along with the commercial profit (Meyerson and Reaser 2003). The global scale of this problem, its legal complexity (Black and Bartlett 2020) and the way it is interwoven with the daily lives in societies around the world, make dealing with this problem extremely challenging even for interdisciplinary research teams.

Human health and wellbeing. Biological invasions certainly have direct and indirect impacts on the health and wellbeing of humans in a variety of ways. The venomous sea slug *Pleurobranchaea maculata* and lionfishes of the genus *Pterois*, along with the red-tide forming dinoflagellates of the genus *Alexandrium*, are conspicuous examples of invasive species introduced in many regions worldwide, where they are considered a direct threat to human health (Carreto et al. 2004; Galil 2018; Farias et al. 2019). In addition, epidemiological research has warned us about many other invasive species that, after being transported and introduced by humans, caused or mediated the occurrence of human mass death over a short period of time. For instance, the virus of yellow fever was repeatedly introduced in the Americas by the transatlantic slave trade, causing epidemic outbreaks between the 15th and the 19th centuries along the Atlantic coast of North America, triggered by

the introduction of its vector, the mosquito *Aedes aegypti* (Lounibos 2002). Interestingly, these epidemics were largely favored by the creation of habitats suitable for mosquitoes in the plantations of the also non-native sugarcane (McNeill 2004). In the early 20th century, at least three epidemics of malaria were recorded across tropical South America following the transport, introduction and local spread of the African malaria vector *Anopheles gambiae* (Lounibos 2002). The first pandemic of cholera (*Vibrio cholerae*) recorded in human history started in the Ganges River delta, India, and spread countrywide in the early 19th century. Active human exchange and constant commercial activities facilitated the fast large-scale spread of the disease by introducing the infectious bacteria to Southeast Asia, Central Asia, the Middle East, eastern Africa, and the Mediterranean coast in a matter of decades (McGrew 1960). Researchers estimated hundreds of thousands of human deaths across all India, and one hundred thousand in the Indonesian island of Java alone (CBC 2008). Since then, there have been six more pandemics of cholera, always mediated by human exchange and/or commercial activities (Maguiña Vargas et al. 2010). The last one started in 2010 when a Nepalese UN peacekeeper team accidentally introduced an aggressive strain of *V. cholera* while visiting Haiti for humanitarian assistance after a 7.0 magnitude earthquake hit the country, killing over 200,000 people (Chin et al. 2011; Frerichs et al. 2012). Like they did with the yellow fever events, epidemiologists tracked the exact origin of the cholera strain introduced in Haiti by applying the same logic used in the study of biological invasions. In 1894, a pandemic outbreak of bubonic plague started in Chinese port cities from where the disease spread to India, Australia and the Americas by introducing infected Norway rats transported by sailing ships or freight vessels along with the flea vector of the plague bacillus (Lounibos 2002). Unlike bacteria and many other taxa, viruses are not formally described as species, however, they can certainly be addressed as invasive species (Schwindt et al. 2018; Núñez et al. 2020). It is clear that not all non-native species become invasive and not all invasive species have a direct negative impact on human health and wellbeing. However, these examples show that it could take one species not only to affect human health but also to entirely reshape the global geopolitical map in a relatively short period of time.

DISCUSSION

Our work advocates for a better integration between the social sciences and the natural sciences to promote radical advances in the way we deal with biological invasions, so frequently reduced to their ecological components by scientists, environmental managers, policymakers and lay people. To achieve this goal, the study of biological invasions needs to improve its intersections with disciplines outside the natural sciences in a way that their backgrounds, perspectives and thinking structures merge and help building more solid frameworks that broadens our understanding of the human dimensions and contexts involved (Shackleton et al. 2019). The set of human dimensions we explored with our case studies, exposes a diverse spectrum of relationships with different stages of the invasion process and many potential synergistic interactions that should contribute to expand the field of biological invasions and our understanding of its social and cultural repercussions (Table 1). The medical, mathematics and computational research have indeed contributed to the study of biological invasions with perspectives, hypotheses and tools developed, for instance, in epidemiology, modeling, satellite imaging or machine learning. The social sciences remain less integrated (Shackleton et al. 2019), and when they are considered, it is often with some kind of ecological perspective (Vaz et al. 2017; Kapitza et al. 2019). However, it is important that the contributing fields remain independent in their perspectives and methods to ensure an objective testing of the ecological hypotheses, reasoning and paradigms (Kapitza et al. 2019). The cultural reinterpretation of the Keystone Species concept (Garibaldi and Turner 2004), the evaluation of human adaptations to invasive species (Howard 2019; Thornton et al. 2019) and the exploration of the dynamics of research collaborations in biological invasions (Abrahams et al. 2019) are inspiring examples of independent analysis. However, important fields of knowledge, including the psychological fundamentals of the human perceptions, values, emotions and common behaviors associated with the transport and introduction of non-native species worldwide remain underattended. How do humans from different cultures and contrasting socioeconomic realities deal with the moral dilemmas associated with the introduction of potentially invasive

Table 1. Human dimensions and case studies discussed in the text and the relationship within the context of biological invasions. In the last column are different proposals of synergies between natural and social sciences related to the knowledge, management and policies of biological invasions.

Tabla 1. Dimensiones humanas y casos de estudio discutidos en el texto, y la relación dentro del contexto de las invasiones biológicas. En la última columna se encuentran diferentes propuestas de sinergias entre las ciencias naturales y sociales relacionadas al conocimiento, manejo y políticas de las invasiones biológicas.

Human dimension	Case study	Relation within the context of biological invasions	Synergies between natural and social sciences
Values	Empowerment and international influence	Species introduction	Strengthening the design and implementation of prevention strategies and policies by understanding the fundamentals of the human fascination for non-native flora and fauna
	Urban art and social communication	Non-native species awareness	Collaborating in the understanding of people's perceptions of non-native species to improve communication across different social sectors
	Ethics and moral	Invasive species control	Cooperating to improve ethic protocols to manage non-native species in many social contexts
	Public Perception and Community-building capacity	Non-native species awareness	Identifying key actors and enhancing the communication across different social sectors to optimize community actions and positive attitudes
	Gender and society	Invasive species impact and management	Engaging and linking stakeholders, indigenous peoples and other local communities to improve gender equity and equality during commonly agreed management strategies
	Religious and spiritual practices	Species introduction, propagule pressure and management	Collaborating to create and improve management alternatives and solutions that integrate religion and science
	Flavors and taste	Non-native species awareness	Strengthening the communication with different social sectors about the risks of invasive species and the importance of management actions
Traditions	Human dispersal history and cultural development	Species introduction and dispersal	Strengthening the knowledge and understanding of the links between historical ecology, social sciences and the drivers of biological invasions
	Tradition and cultural identity	Species introduction and dispersal	Strengthening the links between historical ecology and social sciences to improve the understanding of local storyscapes and their relationship with records of biological invasions across time
Quality of life	Perception of reality	All contexts of biological invasions are related to the case study	Engaging all community sectors to improve communication and management strategies with perspectives that work not only at present time but across different time frames and space scales
	Subsistence	Species introduction	Cooperating in the articulation of local and international policies and other instruments to prevent species introductions
	Biosecurity and homeland security	Species introduction	Strengthening the articulation of national and international policies to prevent species introductions
	Human health and wellbeing	Species introduction and dispersal	Optimizing and collaborating with the coordination of public policies involved in awareness and vector management

non-native species? What motivates people worldwide to keep transporting, exchanging and introducing potentially harmful invasive species regardless of existent legal regulations and the potential consequences? Should the

introduction of invasive species be equally punishable when motivated by subsistence needs and by commercial greed? Under what circumstance should the introduction of non-native species be addressed as a crime? Can

non-native species be legally considered as weapons during wartime? These are some of the many questions associated with the study of biological invasions that should not be addressed from the natural sciences, unilaterally.

Researchers, and lay people, are now increasingly aware of the fact that the impact of invasive species depends on what societal values are affected (Estévez et al. 2015; Bartz and Kowarik 2019). However, many of these contextual values remain veiled, understudied and poorly integrated to current knowledge (Wilson 1998). Most syntheses articles and books in the field of biological invasions do not include anthromes (i.e., ecosystems created and maintained by human activities), as well as many of the cultural aspects associated with people's health and wellbeing (Bartz and Kowarik 2019; Howard 2019). The case studies we present in this article show that for many centuries biological invasions have played, and still play, a powerful role in shaping human cultures by interacting with our artistic expressions, welfare, politics, religion, language, non-religious but deeply spiritual activities, ethic, moral and the perception of reality, changing local ways of thinking, reshaping storyscapes and redefining cultural identities. During the last few decades, the debates about biological invasions have led to the creation of international networks (Schwindt and Bortolus 2017; Díaz et al. 2019) some of which are currently in a great position to catalyze transcultural interactions with transformative power. So far, social science research focused on biological invasions is mostly directed to document the diversity of perceptions of, and attitudes to, invasive species, and the different aesthetic responses among different communities, as well as the pathways for collaboration and mutual understanding between scientists and people in general (Head 2017; Vaz et al. 2017; Kapitza et al. 2019). This is of critical importance in transforming the way we perceive how human societies interact with the problem of biological invasions (Shackleton et al. 2022). Yet we need social scientists not only to expand ecological ideas but also to spearhead in areas where ecologists are unprepared or unfit to advance, strengthening the incorporation of, for instance, the indigenous peoples and local communities' knowledge in order to better understand cultural landscape changes (Archibald et al. 2020) and to effectively design management strategies through participatory

processes including the best network of stakeholders (Lubell et al. 2017). Finding the appropriate language to communicate among cultures is also of critical importance (Copp et al. 2021) and transcultural interpretations of the existing perspectives and perceptions require expert training. Many of the internal debates currently afflicting the scientific community devoted to biological invasions (e.g., disciplinary denialism [Ricciardi and Ryan 2017]; the misleading —often xenophobic— formulation of analogies with international human migratory crisis [Lambertini et al. 2011], and the impact of using emotional language [Tassin and Kull 2015], among others) are crisscrossed by culture-dependent perspectives and perceptions that would be rigorously studied and better understood from the social sciences.

Almost one and a half centuries after Berg's 'transmarine species' and more than sixty years after the publication of the book *The Ecology of Invasions by Animals and Plants*, by Charles Elton (1958), many nations worldwide keep struggling to design and implement internationally coordinated strategies to address the problem of biological invasions effectively (Schwindt and Bortolus 2017; Schwindt et al. 2020; Hulme 2021). Solving this conundrum will require a better understanding of the different cultural and social contexts in which biological invasions are considered and analyzed. We can no longer ignore how profoundly and rapidly biological invasions affect the different human dimensions and how poorly our societies deal with that intersection (Howard 2019). We need to better recognize the bounds shared by disciplines that currently lack fluent interaction and work on common challenges, including the identification of working languages and the unification of key concepts. In a time when human societies seem committed to make transformative changes across continents to solve humanitarian problems (Díaz et al. 2015; Díaz et al. 2019), the study of biological invasions emerges as an attractive platform in which different disciplines and stakeholders and indigenous peoples and local communities, can find common ground for agreement and progress.

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