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A review of the critics of invasion biology

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ABSTRACT

Herein, I review existing criticisms of the field of invasion biology. Firstly, I identifiy problems of conceptual weaknesses, including disagreements regarding: (*i*) definitions of invasive, impact, and pristine conditions, and (*ii*) ecological assumptions such as species equilibrium, niche saturation, and climax communities. Secondly, I discuss methodological problems include the misuse of correlations, biases in impact reviews and risk assessment, and difficulties in predicting the effects of species introductions or eradications. Finally, I analyse the social conflict regarding invasive species management and differences in moral and philosophical foundations. I discuss the recent emergence of alternatives to traditional invasion biology approaches, including the concept of novel ecosystems, conciliation biology, and compassionate conservation. Understanding different value systems will be the first step to reconciling the different perspectives related to this controversial topic.

Key words: exotic species, conservation biology, ethics, biological introductions, native species

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I. INTRODUCTION

Invasion biology is a young discipline that developed into an independent field in the 1980s (Davis & Chew, 2017). Since its inception, invasion biology has focused on three primary research areas: (*i*) establishing which genetic, physiological, or behavioural traits characterize invaders; (*ii*) analysing the invasion process, primarily using models; and (*iii*) estimating the impacts of invasive species on native species and ecosystem processes (Hengeveld, 1994). Invasion biology also includes a management aspect that consists of designing and implementing strategies to control species that have been identified as invasive.

In recent years, an ongoing broad debate surrounding the biology of invasions has 'created an intellectually dynamic and sometimes emotionally charged atmosphere' (Davis, 2006, p. 35). The growth of academic and societal attention paid to invasive species, their impacts, and their control has been accompanied by frequent controversies and conflicts surrounding the management of invasive species and policy responses (Crowley, Hinchliffe, & Mcdonald, 2017). These often include disagreements about the existing scientific evidence and its application as well as ethical, cultural, and political differences and divergent assessments of risk (Estévez *et al.*, 2015). One of the most dramatic facets of this debate is the accusation made by some invasion biologists that those who criticize their discipline are denialists (Russell & Blackburn, 2017; Ricciardi & Ryan, 2018); Munro, Steer, & Linklater (2019) suggested that such a serious accusation could not only provoke odium but also could erode public trust in science and scientists.

Although the field of invasion biology remains a regular target of criticism, those researchers and managers who address other causes of biodiversity loss, such as habitat degradation, overexploitation, or pollution, often receive societal support (Courchamp *et al.*, 2017). The goal of this article is to review existing criticisms of the field of invasion biology and to discuss underlying reasons why this particular discipline appears to receive disapproval from society and other scientists, relative to other fields.

II. CONCEPTUAL AND THEORETICAL PROBLEMS

(1) Distinct traits of invasive species

Predicting which species are probable invaders has been a long-standing goal of invasion ecologists (Kolar & Lodge, 2001). However, the ability of invasion biology to predict invasions and their impacts has been limited (Frost *et al.*, 2019), and no general predictors of invasive ability have been established (Facon *et al.*, 2006). One hypothesis suggests that introduced species are free of natural predators and disease, thus allowing them to become super-competitors (Keane & Crawley, 2002; Callaway & Ridenour, 2004). However, the evidence supporting this hypothesis has not been conclusive (Liu & Stirling, 2006; Ordoñez, Wright, & Olff, 2010; Felker-Quinn, Schweitzer, & Bailey, 2013; Tschinkel & Wilson, 2014; Thomas & Palmer, 2015). By contrast, species that are successful appear to be successful regardless of their native or exotic status: (*i*) invasive aliens exhibit the same sets of traits as expanding, successful natives (Thomson, Hodgson & Rich, Thompson, Hodgson, & Rich, 1995); (*ii*) aliens and natives exhibit similar succession dynamics (Meiners, 2007); and (*iii*) some traits of natives in disturbed, fertile habitats were indistinguishable from those of aliens in similar habitats (Leishman, Thomson, & Cooke, 2010).

(2) When introduced species become native

Invasion biology defines being introduced by humans as a fundamental characteristic of invasive species, which differentiates this process from colonization that occurs naturally. Thus, the process of categorizing species as 'invasive' or 'native' is often difficult. When species were introduced in historical or prehistoric times, it is challenging to categorize them as exotic or native. For example, at least 157 plant species were introduced to Britain by humans between approximately 4000 BC and 500 years ago (Preston, Pearman, & Hall, 2004), and these species have been variously classified as native and/or exotic, depending on the authors (Willis & Birks, 2006).

Carthey & Banks (2012) argued that evolutionary theory predicts that alien predators cannot remain eternally novel; prey species must either become extinct or adapt to the new threat. As local enemies lose their naiveté and coexistence becomes possible, an introduced species must eventually become native. These authors discussed the example of the dingo (*Canis lupus dingo*), which was introduced to Australia approximately 4000 years ago, although its native status remains disputed.

Chew & Hamilton (2011) analysed the concept of biotic nativeness and were categorical when diagnosing the 'native' adjective as 'uninformative, even deceptive' (p. 44). Thompson & Davis (2011) took a different approach for the same problem when they suggested that with continual global changes in nutrients, climate, and disturbance regimes, all species can be considered to be inhabiting novel environments and, therefore, distinctions between native and non-native species are becoming even less ecologically meaningful.

In the modern, human-dominated landscape, an increasingly sharp distinction exists between 'winner' and 'loser' species, and this distinction may have little association with native or alien status (Thompson & Davis, 2011). Rare, restricted species are disappearing, while the common, widespread species are becoming even more abundant and widely dispersed. This phenomenon has been referred to as the homogenization or cosmopolitanization of the global biota (Brown & Sax, 2004).

(3) Including 'impact' in the definition of invasive species

Invasion biologists tend to view any environmental changes produced by non-native species as being harmful.

Sagoff (2005) suggested that if one defines any significant change caused by a non-native species as having negative impact, the statement that non-native species harm ecosystems represents a tautology. Larson, Kueffer, & Zi (2013) proposed that the term 'impact' could simply be replaced with the term 'change' or 'effect'. Facing difficulties evaluating negative impacts, some invasion biologists have proposed that the impact of a species should not be considered at all in the definition of invasiveness (Daehler, 2001; Blackburn, Pyšek, & Bacher, 2011). By contrast, Davis & Thompson (2001) argued that there are compelling conceptual and practical reasons for impact to be included in the defining criteria of an invading species.

Faced with the difficulty of demonstrating impacts of alien species, Simberloff *et al.* (2013) proposed that it must be assumed that exotic species are always dangerous for the following reasons: (*i*) species that initially appeared to be innocuous have often been found, upon closer examination, to have major impacts on one or more native species and sometimes on whole ecosystems; (*ii*) time lags can exist between species introductions and the occurrence of invasions; and (*iii*) impacts will worsen with global climate change.

(4) Species equilibrium, niche saturation, and climax communities

Invasion biology is based on several ecological assumptions and principles, which are not always explicit but must be identified in order to analyse them properly. Brown & Sax (2004) discussed the species equilibrium and niche saturation, which are major assumptions in invasion biology. According to these concepts, a given environment contains only a limited number of niches and, when the biota reaches the carrying capacity for both individuals and species, the ecosystem reaches equilibrium as a climax community [MacArthur (1972), cited by Mckinney & Lockwood, 1999]. Under this condition, the arrival and establishment of a new species will cause the extinction of a native one, such that equilibrium is recovered.

Brown & Sax (2004) described two alternative views: (*i*) one theory postulates that most locations on earth are well below their carrying capacities for both individuals and species because the present levels of abundance and diversity of life are recovering from past disturbance events; and (*ii*) the equilibrium theory of island biogeography implies that, at any given time, the number of species exists in an approximate steady state on oceanic islands and in other isolated habitats and is maintained by a balance between opposing rates of colonization and speciation on the one hand and extinction on the other.

Briggs (2014) introduced the concept of 'accommodation', which refers to the yielding of living space, indicating that a native species that occupies the preferred area will yield to or support an invader, permitting both species to become established in a location where only one species existed previously. The term 'accommodation' includes facilitation, niche sharing, niche compression, and mutualism; thus, accommodation can be applied to almost all invasions that result in colonization without the extinction of native species. Briggs (2014) concluded that exotic species that colonize native ecosystems rarely cause extinctions but, instead, are accommodated by the native species that occupy the appropriate niches or habitats. In terrestrial and marine systems (but not on islands), such diversity gains generally result in a more stable system, with higher productivity and a greater resistance to invasion (Stachowicz & Tilman, 2005; Briggs, 2010).

(5) Pristine environments

The task of invasion biology appears to be to restore pristine environments, eradicating invasive species and returning environments to the conditions found in the original ecosystems. However, it can be challenging to determine the historical state that represents pristine conditions. Hobbs *et al.* (2009) questioned how far back we should look to find the relevant environment and how we can determine the conditions of historic ecosystems. They recognized that the definitions of 'natural', 'historic', and 'altered' are rarely clear and that they are often determined in relation to cultural, national, religious, or personal experiences and values. Few instances of true historical ecosystems remain, due to the pervasiveness of direct and indirect human influences and changes in species distribution and abundance (Vitousek *et al.*, 1997; Sanderson *et al.*, 2002).

Another difficulty with the 'pristine' concept is the argument that biological invasions are a natural process that has always occurred. Briggs (2014) suggested that the palaeontological record clearly indicates the occurrence of numerous species invasions, extending from the Paleozoic through to the Cenozoic, which have resulted in adaptive radiations that significantly increased global biodiversity. Most species that have ever lived are extinct. Those that survived are more likely to be those that have been able to move (invade) as physical and biological environments changed (Thomas, 2018).

III. METHODOLOGICAL PROBLEMS

(1) Correlation *versus* causation

In the field of invasion biology, correlation studies dominate research reports (Hulme *et al.*, 2013). Although it is well known that correlation does not mean causality, numerous studies conclude that expansion of a non-native species caused the decline of native species when these two phenomena occurred simultaneously in the same locations (Gurevitch & Padilla, 2004; Davis, 2009; Thompson, 2014). However, cause and effect in correlation analyses can occur in either direction, and the observed effects may be caused by unmeasured, confounding variables (Warren *et al.*, 2017). An example is provided by the biogeographical distributions of native and exotic plant species in the British isles. Thomas & Palmer (2015) demonstrated that non-native plants did not have a negative impact on British flora at a large scale. They found that both native and introduced plants are responding predominantly to other drivers of environmental change and concluded that negative effects of alien plants have been exaggerated. Nevertheless, a disproportionate number of non-native species remain on lists of harmful British invasive species.

Experimental studies that use control treatments to test the behaviour of a system in the absence of alien species are the best tests of causality. Macdougall & Turkington (2005) were the first to propose a model that formalizes an evaluation of the difference between correlation and causality. They proposed contrasting two alternative hypotheses, called the 'driver' and 'passenger' models. In the first model, the interactive processes (e.g. inter-specific competition) are responsible for the decline of a species; therefore, an experiment that removes the non-native species should result in a direct increase of the richness and relative abundance of native species. In the second model, another variable is responsible for the decline; therefore, the eradication of non-native species should have minimal impacts. Macdougall & Turkington (2005) thus provide a rigorous method that can be used to measure the causes of population declines (Didham *et al.*, 2005; Fig. 1).

(2) Biases in impact reviews

Habitat loss is the most important threat to biodiversity at a global scale (Mazor *et al.*, 2018). Invasion biologists frequently state that the spread of alien species is the second greatest threat (see Section III.4). However, the great majority of contemporaneous extinctions caused by exotics have been confined to islands and other restricted habitats (Davis, 2003, 2009; Briggs, 2013).

Biases occur not only at a geographical scale but also in terms of species, taxa, or functional groups, which may differ significantly in their effects (Gurevitch & Padilla, 2004). Hulme *et al.* (2013) conducted the first detailed critique of quantitative field studies of alien plant impacts. They found that the approaches that have been adopted to date fail to deliver predictive and practical insights due to biases in biogeography and the life forms of the target species, the idiosyncratic choices of responses assessed, and the lack of explicit controls addressing spatial variability. Similar results have been obtained for other taxa when the evidence has been scrutinized in detail. For example, Ricciardi & Cohen (2006) tested the relationship between the invasiveness of an introduced species and its impact on native biodiversity and found no correlations between these variables for introduced plants, mammals, fishes, invertebrates, amphibians, and reptiles, suggesting that the mechanisms underlying invasion and impact are not strongly linked.

Guerin *et al.* (2018) recently discussed another typical source of bias that can be found in reviews that compare non-native and native species using meta-analyses. They found that the ability to extrapolate from these analyses is limited by selection bias towards the worst-offending invaders (as opposed to a random selection of non-native species or conditions), even when the meta-analyses themselves are objective and lead to interesting conclusions. They suggested that the conclusions drawn by these studies are only relevant to invasive species and cannot be extrapolated to diverse, non-native species assemblages or to other individual non-native species.

Another frequent source of bias in impact reviews is the unclear distinction between economic impacts and ecological impacts. Wild species of plants and animals can become pests that threaten agricultural production, damage infrastructure, and even transmit diseases to humans and domestic animals. While these costs are important and relevant, they must be clearly differentiated from costs linked to the risks of species extinction or the functioning of natural ecosystems, as they represent two different problems.

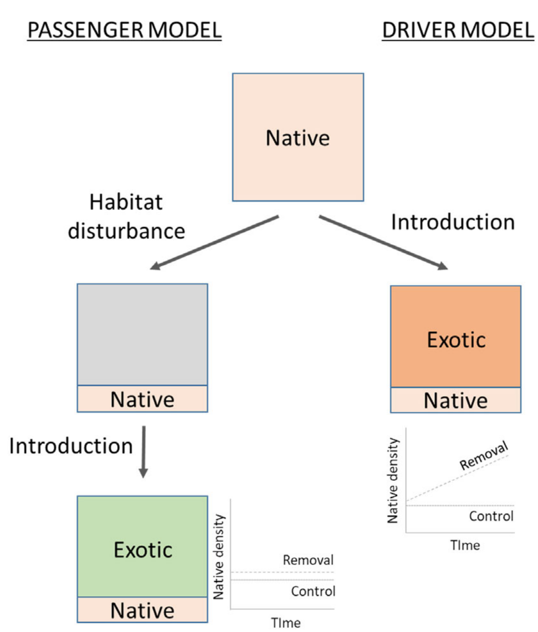

Fig 1. In the passenger model, habitat disturbance has direct negative effects on native species, biotic interactions between invasive and native species are weak or non-existent, and exotic dominance occurs by invaders 'filling the void'. In the driver model, native species are directly displaced by introduced species. Graphics illustrate the predictions of the models: following invasive species removal, the driver model predicts that there will be recovery of native species, while the passenger model predicts no change. Modified from Didham *et al.* (2005).

(3) Groups of experts, scores, and risk assessments

Most global analyses of threats to wildlife, such as those conducted by the International Union for Conservation of Nature (IUCN) and Birdlife International, are based on expert opinions; however, expert bias may be common (Donland *et al.*, 2010). This bias is rarely addressed in conservation planning, which routinely relies on expert groups and opinions for guidance (Asquith, 2001; Burgman, 2002; Bojórquez-Tapia *et al.*, 2003). Perhaps the most radical opinion regarding expert opinion was expressed by Chew (2015): as an example, he analysed the numbers published in an

IUCN report called Extinctions, Fishes, and Conservation and concluded that 'they were not really data regarding fishes; if anything, they were data regarding what a group of self-identified, self-selected experts believed and chose to report about fishes' (p. 19).

During the last decade, an effort has been made to develop impact assessment methods that do not depend solely on the opinions of experts and that can be applied to a considerable number of species and regions. The number of scoring methods and protocols that have been developed is impressive. For example, Roy *et al.* (2018) reviewed 30 available risk and impact assessment protocols (including their own). However, these scoring methods are based on the literature and the available information associated with invasion biology and therefore are affected by several conceptual and methodological problems (Turbé *et al.*, 2017). For example, Strubbe, Shwartz, & Chiron (2011) analysed the first categorisation of invasive bird impacts in Europe that utilised these scoring methods (Kumschick & Nentwig, 2010). They assessed whether the reported impacts and the underlying evidence were compelling enough to consider eradication campaigns. They found that in most cases, the evidence presented to support impact claims was weak and was often based on anecdotal observations associated with small areas instead of on direct scientific research (Fig. 2).

As stated by Kumschick *et al.* (2015, p. 55): 'Despite intensive research during the past decade on the effects of alien species, invasion science still lacks the capacity to accurately predict the impacts of those species and, therefore, to provide timely advice to managers on where limited resources should be allocated'.

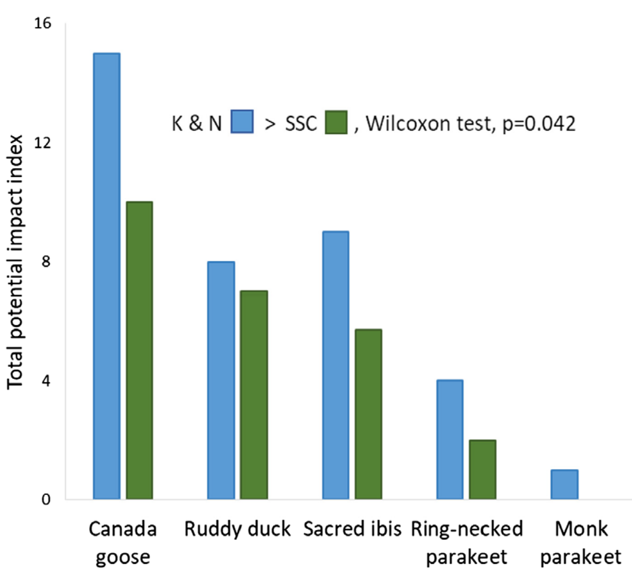

Fig 2. Total potential environmental impacts of five exotic birds in Europe according to Kumschick & Nentwig (2010) (K&N) *versus* Strubbe *et al.* (2011) (SSC). The difference between predictions from these studies was statistically significant. Strubbe *et al.* (2011) estimated less impact and expressed concerns regarding the scientific evidence informing impact risk assessment and management recommendations for invasive birds. Modified from Strubbe *et al.* (2011).

(4) Second greatest threat

Many articles on invasion biology begin with the claim that invasive species are the second greatest threat to biodiversity, behind habitat destruction. Recent studies have questioned the validity of this claim because it relies on data that were skewed by the inclusion of ecosystems or regions with a high prevalence of invasive species and the exclusion of those where invasive species are less threatening (Gurevitch & Padilla, 2004; Yiming & Wilcove, 2005; Venter *et al.*, 2006; Davis, 2009). Chew (2015) conducted an extensive historical analysis of the 'second greatest threat'. He found that commonplace, quantitative assertions that 'invasions' of exotic organisms constitute the second greatest threat of species extinction debuted in Edward O. Wilson's book, *The Diversity of Life* (Wilson, 1992). Chew explained that, based only on three interrelated publications summarizing concerns regarding the conservation status of North American freshwater fishes, Wilson extended the claim to planetary significance, inspiring the most-cited article ever published in the American journal *BioScience*, which subsequently 'underpinned thousands of peer-reviewed publications, government reports, academic and popular books, commentaries, and news stories' (Chew, 2015, p. 7).

(5) Control and eradication

The eradication or decimation of non-native organisms has been successfully performed almost exclusively on islands (Parkes & Panetta, 2009). For example, Genovesi (2011) analysed 911 successful eradications and found that only 2.9% were not performed on islands. Thus, eradication of invasive species in continents and oceans has proved very difficult. Furthermore, the associated costs of eradication programs are often prohibitive, especially for developing countries (Rejmanek & Pitcairn, 2002; Norton, 2009; Panetta, 2009). For example, Reddiex *et al.* (2006) estimated that AU$21.3 m was spent on labour costs alone for red fox (*Vulpes vulpes*) control in Australia from 1998 to 2003.

Lethal control is often assumed to benefit biodiversity, with little *a posteriori* evaluation of the actual efficacy of such programs (Reddiex *et al.*, 2006). For example, Walsh *et al.* (2012) analysed empirical data, collected over 23 years across southern Australia, regarding the impacts of fox baiting on the population of malleefowl (*Leipoa ocellate*), to determine the effectiveness of the strategy. They discovered that limited quantitative evidence exists to support the benefits of fox baiting on malleefowl populations, despite fox baiting representing the primary management action being implemented to protect this nationally threatened, well-studied, and iconic species.

Biotic systems are typically not assembled in additive stepwise fashion and, instead, are subject to steep and difficult-to-predict transitions between states (Suding & Hobbs, 2009). Consequently, dismantling mixed communities by removing

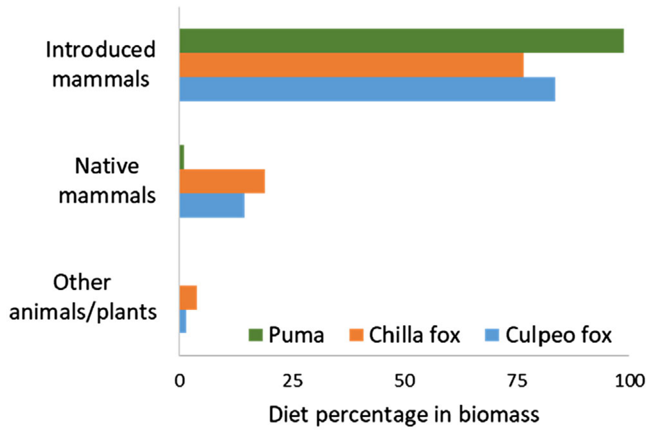

Fig 3. Exotic mammals are the main prey of Patagonian carnivores. Food habits of culpeo foxes (*Lycalopex culpaeus*), chilla foxes (*Lycalopex griseus*), and pumas (*Puma concolor*) in Northern Patagonia, Argentina, between 1989 and 1994. The European hare (*Lepus europaeus*) was the main prey for these three native carnivores. Modified from Novaro *et al.* (2000).

non-native species can be far from straightforward. The ecological and evolutionary impacts of non-native populations that are functionally integrated into new communities can lead to unintended, counter-productive outcomes when incautious eradication strategies are implemented, and often no straightforward methods exist for restoring native communities to pre-invasion states (examples provided by Carroll, 2011).

New approaches suggest that invasive species removal must be analysed in a whole-ecosystem context (Zavaleta, Hobbs, & Mooney, 2001). Exotic species that have been present in an environment for a long time are often rooted within the ecological community, occupying key roles in food webs (e.g. Novaro, Funes, & Walker, 2000; Fig. 3). Consideration should be given to whether the removal of an invasive species will have a net positive result for the native biota, as pest control can result in the loss of positive ecosystem functions provided by exotic species (Zavaleta *et al.*, 2001; Dickman, 2007; Bergstrom *et al.*, 2009).

IV. SOCIAL AND ETHICAL PROBLEMS

In Sections II and III, the difficulties faced by the field of invasion biology with regard to theoretical and methodological issues were analysed. In this section, issues related to the social, psychological, and philosophical background of this discipline are evaluated.

(1) Social conflicts regarding invasive species management

Invasive species management is controversial and often leads to social conflicts (Crowley *et al.*, 2017; Oficialdegui *et al.*, 2020). One reason is that management strategies rarely recognize and address social differences in values and risk perception (Lute & Gore, 2014; Crowley *et al.*, 2017). The most common approach to the management of invasion biology, called the public education approach, is poorly equipped to recognize and address differences in social values and risk perception (Lute & Gore, 2014; Crowley *et al.*, 2017). This top-down approach begins with 'experts' that define the problem, evaluate the evidence and management options, and advise decision makers, who must then persuade 'the public' to accept their decisions, justifications, and supporting evidence.

This approach can only work in cases where (*i*) an exotic species can unequivocally be demonstrated to cause a negative impact on a native species, and (*ii*) the total disappearance of the problem can be scientifically predicted, without excessive economic and social costs and without unexpected negative consequences for the ecosystem. However, rarely have invasion biologists produced such accurate, precise, generally applicable risk-analysis protocols. Even if the scientific data are undisputed, different and equally legitimate social values and cultural traditions will determine whether a species should be designated as an 'invader' that deserves to be managed (Tassin *et al.*, 2017).

Crowley *et al.* (2017) proposed that the incidence and severity of conflicts could be minimized by using the following three key principles designed carefully to reconfigure certain practices within invasive species management: (*i*) paying attention to the socio-political contexts of management; (*ii*) using early and inclusive public engagement; and (*iii*) utilizing open, responsive communication strategies. They concluded that although disagreements regarding invasive species may be inevitable, destructive conflicts regarding their management are not. Similarly, Graham *et al.* (2018) proposed using collective action theory in research and governance for invasive species management.

(2) Language and emotions

Invasion biology regularly uses militaristic language that is derived from the lexical reservoir of war, such as invasion, enemy, battle, combat, attacks, defence, casualties, and victims (Larson, 2005). The use of militaristic metaphors during scientific discourse can motivate overly strong actions or cause unforeseen collateral damage, such as the stigmatization of non-native species (Larson, Nerlich, & Wallis, 2005). Chew & Laubichler (2003) argued that the use of militaristic terminology can have serious consequences, not only for the species defined in this way, but also for the abilities of scientists to understand ecological phenomena and for a society that desires that scientists perform objective interpretations of the natural world. These criticisms become more relevant considering that it would be easy to replace categorizations such as 'native' and 'invasive' with others that do not contain implicit cultural-value judgements.

The bellicose language used in invasion biology could be justified by saying that it motivates conservation action in the short term (Larson *et al.*, 2013). However, it is also easy to interpret this language as a lack of objectivity due to an emotional commitment to the problem (Larson, 2005; Olson, Arroyo-Santos, & Vergara-Silva, 2019). Brown & Sax (2004) suggested that this distrust, dislike, and even loathing towards alien animals and plants is similar to xenophobic attitudes towards other humans. Trudgill (2008) proposed two other types of emotions involved in the behaviour of invasion biologists: nostalgia and guilt.

This conceivable predominance of emotions over facts has been somehow confirmed by the invasion biologists themselves, as reflected in the controversy surrounding the need for 'subjectivity' in studies of invasive species. Larson (2007) argued against objectivity because it implies a policy of non-action that is inconsistent with the conservation values of many invasion biologists, who '...were drawn to their field of study by a concern or love for nature' [Kinchy & Kleinman (2003, p. 872), cited by Larson (2007, p. 949)]. Larson (2007) proclaimed the need to feel emotions, because passion drives action.

(3) Values involved in the problem of invasive species

Lundberg (2010, p. 320) summarized the ethical problem faced by invasion biology as follows: 'The values of nature conservationists should not be confused with the intrinsic values of nature'. Invasion biology appears to be based on a specific set of values in which 'natural' is equated with positive, good, or acceptable, with the corollary that there exists a pure 'natural state' that can and should be preserved; therefore, exotics are viewed as an unnatural, undesirable component of the biota and environment (Brown & Sax, 2004). Botkin (2001) highlighted that underlying many arguments in invasion biology is the assumption that nature exists in an undisturbed steady state. The logical corollary is that biological invasions are unnatural. However, as already discussed in Section II.4, ecology and evolution have demonstrated that natural systems and species are always changing; thus, natural processes should be preserved, not specific, idealized conditions (Trudgill, 2008).

Van Dooren (2011) referred to this idea as 'imagined' nature or an imagined community of species that is understood as deserving to exist. This author suggested that these imaginary communities provide justification for and hence a sense of moral comfort with regards to killing those that do not 'belong'. Similarly, Larson (2007) suggested that invasion biologists hold a type of romantic 'balance of nature' ideal, which reflects a Christian metaphysic; there is a fall from grace, we are in error, and we have a nostalgic wish to return to paradise. In contrast to this view of the natural world, ecologists now emphasize the prevalence of change and flux, which requires the development of a new view of environmental responsibility (Hamlin & Lodge, 2006).

Sandlers (2012) analysed the ethical bases of conservation biology. He argued that because species conservation practices and policies are ultimately justified by preserving the value of a species (or biodiversity), a clear understanding of the nature and basis of species' value is necessary. To understand the value assigned to species, Sandlers devised a classification system for the types of values associated with nature. The broadest categories of value are: (*i*) instrumental, the usefulness value; and (*ii*) final, the value for what something is. Something possesses an objective final value if its value is independent of any actual preferences, attitudes, judgments, emotions, or other evaluative states regarding it.

Most people with a biocentric orientation in their values (Schultz, 2000) will assign an objective final value to animals and plants, defending the principle that all living beings must have value for what they are, regardless of preferences or utility. Both conservationists and animal welfare defenders probably agree in this principle. However, the controversy that arises is which is the unit of value: individual beings or species? Many invasion biologists appear to believe that native species have objective final value, to the detriment of individual living beings. This would explain why it is possible for them to justify mass killings of animals for the sake of a threatened species. However, Sandlers (2012) argued that the assignment of objective value to 'species' is problematic and listed a series of species characteristics that define their moral status: they are non-sentient entities; they are not units of selection in the evolution process; they are not alive (only individuals within a species are alive), therefore, they cannot be killed; species do not have ends or goals; and a species does not have any worth that is distinct from the individuals that comprise a species. As a result, a species cannot be harmed or wronged directly and does not have inherent worth (the very concept of species is highly contested; e.g., Wilkins, 2018). By contrast, Sandlers concluded that individual organisms, such as humans, can be said to have objective values because they possess inherent worth. Although species extinction is considered to be a negative outcome, this is because extinction is bad for the individual organisms, not because it is bad for the species.

This difference in the object receiving final objective value is the moral issue that underlies the frequent conflicts between invasion managers and the animal rights defence agencies. A typical example is the failure of the grey squirrel eradication project in Italy (Genovesi & Bertolino, 2001). Three years of legal struggles between conservationists and animal rights groups halted the eradication campaign. The problem here appears to be entirely related to values. Many invasive biologists surely believe in a type of 'species biocentrism', where species have greater value than individual organisms, whereas animal rights defenders value every individual organism.

(4) Invasion biology in a philosophical context

Larson (2010) proposed analysis of the debate surrounding invasion biology in the broader context of the philosophy of ecology. He explained that two primary views of nature exist, realism and constructivism, and that invasion biology subscribes to the first view, which assumes that the natural world is real and knowable and that facts are true to the extent that they correspond with this reality. By contrast, social scientists subscribe to the perspective of constructivism, which postulates that speaking of nature implies speaking of culture too because nothing can be said about nature without relying on human modes of perception, concepts, needs, and desires (Larson, 2010).

Larson (2010) also referred to 'image schemas', which are studied in the field of cognitive linguistics. An image schema is a pattern of thought that derives from our bodily experiences, which are projected to facilitate our understanding of the phenomena that occur in our environments. The concept of invasion relies on a method for understanding and relating to the world around us. A key component is the 'container' image schema, which envisions one's relationship with the world in terms of a container, with the human inside and the rest of the world outside of the container. The container image schema is also implicit in how we think about invasive species. The container exists around a pre-existing native community that existed before the arrival of a novel species. When a novel species arrives, it crosses the boundary defining the container by entering the native community, invading it. A major implication of the container schema is that a boundary exists around an integrated community, which is implicitly balanced.

The IUCN is likely to have the most orthodox approach to the invasive alien species problem. However, the IUCN published a book, *The Great Reshuffling. Human Dimensions of Invasive Alien Species*, which represents an exception to that tradition (Mcneely, 2004). In particular, a chapter by Hattingh provides a significant message for invasion biologists. He adopts a position similar to Larson's container image schema when proposing that 'the conceptual criterion of historical or natural range requires us to demarcate in space and time a certain area and what it means to be "inside" and "outside" of that area' (Hattingh, 2004, p. 191). He adopted a constructivist approach when he recognized that 'even if we grant the fact that much highly valuable work has been done in invasion biology to develop objective criteria…, it is still humans who introduce the value distinctions between … "good" and "bad" species' (Hattingh, 2004, p. 191). Finally, he pleaded 'for an ethic of conceptual responsibility in which we self-consciously and self-critically locate ourselves within the narratives we use in our discourse about invasive alien species, and take responsibility for the distinctions and value choices we legitimize from within the frameworks of narratives' (Hattingh, 2004, p. 183).

V. DIFFERENT ATTITUDES WITHIN INVASION BIOLOGY

There are at least two studies that have investigated the opinions and attitudes of invasion biologists (Young & Larson, 2011; Humair *et al.*, 2014). Both studies found large differences among specialists, which contrasted with the relatively homogeneous claims in the literature regarding the roles of invasive species in nature (Fig. 4).

I would assert that two positions, with intermediate stances, can be distinguished. One position can be defined as 'zero-tolerance' invasion biology (Tassin *et al.*, 2017), which has the following characteristics: uses militaristic terminology; considers every 'non-native' species to be invasive (and, therefore must be eliminated), regardless of their impacts (Richardson *et al.*, 2000; Blackburn *et al.*, 2011); accepts subjectivity in research as a positive trait (Larson, 2007); accuses those who do not

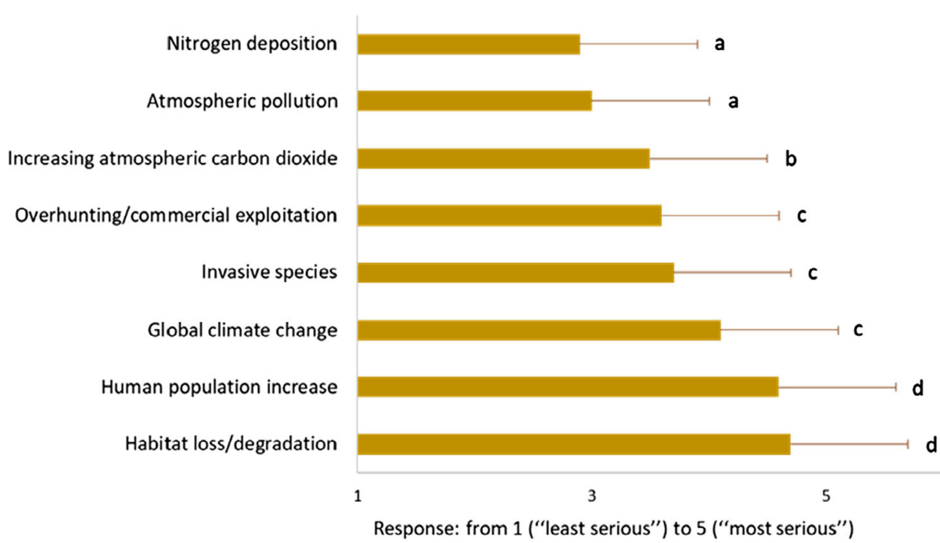

Fig 4. Invasion biologists do not necessarily place invasive species as the second greatest threat to biodiversity: mean (+ standard deviation) evaluation by invasion biologists of eight factors affecting biodiversity. Response options ranged from 1 (least serious) to 5 (most serious). Statistically different means are indicated by different letters (one-way ANOVA with Tukey's test, d.f. = 7, $P < 0.001$). Modified from Young & Larson (2011).

agree with this position of denialism (Russell & Blackburn, 2017; Ricciardi & Ryan, 2018); and are convinced that they have detected a mere fraction of the existing impacts of alien species (Simberloff *et al.*, 2013).

I also suggest that there is a second, moderate position that believes that objectivity is both achievable and desirable for the discipline of invasion biology, both in terms of terminology and for the interpretation of results, and has as its main objective to produce models that predict the impact of non-native species better (e.g. Vilà & Weiner, 2004; Ricciardi & Cohen, 2006; Fridley *et al.*, 2007; Pyšek *et al.*, 2008; Colautti & Richardson, 2009; Boltovskoy, Sylvester, & Paolucci, 2018; Latombe *et al.*, 2019).

VI. ALTERNATIVES TO THE INVASION BIOLOGY APPROACH

In recent years, new approaches have emerged regarding the problem of biological invasions. One is based on the concept of a 'novel ecosystem' (Hobbs, Higgs, & Hall, 2013; Guiden *et al.*, 2019). An ecosystem can be defined by its biotic composition and abiotic conditions. Biotic changes can include significant declines or local extinctions of species and/or significant invasions of species, whereas abiotic changes can occur in climate, land use, pollution, urbanization, and nutrient loads, and both types of factors often change simultaneously and act synergistically (Hobbs *et al.*, 2009). Novel ecosystems can arise, either from the degradation and invasion of 'wild' systems or from the abandonment of intensively managed systems (Hobbs *et al.*, 2006). In the first case, three states can be recognized: historical, hybrid, and novel (Hobbs *et al.*, 2009). In a novel ecosystem, the restoration of historical conditions is difficult or impossible, primarily due to severely changed abiotic conditions making it difficult for species from the original natural ecosystem to establish, even when dispersal barriers are crossed (Hobbs *et al.*, 2006).

Conciliation biology represents an arm of invasion biology that 'focuses not on the prevention or eradication of invasive species but, instead, on the prediction and management of outcomes for longer-term native–non-native interactions at the individual, population, species, community, and ecosystem levels' (Carroll, 2011, p. 186). Conciliation biology recognizes that many non-native species are permanent, that outcomes of native–non-native interactions will vary depending on the scale of assessments and the values assigned to the biotic systems, and that many non-native species may perform positive functions in one or more contexts. Managing such mixed and novel systems will require integrated schemes that are responsive to change. Compared with invader-free communities, invader-perturbed communities are more likely to require the monitoring and management of evolutionary processes. Strong philosophical emphases on prevention, eradication, and restoration may lead to the discounting or discrediting of practices that accept non-native species as ineradicable and, in some cases, desirable (Goodenough, 2010; Carroll, 2011).

Compassionate conservation is a rapidly growing international and cross-disciplinary movement that stipulates that we need a conservation ethic that incorporates the protection of animals as individuals that are valued in their own right and not just as members of species populations (Bekoff, 2010). By considering animal welfare alongside animal conservation, this new discipline proposes the establishment of wildlife conservation frameworks that are explicitly oriented towards managing the lives of individuals and social groups, not just species or populations as a whole. Compassionate conservation declares that invasive species must be treated under animal welfare legislation, not merely labelled as 'pests', which justifies transgressions of humane treatment (Wallach *et al.*, 2018). The proposed innovative approaches to conservation biology, for example, include the use of 'inclusive conservation data' that incorporate non-native and feral populations into the global IUCN *Red List* and local species richness assessments (Wallach *et al.*, 2020). The principles supported by compassionate conservation have recently sparked a heated debate in the scientific community around the issue of ethical values (Wallach *et al.*, 2018, 2019; Driscoll & Watson, 2019; Hayward *et al.*, 2019; Callen *et al.*, 2020).

A common feature of these new approaches is that they are not based on the precept that introduced species are, by definition, detrimental to new ecosystems (Flory & D'Antonio, 2015), and they suggest that exotic species may have conservation value (e.g. D'Antonio & Meyerson, 2002; Gozlan, 2008; Schlaepfer, Sax, & Olden, 2011; Saul, 2013). One of the most promising approaches to objective research is long-term studies that focus on elucidating complex ecosystem processes that include both native and non-native species. Such is the case for (*i*) non-native plants that add to the British flora without negative consequences to native diversity (Thomas & Palmer, 2015); (*ii*) invading oysters that interact with native mussels to form multi-layered mixed reefs in the northern Wadden Sea (Reise *et al.*, 2017); (*iii*) alien-dominated forests that serve important ecological functions (Lugo, 2004; Mascaro, Hughes, & Schnitzer, 2012); (*iv*) increases in local richness in an invaded clade of frogs in Lower Middle America (Pinto-Sánchez, Crawford & Wiens, Pinto-Sanchez, Crawford, & Wiens, 2014); (*v*) local regulation of non-native plant species in New Zealand due to accumulated negative soil feedbacks (Diez *et al.*, 2010); and (*vi*) the detection of life-history evolutionary processes both in native and exotic species that eventually facilitate coexistence (Lankau *et al.*, 2009; Leger & Espeland, 2010; Phillips, Brown, & Shine, 2010).

VII. CONCLUSIONS

(1) Numerous points of debate exist regarding conceptual and methodological approaches of invasive biology. The natural world shows clear signs of over-exploitation, habitat destruction, pollution, wildlife trade, overpopulation, deforestation, poaching, global

warming, the expansion of agricultural frontiers, human waste, desertification, and many other environmental disasters caused by humans. In this context, the proposal that exotic species are a comparable problem is unconvincing for increasing numbers of scientists and managers.

(2) Another conflict operates in the field of ethics and philosophical arguments. While conservation biologists and activists assign maximum value to species, thereby subordinating the lives of individuals to the maintenance of biodiversity, other groups prioritize individuals over species. These differences in moral stance may explain why conservation biologists dedicated to investigating the effects of habitat degradation or climate change receive more acceptance than those who work with non-native species. In the first case, both ethical positions focus on the desire to protect individuals and species, whereas in the second case, their interests come into conflict.

(3) There are other biological disciplines that result in the need to kill animals; however, the ethical conflict is not as intense. For example, when biomedical research concludes that animals are vectors of human disease, the killing of animals has, as its goal, the care of humans, which has indisputable moral value. By contrast, invasion biologists care for animal and plant species, sometimes by killing other animal and plant species that have the same moral status, except for the misfortune of having been transported to alien habitats by humans.

(4) Investigating the values that underlie our attitudes towards non-native species could be the first step to reconciling currently confrontational situations.

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