

# 1 **Conceptual and Ethical Considerations in Invasion Science**

2 Phillip J. Haubrock<sup>1,2,3,\*</sup>, Ben Parker<sup>4,5,#</sup>, Dagmara Błońska<sup>6,5,#</sup>, Elizabeta Briski<sup>7</sup>, Teun Everts<sup>8,9</sup>, Romina D.  
3 Fernandez<sup>10</sup>, Antonín Kouba<sup>2</sup>, Melina Kourantidou<sup>11,12</sup>, Irmak Kurtul<sup>13,5</sup>, Stefano Mammola<sup>14,15,16</sup>, Dmitrii  
4 L. Musolin<sup>17</sup>, Martin A. Nuñez<sup>18</sup>, Julian D. Olden<sup>19</sup>, Jes J. Rasmussen<sup>20</sup>, David Renault<sup>21</sup>, James C. Russell<sup>22</sup>,  
5 Ronaldo Sousa<sup>23</sup>, Ali Serhan Tarkan<sup>6,24\*,#</sup>, J. Robert Britton<sup>5,#</sup>

## 6 **Affiliations**

7 <sup>1</sup>*Department of River Ecology and Conservation, Senckenberg Research Institute and Natural History Museum*  
8 *Frankfurt, 63571, Gelnhausen, Germany*

9 <sup>2</sup>*Faculty of Fisheries and Protection of Waters, South Bohemian Research Center of Aquaculture and Biodiversity of*  
10 *Hydrocenoses, University of South Bohemia in České Budějovice, 389 01, Vodňany, Czech Republic*

11 <sup>3</sup>*CAMB, Center for Applied Mathematics and Bioinformatics, Gulf University for Science and*  
12 *Technology, 73F2+GV4, Hallawy, Kuwait*

13 <sup>4</sup>*Department of Biosciences, Faculty of Health and Life Sciences, University of Exeter, Exeter, Devon EX4 4QD, UK*

14 <sup>5</sup>*Department of Life and Environmental Sciences, Faculty of Science and Technology, Bournemouth University, BH12*  
15 *5BB, Poole, Dorset, UK*

16 <sup>6</sup>*University of Lodz, Faculty of Biology and Environmental Protection, Department of Ecology and Vertebrate*  
17 *Zoology, 90-131, Lodz, Poland*

18 <sup>7</sup>*GEOMAR Helmholtz-Zentrum für Ozeanforschung Kiel, 24148 Kiel, Germany*

19 <sup>8</sup>*Research Institute for Nature and Forest (INBO), Genetic Diversity, 9500, Geraardsbergen, Belgium*

20 <sup>9</sup>*KU Leuven, Department of Biology, Plant Conservation and Population Biology, 3000, Leuven, Belgium*

21 <sup>10</sup>*Instituto de Ecología Regional, Universidad Nacional de Tucumán-CONICET, CC 34, 4107, Yerba Buena, Tucumán,*  
22 *Argentina*

23 <sup>11</sup>*Univ Brest, Ifremer, CNRS, IRD, UMR 6308, AMURE, IUEM, F-29280, Plouzane, France*

24 <sup>12</sup>*Department of Business and Sustainability, Environmental and Business Economics, University of Southern*  
25 *Denmark, 6705 Esbjerg Ø, Denmark*

26 <sup>13</sup>*Marine and Inland Waters Sciences and Technology Department, Faculty of Fisheries, Ege University, 35100, İzmir,*  
27 *Türkiye*

28 <sup>14</sup>*Molecular Ecology Group (MEG), Water Research Institute (IRSA), National Research Council (CNR), Largo*  
29 *Tonolli, 50, Pallanza 28922, Italy. stefano.mammola@cnr.it ORCID: 0000-0002-4471-9055*

- 30 <sup>15</sup>*NBFC, National Biodiversity Future Center, Palermo 90133, Italy*
- 31 <sup>16</sup>*Laboratory for Integrative Biodiversity Research (LIBRe), Finnish Museum of Natural History (LUOMUS),*  
32 *University of Helsinki, Helsinki, Finland*
- 33 <sup>17</sup>*European and Mediterranean Plant Protection Organization (EPPO), 75011, Paris, France*
- 34 <sup>18</sup>*Department of Biology and Biochemistry, University of Houston, Houston, Texas, 77204 USA*
- 35 <sup>19</sup>*School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA 98195, United States*
- 36 <sup>20</sup>*Department of Ecoscience, Aarhus University, 8000 Aarhus C, Denmark*
- 37 <sup>21</sup>*UMR CNRS 6553 ECOBIO [(Ecosystèmes, biodiversité, évolution)], Université Rennes, avenue Général Leclerc,*  
38 *35042 Rennes Cedex, France*
- 39 <sup>22</sup>*School of Biological Sciences, University of Auckland, New Zealand*
- 40 <sup>23</sup>*CBMA – Centre for Molecular and Environmental Biology/ARNET-Aquatic Research Network/ IB-S, Institute of*  
41 *Science and Innovation for Bio-Sustainability, Department of Biology, University of Minho, Campus Gualtar, 4710-*  
42 *057 Braga, Portugal.*
- 43 <sup>24</sup>*Department of Basic Sciences, Faculty of Fisheries, Muğla Sıtkı Koçman University, Muğla, Türkiye*
- 44 <sup>#</sup>*Equally contributing secondary authors*
- 45 <sup>\*</sup>*Corresponding author(s), [phillip.haubrock@senckenberg.de](mailto:phillip.haubrock@senckenberg.de) ; [serhantarkan@gmail.com](mailto:serhantarkan@gmail.com)*

46 **Abstract**

47 Invasion science addresses interconnected ecological, economic, and social challenges posed by the  
48 introduction of non-native species. Hence, invasion scientists have to consider and reconcile  
49 interdisciplinary needs while addressing potential implications of their findings. Navigating diverse  
50 disciplines, including environmental sciences, ecology, economics and the humanities, invasion scientists  
51 seek to arrive at informed decisions on invasion risk, impact, and management. Individual biases,  
52 uncertainties, and systemic pressures influence the ability to maintain objectivity and resist pressures that  
53 might otherwise distort findings or applications. This commentary examines conceptual and ethical  
54 dilemmas within the field of invasion science, particularly reputational and risks of the discipline  
55 perpetuating its own relevance by framing invasions as insurmountable challenges. The discussion  
56 highlights how incentive structures, biased assessments and framing, and conflicts of interest may  
57 compromise the discipline's integrity. We also explore questions surrounding human responsibility to  
58 animal welfare and highlight ethical conundrums in the management of invasive species.

59  
60 **Keywords:** *human responsibility, sustainability science, environmental ethics, ethical dilemmas,*  
61 *philosophical challenges*

62

## 63 **Introduction**

64 Human activities, such as trade, travel, and land-use conversion, have dissolved inherent barriers to the  
65 natural occurrence of species (Banks et al. 2015, Doherty et al. 2021). Many ensuing biological invasions  
66 have drastically shaped the global environmental landscape, especially in recent decades (Simberloff 2014,  
67 Roy et al. 2023), altering terrestrial and aquatic ecosystems alike (Ehrenfeld 2010). The introduction of non-  
68 native species has disrupted native biodiversity (Li et al. 2016, Olden et al. 2018) and altered recipient  
69 communities and ecosystem functions (Vilà and Hulme 2017). In some cases, biological invasions are  
70 leading to severe economic impacts (Cuthbert et al. 2021, Diagne et al. 2021) and pose significant challenges  
71 to human societies, affecting customary ways of using natural resources (e.g. agriculture, fisheries, forestry  
72 and hunting) and human health and well-being (e.g. the spread of species or new diseases that may be  
73 dangerous for humans) (Bacher et al. 2023). Moreover, biological invasions may even affect our perception  
74 of nature by shifting people’s understanding of what is a “pristine” ecosystem (Soga and Gaston 2018) and  
75 result in the emergence of new bio-phobias (i.e. aversions or fears toward certain species or other elements  
76 of the natural world that pose little or no threat to humans; Soga et al. 2023), especially when non-native  
77 species vector pathogens are introduced (Cuthbert et al. 2023). Invasion science has thus emerged as a  
78 critical discipline, predominantly within ecology, tasked with understanding, preventing, and managing the  
79 effects of non-native species on both natural ecosystems and human societies (Lockwood et al. 2013,  
80 Epanchin-Niell 2017, Shackleton et al. 2019).

81 The urgency of tackling biological invasions has been underscored by international agreements and  
82 conservation targets, such as the Convention on Biological Diversity’s (CBD) Aichi Biodiversity Target 9,  
83 that highlighted the need to identify non-native species and their pathways of introduction and spread and  
84 implement management strategies globally (Essl et al. 2020). The Target 6 of the Kunming-Montreal Global  
85 Biodiversity Framework, negotiated in 2024 through the Conference of the Parties of the CBD, went even  
86 further: Although details on how this will be achieved, funded, and implemented remains a pressing  
87 question, it ambitiously aims to reduce the rates of introduction and establishment of known or potential  
88 invasive non-native species by at least 50% by 2030 (<https://www.cbd.int/gbf/targets/6>). One of the  
89 considered tools is rewilding, which triggered the debate on species introductions and reintroductions.  
90 Rewilding focuses on restoring entire ecosystems by enhancing ecological processes rather than targeting  
91 specific species or habitats. Effective rewilding strengthens ecosystem resilience to invasions and stressors;  
92 however, unpredictability of species recolonization raises legitimate concerns (Guareschi et al. 2024). The  
93 challenges facing invasion science are not solely technical or logistical in nature. The discipline is  
94 increasingly confronted with a range of practical, scientific and ethical concerns that underlie its very  
95 foundations (Peretti 1998, Hyatt 2002, Davis et al. 2011). As the young field is maturing, invasion science

96 must grapple with the potential consequences of its own practices, including the vocabulary used to  
97 communicate (Kueffer and Larson 2014, Golebie et al. 2022, Guareschi et al. 2024), the intricacies of  
98 weighing the benefits versus costs of non-native species introductions (Reaser et al. 2003, Vimercati et al.  
99 2020, Sax et al. 2022), and the ethical implications of removing individuals from natural ecosystems  
100 (Lockwood 1996, Clark 2015, Olszańska et al. 2016).

101         This commentary seeks to critically explore these issues, with a particular focus on the ways in  
102 which the structure and incentives of the field of invasion science may inadvertently perpetuate the very  
103 challenges it aims to address. While invasion science plays a crucial role in tackling some of these issues  
104 due to meticulous and ongoing research into every aspect related to biological invasions, it is essential that  
105 we also critically examine how the framing of invasion science, the pressures associated with securing  
106 ongoing research funding and potential conflicts of interest may shape the discipline in ways that  
107 compromise its integrity. This commentary aims to explore the deeper questions surrounding the definition  
108 of invasiveness, human responsibility in causing and managing invasions, as well as the ethics and  
109 motivations of intervening in natural ecosystems. We hope to inspire thoughtful reflection, open and honest  
110 dialogue within the invasion science community, advocating for a more ethically and philosophically  
111 grounded approach. Our goal is to encourage the field's evolution toward meaningful advancements,  
112 informed communication, and constructive conversations, ultimately enhancing its credibility and  
113 effectiveness in serving both ecological and societal needs. While focusing on invasive non-native species  
114 (however defined; Soto et al. 2024), we recognize that the dilemmas and challenges discussed have wider  
115 relevance to conservation, environmental sciences, and natural resource management.

## 116 **The Role and Importance of Invasion Science**

117 Invasion science is concerned with understanding and managing the causes and consequences of biological  
118 invasions. Its objectives are multifaceted, ranging from (1) identifying relevant vectors and pathways  
119 through which species are introduced to new regions (McGeoch et al. 2016), (2) predicting which non-  
120 native species may ultimately become a burden to the recipient ecosystems (Heger and Trepl 2003, Vilizzi  
121 et al. 2021), (3) forecasting the environmental conditions (human disturbance, biotic resistance, etc.) that  
122 make some habitats more susceptible to invasions than others (Torres et al. 2023), (4) understanding the  
123 interconnected ecological and societal impacts of these invasions (Simberloff et al. 2013), and (5)  
124 developing both proactive strategies to prevent introduction and establishment (e.g. biosecurity protocols)  
125 and reactive strategies to mitigate the effects of those established (e.g. (functional) eradication; Robertson  
126 et al. 2020, Green and Grosholz 2021). The contributions of invasion science as a discipline therefore extend  
127 beyond academic research, being deeply embedded in practical efforts to protect and restore ecosystems,

128 conserve biodiversity, and safeguard human livelihoods (Britton 2023), with regular conflicts within and  
129 trade-offs among these objectives (Frawley and McCalman 2014, Chew 2015, Kourantidou et al. 2022).

130 Despite being a relatively young discipline, invasion science has had a broad influence on policy  
131 and decision-making (Essl et al. 2020), shaping international agreements and national policies aimed at  
132 preventing the introduction and spread of invasive species (Early et al. 2016, Meyerson et al. 2022).  
133 However, invasion science must remain adaptable and responsive, as its relevance and effectiveness depend  
134 on continuously evolving to address complex and ever-changing challenges posed by globalization  
135 (Meyerson & Mooney 2007), climate change (Brönnimann and Brönnimann 2015), environment (Foley et  
136 al. 2013, Madhok 2021) and technological shifts (Larson et al. 2020). The discipline's continued relevance,  
137 effectiveness, and integrity hinges not only on its adaptability but also on its ability to address ethical  
138 concerns and avoid conflicts of interest (Frank 2021). Given its growing influence on policy and  
139 management decisions, invasion science must remain vigilant against biases and subjectivity that could  
140 undermine its credibility (Larson 2007, Ricciardi and Ryan 2018, Cassini 2020). This vigilance includes  
141 framing non-native species responsibly based on current knowledge (Pereyra et al. 2024, Simberloff et al.  
142 2024), critically examining the motivations behind research priorities, and resisting the pressures of a  
143 'publish or perish' system that incentivizes quick, surface-level science aimed more at career advancement  
144 than at fostering long-term solutions (Paasche and Österblom 2019, Urai and Kelly 2023).

## 145 **The Philosophical Nature of Invasions and Human Responsibility**

146 Should biological invasions be considered a natural phenomenon if they are linked to human activity? Some  
147 researchers view biological invasions as processes that are inherently natural, but significantly accelerated  
148 by human activity, involving species expanding their native range with or without human mediation  
149 (Williamson 1996, Davis 2009). Additionally, some may distinguish range expansions of those without, or  
150 with less clear, involvement of human-induced environmental changes (Essl et al. 2019). Others have argued  
151 that invasion science should be concerned exclusively with species that overcome natural barriers to  
152 dispersion owing to human intervention. This is because a species' occurrence in an area can only be  
153 regarded as native if the occurrence is independent of human activities (Pyšek 1995, Oficialdegui et al.  
154 2024). From a perspective of *impact* all these dispersal processes, regardless of their spontaneity, may be  
155 relevant, as even species naturally expanding their range can have ecological, economic, and social  
156 consequences that parallel those of non-native species introduced to new regions. Such consequences can  
157 encompass damages to economies, changing environmental conditions, biotic interactions, and ecosystem  
158 functioning which can be responsible for regime shifts and local extinctions in a worst-case scenario  
159 (Zarzczyński et al. 2023). While immigration, emigration, and extinctions are inherent parts of eco-

160 evolutionary dynamics, it remains crucial to minimize the human-driven acceleration or general alteration  
161 of these processes. Therefore, “naturalness” of range expansion cannot be the sole valid argument to allow  
162 or prevent invasions. Ultimately, the most logical distinction may involve whether human mediation  
163 contributes to a species' movement into a new area, as these actions fundamentally alter the pace and scope  
164 of these natural dynamics, and the responsibility of duty to respond.

165         The definition of what constitutes an "invasive" non-native species (see for instance Soto et al.  
166 2024) or the concepts of nativeness and non-nativeness (Davis et al. 2011, Oficialdegui et al. 2024) are in  
167 themselves topics of ongoing debate. Traditionally, a non-native species is defined as an organism  
168 introduced by humans (accidentally or intentionally) into an area where it has no evolutionary history (Soto  
169 et al. 2024). The term “invasiveness” has been commonly applied by institutions like the IUCN or the CBD  
170 to describe non-native species that harm the environment, human health, or the economy, and that may also  
171 be widespread (Richardson and Pyšek 2006). However, these definitions raise some fundamental questions.  
172 What does it—scientifically and practically—mean for a species to be 'non-native' (Djuraeva and Cathedral  
173 2020, Oficialdegui et al. 2024), especially when some argue that nativeness cannot be fully or objectively  
174 defined? Do species inherently belong wherever they currently exist or are considered natural, regardless of  
175 their duration of presence or their evolutionary and migratory origins? How do we [objectively] determine  
176 the threshold for what constitutes ‘harm’—should this threshold be binary or might a more gradual,  
177 quantitative approach offer better clarity (Crystal-Ornelas and Lockwood 2020)? How can we objectively  
178 quantify the wide diversity of ecological impacts and what kind of metrics can we develop to measure and  
179 report impacts (Bernardo-Madrid et al. 2022)? When defining spread, do we focus on individual ecosystems  
180 (e.g. rivers) or larger landscapes such as catchments (Haubrock et al. 2024b)? And should ecosystems be  
181 managed to preserve a specific state, or should they be allowed to evolve autonomously, even if that means  
182 accepting the presence of non-native species (Schlaepfer et al. 2011, Gbedomon et al. 2020)? These  
183 questions are central to invasion science but have no unequivocal answers. Even though humans have a  
184 natural tendency to understand reality by categorizing things and phenomena into fixed groups, a process  
185 known as “category learning” (Ashby and Maddox 2005), any such attempt is prone to oversimplify  
186 complex and nuanced phenomena. This challenge should encourage reflections on the rapidly evolving  
187 nature of the field and invite a more nuanced understanding of invasion science’s foundational assumptions.

### 188 *Manage, maintain, or do nothing?*

189 A central debate revolves around whether ecosystems should be restored or, when still in an uninvaded (i.e.  
190 pristine) healthy state unaffected by human influence and stressors, maintained in such a pre-invasion state,  
191 or whether they should be allowed to adapt and evolve in response to the presence of non-native species

192 (Cassini 2020, Warren 2023). Some argue that all species, including humans, are part of nature's dynamic  
193 processes (Marean 2015, Graf 2022), and that efforts to eradicate non-native species may have unwanted  
194 and unintended consequences for native species and ecosystems (Zavaleta et al. 2001, Crowley et al. 2017).  
195 For example, many management strategies for eradicating non-native species (e.g., the introduction of  
196 parasites, and predators, use of sexual interferents, anticoagulants, other substances and systematic trapping)  
197 have been shown to sometimes also harm non-target species (Lohr and Davis 2018). Besides, concerns  
198 surrounding the eradication of non-native species (Inglis 2020), particularly in large-scale eradication  
199 efforts, poses significant double standards (Fenoglio et al. 2018) and moral dilemmas, especially when these  
200 species have become a part of the local ecosystem (Kopf et al. 2017, Parke and Russell 2018). Many people,  
201 including scientists, oppose the culling of non-native animal species for ethical reasons (animal suffering)  
202 or emotional attachment. For example, efforts to eradicate gray squirrels (*Sciurus carolinensis*) in the UK  
203 have largely failed, partly due to public resistance (Dunn et al. 2018), despite the damage gray squirrels  
204 cause to native ecosystems including the near extinction of red squirrels (*Sciurus vulgaris*). The difficulty  
205 of eradicating established invasive non-native species also raises practical issues (but see Spatz et al. [2022]  
206 and Benkwitt et al. [2021] for successful eradications on islands), and control efforts can be costly and  
207 require continuous intervention (Green and Grosholz 2021). However, the suppression of the invader's  
208 population to levels below those that cause unacceptable ecological damage can be feasible ("functional  
209 eradication"; Green and Grosholz 2021). Regardless of the skepticism revolving around eradication, a  
210 considerable number of studies demonstrate that it is possible to eradicate a broad range of taxonomic  
211 groups, in diverse ecosystems, with positive consequences for co-occurring native species (Hoffmann 2010,  
212 Beltran et al. 2014, Tiberti et al. 2019). Moreover, the removal of non-native species can lead to the  
213 simultaneous elimination of associated pathogens responsible for emerging infectious diseases, providing  
214 an additional collateral benefit (Lafferty et al. 2018, Hossack et al. 2023).

215 Finally, the question whether to maintain or manage is context-dependent because some non-native  
216 species may, after an initial disruption, integrate into ecosystems and provide new (possibly beneficial)  
217 ecological roles or economic opportunities. The case of the Australian redclaw crayfish (*Cherax*  
218 *quadricarinatus*) in parts of Africa, Asia, and South America illustrates the complexity and context-  
219 dependency of assessing invasive non-native species: initially introduced as an aquaculture species and later  
220 establishing wild populations, the redclaw crayfish is seen by invasion scientists as a potential threat to  
221 native ecosystems and has been shown to damage fishing nets and caught fish (Madzivanzira et al. 2021).  
222 However, this species has simultaneously provided an important source of protein for low-income  
223 communities and economic benefits through fisheries (Andriantsoa et al. 2020, Haubrock et al. 2021).  
224 Hence, efforts to manage the redclaw crayfish, while challenging and ecologically reasonable (Mashar and

225 Aryasa 2021), raise questions about whether eradication or control measures would be socio-economically  
226 viable, given the species' contributions to local livelihoods (Nunes et al. 2017, Haubrock et al. 2021).

227 For these reasons, managers and policy makers face dilemmas regarding whether a particular  
228 species in a certain ecosystem should be managed and if so, whether the goal should be maintenance or  
229 eradication. In ethical theory, three schools—consequentialism, deontology, and virtue ethics (Roby  
230 2018)—offer distinct approaches to evaluating moral dilemmas, each reflecting different moral priorities  
231 relevant to invasion science. Consequentialism, for instance, focuses on outcomes and may justify actions  
232 that reduce harm caused by non-native species, even if such actions require lethal control. Deontological  
233 ethics, on the other hand, prioritizes adherence to rules or duties, viewing certain actions—like killing  
234 sentient beings—as inherently wrong, regardless of outcomes (as long as the harm on non-native species is  
235 not considered in the assessment). Meanwhile, virtue ethics centers on character and intention, encouraging  
236 compassion and balance in conservation decisions. Latombe et al. (2024) illustrate these ethical tensions  
237 using the ‘trolley problem’ as a powerful thought experiment, highlighting different asymmetry variations  
238 relevant for conservation: (i) asymmetry of numbers (different numbers and ratio of entities of nature are  
239 affected); (ii) asymmetry of victims (different species are affected); (iii) asymmetry of impacts, (iv) spatial  
240 and temporal asymmetry; and (v) uncertainty and unforeseen consequences variation. These dilemmas also  
241 reflect competing ethical perspectives in invasion science: an ecocentric view, which prioritizes ecosystem  
242 integrity; a sentientist view, which seeks to minimize suffering for all sentient beings; a biocentric view,  
243 which values all life forms equally; and an anthropocentric view, which emphasizes human interests. In  
244 conservation, similar dilemmas arise when deciding whether to sacrifice potentially harmful non-native  
245 species to protect or preserve ecosystems due to intrinsic rights or ethical concerns about suffering (Kopnina  
246 and Coghlan 2022). Some species may be threatened in their native regions, while being introduced and/or  
247 invasive in other parts of the world and thus potentially acting as rescue populations (Hume et al. 2021).  
248 These conflicting ethical perspectives shape the moral landscape of invasion science, where each framework  
249 could lead to different decisions regarding the management of invasive non-native species. Incorporating  
250 these ethical dimensions into invasion science allows for more nuanced decision-making that accounts for  
251 both ecological notions and human values.

252 Another dimension of this debate involves the concept of "novel ecosystems" and alternative stable  
253 states. As introduced non-native species become entrenched in their new environments, they often create  
254 ecosystems that are significantly altered and often impoverished (in terms of biodiversity, ecosystem  
255 services, etc.) compared to the more ‘pristine’ pre-invasion conditions, raising questions about whether these  
256 systems should be considered “natural” or valued in their own right (Didham et al. 2005). On the other hand,  
257 some argue that these novel ecosystems could be recognized and managed for their emergent properties,

258 such as unique ecosystem functions or services that they now provide thanks to the presence of new species  
259 (Davis et al. 2011). Whether these emergent qualities justify a shift in management goals remains a critical  
260 question that should be carefully considered. Recognizing these different values associated with native  
261 versus non-native ecosystems is critical. Restoration of historical conditions may remain a priority,  
262 particularly in cases where native species and ecosystem functions can still be recovered. Yet where non-  
263 native species of high functional importance may be extirpated, the economic cost of restoration might not  
264 be justified. For instance, an urban park dominated by non-native trees may serve as one of the few  
265 accessible green spaces in a heavily urbanized environment. While ecologists would argue for a replacement  
266 by native counterparts, urban planners may emphasize that non-native trees, which are typically fast-  
267 growing, play a key role for the well-being of the inhabitants of the cities, offering aesthetic value, regulating  
268 microclimatic conditions through shading, and many other ecosystem services (Almas 2017). Consequently,  
269 the management of urban green spaces becomes a balance between human perceptions, needs, and use  
270 versus the ecological requirements to preserve and enhance native biodiversity (Aronson et al. 2017).

271 An additional concern is that the lack of pre-invasion data (i.e., baseline information), which are  
272 still scarce in several geographic contexts and ecosystems (Haubrock et al. 2024c), can complicate  
273 assessments of the full ecological impact of invasive non-native species and hinder the development of  
274 effective management strategies (Pergl et al. 2020). The detection of non-native species in an ecosystem  
275 often triggers an escalation in monitoring efforts, leading to more frequent and systematic observations  
276 through a positive feedback loop. However, many ecosystems have historically lacked consistent  
277 monitoring. Where available, recent advancements in monitoring techniques, such as environmental DNA,  
278 render comparisons with conventional methods challenging (Everts et al. 2024), resulting in blurred  
279 comparisons between historic and recent data on species distributions and population dynamics (Haubrock  
280 et al. 2023), which has especially been a problem in the context of cryptogenic species in aquatic ecosystems  
281 (Katsanevakis et al. 2020).

282 Finally, the use of non-native species to fill empty niches can be seen as a pragmatic approach,  
283 although it raises further ethical and ecological questions about whether this is a form of acceptable  
284 ecosystem manipulation or an exacerbation of existing ecological problems (Chevalier et al. 2024).  
285 Moreover, this issue becomes even more complex when advocating for some of these rather impactful non-  
286 natives as now being responsible for key ecosystem functions (Guareschi et al. 2024). For example, rats can  
287 pollinate or disperse seeds of rare plant species, sometimes being the almost exclusive species present  
288 capable of performing these roles—despite being the same rats that previously decimated bird populations  
289 that once fulfilled those very functions (Pattimore and Wilcove 2012).

290           These aforementioned points open up the following two broader questions about the goals of  
291 conservation and ecological management (e.g. Kim et al. 2006, Papeş et al. 2011).

292 What does invasion science strive to achieve?

293 From a consequentialist perspective, one might ask what outcomes should be prioritized to achieve the  
294 “greater good”: should the focus be on mitigating the damage caused by past human activities and  
295 invasions, or should we prioritize preventing future invasions by changing current behaviors and policies?  
296 A deontological perspective, however, might focus on identifying what actions are inherently “right”—for  
297 instance, protecting native biodiversity as a matter of principle, regardless of the cost-benefit balance of  
298 outcomes. These differing ethical lenses lead to critical questions about conservation goals. Should we  
299 focus on restricting global trade and travel to minimize the risk of future invasions, even at the cost of  
300 economic and lifestyle impacts? For instance, the development of regulatory frameworks such as the  
301 International Maritime Organization's Ballast Water Management Convention (IMO 2017, Park et al. 2020)  
302 regulating the transfer of aquatic species through ship ballast water, reflects the direct application of  
303 invasion science to global policy, often yielding positive outcomes. Such stringent ballast water regulations  
304 in the Great Lakes demonstrate it is possible to reduce new introductions without restricting trade and  
305 travel, balancing ecological protection with human activity (Ricciardi and MacIsaac 2022). Nevertheless,  
306 questions remain about how much society should limit its actions to preempt future invasions—measures  
307 that may pose considerable economic and social trade-offs.

308 How can invasion science achieve its goals?

309 Once goals are established, the next consideration is how to best achieve them. A crucial aspect of non-  
310 native species management is determining the most effective methods to reach conservation objectives,  
311 which often requires scientific, objective approaches informed by cost-benefit analyses. For example, if  
312 non-native species introductions cannot be entirely prevented, there is a question of whether resources  
313 should be invested in scaling up systematic monitoring and innovative techniques to detect early invasion  
314 stages, improving the chances of eradication (Martinez et al. 2020, Haubrock et al. 2024d). Here, the rate  
315 of species introductions becomes highly relevant, as lower rates provide more opportunities to manage  
316 impacts before they escalate. Alternatively, should resources focus on restoration efforts to mitigate the  
317 impacts of invasions that have already occurred (Green and Grosholz 2021)? Deciding between prevention,  
318 monitoring, and restoration involves trade-offs that must be carefully weighed according to the context of  
319 each invasion and must include ecological, social, and economic impacts, which may differ based on both  
320 local conditions and the anticipated consequences of specific actions (Rout et al. 2011, Smart et al. 2020).

321           Understanding the role of anthropogenic factors in biological invasions is crucial for effectively  
322 managing these events, as human activities (such as global trade, urbanization, and habitat destruction) are  
323 primary drivers of this phenomenon (Hulme 2007, Rodríguez-Labajos et al. 2009, Dalmazzone and  
324 Giaccaria 2014, Capinha et al. 2023). However, while much attention has been given to the impacts, less  
325 emphasis continues to be placed on anthropogenic factors that facilitate introductions and spread, such as  
326 unregulated trade and consumer behavior (Levine and D'Antonio 2003, Lockwood et al. 2019, Jarić et al.  
327 2020). This is despite the problem that even if a non-native species appears neutral or benign in a specific  
328 place or region, its impact is influenced by local context dependencies (Catford et al. 2022). The range  
329 expansion of a non-native species can lead to negative ecosystem effects elsewhere, sometimes even after a  
330 lag period. Such 'sleeper' populations may persist at low abundances for years or even decades, becoming  
331 disruptive only when triggered by certain environmental changes (Spear et al. 2021; Everts et al. 2024,  
332 Sousa et al. 2024). Additionally, the invasiveness of one non-native species may depend on the presence of  
333 another non-native species, which alters ecosystem properties in ways that facilitate the establishment and  
334 proliferation of the first species (O'Loughlin and Green 2017). Acknowledging the numerous factors that  
335 can render a non-native species problematic in one but not another context raises important questions about  
336 the transferability of risk and impact assessment tools for non-native species and suggests that any  
337 assessment should be population-level based (rather than focusing on taxonomic identities) to yield the most  
338 accurate outcomes for informing management strategies (Haubrock et al. 2024b, Tarkan et al. 2024). All of  
339 this may be responsible for inconsistencies in management prioritization for non-native species due to e.g.  
340 different outcomes across a range of assessment and screening (Błońska et al. 2024). While improving risk  
341 assessments and management prioritization for non-native species is essential, these measures merely  
342 address the symptoms rather than the root causes of biological invasions. Effective long-term solutions  
343 require proactive strategies that target the sources of introductions—such as stricter regulations on trade,  
344 improved public awareness, and more robust monitoring at borders (Lodge et al. 2006, Vander Zanden et  
345 al. 2010)—to reduce the likelihood of new species becoming established in the first place.

#### 346 *Preserving heritage or embracing change?*

347 Value-laden discussions ultimately flavor the decision on which species “belong” in an ecosystem, shifting  
348 discussions towards more moral dimensions that necessitate thoughtful reflection. For instance, the invasive  
349 European starling (*Sturnus vulgaris*) in Argentina (Palacio et al. 2016) and the common carp (*Cyprinus*  
350 *carpio*) in some European’s freshwaters (Badiou et al. 2011) have, despite their often negative effects, now  
351 become integral parts of their respective ecosystems (Vilizzi 2012), even serving as a valuable recreational  
352 resource (Britton 2023). This raises two questions (1) if these well-established and harmful non-native  
353 species, which have adapted to their new environments (in some cases in Europe for several centuries) and

354 may even provide certain ecological functions, should be removed in favor of restoring native species, and  
355 (2) how threatening is the presence of the non-native species to the native species in recipient ecosystems.  
356 Should society accept them as part of the evolving ecological landscape (Marris 2013) or should we manage  
357 them in an attempt to preserve pristine pre-invasion conditions? This dilemma forces invasion scientists to  
358 confront the question of whether their goal is to restore the past or to manage threats for the foreseeable  
359 future (Ruiz-Navarro et al. 2016)—a future where, on vastly different timescales, humans may well go  
360 extinct or a virtually new Pangaea in which many biogeographic boundaries are erased, allowing many  
361 species to freely disperse across once-separate lands and oceans (Watson and Watson 2020).

362 Another layer of complexity is added when considering the cultural and social dimensions of non-  
363 native species introductions (Nuñez and Simberloff 2005, Nuñez et al. 2018). In some cases, non-native  
364 species have become culturally integral to local communities and hold intrinsic, instrumental, and other  
365 values (Roy et al. 2023), complicating efforts to control or eradicate them. For example, the wild horse  
366 (*Equus ferus caballus*) in the western United States, while a non-native species, is deeply embedded in  
367 American culture and history (Bhattacharyya et al. 2011). Efforts to manage wild horse populations,  
368 therefore, must navigate not only ecological considerations but also cultural and ethical ones. An even  
369 clearer example is the release of captive “prayer animals” by Buddhists (Liu et al. 2012, Everard et al. 2019,  
370 Magellan 2019). Although such practices must not be endorsed, given the deep religious significance,  
371 discussions on the impact of non-native species involved must be approached with respect and cultural  
372 sensitivity. Ultimately, recognizing the intrinsic, instrumental, and cultural values tied to non-native species  
373 highlights complex value comparisons and ethical dilemmas that invasion scientists ought to consider  
374 thoughtfully in management and communication strategies.

## 375 **Ethical Conundrums**

376 The ethical dilemmas in invasion science are perhaps best exemplified by the cost-benefit analyses  
377 underlying impact assessments of non-native species. While scientists, managers, and society at large  
378 generally seek to advance knowledge and/or improve societal outcomes, perceptions of 'improvement' can  
379 vary greatly depending on context and perspective. Invasion scientists, for instance, are often drawn to the  
380 field by a predilection for nature conservation and a commitment to addressing threats such as the impacts  
381 of non-native species, a perspective that can shape research focus and priorities. Those who view non-native  
382 species as a significant threat often conclude that the costs of biological invasions outweigh any benefits  
383 (Carneiro et al. 2024). Cost-benefit analyses of non-native species, however, often reveal that benefits  
384 accrue to specific groups (e.g., sport fishery managers), while broader societal costs (e.g., eradication)  
385 depend on socioeconomic and geopolitical contexts, emphasizing the need for inclusive, transdisciplinary

386 approaches to management (Pocock et al. 2020; Schlaepfer et al. 2011; García-Llorente et al. 2011; Sutcliffe  
387 et al. 2018; Guareschi et al. 2024). Recognizing the normative aspects in evaluating the costs and benefits  
388 of non-native species is therefore crucial, as perceptions of value can vary greatly across different social and  
389 geographical contexts (Kelsch et al. 2020). Real-world examples can illustrate the ethical dilemmas faced  
390 by invasion science. One well-known example is the management of the invasive non-native European  
391 green crab (*Carcinus maenas*) in North America which presents a complex ethical challenge, highlighting  
392 a conflict between conservation goals and unintended consequences. While the species is considered highly  
393 problematic by posing a threat to native biodiversity, control efforts have raised concerns about collateral  
394 damage to non-target species and ecosystems (Jivoff 2002), especially since control efforts are often  
395 ineffective (Ens et al. 2022). Conversely, successful resolutions can demonstrate how the discipline can  
396 navigate these challenges. The attempted eradication of the invasive non-native brown tree snake (*Boiga*  
397 *irregularis*) from some Pacific islands relied on combining scientific research, public engagement, and  
398 ethical decision-making, yielding partial success through interception of new incursions (Kaiser and  
399 Roumasset 2002, Clark et al. 2017). This emphasizes that it can be possible to address non-native species  
400 problems in a way that balances ecological, social, and ethical considerations.

#### 401 *From potentially perpetual problems to solving the unsolvable*

402 Many scientific disciplines have increasingly become concerned with ethics. A primary epistemological  
403 concern found in many scientific disciplines is the perpetuation of the problem it seeks to solve (Ioannidis  
404 2012). This issue could be particularly acute in invasion science given the incentive structures that often  
405 drive scientific research and the need for non-native species to be portrayed as a major problem to justify  
406 research or management project proposals. Where research funding is highly competitive, dwindling, and  
407 often sourced from government funds, it may be directed away from other worthwhile research that offers  
408 more tangible societal and environmental returns. This is, however, not to argue that biological invasions  
409 are not a problem, but rather that the reliance on funding and professional recognition (van Dalen and  
410 Henkens 2012) may inadvertently incentivise invasion scientists to frame the problem of invasive non-  
411 native species as ongoing or unsolvable (van Dalen and Henkens 2012). For example, this may lead to a  
412 focus on the most sensational or alarming aspects of invasions, sometimes at the expense of identifying  
413 sustainable solutions. Although more research on this issue may be needed in invasion science specifically,  
414 studies from related fields suggest that research framing can be influenced by funding and professional  
415 incentives (van Dalen and Henkens 2012, Bratton 2018, Intemann 2022).

416 As a case in point, the use of the term “invasive”, often without particular evidence (Roberts et al.  
417 2013, Soto et al. 2024), is symptomatic of this sensationalism through exaggeration and hyperbole (Kimmel

418 et al. 2023). Researchers frequently refer to the “100 of the World's Worst Invasive Alien Species” (Lowe  
419 et al. 2000) to underscore the significance of their target organism, overlooking that the list was limited and  
420 never intended to be comprehensive and lacks, after a quarter of a century's worth of evidence, empirical  
421 support for the impact of some listed species, particularly in the Global South (Cuthbert et al. 2022).  
422 Paradoxically, research findings can be at times overstated, presenting the issue as neatly “solved”, yet  
423 accompanied by vague and generalized calls for additional data collection—raising questions about whether  
424 the cost of gathering more data is truly justified in relation to the actual impact. This ultimately leads to  
425 many conclusions being based on assumptions or theoretical models rather than robust, real-world impact  
426 data (Ricciardi and Simberloff 2009). In the absence of such adequate data, theoretical frameworks can  
427 serve as a (necessary) shortcut for invasion scientists to bolster their arguments and heighten awareness of  
428 potential threats. However, this approach can be problematic, as it risks damaging the credibility of the field.  
429 By emphasizing speculative or worst-case scenarios without sufficient empirical support (i.e. framing a non-  
430 native species as invasive without evidence), the discipline may inadvertently foster an atmosphere of  
431 urgency that may not always align with evidence (Mattingly et al. 2020, Sagoff 2020, Pereyra et al. 2024).

### 432 *Challenges in the Framing of Invasion Science*

433 The reliance on speculative studies in invasion science, for example unverified claims about the inevitable  
434 spread or impact of non-native species, can also result in an echo chamber effect. This occurs when initial  
435 assumptions—such as the idea that all non-native species are inherently harmful—are repeatedly reinforced  
436 without proper validation (Karst et al. 2023). Such cycles entrench dominant narratives, stifle consideration  
437 of more balanced or evidence-based approaches and risk biasing the management of non-native species  
438 (Sutherland and Wordley 2017, Pereyra et al. 2024). For example, resources may be inefficiently allocated  
439 toward presumed threats instead of focusing on verified ecological and societal impacts. This diversion not  
440 only reduces the efficacy of management actions but also risks favoring short-term economic or political  
441 gains over long-term ecological stability (Kourantidou and Kaiser 2021). In the long term, these practices  
442 might undermine the credibility of invasion science and diminish its capacity to positively influence  
443 biodiversity conservation and ecosystem management.

444 Furthermore, we also posit that a seemingly “unsolvable” narrative in invasion science is unhelpful and  
445 inaccurate for several reasons. Such a narrative erodes public trust in the discipline and discards many of  
446 the success cases that should be celebrated and more broadly disseminated (Parkes and Panetta 2009,  
447 Courchamp et al. 2011, Pennisi 2024). Failure to recognize the positive outcomes of past management  
448 actions adequately may create public and stakeholder apathy—if the problem is unsolvable, why waste  
449 resources on it?—and, ultimately, may only further perpetuate the framing problem. Additionally, framing

450 the issue as “unsolvable” may discourage the involvement of scientists and stakeholders who would  
451 otherwise engage positively with the issues, while also reducing individual accountability for non-native  
452 introductions and mitigation.

453         Selective framing of issues is another concern. According to a recent review of the published  
454 literature, introduced species were framed negatively by scientists regardless of attributed harm to the  
455 environment (Pereyra et al. 2024). However, Simberloff et al. (2024) noted that such analyses may be  
456 limited by their focus on introduction sections, which are often dedicated to emphasizing the importance of  
457 the topic and may not reflect the more nuanced perspectives typically found in the discussion or conclusion  
458 sections. Studies have revealed that researchers often prioritize the most visible or easily addressed aspects  
459 of non-native species, such as their impacts on charismatic species or economically valuable ecosystem  
460 services, while overlooking other important but less-attention grabbing or impactful effects (Thomsen et al.  
461 2014). The resulting lack of comprehensiveness can marginalize the social and cultural impacts of invasions  
462 on e.g. indigenous communities (Gozlan 2017, Witt 2017), and result in a neglect of non-native species that  
463 are less charismatic (Pyšek et al. 2008). Considering the “publish or perish” culture permeating today’s  
464 academia (van Dalen and Henkens 2012), it is reasonable to assume that researchers selectively study  
465 “appealing” non-native species. This tendency is similar to the over-use of buzzwords (e.g. “megafauna”)  
466 and can bias assessments by directing efforts towards species perceived as having significant impacts as  
467 such studies are more likely to produce results that can be published in high-impact journals (Parker et al.  
468 2016). Moreover, not all non-native populations become “invasive” (either by spreading or having a  
469 detectable impact; Soto et al. 2024) and not all non-native species present the same level of threat  
470 (Goodenough 2010). However, while many studies focus on abundant invaders that cause significant  
471 ecological changes—potentially leading to an overestimation of the average impact of non-native species  
472 (Gozlan 2008)—it is often the cumulative impact of these highly impactful species, regardless of the total  
473 number of species introduced, that poses the most critical challenges for ecosystems and management  
474 efforts. This can result in an overemphasis on certain non-native species while overlooking others that might  
475 also play important roles in introduced ecosystems. To ensure effective management, it is essential to also  
476 document and study cases where non-native species have positive, neutral, or relatively benign impacts (e.g.  
477 Fobert et al. 2011, Sax et al. 2022; Bacher et al., 2023) or where the resistance of native species and  
478 ecosystems remains strong against arising effects (Britton 2023, Nicolosi et al. 2023).

479         Additionally, while challenges such as publication bias and funding limitations affect many  
480 scientific fields, they carry particular implications for invasion science, where studies are often prioritized  
481 based on observable impacts. The so-called “file drawer problem” (Franco et al. 2014) can lead to a  
482 publication bias that emphasizes the most dramatic cases of non-native species effects, underrepresenting

483 studies that find neutral or less impactful results. Indirect or spurious correlations can skew our  
484 understanding by creating a disproportionate focus on high-impact species (Everts et al. 2024), potentially  
485 leading to an incomplete view of non-native species ecology. In turn, these biases may reduce chances for  
486 funding follow-up research on less impactful non-native species. This bias not only limits funding for  
487 research on less impactful species but also perpetuates alarming narratives, rather than recognizing that non-  
488 native species often reflect for instance pre-existing ecosystem degradation (MacDougall and Turkington  
489 2005), leading to misattributions of causality when declines in natives may result from shared external  
490 pressures (Cassini 2020). A prime example can be seen in the widely cited list of the "100 of the World's  
491 Worst Invasive Species" (Lowe et al. 2000), which, while useful for raising awareness about biological  
492 invasions, has faced criticism for its biogeographic and taxonomic biases rather than a comprehensive  
493 scientific assessment of global non-native species impacts (Hirsch et al. 2016, Cuthbert et al. 2022).  
494 Although these lists serve as effective tools for public engagement, their reliance on subjective voting  
495 procedures and limited data can result in unintended prioritization biases. Concomitantly, there is a notable  
496 bias documenting non-native species problems in the global South, where ecosystems, socioeconomics, and  
497 environmental challenges differ markedly from those in the North (Nuñez and Pauchard 2010, Speziale et  
498 al. 2012, Zenni et al. 2017, Guareschi et al. 2024, Jenkins et al. 2024). Aside from the global South, this  
499 bias is also evident in difficult-to-study regions (e.g. the Arctic) or ecosystems (e.g. caves and other  
500 subterranean habitats), where unique environmental conditions complicate both research and management  
501 efforts, leading to further underrepresentation in the literature (Kaiser and Kourantidou 2021, Nicolosi et al.  
502 2023) and reflecting broader global research gaps and biases evident in assessments such as IPBES (Roy et  
503 al. 2023). Similarly, language barriers and a reliance on accessible online data, primarily gathered by  
504 researchers from wealthier regions focusing on broad-scale ecological patterns, exacerbate the  
505 underrepresentation of non-native species research from the global South. This skewed understanding  
506 reflects not only academic bias, but also broader global inequalities tied to limited scientific capacity in  
507 under-resourced regions. Also, beyond the scientific terminology in invasion biology, a cultural language  
508 barrier can arise when an invasive species is not only biologically unfamiliar but also new to the local culture  
509 and society. The lack of specific terms to easily name or describe the new non-native species can result in  
510 distinct differences in the values and perceptions associated with them (Guareschi et al. 2024).

### 511 *Legislative Compliance and Cost-Benefit Analysis*

512 Another dilemma arises from the implementation of new legislation. Pietrzyk-Kaszyńska et al. (2023)  
513 analyzed a case study on the enforcement of the European Union's regulation on non-native species  
514 (Regulation (EU) 1143/2014) in Poland, focusing on institutions and scientists conducting research on non-  
515 native species. Final implementation of the regulation implied that all actions (e.g. handling, transport, stock,

516 reproduction) on listed non-native species that may threaten native species or habitats are allowed only  
517 under permission of the *General or Regional Directorate of Environmental Protection*, applying to  
518 everyone, from individual citizens to scientific institutions. A survey among Polish scientists revealed a  
519 very low number of permit applications and limited awareness of the current law, including within scientific  
520 units. Improper enforcement of legal regulations and public policies was also highlighted to have long-term  
521 implications for the ability to conduct research with researchers faced with the dilemma of whether to  
522 continue their ongoing, often EU-funded, projects without the newly required permits or to comply with  
523 updated legal regulations, potentially halting their studies (Stoett 2010). The survey results suggest that  
524 when faced with the choice between jeopardizing a current project and proceeding with it despite the new  
525 regulations, opting for the latter might be seen as a last resort. Additionally, the researchers noted that new  
526 regulations have negatively impacted their work related to non-native species, with the results also  
527 suggesting widespread noncompliance with legal requirements among scientists (Pietrzyk-Kaszyńska et al.  
528 2023). However, it is important to clarify that the solution is not to argue for an exemption for scientists but  
529 rather to advocate for clearer, more accessible permit processes and policies that facilitate research while  
530 ensuring environmental protection. Striking a balance between rigorous non-native species regulations and  
531 the practical need of scientific research is crucial to both advancing knowledge and adhering to legal  
532 frameworks.

533           Moreover, even within a society, the costs and benefits of non-native species may differ markedly  
534 between different individuals and stakeholders based on derived benefits and costs, values, experiences, and  
535 general views around morality and ethics (Sutcliffe et al. 2018). While a manager may invoke a  
536 consequentialist approach (the ends justifying the means) to eradicate a harmful non-native species, this  
537 may be unacceptable to others with a relational view on animal rights where the moral status of a living  
538 being is determined instead by its relationship with humans (Bremner and Park 2007). Additionally, most  
539 non-native species were introduced as a result of anthropogenic activities, often with beneficial intentions  
540 (e.g., for agriculture or companionship), which can lead to more favorable public perceptions and further  
541 complicate the ethical debate (Shackleton et al. 2019). When non-native organisms are considered  
542 charismatic and desirable by some, for example, gray squirrels within the UK and the raccoon (*Procyon*  
543 *lotor*) within Germany, the significant negative impacts on native ecosystems may be overlooked due to a  
544 favorable public perception (Dunn et al. 2018). Moreover, this perceived cost-benefit dimension often  
545 intersects with political interests, where politicians may intentionally overlook the introduction of non-  
546 native species in exchange for public support, particularly by promoting activities like sport fishing or  
547 hunting that resonate with their voter base (Maguire 2004, Ready et al. 2016). Given their short-term  
548 political horizons, long-term conservation goals can be deprioritized in favor of immediate gains. As

549 invasion science encompasses both social and environmental responsibilities, and is often funded by the  
550 public, it must be responsive to evolving societal views and ethical values when determining actions, despite  
551 the occasional ethical dilemmas that may result.

552         The challenge of effectively communicating the distinction between native and non-native species  
553 presents another dilemma, as it raises fundamental questions about how we value and define nature,  
554 determine which species belong where, and justify management actions to a public that may be increasingly  
555 disconnected from historical biodiversity (Gadgil et al. 1993, Taylor 2011, Wägele 2014). As such, it is  
556 crucial for invasion scientists to address the broader public's understanding of biodiversity and the  
557 distinction between native, non-native, and invasive non-native species to ensure effective policy-making  
558 and public engagement (Selge et al. 2011). The erosion of ecological memory across generations, where  
559 younger people may lack the historical reference points of what "wild nature" once looked like, however,  
560 exacerbates this challenge (Leccardi et al. 2023), a phenomenon known as shifting baseline syndrome (Pauly  
561 1995, Soga and Gaston 2024). As a result, "biodiversity" often becomes a vague concept, making it harder  
562 for the public to grasp why some species are considered harmful invaders and others valuable contributors  
563 to ecosystems (Meinard et al. 2019). This "management" or "conservation" paradox complicates  
564 conservation efforts, as policies and decisions may lose public support if local residents cannot differentiate  
565 between or relate to species that authorities in charge of management wish to protect or remove (Allison  
566 2012, Wolf et al. 2019). To guide effective action, it is essential to assess both species- and population-level  
567 impacts, contextualizing any incidental benefits within the specific regions and communities affected to  
568 develop well-prioritized, context-sensitive conservation strategies (Guareschi et al. 2024). Invasion  
569 scientists must work alongside biodiversity conservationists to not only refine and unify their narratives but  
570 also develop clear, compelling communication strategies that help the public and policymakers appreciate  
571 the necessity of managing species for both ecological integrity and long-term societal benefit.

## 572 **Conclusions: Evolving and Adapting Invasion Science**

573 Invasion science stands at a critical juncture, facing the dual challenge of addressing the complexity of  
574 biological invasions and meeting the evolving expectations of society. As invasion scientists, we recognize  
575 the importance of self-reflection and constructive engagement to tackle pressing ecological challenges. To  
576 ensure its continued relevance, the field must embrace a forward-looking, interdisciplinary approach. Based  
577 on the discussions in this commentary, we propose the following key directions for evolution and adaptation  
578 in invasion science:

- 579 1. *Shift from Reactive to Proactive Management:* Prevention should take precedence over remediation,  
580 with greater emphasis on proactive measures such as biosecurity protocols, early detection  
581 surveillance systems, and public education campaigns. Proactive approaches not only save  
582 resources but also minimize ecological disruptions by targeting invasion pathways before non-  
583 native species establish (Leung et al. 2002, Early et al. 2016). For instance, stringent biosecurity  
584 measures have proven effective in reducing the likelihood of introductions in high-risk areas like  
585 islands, where biodiversity is particularly vulnerable (Roy et al. 2023).
- 586 2. *Embrace Interdisciplinary and Transdisciplinary Collaboration:* Solving the complex challenges  
587 posed by biological invasions requires integrating insights from ecology, social sciences, and the  
588 humanities (Shackleton et al. 2019). These interdisciplinary efforts should be complemented by  
589 close partnerships with stakeholders, policymakers, and coordinated decision-making bodies  
590 (Kurtul and Haubrock 2024). Such collaborations ensure that management strategies are not only  
591 scientifically sound but socially acceptable and ethically grounded. For example, engaging local  
592 communities in co-designing management solutions can enhance compliance and effectiveness  
593 (Vaz et al. 2017).
- 594 3. *Address Global Inequities and Research Biases:* Overcoming the underrepresentation of non-native  
595 species research in the global South, the e.g. inclusion of indigenous people and incorporation of  
596 their perspectives where relevant (Wehi et al. 2024), and other under-studied regions is critical to  
597 achieving a more comprehensive understanding of biological invasions (Nuñez and Pauchard 2010,  
598 Zenni et al. 2017). Investments in capacity building, inclusive collaboration, and equitable access  
599 to resources can bridge these gaps and help correct the global imbalance in invasion science (Díaz  
600 et al. 2019). Addressing such inequities will also strengthen the ability to respond to invasions in  
601 the most vulnerable and biodiverse regions.
- 602 4. *Incorporate Ethical and Cultural Dimensions:* Invasion science must acknowledge and address the  
603 ethical implications of management decisions, including differing cultural perceptions of non-native  
604 species (Guareschi et al. 2024). For instance, non-native species that are considered pests in one  
605 region may be valued resources in another, highlighting the need for nuanced approaches.  
606 Understanding and respecting these dimensions will foster more equitable and inclusive solutions,  
607 ensuring that management strategies reflect the values and priorities of all stakeholders involved.
- 608 5. *Advance Fundamental Ecological and Evolutionary Knowledge:* Beyond its applied aspects,  
609 invasion science contributes to our understanding of ecological and evolutionary processes, such as  
610 species dispersal, adaptation, and interactions (Cox 2013). These insights not only inform invasion

611 management but also intersect with broader conservation efforts, including habitat restoration,  
612 climate change mitigation, and biodiversity protection. By enhancing ecosystem resistance and  
613 resilience, invasion science can play a critical role in safeguarding ecological integrity in the face  
614 of accelerating global change.

615 By focusing on these priorities, invasion science can evolve to meet the challenges of a rapidly changing  
616 world. Balancing effective management with ethical considerations and interdisciplinary collaboration will  
617 ensure the field remains a vital force in achieving ecological sustainability and social responsibility.

## 618 **Acknowledgements**

619 RS was supported by the Portuguese Foundation for Science and Technology (FCT) through national funds  
620 under the project MULTI-CRASH: Multi-dimensional ecological cascades triggered by an invasive species  
621 in pristine habitats (PTDC/CTA-AMB/0510/2021) (<https://doi.org/10.54499/PTDC/CTA-AMB/0510/2021>). DB was supported by a Marie Curie Individual Fellowship HORIZON-MSCA-2022-PF-  
622 01 (project 101105250 – PROSPER) within the European Union’s Horizon 2022 research and innovation  
623 programme, funded by UKRI. JP was supported by the by the project no. 20-10349J. TE was supported by  
624 a Research Foundation Flanders (FWO) fellowship (No. 1S01822N). SM acknowledges support of NBFC,  
625 funded by the Italian Ministry of University and Research, P.N.R.R., Missione 4, Componente 2, “Dalla  
626 ricerca all’impresa”, Investimento 1.4, Project CN00000033.  
627

## 628 **References**

- 629 Allison SK. 2012. The Paradox of Invasive Species in Ecological Restoration: Do Restorationists Worry about  
630 Them Too Much or Too Little? Pages 265–275 in *Invasive and Introduced Plants and Animals*. Routledge.
- 631 Almas AD. 2017. Native trees, urban forest management planning, and residents: Knowledge, attitudes, and  
632 actions. University of Toronto (Canada). ProQuest Dissertations & Theses, 10250147.
- 633 Andriantsoa R, Jones JPG, Achimescu V, Randrianarison H, Raselimanana M, Andriatsitohaina M, Rasamy J,  
634 Lyko F. 2020. Perceived socio-economic impacts of the marbled crayfish invasion in Madagascar. *PLOS*  
635 *ONE* 15: e0231773.
- 636 Aronson MF, Lepczyk CA, Evans KL, Goddard MA, Lerman SB, MacIvor JS, Nilon CH, Vargo T. 2017.  
637 Biodiversity in the city: key challenges for urban green space management. *Frontiers in Ecology and the*  
638 *Environment* 15: 189–196.
- 639 Ashby FG, Maddox WT. 2005. Human Category Learning. *Annual Review of Psychology* 56: 149–178.
- 640 Bacher S, Galil BS, Nuñez MA, Ansong M, Cassey P, Dehnen-Schmutz K, Fayvush G, Hiremath AJ, Ikegami  
641 M, Martinou AF, McDermott SM, Preda C, Vilà M, Weyl OLF, Fernandez RD, Ryan-Colton E. 2023.  
642 Chapter 4: Impacts of biological invasions on nature, nature's contributions to people, and good quality of  
643 life. In: *Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental*  
644 *Science-Policy Platform on Biodiversity and Ecosystem Services*. Roy HE, Pauchard A, Stoett P, and  
645 Renard Truong T. (eds.). IPBES secretariat, Bonn, Germany.)
- 646 Badiou P, Goldsborough LG, Wrubleski D. 2011. Impacts of the common carp (*Cyprinus carpio*) on freshwater  
647 ecosystems: a review. Pages 121–146 in *Carp: habitat, management and diseases*. Nova Science Publishers,  
648 Inc.
- 649 Banks NC, Paini DR, Bayliss KL, Hodda M. 2015. The role of global trade and transport network topology in  
650 the human-mediated dispersal of alien species. *Ecology Letters* 18: 188–199.
- 651 Beltran RS, Kreidler N, Van Vuren DH, Morrison SA, Zavaleta ES, Newton K, Tershy BR, Croll DA. 2014.  
652 Passive recovery of vegetation after herbivore eradication on Santa Cruz Island, California. *Restoration*  
653 *Ecology* 22: 790–797.
- 654 Benkwitt CE, Gunn RL, Le Corre M, Carr P, Graham NAJ. 2021. Rat eradication restores nutrient subsidies  
655 from seabirds across terrestrial and marine ecosystems. *Current Biology* 31: 2704-2711.e4.
- 656 Bernardo-Madrid R, González-Moreno P, Gallardo B, Bacher S, Vilà M. 2022. Consistency in impact  
657 assessments of invasive species is generally high and depends on protocols and impact types. *NeoBiota* 76:  
658 163–190.
- 659 Bhattacharyya J, Slocombe DS, Murphy SD. 2011. The “Wild” or “Feral” distraction: Effects of cultural  
660 understandings on management controversy over free-ranging horses (*Equus ferus caballus*). *Human*  
661 *Ecology* 39: 613–625.

662 Błońska D, Grabowska J, Tarkan AS, Soto I, Haubrock PJ. 2024. Prioritising non-native fish species for  
663 management actions in three Polish rivers using the newly developed tool Dispersal-Origin-Status-Impact  
664 scheme. *PeerJ* 12: e18300.

665 Bratton LA. 2018. Examining exaggerated claims in science communication. Cardiff University (Doctoral  
666 dissertation).

667 Bremner A, Park K. 2007. Public attitudes to the management of invasive non-native species in Scotland.  
668 *Biological Conservation* 139: 306–314.

669 Britton JR. 2023. Contemporary perspectives on the ecological impacts of invasive freshwater fishes. *Journal*  
670 *of Fish Biology* 103: 752–764.

671 Brönnimann S, Brönnimann S. 2015. Climatic changes since 1700. Pages 167–321. Springer International  
672 Publishing.

673 Capinha C, Essl F, Porto M, Seebens H. 2023. The worldwide networks of spread of recorded alien species.  
674 *Proceedings of the National Academy of Sciences* 120: e2201911120.

675 Carneiro L, Hulme PE, Cuthbert RN, Kourantidou M, Bang A, Haubrock PJ, Bradshaw CJA, Balzani P, Bacher  
676 S, Latombe G, Bodey TW, Probert AF, Quilodrán CS, Courchamp F. 2024. Benefits do not balance costs  
677 of biological invasions. *BioScience* 74: 340–344.

678 Cassini MH. 2020. A review of the critics of invasion biology. *Biological Reviews* 95: 1467–1478.

679 Catford JA, Wilson JRU, Pyšek P, Hulme PE, Duncan RP. 2022. Addressing context dependence in ecology.  
680 *Trends in Ecology & Evolution* 37: 158–170.

681 Chevalier M, Broennimann O, Guisan A. 2024. Climate change may reveal currently unavailable parts of  
682 species' ecological niches. *Nature Ecology & Evolution* 8: 1298–1310.

683 Chew MK. 2015. Ecologists, environmentalists, experts, and the invasion of the 'second greatest threat'.  
684 *International Review of Environmental History* 1: 7–40.

685 Clark JL. 2015. Uncharismatic Invasives. *Environmental Humanities* 6: 29–52.

686 Clark L, Clark C, Siers S. 2017. Brown tree snakes: methods and approaches for control. Pages 107–134 in  
687 *Ecology and management of terrestrial vertebrate invasive species in the United States*. CRC Press.

688 Courchamp F, Caut S, Bonnaud E, Bourgeois K, Angulo E, Watari Y. 2011. Eradication of alien invasive  
689 species: surprise effects and conservation successes. *Island Invasives: Eradication and Management* 285–  
690 289.

691 Cox GW. 2013. Alien species and evolution: the evolutionary ecology of exotic plants, animals, microbes, and  
692 interacting native species. Island Press.

693 Crowley SL, Hinchliffe S, McDonald RA. 2017. Conflict in invasive species management. *Frontiers in Ecology*  
694 *and the Environment* 15: 133–141.

695 Crystal-Ornelas R, Lockwood JL. 2020. The ‘known unknowns’ of invasive species impact measurement.  
696 *Biological Invasions* 22: 1513–1525.

697 Cuthbert RN, Darriet F, Chabrierie O, Lenoir J, Courchamp F, Claeys C, Robert V, Jourdain F, Ulmer R, Diagne  
698 C, Ayala D, Simard F, Morand S, Renault D. 2023. Invasive hematophagous arthropods and associated  
699 diseases in a changing world. *Parasites & Vectors* 16: 291.

700 Cuthbert RN, Diagne C, Haubrock PJ, Turbelin AJ, Courchamp F. 2022. Are the “100 of the world’s worst”  
701 invasive species also the costliest? *Biological Invasions* 24: 1895–1904.

702 Cuthbert RN, Pattison Z, Taylor NG, Verbrugge L, Diagne C, Ahmed DA, Leroy B, Angulo E, Briski E,  
703 Capinha C, Catford JA, Dalu T, Essl F, Gozlan RE, Haubrock PJ, Kourantidou M, Kramer AM, Renault D,  
704 Wasserman RJ, Courchamp F. 2021. Global economic costs of aquatic invasive alien species. *Science of*  
705 *the Total Environment* 775: 145238.

706 van Dalen HP, Henkens K. 2012. Intended and unintended consequences of a publish-or-perish culture: A  
707 worldwide survey. *Journal of the American Society for Information Science and Technology* 63: 1282–  
708 1293.

709 Dalmazzone S, Giaccaria S. 2014. Economic drivers of biological invasions: A worldwide, bio-geographic  
710 analysis. *Ecological Economics* 105: 154–165.

711 Davis MA. 2009. *Invasion biology*. Oxford University Press.

712 Davis MA, Chew MK, Hobbs RJ, Lugo AE, Ewel JJ, Vermeij GJ, Brown JH, Rosenzweig ML, Gardener MR,  
713 Carroll SP, Thompson K, Pickett STA, Stromberg JC, Tredici P Del, Suding KN, Ehrenfeld JG, Philip  
714 Grime J, Mascaro J, Briggs JC. 2011. Don’t judge species on their origins. *Nature* 474: 153–154.

715 Diagne C, Leroy B, Vaissière A-C, Gozlan RE, Roiz D, Jarić I, Salles J-M, Bradshaw CJA, Courchamp F.  
716 2021. High and rising economic costs of biological invasions worldwide. *Nature* 592: 571–576.

717 Díaz S, Settele J, Brondízio ES, Ngo HT, Agard J, Arneeth A, Balvanera P, Brauman KA, Butchart SHM, Chan  
718 KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D,  
719 Pfaff A, Polasky S, Purvis A, Razaque J, Reyers B, Chowdhury RR, Shin Y-J, Visseren-Hamakers I, Willis  
720 KJ, Zayas CN. 2019. Pervasive human-driven decline of life on Earth points to the need for transformative  
721 change. *Science* 366: eaax3100.

722 Didham RK, Tylianakis JM, Hutchison MA, Ewers RM, Gemmill NJ. 2005. Are invasive species the drivers  
723 of ecological change? *Trends in Ecology & Evolution* 20: 470–474.

724 Djuraeva M, Catedral L. 2020. Habitus and imagined ideals: Attending to (un)consciousness in discourses of  
725 (non)nativeness. *International Multilingual Research Journal* 14: 270–285.

726 Doherty TS, Hays GC, Driscoll DA. 2021. Human disturbance causes widespread disruption of animal  
727 movement. *Nature Ecology & Evolution* 5: 513–519.

728 Dunn M, Marzano M, Forster J, Gill RMA. 2018. Public attitudes towards “pest” management: Perceptions on  
729 squirrel management strategies in the UK. *Biological Conservation* 222: 52–63.

730 Early R, Bradley BA, Dukes JS, Lawler JJ, Olden JD, Blumenthal DM, Gonzalez P, Grosholz ED, Ibañez I,  
731 Miller LP, Sorte CJB, Tatem AJ. 2016. Global threats from invasive alien species in the twenty-first century  
732 and national response capacities. *Nature Communications* 7: 12485.

733 Ehrenfeld JG. 2010. Ecosystem consequences of biological invasions. *Annual Review of Ecology, Evolution,*  
734 *and Systematics* 41: 59–80.

735 Ens NJ, Harvey B, Davies MM, Thomson HM, Meyers KJ, Yakimishyn J, Lee LC, McCord ME, Gerwing TG.  
736 2022. The Green Wave: reviewing the environmental impacts of the invasive European green crab (*Carcinus*  
737 *maenas*) and potential management approaches. *Environmental Reviews* 30: 306–322.

738 Epanchin-Niell RS. 2017. Economics of invasive species policy and management. *Biological Invasions* 19:  
739 3333–3354.

740 Essl F, Dullinger S, Genovesi P, Hulme PE, Jeschke JM, Katsanevakis S, Kühn I, Lenzner B, Pauchard A,  
741 Pyšek P, Rabitsch W, Richardson DM, Seebens H, van Kleunen M, van der Putten WH, Vilà M, Bacher S.  
742 2019. A conceptual framework for range-expanding species that track human-induced environmental  
743 change. *BioScience* 69: 908–919.

744 Essl F, Latombe G, Lenzner B, Pagad S, Seebens H, Smith K, Wilson JRU, Genovesi P. 2020. The Convention  
745 on Biological Diversity (CBD)’s Post-2020 target on invasive alien species – what should it include and  
746 how should it be monitored? *NeoBiota* 62: 99–121.

747 Everard M, Pinder AC, Raghavan R, Kataria G. 2019. Are well-intended Buddhist practices an under-  
748 appreciated threat to global aquatic biodiversity? *Aquatic Conservation: Marine and Freshwater Ecosystems*  
749 29: 136–141.

750 Everts T, Van Driessche C, Neyrinck S, Haegeman A, Ruttink T, Jacquemyn H, Brys R. 2024. Phenological  
751 mismatches mitigate the ecological impact of a biological invader on amphibian communities. *Ecological*  
752 *Applications* 34: e3017.

753 Fenoglio S, Boano G, Delmastro GB. 2018. Conservation and prejudice: why adopt double standards for fish  
754 and homoeothermic vertebrates? *The European Zoological Journal* 85: 226–227.

755 Fobert E, Fox MG, Ridgway M, Copp GH. 2011. Heated competition: how climate change will affect non-  
756 native pumpkinseed *Lepomis gibbosus* and native perch *Perca fluviatilis* interactions in the U.K. *Journal of*  
757 *Fish Biology* 79: 1592–1607.

758 Foley SF, Gronenborn D, Andreae MO, Kadereit JW, Esper J, Scholz D, Pöschl U, Jacob DE, Schöne BR,  
759 Schreg R, Vött A, Jordan D, Lelieveld J, Weller CG, Alt KW, Gaudzinski-Windheuser S, Bruhn K-C, Tost  
760 H, Sirocko F, Crutzen PJ. 2013. The Palaeoanthropocene – The beginnings of anthropogenic environmental  
761 change. *Anthropocene* 3: 83–88.

762 Franco A, Malhotra N, Simonovits G. 2014. Publication bias in the social sciences: Unlocking the file drawer.  
763 *Science* 345: 1502–1505.

764 Frank DM. 2021. Disagreement or denialism? “Invasive species denialism” and ethical disagreement in  
765 science. *Synthese* 198: 6085–6113.

766 Frawley J, McCalman I. 2014. Rethinking invasion ecologies from the environmental humanities. London:  
767 Routledge.

768 Gadgil M, Berkes F, Folke C. 1993. Indigenous knowledge for biodiversity conservation. Pages 506-511 in  
769 *Foundations of Socio-Environmental Research. AMBIO-STOCKHOLM- 22*: 151–151.

770 García-Llorente M, Martín-López B, Nunes PALD, González JA, Alcorlo P, Montes C. 2011. Analyzing the  
771 social factors that influence willingness to pay for invasive alien species management under two different  
772 strategies: eradication and prevention. *Environmental Management* 48: 418–435.

773 Gbedomon RC, Salako VK, Schlaepfer MA. 2020. Diverse views among scientists on non-native species.  
774 *NeoBiota* 54: 49–69.

775 Golebie EJ, van Riper CJ, Arlinghaus R, Gaddy M, Jang S, Kochalski S, Lu Y, Olden JD, Stedman R, Suski  
776 C. 2022. Words matter: a systematic review of communication in non-native aquatic species literature.  
777 *NeoBiota* 74: 1–28.

778 Goodenough A. 2010. Are the ecological impacts of alien species misrepresented? A review of the “native  
779 good, alien bad” philosophy. *Community Ecology* 11: 13–21.

780 Gozlan RE. 2008. Introduction of non-native freshwater fish: is it all bad? *Fish and Fisheries* 9: 106–115.

781 Gozlan RE. 2017. Interference of Non-native Species with Fisheries and Aquaculture. Pages 119–137 in *Impact*  
782 *of Biological Invasions on Ecosystem Services*. Springer International Publishing.

783 Graf M. 2022. Are humans an invasive species? How the development of our world has continuously  
784 encroached on wildlife. *Comm-entary* 18: 13–13.

785 Green SJ, Grosholz ED. 2021. Functional eradication as a framework for invasive species control. *Frontiers in*  
786 *Ecology and the Environment* 19: 98–107.

787 Guareschi S, Mathers KL, South J, Navarro LM, Renals T, Hiley A, Antonsich M, Bolpagni R, Bortolus A,  
788 Genovesi P, Jere A, Madzivanzira TC, Phaka FM, Novoa A, Olden JD, Saccó M, Shackleton RT, Vilà M,  
789 Wood PJ. 2024. Framing challenges and polarized issues in invasion science: toward an interdisciplinary  
790 agenda. *BioScience* biae084.

791 Haubrock PJ, Carneiro L, Macêdo RL, Balzani P, Soto I, Rasmussen JJ, Wiberg-Larsen P, Csabai Z, Várbiro  
792 G, Murphy JF, Jones JI, Verdonschot RCM, Verdonschot P, van der Lee G, Ahmed DA. 2023. Advancing  
793 our understanding of biological invasions with long-term biomonitoring data. *Biological Invasions* 25:  
794 3637–3649.

795 Haubrock PJ, Kurtul I, Macêdo RL, Mammola S, Franco ACS, Soto I. 2024a. Competency in invasion science:  
796 addressing stagnation challenges by promoting innovation and creative thinking. *Environmental*  
797 *Management* 74: 916-927.

798 Haubrock PJ, Oficialdegui FJ, Zeng Y, Patoka J, Yeo DCJ, Kouba A. 2021. The redclaw crayfish: A prominent  
799 aquaculture species with invasive potential in tropical and subtropical biodiversity hotspots. *Reviews in*  
800 *Aquaculture* 13: 1488–1530.

801 Haubrock PJ, Soto I, Ahmed DA, Ansari AR, Tarkan AS, Kurtul I, Macêdo RL, Lázaro-Lobo A, Toutain M,  
802 Parker B, Błońska D, Guareschi S, Cano-Barbacil C, Dominguez Almela V, Andreou D, Moyano J, Akalın  
803 S, Kaya C, Bayçelebi E, Yoğurtçuoğlu B, Briski E, Aksu S, Emiroğlu Ö, Mammola S, De Santis V,  
804 Kourantidou M, Pincheira-Donoso D, Britton JR, Kouba A, Dolan EJ, Kirichenko NI, García-Berthou E,  
805 Renault D, Fernandez RD, Yapıcı S, Giannetto D, Nuñez MA, Hudgins EJ, Pergl J, Milardi M, Musolin  
806 DL, Cuthbert RN. 2024b. Biological invasions are a population-level rather than a species-level  
807 phenomenon. *Global Change Biology* 30: e17312.

808 Haubrock PJ, Soto I, Kurtul I, Kouba A. 2024c. Are long-term biomonitoring efforts overlooking crayfish in  
809 European rivers? *Environmental Sciences Europe* 36: 70.

810 Haubrock PJ, Soto I, Tarkan AS, Macêdo RL, Kouba A, Cuthbert RN, Briski E, Everts T, Kurtul I. 2024d.  
811 Socioeconomic prerequisites determine national long-term biomonitoring efforts. *Journal of Environmental*  
812 *Management* 370: 122431.

813 Heger T, Trepl L. 2003. Predicting Biological Invasions. *Biological Invasions* 5: 301–309.

814 Hirsch PE, N’Guyen A, Adrian-Kalchhauser I, Burkhardt-Holm P. 2016. What do we really know about the  
815 impacts of one of the 100 worst invaders in Europe? A reality check. *Ambio* 45: 267–279.

816 Hoffmann BD. 2010. Ecological restoration following the local eradication of an invasive ant in northern  
817 Australia. *Biological Invasions* 12: 959–969.

818 Hossack BR, Hall D, Crawford CL, Goldberg CS, Muths E, Sigafus BH, Chambert T. 2023. Successful  
819 eradication of invasive American bullfrogs leads to coextirpation of emerging pathogens. *Conservation*  
820 *Letters* 16: e12970.

821 Hulme PE. 2007. Biological invasions in Europe: drivers, pressures, states, impacts and responses. Pages 56–  
822 80 in *Biodiversity under threat*, vol. 25.

823 Hume JB, Almeida PR, Buckley CM, Criger LA, Madenjian CP, Robinson KF, Wang CJ, Muir AM. 2021.  
824 Managing native and non-native sea lamprey (*Petromyzon marinus*) through anthropogenic change: A  
825 prospective assessment of key threats and uncertainties. *Journal of Great Lakes Research* 47: 704–722.

826 Hyatt L. 2002. Nature out of place: Biological invasions in the global age. *The Quarterly Review of Biology*  
827 77: 218–219.

828 IMO. 2017. International Convention for the Control and Management of Ships Ballast Water and Sediments.

829 Inglis MI. 2020. Wildlife ethics and practice: why we need to change the way we talk about ‘invasive species’.  
830 *Journal of Agricultural and Environmental Ethics* 33: 299–313.

831 Intemann K. 2022. Understanding the problem of “hype”: exaggeration, values, and trust in science. *Canadian*  
832 *Journal of Philosophy* 52: 279–294.

833 Ioannidis JPA. 2012. Why science is not necessarily self-correcting. *Perspectives on Psychological Science* 7:  
834 645–654.

835 Jarić I, Courchamp F, Correia RA, Crowley SL, Essl F, Fischer A, González-Moreno P, Kalinkat G, Lambin  
836 X, Lenzner B, Meinard Y, Mill A, Musseau C, Novoa A, Pergl J, Pyšek P, Pyšková K, Robertson P, von  
837 Schmalensee M, Shackleton RT, Stefansson RA, Štajerová K, Veríssimo D, Jeschke JM. 2020. The role of  
838 species charisma in biological invasions. *Frontiers in Ecology and the Environment* 18: 345–353.

839 Jenkins DG, Bevan HR, Chen W, Hart JD, Lindsay A, Macamo L, Negash M, Ohyama L, Pandolfi A, Zaragoza  
840 G. 2024. Biogeography of the world’s worst invasive species has spatially biased knowledge gaps but is  
841 predictable. *Frontiers of Biogeography* 16.

842 Jivoff P. 2002. Global Invader: The European Green Crab. *The Quarterly Review of Biology* 77: 471–472.

843 Kaiser B, Roumasset J. 2002. Optimal public control of exotic species: preventing the brown tree snake from  
844 invading Hawaii in Proceedings of the 77<sup>th</sup> Annual Western Agricultural Economic Association  
845 International Conference. June 2002.

846 Kaiser BA, Kourantidou M. 2021. Invasive alien species in changing marine Arctic economies and ecosystems.  
847 *CABI Reviews*.

848 Karst J, Jones MD, Hoeksema JD. 2023. Positive citation bias and overinterpreted results lead to  
849 misinformation on common mycorrhizal networks in forests. *Nature Ecology & Evolution* 7: 501–511.

850 Katsanevakis S, Poursanidis D, Hoffman R, Rizgalla J, Rothman SB-S, Levitt-Barmats Y, Hadjioannou L,  
851 Trkov D, Garmendia JM, Rizzo M, Bartolo AG, Bariche M, Tomas F, Kleitou P, Schembri PJ, Kletou D,  
852 Tiralongo F, Pergent C, Pergent G, Azzurro E, Bilecenoglu M, Lodola A, Ballesteros E, Gerovasileiou V,  
853 Verlaque M, Occhipinti-Ambrogi A, Kytinou E, Dailianis T, Ferrario J, Crocetta F, Jimenez C, Evans J,  
854 Ragkousis M, Lipej L, Borg JA, Dimitriadis C, Chatzigeorgiou G, Albano PG, Kalogirou S, Bazairi H,  
855 Espinosa F, Ben Souissi J, Tsiamis K, Badalamenti F, Langeneck J, Noel P, Deidun A, Marchini A,  
856 Skouradakis G, Royo L, Sini M, Bianchi CN, Sghaier Y-R, Ghanem R, Doumpas N, Zaouali J, Tsirintanis  
857 K, Papadakis O, Morri C, Çinar ME, Terrados J, Insacco G, Zava B, Soufi-Kechaou E, Piazza L, Ounifi Ben  
858 Amor K, Andriotis E, Gambi MC, Ben Amor MM, Garrabou J, Linares C, Fortič A, Digenis M, Cebrian E,  
859 Fourt M, Zotou M, Castriota L, Di Martino V, Rosso A, Pipitone C, Falautano M, García M, Zakhama-  
860 Sraieb R, Khamassi F, Mannino AM, Ktari MH, Kosma I, Rifi M, Karachle PK, Yapıcı S, Bos AR, Balistreri  
861 P, Ramos Esplá AA, Tempesti J, Inglese O, Giovos I, Damalas D, Benhissoune S, Huseyinoglu MF, Rjiba-  
862 Bahri W, Santamaría J, Orlando-Bonaca M, Izquierdo A, Stamouli C, Montefalcone M, Cerim H, Golo R,

863 Tsioli S, Orfanidis S, Michailidis N, Gaglioti M, Taşkın E, Mancuso E, Žunec A, Cvitković I, Filiz H,  
864 Sanfilippo R, Siapatis A, Mavrič B, Karaa S, Türker A, Monniot F, Verdura J, El Ouamari N, Selfati M,  
865 Zenetos A. 2020. Unpublished Mediterranean records of marine alien and cryptogenic species. *BioInvasions*  
866 *Records* 9: 165–182.

867 Kelsch A, Takahashi Y, Dasgupta R, Mader AD, Johnson BA, Kumar P. 2020. Invasive alien species and local  
868 communities in socio-ecological production landscapes and seascapes: A systematic review and analysis.  
869 *Environmental Science & Policy* 112: 275–281.

870 Kim CS, Lubowski RN, Lewandrowski J, Eiswerth ME. 2006. Prevention or control: optimal government  
871 policies for invasive species management. *Agricultural and Resource Economics Review* 35: 29–40.

872 Kimmel K, Avolio ML, Ferraro PJ. 2023. Empirical evidence of widespread exaggeration bias and selective  
873 reporting in ecology. *Nature Ecology & Evolution* 7: 1525–1536.

874 Kopf RK, Nimmo DG, Humphries P, Baumgartner LJ, Bode M, Bond NR, Byrom AE, Cucherousset J, Keller  
875 RP, King AJ, McGinness HM, Moyle PB, Olden JD. 2017. Confronting the risks of large-scale invasive  
876 species control. *Nature Ecology & Evolution* 1: 0172.

877 Koprina H, Coghlan S. 2022. Invasion biology and its discontents: Human supremacy, language, and animal  
878 treatment. *Visions for Sustainability* 17: 6512.

879 Korres NE, Burgos NR, Travlos I, Vurro M, Gitsopoulos TK, Varanasi VK, Duke SO, Kudsk P, Brabham C,  
880 Rouse CE, Salas-Perez R. 2019. New directions for integrated weed management: Modern technologies,  
881 tools and knowledge discovery. *Advances in Agronomy* 155: 243-319.

882 Kourantidou M, Haubrock PJ, Cuthbert RN, Bodey TW, Lenzner B, Gozlan RE, Nuñez MA, Salles J-M,  
883 Diagne C, Courchamp F. 2022. Invasive alien species as simultaneous benefits and burdens: trends,  
884 stakeholder perceptions and management. *Biological Invasions* 24: 1905–1926.

885 Kourantidou M, Kaiser BA. 2021. Allocation of research resources for commercially valuable invasions:  
886 Norway's red king crab fishery. *Fisheries Research* 237: 105871.

887 Kueffer C, Larson BMH. 2014. Responsible use of language in scientific writing and science communication.  
888 *BioScience* 64: 719–724.

889 Kurtul I, Haubrock PJ. 2024. The need of centralized coordination to counter biological invasions in the  
890 European Union. *Environmental Sciences Europe* 36: 129.

891 Lafferty KD, McLaughlin JP, Gruner DS, Bogar TA, Bui A, Childress JN, Espinoza M, Forbes ES, Johnston  
892 CA, Klope M, Miller-ter Kuile A, Lee M, Plummer KA, Weber DA, Young RT, Young HS. 2018. Local  
893 extinction of the Asian tiger mosquito (*Aedes albopictus*) following rat eradication on Palmyra Atoll.  
894 *Biology Letters* 14: 20170743.

895 Larson BMH. 2007. An alien approach to invasive species: objectivity and society in invasion biology.  
896 *Biological Invasions* 9: 947–956.

897 Larson ER, Graham BM, Achury R, Coon JJ, Daniels MK, Gambrell DK, Jonasen KL, King GD, LaRacunte  
898 N, Perrin-Stowe TI, Reed EM, Rice CJ, Ruzi SA, Thairu MW, Wilson JC, Suarez A V. 2020. From eDNA  
899 to citizen science: emerging tools for the early detection of invasive species. *Frontiers in Ecology and the*  
900 *Environment* 18: 194–202.

901 Latombe G, Arbieu U, Bacher S, Canessa S, Courchamp F, Dullinger S, Glaser M, Lenzner B, Jarić I, Schertler  
902 A, Essl F, Wilson JR. 2024. Clarifying ethical stances in conservation: a trolley problem thought  
903 experiment. *EcoEvoRxiv* [Preprint.] 24 May 2024. [accessed 6 November 2024] Available from:  
904 <https://doi.org/10.32942/x2dp54>

905 Leccardi C, Jedlowski P, Cavalli A. 2023. Memory and Future through the Generations. Pages 80–112 in  
906 *Exploring New Temporal Horizons*. Bristol University Press.

907 Leung B, Lodge DM, Finnoff D, Shogren JF, Lewis MA, Lamberti G. 2002. An ounce of prevention or a pound  
908 of cure: bioeconomic risk analysis of invasive species. *Proceedings of the Royal Society of London. Series*  
909 *B: Biological Sciences* 269: 2407–2413.

910 Levine JM, D’Antonio CM. 2003. Forecasting biological invasions with increasing international trade.  
911 *Conservation Biology* 17: 322–326.

912 Li X, Liu X, Kraus F, Tingley R, Li Y. 2016. Risk of biological invasions is concentrated in biodiversity  
913 hotspots. *Frontiers in Ecology and the Environment* 14: 411–417.

914 Liu X, McGarrity ME, Li Y. 2012. The influence of traditional Buddhist wildlife release on biological  
915 invasions. *Conservation Letters* 5: 107–114.

916 Lockwood JA. 1996. The ethics of biological control: Understanding the moral implications of our most  
917 powerful ecological technology. *Agriculture and Human Values* 13: 2–19.

918 Lockwood JL, Hoopes MF, Marchetti MP. 2013. *Invasion ecology*. John Wiley & Sons.

919 Lockwood JL, Welbourne DJ, Romagosa CM, Cassey P, Mandrak NE, Strecker A, Leung B, Stringham OC,  
920 Udell B, Episcopio-Sturgeon DJ, Tlusty MF, Sinclair J, Springborn MR, Pienaar EF, Rhyne AL, Keller R.  
921 2019. When pets become pests: the role of the exotic pet trade in producing invasive vertebrate animals.  
922 *Frontiers in Ecology and the Environment* 17: 323–330.

923 Lodge DM, Williams S, MacIsaac HJ, Hayes KR, Leung B, Reichard S, Moyle PB, Smith M, Andow DA,  
924 Carlton JT, McMichael A. 2006. Biological invasions: recommendations for US policy and management.  
925 *Ecological Applications* 16: 2035–2054.

926 Lohr MT, Davis RA. 2018. Anticoagulant rodenticide use, non-target impacts and regulation: A case study  
927 from Australia. *Science of the Total Environment* 634: 1372–1384.

928 Lowe S, Browne M, Boudjelas S, De Poorter M. 2000. 100 of the world’s worst invasive alien species: a  
929 selection from the global invasive species database. Auckland: Invasive Species Specialist Group.

930 MacDougall AS, Turkington R. 2005. Are invasive species the drivers or passengers of change in degraded  
931 ecosystems? *Ecology* 86: 42–55.

932 Madhok A. 2021. Globalization, de-globalization, and re-globalization: Some historical context and the impact  
933 of the COVID pandemic. *BRQ Business Research Quarterly* 24: 199–203.

934 Madzivanzira TC, South J, Ellender BR, Chalmers R, Chisule G, Coppinger CR, Khaebeb FH, Jacobs FJ,  
935 Chomba M, Musando B, Mwale C, Nihwatiwa T, Rennie CL, Richardson N, Weyl OLF. 2021. Distribution  
936 and establishment of the alien Australian redclaw crayfish, *Cherax quadricarinatus*, in the Zambezi Basin.  
937 *Aquatic Conservation: Marine and Freshwater Ecosystems* 31: 3156–3168.

938 Magellan K. 2019. Prayer animal release: An understudied pathway for introduction of invasive aquatic species.  
939 *Aquatic Ecosystem Health & Management* 22: 452–461.

940 Maguire LA. 2004. What can decision analysis do for invasive species management? *Risk Analysis* 24: 859–  
941 868.

942 Marean CW. 2015. The most invasive species of all. *Scientific American* 313: 32–39.

943 Marris E. 2013. *Rambunctious garden: saving nature in a post-wild world*. Bloomsbury Publishing USA.

944 Martinez B, Reaser JK, Dehgan A, Zamft B, Baisch D, McCormick C, Giordano AJ, Aicher R, Selbe S. 2020.  
945 Technology innovation: advancing capacities for the early detection of and rapid response to invasive  
946 species. *Biological Invasions* 22: 75–100.

947 Mashar A, Aryasa S. 2021. Management policy of invasive species red claw crayfish (*Cherax quadricarinatus*)  
948 at Lido Lake, Bogor Regency. *IOP Conference Series: Earth and Environmental Science* 744: 012090.

949 Mattingly KZ, Pelletier TA, Lanterman J, Frevola D, Stucke B, Kinney K, Schwartz R, Spacht D, Dixon G,  
950 Hovick SM. 2020. Disconnects between Communicated Impact and Ecological Impact of Biological  
951 Invasions. *BioScience* 70: 252–263.

952 McGeoch MA, Genovesi P, Bellingham PJ, Costello MJ, McGrannachan C, Sheppard A. 2016. Prioritizing  
953 species, pathways, and sites to achieve conservation targets for biological invasion. *Biological Invasions*  
954 18: 299–314.

955 Meinard Y, Coq S, Schmid B. 2019. The Vagueness of “Biodiversity” and Its Implications in Conservation  
956 Practice. *From Assessing to Conserving Biodiversity: Conceptual and Practical Challenges*: 353-374.

957 Meyerson LA, Mooney HA. 2007. Invasive alien species in an era of globalization. *Frontiers in Ecology and*  
958 *the Environment*: 5, 199-208.

959 Meyerson LA, Pauchard A, Brundu G, Carlton JT, Hierro JL, Kueffer C, Pandit MK, Pyšek P, Richardson DM,  
960 Packer JG. 2022. Moving Toward Global Strategies for Managing Invasive Alien Species. Pages 331–360  
961 in *Global Plant Invasions*. Springer International Publishing.

962 Nicolosi G, Mammola S, Verbrugge L, Isaia M. 2023. Aliens in caves: the global dimension of biological  
963 invasions in subterranean ecosystems. *Biological Reviews* 98: 849–867.

964 Nunes AL, Zengeya TA, Hoffman AC, Measey GJ, Weyl OLF. 2017. Distribution and establishment of the  
965 alien Australian redclaw crayfish, *Cherax quadricarinatus*, in South Africa and Swaziland. PeerJ 5: e3135.

966 Nuñez MA, Dimarco RD, Simberloff D. 2018. Why Some Exotic Species Are Deeply Integrated into Local  
967 Cultures While Others Are Reviled. From Biocultural Homogenization to Biocultural Conservation: 219–  
968 231.

969 Nuñez MA, Pauchard A. 2010. Biological invasions in developing and developed countries: does one model  
970 fit all? Biological Invasions 12: 707–714.

971 Nuñez MA, Simberloff D. 2005. Invasive Species and the Cultural Keystone Species Concept. Ecology and  
972 Society 10: 4.

973 Oficialdegui FJ, South J, Courchamp F, Clavero M. 2024. Nativeness is a binary concept —Invasiveness and  
974 its management are not. Biological Conservation 294: 110631.

975 Olden JD, Comte L, Giam X. 2018. The Homogocene: a research prospectus for the study of biotic  
976 homogenisation. NeoBiota 37: 23–36.

977 O’Loughlin LS, Green PT. 2017. Secondary invasion: When invasion success is contingent on other invaders  
978 altering the properties of recipient ecosystems. Ecology and Evolution 7: 7628–7637.

979 Olszańska A, Solarz W, Najberek K. 2016. To kill or not to kill—Practitioners’ opinions on invasive alien  
980 species management as a step towards enhancing control of biological invasions. Environmental Science &  
981 Policy 58: 107–116.

982 Paasche Ø, Österblom H. 2019. Unsustainable science. One Earth 1: 39–41.

983 Palacio FX, Maragliano RE, Montalti D. 2016. Functional role of the invasive European Starling, *Sturnus*  
984 *vulgaris*, in Argentina. Emu 116: 387–393.

985 Papeş M, Sällström M, Asplund TR, Vander Zanden MJ. 2011. Invasive species research to meet the needs of  
986 resource management and planning. Conservation Biology 25: 867–872.

987 Park H-S, Kim B-R, Lee J-S, Chung H-U. 2020. A Study on the industrial competitiveness of ballast water  
988 management system in compliance with the international maritime organization ballast water management  
989 convention in Korea. Journal of the Korean Society of Marine Environment and Safety 26: 483–492.

990 Parke E, Russell J. 2018. Ethical responsibilities in invasion biology. The Ecological Citizen 2: 17–19.

991 Parker TH, Forstmeier W, Koricheva J, Fidler F, Hadfield JD, Chee YE, Kelly CD, Gurevitch J, Nakagawa S.  
992 2016. Transparency in ecology and evolution: real problems, real solutions. Trends in Ecology & Evolution  
993 31: 711–719.

994 Parkes JP, Panetta FD. 2009. Eradication of invasive species: progress and emerging issues in the 21<sup>st</sup> century.  
995 Invasive species management. A handbook of principles and techniques. Oxford University Press.

996 Pattemore DE, Wilcove DS. 2012. Invasive rats and recent colonist birds partially compensate for the loss of  
997 endemic New Zealand pollinators. *Proceedings of the Royal Society B: Biological Sciences* 279: 1597–  
998 1605.

999 Pauly D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. *Trends in Ecology & Evolution* 10.  
1000 Pennisi E. 2024. The global war on island rats. *Science (New York, NY)* 385: 1290–1291.

1001 Peretti JH. 1998. Nativism and nature: rethinking biological invasion. *Environmental Values* 7: 183–192.

1002 Pereyra PJ, de la Barra P, Amione LLD, Arcángel A, Marelló Buch BM, Rodríguez E, Mazzolari A, Maldonado  
1003 MA, Hünicken L, Wallach AD. 2024. Systematic and persistent bias against introduced species. *BioScience*  
1004 74: 44–53.

1005 Pergl J, Pyšek P, Essl F, Jeschke JM, Courchamp F, Geist J, Hejda M, Kowarik I, Mill A, Musseau C, Pipek P,  
1006 Saul W, von Schmalensee M, Strayer D. 2020. Need for routine tracking of biological invasions.  
1007 *Conservation Biology* 34: 1311–1314.

1008 Pietrzyk-Kaszyńska A, Olszańska A, Najberek K, Maciaszek R, Solarz W. 2023. What starts with laughter  
1009 ends in tears: Invasive alien species regulations should not hinder scientific research. *Conservation Letters*  
1010 17: e12986.

1011 Pocock MJ, Marzano M, Bullas-Appleton E, Dyke A, De Groot M, Shuttleworth CM, White R. 2020. Ethical  
1012 dilemmas when using citizen science for early detection of invasive tree pests and diseases. *Management of*  
1013 *Biological Invasions* 11: 720–732.

1014 Pyšek P. 1995. On the terminology used in plant invasion studies. *Plant invasions: general aspects and special*  
1015 *problems*: 3, 71–81.

1016 Pyšek P, Richardson DM, Pergl J, Jarošík V, Sixtová Z, Weber E. 2008. Geographical and taxonomic biases in  
1017 invasion ecology. *Trends in Ecology & Evolution* 23: 237–244.

1018 Ready R, Lauber TB, Poe G, Rudstam L, Stedman R, Connelly N. 2016. Impacts of aquatic invasive species  
1019 on sport fish and recreational fishing in the Great Lakes: possible future scenarios. HDRU Publ. No. 16-1.  
1020 Dept. of Nat. Resour., Coll. Agric. and Life Sci., Cornell Univ., Ithaca, N.Y. 91 pp

1021 Reaser JK, Gutierrez A, Meyerson L. 2003. Biological invasions: does the cost outweigh the benefits?  
1022 *BioScience* 53: 598–600.

1023 Ricciardi A, MacIsaac HJ. 2022. Vector control reduces the rate of species invasion in the world's largest  
1024 freshwater ecosystem. *Conservation Letters* 15: e12866.

1025 Ricciardi A, Ryan R. 2018. The exponential growth of invasive species denialism. *Biological Invasions* 20:  
1026 549–553.

1027 Ricciardi A, Simberloff D. 2009. Assisted colonization is not a viable conservation strategy. *Trends in Ecology*  
1028 *& Evolution* 24: 248–253.

1029 Richardson DM, Pyšek P. 2006. Plant invasions: merging the concepts of species invasiveness and community  
1030 invasibility. *Progress in Physical Geography: Earth and Environment* 30: 409–431.

1031 Roberts PD, Diaz-Soltero H, Hemming DJ, Parr MJ, Wakefield NH, Wright HJ. 2013. What is the evidence  
1032 that invasive species are a significant contributor to the decline or loss of threatened species? A systematic  
1033 review map. *Environmental Evidence* 2: 5.

1034 Robertson PA, Mill A, Novoa A, Jeschke JM, Essl F, Gallardo B, Geist J, Jarić I, Lambin X, Musseau C, Pergl  
1035 J, Pyšek P, Rabitsch W, von Schmalensee M, Shirley M, Strayer DL, Stefansson RA, Smith K, Booy O.  
1036 2020. A proposed unified framework to describe the management of biological invasions. *Biological*  
1037 *Invasions* 22: 2633–2645.

1038 Roby B. 2018. Virtue ethics, deontology, and consequentialism.

1039 Rodríguez-Labajos B, Binimelis R, Monterroso I. 2009. Multi-level driving forces of biological invasions.  
1040 *Ecological Economics* 69: 63–75.

1041 Rout TM, Moore JL, Possingham HP, McCarthy MA. 2011. Allocating biosecurity resources between  
1042 preventing, detecting, and eradicating island invasions. *Ecological Economics* 71: 54–62.

1043 Roy HE, Pauchard A, Stoett P, Renard Truong T, Bacher S, Galil BS, Hulme PE, Ikeda T, Sankaran KV,  
1044 McGeoch MA, Meyerson LA, Nuñez MA, Ordonez A, Rahla SJ, Schwindt E, Seebens H, Sheppard AW,,  
1045 Vandvik V. 2023. Summary for Policymakers of the Thematic Assessment Report on Invasive Alien Species  
1046 and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem  
1047 Services. *IPBES Invasive Alien Species Assessment*: 1-56.

1048 Ruiz-Navarro A, Gillingham PK, Britton JR. 2016. Predicting shifts in the climate space of freshwater fishes  
1049 in Great Britain due to climate change. *Biological Conservation* 203: 33–42.

1050 Sagoff M. 2020. Fact and value in invasion biology. *Conservation Biology* 34: 581–588.

1051 Sax DF, Schlaepfer MA, Olden JD. 2022. Valuing the contributions of non-native species to people and nature.  
1052 *Trends in Ecology & Evolution* 37: 1058–1066.

1053 Schlaepfer MA. 2018. Do non-native species contribute to biodiversity? *PLOS Biology* 16: e2005568.

1054 Schlaepfer MA, Sax DF, Olden JD. 2011. The potential conservation value of non-native species. *Conservation*  
1055 *Biology* 25: 428–437.

1056 Selge S, Fischer A, van der Wal R. 2011. Public and professional views on invasive non-native species – A  
1057 qualitative social scientific investigation. *Biological Conservation* 144: 3089–3097.

1058 Shackleton RT, Larson BMH, Novoa A, Richardson DM, Kull CA. 2019. The human and social dimensions  
1059 of invasion science and management. *Journal of Environmental Management* 229: 1–9.

1060 Simberloff D. 2014. Biological invasions: What’s worth fighting and what can be won? *Ecological Engineering*  
1061 65: 112–121.

1062 Simberloff D, Bortolus A, Carlton JT, Courchamp F, Cuthbert RN, Hulme PE, Lockwood JL, Meyerson LA,  
1063 Nuñez MA, Ricciardi A, Richardson DM, Swindt E. 2024. Systematic and persistent bias against invasion  
1064 science: Framing conservation scientists. *BioScience* 74: 312–314.

1065 Simberloff D, Martin J-L, Genovesi P, Maris V, Wardle DA, Aronson J, Courchamp F, Galil B, García-Berthou  
1066 E, Pascal M, Pyšek P, Sousa R, Tabacchi E, Vilà M. 2013. Impacts of biological invasions: what’s what and  
1067 the way forward. *Trends in Ecology & Evolution* 28: 58–66.

1068 Smart AS, Tingley R, Phillips BL. 2020. Estimating the benefit of quarantine: eradicating invasive cane toads  
1069 from islands. *NeoBiota* 60: 117–136.

1070 Soga M, Gaston KJ. 2018. Shifting baseline syndrome: causes, consequences, and implications. *Frontiers in*  
1071 *Ecology and the Environment* 16: 222–230.

1072 Soga M, Gaston KJ. 2024. Global synthesis indicates widespread occurrence of shifting baseline syndrome.  
1073 *BioScience* 74: 686–694.

1074 Soga M, Gaston KJ, Fukano Y, Evans MJ. 2023. The vicious cycle of biophobia. *Trends in Ecology &*  
1075 *Evolution* 38: 512–520.

1076 Soto I, Ahmed DA, Balzani P, Cuthbert RN, Haubrock PJ. 2023. Sigmoidal curves reflect impacts and  
1077 dynamics of aquatic invasive species. *Science of the Total Environment* 872: 161818.

1078 Soto I, Balzani P, Carneiro L, Cuthbert RN, Macêdo R, Serhan Tarkan A, Ahmed DA, Bang A, Bacela-  
1079 Szychalska K, Bailey SA, Baudry T, Ballesteros-Mejia L, Bortolus A, Briski E, Britton JR, Buñic M,  
1080 Camacho-Cervantes M, Cano-Barbacil C, Copilaş-Ciocianu D, Coughlan NE, Courtois P, Csabai Z, Dalu  
1081 T, De Santis V, Dickey JWE, Dimarco RD, Falk-Andersson J, Fernandez RD, Florencio M, Franco ACS,  
1082 García-Berthou E, Giannetto D, Glavendekic MM, Grabowski M, Heringer G, Herrera I, Huang W,  
1083 Kamelamela KL, Kirichenko NI, Kouba A, Kourantidou M, Kurtul I, Laufer G, Lipták B, Liu C, López-  
1084 López E, Lozano V, Mammola S, Marchini A, Meshkova V, Milardi M, Musolin DL, Nuñez MA,  
1085 Oficialdegui FJ, Patoka J, Pattison Z, Pincheira-Donoso D, Piria M, Probert AF, Rasmussen JJ, Renault D,  
1086 Ribeiro F, Rilov G, Robinson TB, Sanchez AE, Swindt E, South J, Stoett P, Verreycken H, Vilizzi L,  
1087 Wang Y, Watari Y, Wehi PM, Weiperth A, Wiberg-Larsen P, Yapıcı S, Yoğurtçuoğlu B, Zenni RD, Galil  
1088 BS, Dick JTA, Russell JC, Ricciardi A, Simberloff D, Bradshaw CJA, Haubrock PJ. 2024. Taming the  
1089 terminological tempest in invasion science. *Biological Reviews* 99: 1357–1390.

1090 Sousa R, Nogueira JG, Padilha J. 2024. Moving from the species to the population level in biological invasions.  
1091 *Global Change Biology* 30.

1092 Spatz DR, Holmes ND, Will DJ, Hein S, Carter ZT, Fewster RM, Keitt B, Genovesi P, Samaniego A, Croll  
1093 DA, Tershy BR, Russell JC. 2022. The global contribution of invasive vertebrate eradication as a key island  
1094 restoration tool. *Scientific Reports* 12: 13391.

1095 Spear MJ, Walsh JR, Ricciardi A, Zanden MJ Vander. 2021. The invasion ecology of sleeper populations:  
1096 prevalence, persistence, and abrupt shifts. *BioScience* 71: 357–369.

1097 Speziale KL, Lambertucci SA, Carrete M, Tella JL. 2012. Dealing with non-native species: what makes the  
1098 difference in South America? *Biological Invasions* 14: 1609–1621.

1099 Stoett P. 2010. Framing bioinvasion: biodiversity, climate change, security, trade, and global governance.  
1100 *Global Governance* 16: 103.

1101 Sutcliffe C, Quinn CH, Shannon C, Glover A, Dunn AM. 2018. Exploring the attitudes to and uptake of  
1102 biosecurity practices for invasive non-native species: views amongst stakeholder organisations working in  
1103 UK natural environments. *Biological Invasions* 20: 399–411.

1104 Sutherland WJ, Wordley CFR. 2017. Evidence complacency hampers conservation. *Nature Ecology &*  
1105 *Evolution* 1: 1215–1216.

1106 Tarkan AS, Emiroğlu Ö, Aksu S, Kurtul I, Błońska D, Bayçelebi E, Soto I, Chan S, Haubrock P, Bradshaw C.  
1107 2024. Prioritising non-native and translocated species for management using the Dispersal-Origin-Status-  
1108 Impact (DOSI) scheme. *Scientific Reports* 10.1038/S41598-024-82284-Z

1109 Taylor PW. 2011. *Respect for nature: A theory of environmental ethics*. Princeton University Press.

1110 Thomsen M, Wernberg T, Olden J, Byers JE, Bruno J, Silliman B, Schiel D. 2014. Forty years of experiments  
1111 on aquatic invasive species: are study biases limiting our understanding of impacts? *NeoBiota* 22: 1–22.

1112 Tiberti R, Bogliani G, Brighenti S, Iacobuzio R, Liautaud K, Rolla M, von Hardenberg A, Bassano B. 2019.  
1113 Recovery of high mountain Alpine lakes after the eradication of introduced brook trout *Salvelinus fontinalis*  
1114 using non-chemical methods. *Biological Invasions* 21: 875–894.

1115 Torres A, Morán-López T, Rodríguez-Cabal MA, Núñez MA. 2023. Timing of invasive species removal  
1116 influences nonnative biotic resistance and trajectories of community reassembly. *Journal of Ecology* 111:  
1117 2342–2356.

1118 Urai AE, Kelly C. 2023. Rethinking academia in a time of climate crisis. *eLife* 12: e84991.

1119 Vaz AS, Kueffer C, Kull CA, Richardson DM, Schindler S, Muñoz-Pajares AJ, Vicente JR, Martins J, Hui C,  
1120 Kühn I, Honrado JP. 2017. The progress of interdisciplinarity in invasion science. *Ambio* 46: 428–442.

1121 Vilà M, Hulme PE. 2017. *Impact of Biological Invasions on Ecosystem Services*. Springer International  
1122 Publishing.

1123 Vilizzi L. 2012. The common carp, *Cyprinus carpio*, in the Mediterranean region: origin, distribution,  
1124 economic benefits, impacts and management. *Fisheries Management and Ecology* 19: 93–110.

1125 Vilizzi L, Copp GH, Hill JE, Adamovich B, Aislabie L, Akin D, Al-Faisal AJ, Almeida D, Azmai MNA, Bakiu  
1126 R, Bellati A, Bernier R, Bies JM, Bilge G, Branco P, Bui TD, Canning-Clode J, Cardoso Ramos HA,  
1127 Castellanos-Galindo GA, Castro N, Chaichana R, Chainho P, Chan J, Cunico AM, Curd A, Dangchana P,  
1128 Dashinov D, Davison PI, de Camargo MP, Dodd JA, Durland Donahou AL, Edsman L, Ekmekçi FG,

1129 Elphinstone-Davis J, Erős T, Evangelista C, Fenwick G, Ferincz Á, Ferreira T, Feunteun E, Filiz H, Forneck  
1130 SC, Gajduchenko HS, Gama Monteiro J, Gestoso I, Giannetto D, Gilles AS, Gizzi F, Glamuzina B,  
1131 Glamuzina L, Goldsmit J, Gollasch S, Gouletquer P, Grabowska J, Harmer R, Haubrock PJ, He D, Hean  
1132 JW, Herczeg G, Howland KL, İlhan A, Interesova E, Jakubčinová K, Jelmert A, Johnsen SI, Kakareko T,  
1133 Kanongdate K, Killi N, Kim J-E, Kırankaya ŞG, Kňazovická D, Kopecký O, Kostov V, Koutsikos N, Kozić  
1134 S, Kuljanishvili T, Kumar B, Kumar L, Kurita Y, Kurtul I, Lazzaro L, Lee L, Lehtiniemi M, Leonardi G,  
1135 Leuven RSEW, Li S, Lipinskaya T, Liu F, Lloyd L, Lorenzoni M, Luna SA, Lyons TJ, Magellan K,  
1136 Malmstrøm M, Marchini A, Marr SM, Masson G, Masson L, McKenzie CH, Memedemin D, Mendoza R,  
1137 Minchin D, Miossec L, Moghaddas SD, Moshobane MC, Mumladze L, Naddafi R, Najafi-Majid E, Năstase  
1138 A, Năvodaru I, Neal JW, Nienhuis S, Nimtim M, Nolan ET, Occhipinti-Ambrogi A, Ojaveer H, Olenin S,  
1139 Olsson K, Onikura N, O’Shaughnessy K, Paganelli D, Parretti P, Patoka J, Pavia RTB, Pellitteri-Rosa D,  
1140 Pelletier-Rousseau M, Peralta EM, Perdikaris C, Pietraszewski D, Piria M, Pitois S, Pompei L, Poulet N,  
1141 Preda C, Puntilla-Dodd R, Qashqaei AT, Radočaj T, Rahmani H, Raj S, Reeves D, Ristovska M, Rizevsky  
1142 V, Robertson DR, Robertson P, Ruykys L, Saba AO, Santos JM, Sarı HM, Segurado P, Semenchenko V,  
1143 Senanan W, Simard N, Simonović P, Skóra ME, Slovák Švolíková K, Smeti E, Šmídová T, Špelić I,  
1144 Srébalienė G, Stasolla G, Stebbing P, Števoe B, Suresh VR, Szajbert B, Ta KAT, Tarkan AS, Tempesti J,  
1145 Therriault TW, Tidbury HJ, Top-Karakuş N, Tricarico E, Troca DFA, Tsiamis K, Tuckett QM, Tutman P,  
1146 Uyan U, Uzunova E, Vardakas L, Velle G, Verreycken H, Vintsek L, Wei H, Weiperth A, Weyl OLF,  
1147 Winter ER, Włodarczyk R, Wood LE, Yang R, Yapıcı S, Yeo SSB, Yoğurtçuoğlu B, Yunnice ALE, Zhu Y,  
1148 Zięba G, Žitňanová K, Clarke S. 2021. A global-scale screening of non-native aquatic organisms to identify  
1149 potentially invasive species under current and future climate conditions. *Science of the Total Environment*  
1150 788: 147868.

1151 Vimercati G, Kumschick S, Probert AF, Volery L, Bacher S. 2020. The importance of assessing positive and  
1152 beneficial impacts of alien species. *NeoBiota* 62: 525–545.

1153 Wägele J-W. 2014. The necessity for biodiversity research: We are responsible for the quality of life of coming  
1154 generations. Pages 23–38 in *Concepts and values in biodiversity*. Routledge.

1155 Warren CR. 2023. Beyond ‘native v. alien’: critiques of the native/alien paradigm in the Anthropocene, and  
1156 their implications. *Ethics, Policy & Environment* 26: 287–317.

1157 Watson MJ, Watson DM. 2020. Post-Anthropocene conservation. *Trends in Ecology & Evolution* 35: 1–3.

1158 Wehi PM, Kamelamela KL, Whyte K, Watene K, Reo N. 2023. Contribution of Indigenous Peoples’  
1159 understandings and relational frameworks to invasive alien species management. *People and Nature*: 5,  
1160 1403-1414.

1161 Williamson M. 1996. *Biological invasions*. Springer Science & Business Media.

- 1162 Witt ABR. 2017. Use of Non-native Species for Poverty Alleviation in Developing Economies. Pages 295–310  
1163 in *Impact of Biological Invasions on Ecosystem Services*. Springer International Publishing.
- 1164 Wolf ID, Croft DB, Green RJ. 2019. Nature conservation and nature-based tourism: a paradox? *Environments*  
1165 6: 104.
- 1166 Vander Zanden MJ, Hansen GJA, Higgins SN, Kornis MS. 2010. A pound of prevention, plus a pound of cure:  
1167 Early detection and eradication of invasive species in the Laurentian Great Lakes. *Journal of Great Lakes*  
1168 *Research* 36: 199–205.
- 1169 Zarzyczny KM, Rius M, Williams ST, Fenberg PB. 2023. The ecological and evolutionary consequences of  
1170 tropicalisation. *Trends in Ecology & Evolution* 39: 267–279.
- 1171 Zavaleta ES, Hobbs RJ, Mooney HA. 2001. Viewing invasive species removal in a whole-ecosystem context.  
1172 *Trends in Ecology & Evolution* 16: 454–459.
- 1173 Zenni RD, Ziller SR, Pauchard A, Rodriguez-Cabal M, Nuñez MA. 2017. Invasion science in the developing  
1174 world: a response to Ricciardi et al. *Trends in Ecology & Evolution* 32: 807–808.  
1175