Conservation Biology

Consensus and controversy in the discipline of invasion science

Ross T. Shackleton[1,2,3] | **Giovanni Vimercati**[4] | **Anna F. Probert**[4] | **Sven Bacher**[4] |
Christian A. Kull[3] | **Ana Novoa**[5]

[1]Swiss Federal Institute for Forest Snow and
Landscape Research WSL, Birmensdorf, Switzerland

[2]Centre for Invasion Biology, Department of Botany
and Zoology, Stellenbosch University, Stellenbosch,
South Africa

[3]Institute of Geography and Sustainability,
University of Lausanne, Lausanne, Switzerland

[4]Department of Biology, Unit Ecology and
Evolution, University of Fribourg, Fribourg,
Switzerland

[5]Department of Invasion Ecology, Institute of
Botany, Czech Academy of Sciences, Průhonice,
Czech Republic

Correspondence
Ross T. Shackleton, Swiss Federal Institute for Forest
Snow and Landscape Research WSL, Zürcherstrasse
111, CH-8903 Birmensdorf, Switzerland.
Email: rtshackleton@gmail.com

Article impact statement: Polarization in invasion
science links to differences in values, management
approaches, terminology use, and perspective on
species' impacts.

Funding information
Swiss National Science Foundation , Grant/Award
Numbers: 31003A-179491, 31BD30-184114;
Belmont Forum-BiodivERsA Swiss National
Science Foundation; Czech Science Foundation,
Grant/Award Number: EXPRO Grant No.
19-28807X; Czech Academy of Sciences,
Grant/Award Number: Long-
termresearchdevelopmentprojectRVO67985939

Abstract

Approaches, values, and perceptions in invasion science are highly dynamic, and like in
other disciplines, views among different people can diverge. This has led to debate in the
field specifically surrounding the core themes of values, management, impacts, and termi-
nology. Considering these debates, we surveyed 698 scientists and practitioners globally
to assess levels of polarization (opposing views) on core and contentious topics. The sur-
vey was distributed online (via Google Forms) and promoted through listservs and social
media. Although there were generally high levels of consensus among respondents, there
was some polarization (scores of ≥0.39 [top quartile]). Relating to values, there was high
polarization regarding claims of invasive species denialism, whether invasive species con-
tribute to biodiversity, and how biodiversity reporting should be conducted. With regard
to management, there were polarized views on banning the commercial use of beneficial
invasive species, the extent to which stakeholders' perceptions should influence manage-
ment, whether invasive species use alone is an appropriate control strategy, and whether
eradication of invasive plants is possible. For impacts, there was high polarization con-
cerning whether invasive species drive or are a side effect of degradation and whether
invasive species benefits are understated. For terminology, polarized views related to defin-
ing invasive species based only on spread, whether species can be labeled as invasive in
their native ranges, and whether language used is too xenophobic. Factor and regression
analysis revealed that views were particularly divergent between people working on differ-
ent invasive taxa (plants and mammals) and in different disciplines (between biologists
and social scientists), between academics and practitioners, and between world regions
(between Africa and the Global North). Unlike in other studies, age and gender had a
limited influence on response patterns. Better integration globally and between disciplines,
taxa, and sectors (e.g., academic vs. practitioners) could help build broader understanding
and consensus.

KEYWORDS
conflict, environmental ethics, environmental policy and management, invasive alien species, scientific debate and
progression

Resumen

Los enfoques, valores y percepciones en el campo de las invasiones biológicas son muy
dinámicos, y como en otras disciplinas científicas, los expertos pueden tener distintas opin-
iones. Esto ha creado debates, especialmente sobre temas relacionados con valores, gestión,
impactos y terminología. Considerando estos debates, encuestamos a 698 científicos y
gestores de todo el mundo para evaluar sus niveles de polarización (opiniones opuestas)

sobre una serie de temas fundamentales y polémicos. La encuesta fue distribuida a través de internet (a través de Google Forms) y promovida por medio de listas de correo electrónico y redes sociales. Aunque, en general, hubo consenso entre los encuestados, hubo cierta polarización (puntuaciones de ≥ 0.39 [cuartil más alto]). En relación con valores, hubo una gran polarización sobre aquellas declaraciones relacionadas con el negacionismo de especies invasoras, si las especies invasoras contribuyen a aumentar la biodiversidad y cómo se deberían llevar a cabo los informes sobre biodiversidad. En relación con la gestión, hubo opiniones polarizadas sobre la prohibición del uso comercial de especies invasoras beneficiosas, si la opinión de las partes interesadas debería influir en la gestión, si el uso de especies invasoras por sí solo es una estrategia de control adecuada y si la erradicación de plantas invasoras es factible. En cuanto a impactos, hubo gran polarización en cuanto a sí las especies invasoras conducen a o son un efecto lateral de la degradación de ecosistemas y ssi los beneficios de las especies invasoras están subestimados. En cuanto a terminología, encontramos opiniones polarizadas relacionadas con definir especies invasoras exclusivamente en base a su expansión, si las especies se pueden considerar invasoras en sus rangos de distribución nativos y si el lenguaje utilizado en el campo de las invasiones biológicas es xenofóbico. Los análisis factoriales y de regresión revelaron que las opiniones de los expertos encuestados fueron particularmente divergentes entre personas que trabajan con diferentes taxones (plantas y mamíferos) en diferentes disciplinas (entre biólogos y sociólogos), entre científicos y gestores y entre regiones del mundo (entre países de África y del hemisferio Norte). A diferencia de otros estudios, la edad y el género tuvieron una influencia limitada sobre lass respuestas obtenidas. Una mejor integración global y entre disciplinas, taxones y sectores (o. e., investigadores vs. gestores) podría contribuir a alcanzar un mayor entendimiento y consenso.

PALABRAS CLAVE
conflicto, debate y desarrollo científico, especies exóticas invasoras, ética ambiental, política y gestión ambiental

INTRODUCTION

There are often different philosophies, ideologies, and approaches to environmental research and conservation management that can cause disagreement and debate (Baldauf & de Oliveira Lunardi, 2020; Lute et al., 2018; Moore et al., 2009; Sandbrook et al., 2019). Understanding different perspectives and discourses, and finding solutions to contentious issues and polarized debates, can be crucial for moving research disciplines forward (Courchamp et al., 2017; Engelhardt et al., 1987). Failure to do so can compromise the common goals and interests of opposing parties and limit scientific progress (Norberg et al., 2022).

This is true for the relatively new field of invasion science, which is the transdisciplinary study of "the causes and consequences of the introduction of organisms to the areas outside their native ranges" (Richardson & Ricciardi, 2013). In invasion science, several debates have been prevalent over the last 20 years (Frank, 2021; Gbedomon et al., 2020; Humair et al., 2014; Richardson & Ricciardi, 2013; Young & Larson, 2011), and problems with uncertainty are still common (Latombe et al., 2019; Probert et al., 2020). Addressing these debates and uncertainties is critical for reducing the negative impacts that biological invasions have on the conservation of biodiversity and ecosystems globally.

In the invasion science literature, there have been critiques and debates particularly surrounding 4 core themes that are often interrelated: values, management, impacts, and, terminology (Table 1). These debates are likely driven by contrasting personal conceptions, values, theoretical stances, work approaches, languages, and a result of disparate socioecological contexts and working conditions across the world (Gbedomon et al., 2020; Hodges, 2008; Sandbrook et al., 2019).

Like in other fields, as invasion science continues to evolve, divergence in people's views and associated disputes are expected, and indeed desirable to a certain extent, as a part of scientific progression, circulation, consolidation, and uptake (Bourdieu, 1975; Kuhn, 1962; Mace, 2014). Healthy competition and debate within a field is useful; however, it can become counterproductive if issues persist and are not properly identified and meaningfully addressed (Doran & Zimmerman, 2009). Publications with emotive titles such as "Another Call for the End of Invasion Biology" (Valéry et al., 2013) and "Non-natives: 141 Scientists Object" (Simberloff et al., 2011) suggest that major dichotomies and disagreements might exist in invasion science, which may cause challenges for the field and for associated conservation initiatives.

Studies assessing consensus among researchers in relation to global change and conservation challenges have highlighted that factors such as gender and age (Sandbrook et al., 2019), disciplinary training (Gbedomon et al., 2020), research networks (Abrahams et al., 2019), and cultural and political orientation (Carlton et al., 2015) can have a significant influence on scientific views and values as well as knowledge production and

TABLE 1 Key themes of debate in the invasion science literature*

Broad themes of debate and critique	Examples from the literature
Values	Crowley et al., 2017; Davis & Chew, 2017; Russell & Blackburn, 2017a, 2017b; Tassin et al., 2017
	Nuñez et al., 2021; Pauchard et al., 2018; Schlaepfer, 2018a, 2018b
Management	Clavero & García-Berthou, 2005; Gurevitch & Padilla, 2004; Simberloff & Stiling, 1996
	Messing & Wright, 2006
	Webber et al., 2015
Impacts	Alyokhin, 2011; Davis et al., 2011; Lerdau & Wickham, 2011; Simberloff et al., 2011
	Schlaepfer et al., 2011, 2012; Vitule et al., 2012
	Dickie et al., 2014; Kull & Tassin, 2012; Low, 2012a, 2012b
	Hulme et al., 2015; Thomas & Palmer, 2015
Terminology	Subramaniam, 2001
	Simberloff, 2003
	Gilroy et al., 2016; Hulme et al., 2017; Larson, 2005
	Essl et al., 2019; Wilson, 2020
Relating to multiple themes	Brown & Sax, 2004, 2005; Cassey et al., 2005
	Richardson et al., 2008; Warren, 2007
	Blondel et al., 2014; Simberloff & Vitule, 2014; Valéry et al., 2013; Young & Larson, 2011
	Frank et al., 2019; Guiaşu & Tindale, 2018
	Cuthbert et al., 2020; Fall, 2021; Sagoff, 2020

*The list is not exhaustive. Papers listed in the same line are debated topics with directed responses and in some cases further replies.

uptake. However, in invasion science previous research on debates within the field has often targeted only certain issues and from the perspectives of a limited set of stakeholders (e.g., Gbedomon et al., 2020; Simberloff et al., 2011; Young & Larson, 2011). Because invasion science addresses a wide range of taxa and ecosystems globally, and ranges from theoretical to applied, it is important to consider contentious issues and debates more broadly.

In light of this we aimed to identify levels of disagreement across the 4 key themes (Table 1) and the factors that might cause disagreement. In particular, we aimed to assess how different sociodemographic and work contexts affect people's views and values regarding invasion science. We expected differences in perspectives to be primarily associated with work roles and the disciplinary, geographic, and taxonomic focus of respondents.

METHODS

Survey

To identify levels of consensus and disagreement, we designed a Likert scale questionnaire composed of various statements relating to the debated topics we identified after assessing the literature. Likert scales relate to statements used in questionnaires that are answered through ranking scales (e.g., from agree to disagree) and are a common method in social science research used to assess peoples' knowledge, perceptions, and values (Nemoto & Beglar, 2014). In a half-day workshop, we brainstormed relevant statements that predominantly, but not exclusively, covered topics relating to 4 core themes: values, management, impacts, and terminology. Some statements cut across more than one of the themes, which is unavoidable given the cross-disciplinary nature of invasion science (Table 1). After the initial half-day planning workshop and the addition or removal of statements over 2 months by all authors, we created a list of 130 statements as potential candidates for the questionnaire. Following this, we had a 1-day workshop in which all authors worked to narrow down the list to ≤50 statements aiming to reduce redundancies and limit the number of questions to minimize respondent fatigue. We further revised the remaining statements to ensure they were clear and concise and covered the 4 themes adequately. We included positively and negatively worded statements to control for acquiescence bias (Winkler et al., 1982). The Likert scale had 8 response options for each statement, including s*trongly agree, agree, slightly agree, neutral, slightly disagree, disagree, strongly disagree*, and *do not know*. We tested the survey among 12 researchers and practitioners from different backgrounds (e.g., career stage, geographic region, research focus) and made further revisions based on their feedback. The final survey consisted of 47 statements, 2 open-ended questions, and 20 questions relating to the respondents' research and demographic background. The survey was in English and primarily administered online with Google Forms. An online spreadsheet version was also circulated to respondents who could not access Google Forms (e.g., in China).

The survey was distributed through different platforms such as conferences, listservers, personal email lists of the authors, and on social media to target scientists and practitioners working within invasion science. We also asked colleagues to forward the survey within their networks to increase sample sizes through snowball sampling. The online survey was available for participation over 6 months from 10 September 2019 to 10 March 2020. Incomplete responses (32) were removed, leading to a total of 698 responses for use in our final data analyses. Ethical considerations relating to voluntary and informed consent and anonymity were adhered to for this study.

Data analyses

All analyses and data visualization were performed using R 4.0.4. We calculated polarization scores ranging from 0 to 1 for each Likert statement with the package agrmt 1.42.4 (Ruedin, 2020). We classified the upper and lower quartiles as high and low polarization and the remainder as moderate polarization (low polarization ≤0.27 and high polarization ≥0.39). Higher polarization scores illustrate lower levels of consensus (i.e., increased controversy).

We used factor analysis to reduce the data set into fundamental constructs sharing common response patterns.

We performed exploratory factor analysis (EFA) on half (randomly selected) of the data set with the package psych 1.9.12 (Revelle, 2019). The results were used to test for construct validity in confirmatory factor analysis (CFA). Internal consistency and the data's appropriateness for factor analysis were assessed using Cronbach's alpha reliability coefficient and the Kaiser–Meyer–Olkin measure of sampling adequacy (KMO). These scores were adequate for further analysis (Appendix S1). To identify the optimal number of factors, we used the nScree() function from package nFactors 2.1 (Raiche & Magis, 2020) (Appendix S1), which calculates the level of agreement between multiple eigenvalue-based methods. When multiple solutions had a similar level of agreement between methods, we chose the solution with the highest number of items loading very strongly (≥0.6) on each factor (Furr, 2011) and the highest number of factors. After selecting the optimal number of factors, we obtained the factor loadings of all statements with maximum likelihood extraction with Oblimin rotation to identify statements that did not load strongly on any factor (<0.4). We removed statements that loaded poorly (<0.4) and then refitted the model to check for consistency.

After obtaining the factorial structure from the EFA analysis, we applied this to the fitting data set (second half of the data) to test for construct validity through CFA. We removed statements that did not load strongly in the CFA (<0.4) to obtain simple factorial structures as done in the EFA (Sandbrook et al., 2019). The CFA and multiple goodness-of-fit indices were computed in the package lavaan 0.6-9 (Rosseel, 2012) to determine how well the factorial structure from the EFA fitted the other half of the response database (Appendix S1). The CFA indices showed a satisfactory fit (Appendix S1); therefore, we ran a factorial analysis (maximum likelihood and Oblimin rotation) on the full data set based on the structure from the CFA with the factor.scores command from the psych package 1.9.12 (Revelle, 2019). Based on this, 4 distinct factors were retained. To broadly quantify the main attitude of the respondents within each construct, we also generated fictional scores for a hypothetical respondent who was neutral toward all statements, following Sandbrook et al. (2019).

We used multiple regression analysis to explore whether response patterns to the 4 factors vary according to respondents' sociodemographic characteristics. These characteristics included gender (female, male, other), age class (<26, 26−35, 36−45, 46−55, 56−65, >65), work focal region (Africa, Asia and the Middle East, Central and South America, Europe, North America, Oceania, multiple continents or global [>2]), work area (academic, practitioner, policy maker, research and practice, multiple, other), taxonomic expertise (plants, birds, fish, herpetofauna, invertebrates, mammals, microbes, multiple taxa, not applicable [i.e., human focus and nonspecific]), disciplinary expertise (applied, environmental science or geography, humanities, multidisciplinary, social sciences, biology, other), and experience in bioscience (yes, no). For each variable, we used the category with the highest number of responses as the baseline (Wood et al., 2022). We also performed cluster analysis with mclust 5.4.7 (Scrucca et al., 2016) to investigate whether respondents clustered into groups with contrasting response patterns across factors and whether these groups correlated with respondents' sociodemographic characteristics. Because no assumptions could be made regarding the optimal number of clusters and their geometric properties, we computed a set of candidate models characterized by different numbers of clusters (1–15) and different geometric configurations ($n = 14$, e.g., spherical, equal volume; spherical, unequal volume; ellipsoidal, equal volume and orientation) for a total of 210 models, which is the product between the different number of clusters and the different geometric configurations (Appendix S1). Models were compared based on the Bayesian information criterion (BIC), and the model with the highest BIC was chosen, as recommended in Fraley and Raftery (2007). Furthermore, we conducted chi-square analysis to explore whether respondent sociodemographic information (same variables as above) explained the best cluster solution.

RESULTS

Response group profile

Most respondents worked on multiple invasive taxa (44%), followed by those working only on plants (32%) or invertebrates (11%). Less than 10% of respondents worked solely on other taxonomic groups or were not taxon-specific researchers (i.e., focused on humans). One-third of all respondents worked in Europe (32%), followed by North America (18%), Oceania (15%), and multiple global regions (15%), with the remainder working in Asia, Middle East, Africa, and Central and South America. Most respondents had a biological science focus (84%); the rest were highly interdisciplinary or came from the social sciences and humanities. The majority of respondents were academics (61%), with the remainder working mainly in policy or practice. Most respondents (60%) had a PhD, followed by those with an MS (26%). Roughly a quarter of respondents fell into each of the following 4 age groups: 26−35, 36−45, 46−55, and 56−65; very few were younger than 26 or older than 65. There were more male (61%) than female respondents.

Consensus and polarization in views

We considered consensus and divergence in opinions according to the 4 broad themes relating to values, management, impacts, and terminology (Table 1) and in terms of polarization, where lower polarization reveals greater consensus among all respondents (Figure 1). Many of the Likert indicator statements address more than 1 of the 4 themes, and to prevent repetition, these crosscutting concepts were mentioned only under 1 theme that was considered the most relevant.

Values

There was a low polarization (good consensus) in views as to whether conflicting opinions between researchers are overstated
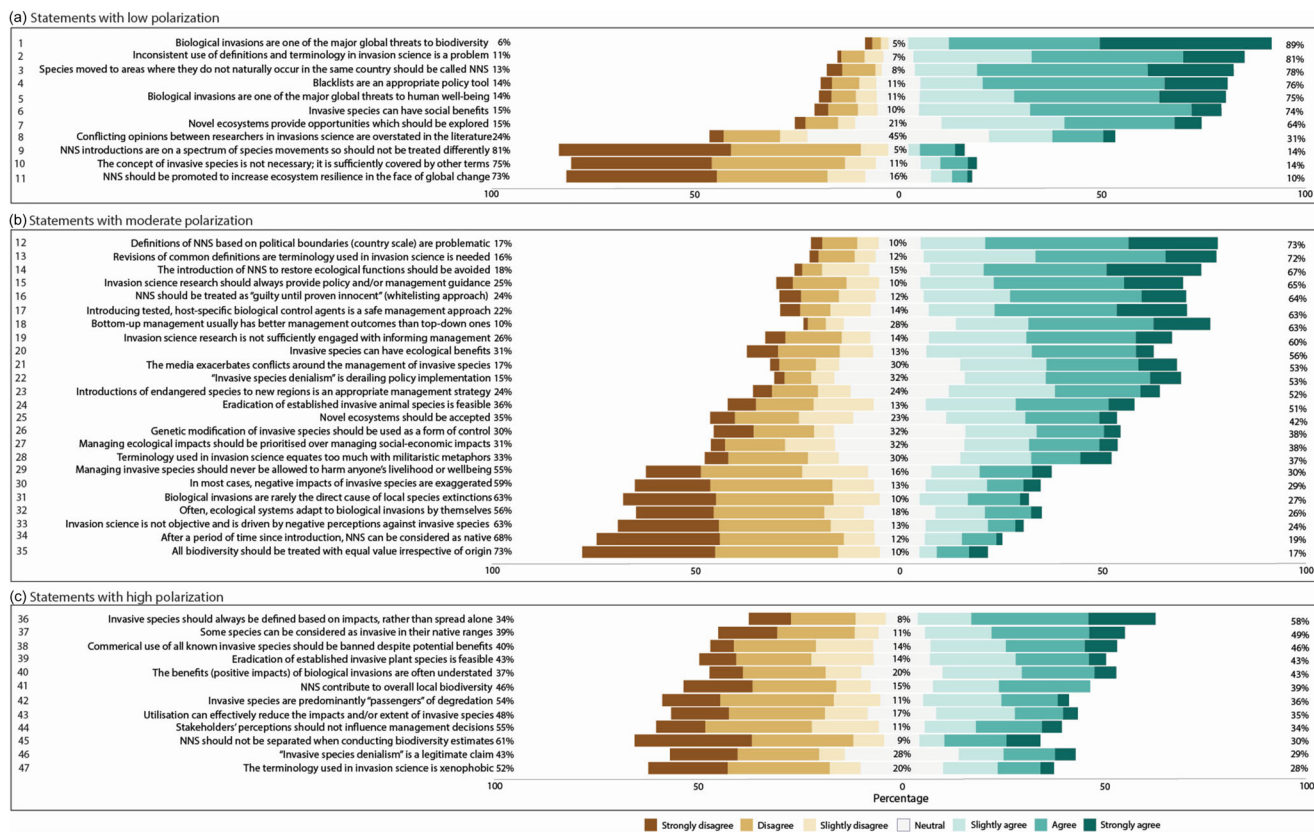
FIGURE 1 Views of survey respondents in relation to debated issues in invasion science. The 47 Likert (ranking) statements are listed and categorized as having (a) low polarization (scores ≤0.27), (b) moderate polarization (scores from 0.28 to 0.38), and (c) high polarization (scores of ≥0.39). Some of the statements have been shortened slightly for formatting reasons (original statements in the Appendix S2) (NNS, non-native species). The statements are numbered and referred to in the text, but this is not the order in which they were asked. A list of statements in order from high to low agreement and polarization scores for each statement is in Appendix S1.

in the literature or not (Q8, most respondents were neutral) (Figure 1), whether the novel ecosystem concept (i.e., places that have been altered in structure and function by human agency, including non-native species [NNS]) should be explored (Q7, 64% agree), and whether NNS introductions should not be treated as a unique concept (Q9, 81% disagree).

There was moderate polarization that all biodiversity should be treated with equal value irrespective of origin (Q35, 73% disagree), that invasive species denialism may affect policy and management (Q22, 53% agree), that invasion science is not objective (Q33, 63% disagree), whether the media can exacerbate conflicts surrounding invasive species management (Q21, 53% agree), that intentional introductions of NNS for ecological restoration should be avoided (Q14, 67% agree), and whether novel ecosystems should be accepted (Q25, 42% agree and 35% disagree).

There was high polarization in views around not separating NNS from native species in biodiversity reporting (Q45, 61% disagree and 30% agree), whether NNS species should be considered contributors to local biodiversity (Q41, 46% disagree and 39% agree), and whether invasive species denialism is a legitimate claim (Q46, 43% disagree and 29% agree).

Management

There was low polarization in views that blacklists (species regulated as innocent until proven guilty) are an appropriate policy tool (Q4, 76% agree) (Figure 1), and whether NNS should be promoted to increase ecosystem resilience (Q11, 73% disagree).

There was moderate polarization toward the whitelisting policy approach (species regulated as guilty until proven innocent) (Q16, 64% agree), whether invasion science sufficiently informs management (Q15, 60% agree), the importance of engaging different stakeholders in management responses drawing on bottom-up approaches (Q18, 63% agree), whether it is acceptable for invasive species management to harm people's livelihoods and well-being (Q29, 55% disagree and 30% agree), the prioritization of ecological impacts over social ones (Q27, 31% disagree and 38% agree, although many respondents [32%] were neutral on this point), whether invasion science should always provide policy or management guidance (Q19, 65% agree), and whether the introduction of endangered species to new locations is an appropriate management strategy (Q23, 52% agree). There was also moderate polarization as to whether biological control (Q17, 22% disagree and 63% agree) and, to a greater extent, genetic modification of invasive species are

safe control approaches (Q26, 30% disagree and 38% agree), and whether the eradication of mammals is feasible (Q24, 51% agree). For plants, there was high polarization on this point (Q39, each 43% agree and disagree).

There was also high polarization in views among respondents relating to whether commercially important but potentially invasive species should be banned (Q38, 40% disagree and 46% agree), whether stakeholder perceptions should influence management decisions (Q44, 55% disagree and 34% agree), and whether utilization alone (promoting the use of invasive species) can effectively manage invasive species (Q43, 48% disagree and 35% agree).

Impacts

There was low polarization (good consensus) that invasive species are a major global threat; however, respondents viewed them as slightly more of a biological threat (Q1, 89% agree) than a social one (Q5, 75% agree) (Figure 1). There was also a low polarization in views that invasive species can have social benefits (Q6, 74% agree), but slightly less so in relation to ecological benefits (Q20, 56% agree), where there were moderate levels of polarization. There was also moderate polarization around the view that biological invasions as a whole are rarely the direct cause of native species extinctions (Q31, 63% disagree), whether ecosystems can adapt to biological invasions naturally over time (Q32, 56% disagree), and whether the negative impacts of invasive species are exaggerated (Q30, 59% agree).

There was a high polarization in views as to whether invasive species are predominantly passengers (i.e., profit from environmental changes caused by other drivers) of impacts and change, as opposed to being key drivers of change (i.e., the cause of environmental change) (Q42, 54% disagree and 36% agree), and whether the benefits of invasive species are understated (Q40, 43% agree and 37% disagree).

Terminology

There was low polarization (good consensus) in views among respondents that biological invasions are a distinct phenomenon (Q10, 75% disagree) (Figure 1). Most respondents believed that the inconsistent use of definitions is a problem; polarization was low on this point (Q2, 81% agree). Furthermore, there was low polarization in views as to whether a species moved from one area in a country to a new area in the same country (where it does not naturally occur) should be categorized as an NNS (Q3, 78% agree) and whether using time frames to delineate native species from NNS is problematic (Q34, 68% agree).

There was moderate polarization regarding whether invasion science terminology uses too many militaristic metaphors (Q28, 33% disagree and 37% agree), whether using country borders to define NNS is problematic (Q12, 73% agree), and whether there is an overall need for revision and clarification of key definitions (Q13, 72% agree).

There was high polarization in views that terminology used in invasion science is xenophobic (Q49, 52% disagree and 28% agree), whether definitions of invasive species should always be based on impact rather than spread alone (Q36, 34% disagree and 58% agree), and whether some species can be considered invasive in their native ranges (Q37, 39% disagree and 49% agree).

Effects of respondents' sociodemographic backgrounds on their views

In some cases, sociodemographic characteristics significantly influenced the way participants responded to the 4 factors (Figure 2; Table 2). These 4 factors broadly resemble the 4 themes (Table 1) of statements (e.g., factor 1 is associated with values encompassing multiple themes, factor 2 is associated with management, factor 3 with impacts, and factor 4 with terminology).

Regression analyses

Respondents' age and gender did not significantly influence the way people answered any of the factors, although other sociodemographic factors did (Figure 2). For example, the region where respondents worked influenced their response patterns. In particular, respondents from Oceania and North America, and those who work more globally, were also more likely to respond negatively to the values factor as compared with the base group Europe (Figure 2). Respondents from Oceania and those working in multiple regions globally were more likely to answer positively to the management factor, suggesting they have a more positive outlook toward management feasibility. Furthermore, respondents working in Africa or on multiple continents were more inclined to answer positively to the impacts factor and thus were more likely to acknowledge the benefits of invasive species than those in Europe, North America, and Oceania.

Respondent work roles (e.g., academic, practitioner, policy maker) had one of the largest effects on the way statements were answered in all 4 factors (Figure 2). Nonacademics were significantly more likely to answer negatively to the values-, impact-, and terminology-related factors than the base group academics, suggesting they had different core values, were less likely to acknowledge positive impacts, and were more content with current terminology. Practitioners were also more likely to answer positively to the management factor, suggesting they considered management more feasible than academics.

The taxa that respondents primarily worked with also had significant effects on responses to statements (Figure 2). Those without a taxonomic focus (e.g., social scientists working with people, not applicable category) and those solely working on plants were more inclined to answer positively toward the values factor as compared with those working on the base group multiple taxa. Respondents working with plants and invertebrates were more likely to answer negatively to the management
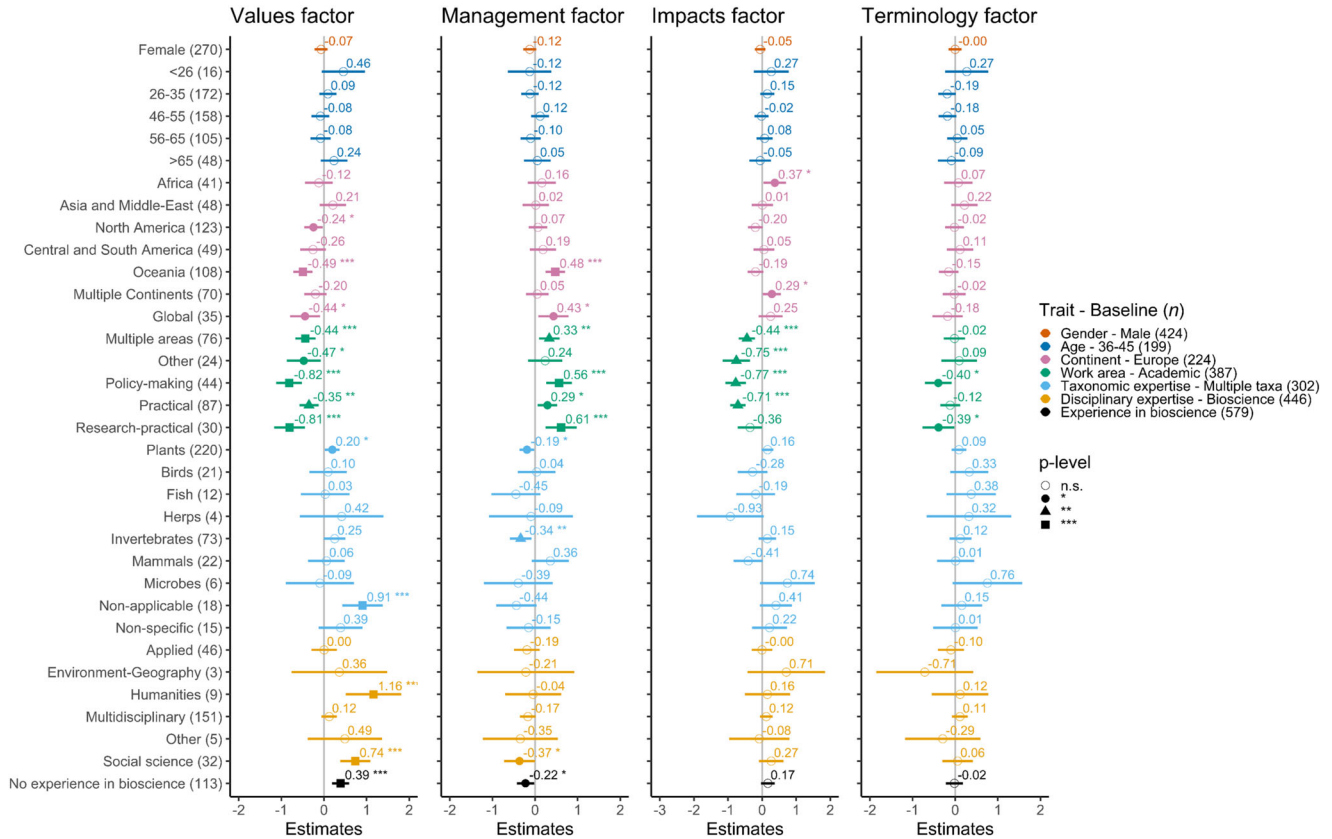
FIGURE 2 Relationship between sociodemographic characteristics of respondents and their response patterns in each of the 4 factors related to values, management, impacts, and terminology in the invasion science field (shapes and horizontal lines, mean difference from baseline logits [vertical gray line] at 95% CIs; numbers in parentheses, number of respondents in the base group; $*p < 0.05$; $**p < 0.01$; $***p < 0.001$). The categorical group with the greatest number of respondents is the baseline for each of the sociodemographic variables (base groups are in the key).

factor than those working on multiple and other taxa (e.g., mammals), implying they have a more optimistic outlook on invasive species control. Taxonomic research focus had no effect on how respondents responded to the impacts factor. Similarly, taxonomic research focus did not influence how respondents responded to the terminology factor, suggesting that definitions are generally applicable across all taxa.

Respondents' disciplinary focus significantly influenced the way they answered the statements (Figure 2). In particular, respondents from the social sciences and humanities were more inclined to answer positively toward statements in the values factor than biologists. Furthermore, social scientists were more likely to answer negatively toward the management factor, suggesting they had different expectations concerning management and eradication feasibility compared with biologists.

Cluster analyses

Additionally, cluster analysis revealed 4 groups with contrasting response patterns across the 4 factors (Figure 3). Sociodemographic characteristics associated with work area and discipline primarily explained the different groups. To easily describe the respondents in each group, we named them according to the

general trends in each group's attitudes: the reference group, challenging group, practical group, and conservative group (Figures 3 & 4). The values-, impact-, and terminology-based factors explained significant differences in clustering between groups of respondents; however, the management factor did not.

Respondents in the reference group (Figures 3 & 4) tended to disagree with value-focused statements that (values factor) (Figures 3a,b,d & 4) recognized the existence of invasive species benefits (impacts factor) (Figures 3b,c,f & 4a,c), and advocated that invasion science terminology should be revised (terminology factor) (Figures 3d–f & 4b). The relative majority of respondents fell into this group ($n = 268$) (Figure 4), and most (89%) were from the biological sciences.

Respondents from the challenging group (Figures 3 & 4) advocated that invasion science terminology should be revised (terminology factor) (Figures 3d–f & 4b); mostly agreed with, or were neutral toward, statements critiquing invasion science (values factor) (Figures 3a,b,d & 4); and supported the existence of benefits of invasive species (impacts factor) (Figures 3b,c,f & 4a,c). These respondents were mainly academics (Figure 4a) and less involved in practical and policy-making activities (Figure 4b), and a larger proportion of them worked outside the biological sciences compared with the other groups (Figure 4c).

TABLE 2 The 4 factors, their associated Likert (ranking) scale statements, and their loading based on the confirmatory 4-factor analyses from a survey of researchers and practitioners to determine levels of consensus and polarization in the field of invasion science

Factors	Likert statement	Statement loading*
Values focused	Q10. The concept of invasive species is not necessary; it is sufficiently covered by other terms	0.71
	Q30. In most cases, negative impacts of invasive species are exaggerated	0.68
	Q42. Invasion science is not objective and driven by negative perceptions against invasive species	0.66
	Q1. Biological invasions are one of the major global threats to biodiversity	−0.66
	Q9. NNS introductions are on a spectrum of species movements so should not be treated differently	0.65
	Q35. All biodiversity should be treated with equal value irrespective of origin	0.56
	Q5. Biological invasions are one of the major global threats to human well-being	−0.55
	Q34. After a period of time since introduction, NNS can be considered as native	0.54
	Q32. Often, ecological systems adapt to biological invasions by themselves	0.54
	Q31. Biological invasions are rarely the direct cause of local species extinctions	0.53
	Q47. The terminology used in invasion science is xenophobic	0.52
	Q25. Novel ecosystems should be accepted	0.47
	Q45. NNS species should not be separated when conducting biodiversity estimates	0.46
	Q28. Terminology used in invasion science equates too much with militaristic metaphors	0.4
Management focused	Q24. Eradication of established invasive plant species is feasible	0.91
	Q39. Eradication of established invasive animal species is feasible	0.78
Impacts focused	Q20. Invasive species can have ecological benefits	0.81
	Q6. Invasive species can have social benefits	0.78
	Q40. The benefits (positive impacts) of biological invasions are often understated	0.49
Terminology focused	Q13. Revisions of common definitions and terminology used in invasion science are needed	0.76
	Q2. Inconsistent use of definitions and terminology in invasion science is a problem	0.7

*Loading represents the correlation of a statement with its derived factor. The statement loading cut-off is 0.4. Statements with a negative loading indicate inverse response patterns with the factor.
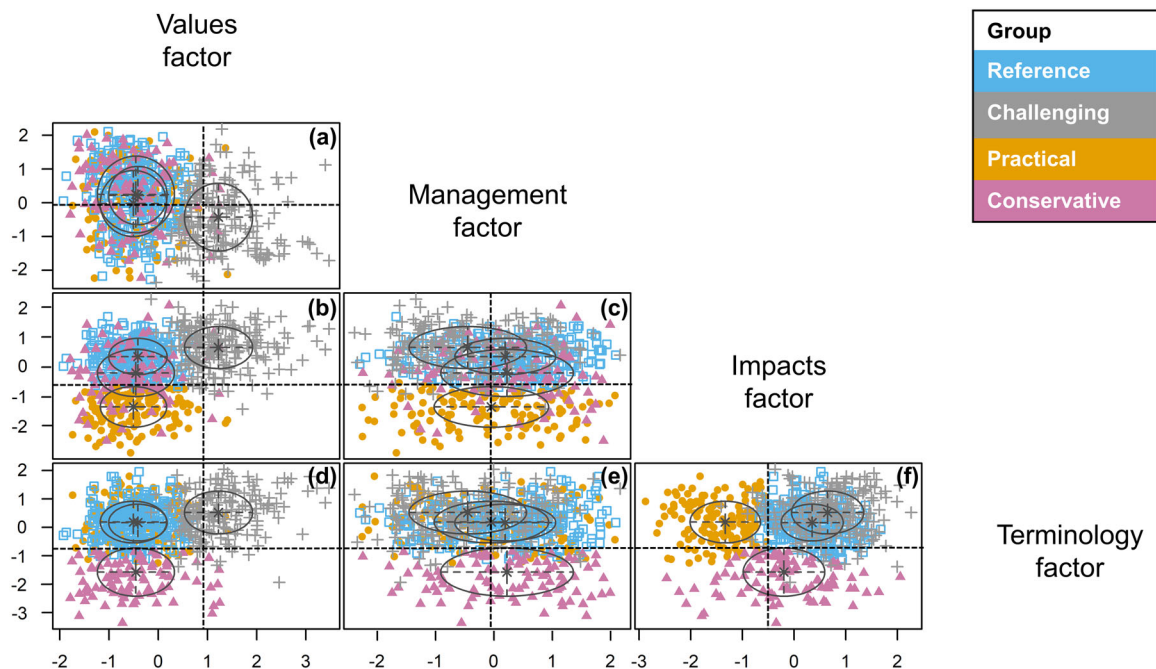

FIGURE 3 A cluster analysis of the 4 groups of survey participants (reference, challenging, practical, and conservative) and the 4 response factors related to (a, b, f) values, (b, c, r) management, (b, c, f) impacts, and (d, e, f) terminology (Table 2) in the invasion science field (dashed lines, fictional scores for a hypothetical respondent who is neutral toward all statements [Appendix S1]; blue squares, reference group; gray crosses, challenging group; yellow dots, practical group; violet triangles, conservative group; refer to the "Cluster analysis" section for the group defenitions).
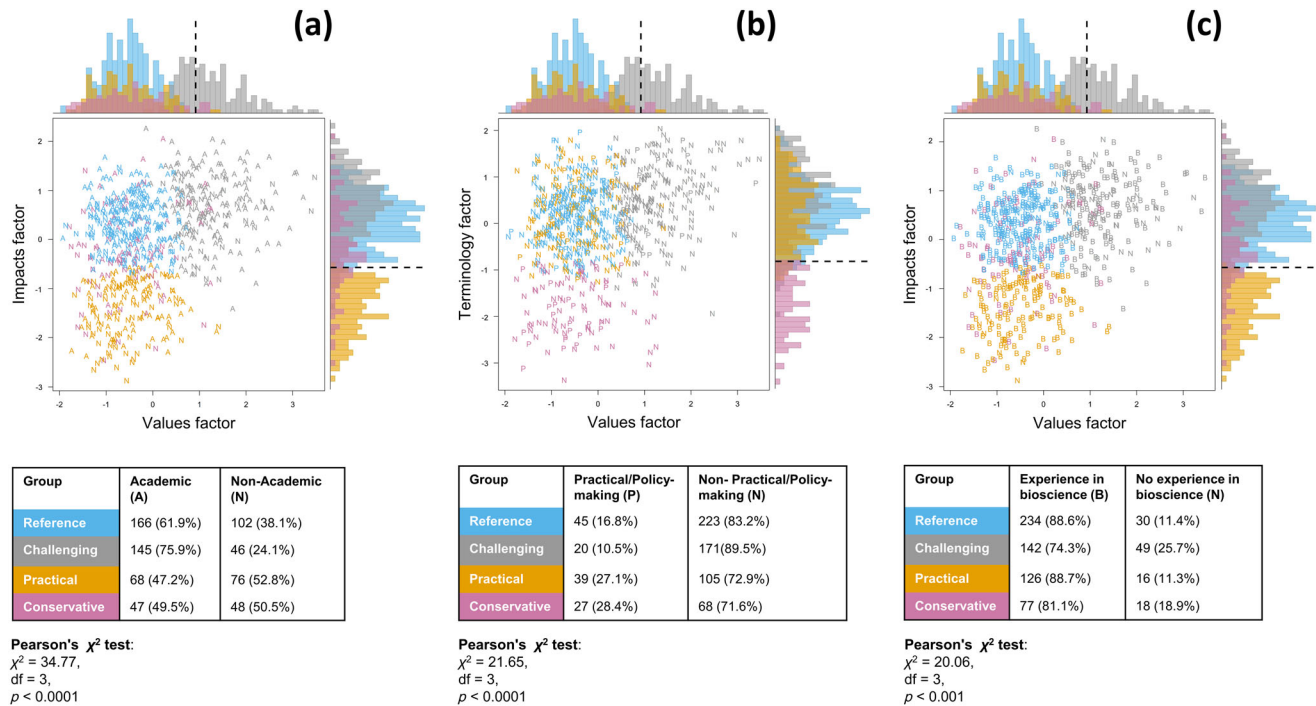
FIGURE 4 Results of chi-squared tests comparing response patterns between the values, impacts, and terminology factors (management factor not included because it does not describe any of the groups [Table 2]) and the 4 groups of respondents (blue squares, respondents from the reference group; gray crosses, respondents from the challenging group; yellow dots, respondents from the practical group; violet triangles, respondents from the conservative group based on the cluster analyses [Figure 3]; dashed line, fictional scores for a hypothetical respondent who is neutral toward all statements [Appendix S1]; refer to the "Cluster analysis" section for the group defenitions). The number and percentage of respondents in each group and category class and the chi-square test results are reported in tables below the graphs. Graphs (a) and (c) coincide with Figure 3b, and graph (b) coincides with Figure 3d.

Respondents in the practical group (Figures 3 & 4) disagreed with statements that critiqued invasion science (values factor) (Figures 3a,b,d & 4); rejected the existence of invasive species benefits (impacts factor) (Figures 3b,c,f & 4a,c); and advocated that invasion science terminology should be revised (terminology factor) (Figures 3d–f & 4b). To a greater extent, respondents in this group were practitioners or policy makers as compared with the reference and the challenging groups (Figure 4b) and generally had high levels of experience in the biological sciences (Figure 4c).

Respondents in the conservative group (Figures 3 & 4) disagreed that invasion science terminology should be revised (terminology factor) (Figures 3d–f & 4b) and with statements that critiqued traditional invasion science values (values factor) (Figures 3a,b,d & 4). They were also less likely to acknowledge that invasive species can have benefits (impacts factor) (Figures 3b,c,f & 4a,c). Respondents in this group worked in practice or policy making to a greater extent than respondents from the reference and challenging groups (Figure 4a,b).

DISCUSSION

Invasion science is a relatively new research discipline that has seen an explosion of ideas, theories, and frameworks over the past 30 years (Richardson & Pyšek, 2008; Wilson et al., 2020),

and our results highlight that many core values and concepts are shared through having low polarization scores and high levels of agreement or disagreement. However, there are still nuanced perspectives illustrated by high polarization toward some statements, and distinct clusters of respondents. Overall, improving understanding of people's views in the field can help with interoperating debates, decisions, scientific results, and the development of more just policy and management plans to ensure effective conservation (Bronowski, 2011).

There is a lack of consensus surrounding some value-related topics, in particular, debates around NNS reporting in biodiversity estimates (Gbedomon et al., 2020), whether NNS contribute to biodiversity, and whether denialism is a legitimate claim (Russell & Blackburn, 2017a). With regard to management, there was polarization around whether plant eradications are feasible, the regulation of commercially important species, the extent to which stakeholders should influence management decisions, and whether utilization is an effective control approach. For some of these issues (e.g., utilization), there is a lack of scientific evidence as to whether this management approach is effective or not, and systematic studies to test this are needed (rigorous scientific research should help improve consensus on this topic and others). Regarding impacts, the drivers-versus-passengers debate (Davis et al., 2011) still has high levels of polarization as does the extent to which benefits of NNS should be acknowledged. Some social science and

humanities researchers have supported the idea that invasive species can have benefits (e.g., Tassin & Kull, 2015), and this is being increasingly acknowledged by researchers from the biological sciences (Vimercati et al., 2020). Therefore, contention surrounding this issue might decrease over time. There was also a high polarization in views around some terminology in the field, a similar issue identified by Young and Larson (2011). Definitions used today are primarily derived from the literature of the early 2000s (e.g., Pyšek et al., 2004; Richardson et al., 2000) and may be outdated. This suggests that core definitions might need to be revisited and better consolidated, even though this has already been attempted (Blackburn et al., 2011; Richardson et al., 2011). It should be also acknowledged that a diversity of definitions, although sometimes confusing and contentious, does push scientists and practitioners to question and be explicit about the assumptions behind the definitions, thus potentially contributing to the advancement of a field in the long term (Hodges, 2008).

Despite our attempts to obtain broad, global representation, there were some biases in our data set. For example, there were more male, biologically orientated, plant-focused, and Northern Hemisphere respondents, and the views in certain continents were dominated by 1 or 2 countries, for example, South African respondents in Africa. To some extent, these biases reflect the status of the field and the potential issues of using a monolingual survey (Amano et al., 2016; Pyšek et al., 2008). Interestingly, we found that age and gender did not significantly impact people's views (Figure 2), which is in contrast to similar studies on broader conservation debates (e.g., Sandbrook et al., 2019).

As expected, disciplinary training (e.g., biology, social science) and work area (e.g., academic, practitioner) had the most significant influence on respondents' answering patterns and may lead to the greatest polarization in views over core issues in the invasion science field. This is in part similar to the findings of Gbedomon et al. (2020), but such differences are also present in other ecological and conservation-related research disciplines (Larson et al., 2009). Key debates in invasion science are often between researchers from different academic disciplines, such as social scientists and biologists, rather than within disciplines; thus, differences are to be expected. Furthermore, many social science and humanities researchers take on an approach that they call critical studies, which aims to question and challenge current concepts, theories, and paradigms (Calhoun, 1995), which is not yet common and well understood in the natural sciences and can lead to reactive conflicts rather than constructive ones. We suspect that as interdisciplinarity grows in the field, values and understanding between biologists and social scientists may start to increasingly converge (Vaz et al., 2017).

To a lesser extent, we found that the taxonomic focus (e.g., plants, animals) and work region (different continents) of respondents also affected response patterns. This is similar to the findings of Bernos et al. (2022), who identified that work region affected people's acceptance of genetic biological control for aquatic invasive species. Unsurprisingly, practitioners and respondents from Oceania were more likely to respond positively to the management factor, and those working on

plants and invertebrates were more likely to respond negatively to the management factor. Oceania has some of the most comprehensive invasive species management plans globally, and, in general, mammals are easier to successfully control than plants (Shackleton et al., 2020). On islands, impacts are commonly more pronounced; however, management is also often more successful leading to wide-reaching benefits, which might describe the more positive outlooks by respondents from Oceania (Russell et al., 2017). Interestingly, respondents working in Africa acknowledge invasive species benefits more than those working in Oceania and the Global North. This is probably because in Africa many invasive species were introduced and are still promoted for economic and development purposes and remain crucial for local rural livelihoods (Kull & Tassin, 2012; Shackleton et al., 2019). It is also unsurprising that practitioners, whose job is to reduce the impacts of invasive species, are less likely to acknowledge their benefits.

Here, we provide a broad overview of global trends on consensus and polarization in the field of invasion science. Further studies building on our findings, but using different approaches (e.g., from social sciences), could provide additional context to the persisting controversies in the invasion science field (Fall, 2021). To overcome issues associated with polarization in views, in particular, between different disciplinary fields and work sectors, more transdisciplinary research, multinational collaboration, and engagement among stakeholders are needed (Novoa et al., 2016; Packer et al., 2017). This will help broaden views, improve communication, break down disciplinary barriers, and better expose the perspectives and experiences of others to build understanding, consensus, and collaboration (Connick & Innes, 2003; Novoa et al., 2018). For example, Abrahams et al. (2019) highlight that in South Africa (a world leader in invasion science) there are weak links among social, economic, and practical research and more general invasion ecology work. Improved collaboration might also help to consolidate research implementation gaps and foster better agreement and engagement between researchers and practitioners and other stakeholders (Knight et al., 2008). This is particularly pertinent because our results highlight that people working in invasion science believe that enhancing engagement among different stakeholders is essential, which mirrors findings by Young and Larson (2011); however, this is still uncommon in practice (Matzek et al., 2015).

ACKNOWLEDGMENTS

ORCID

Ross T. Shackleton https://orcid.org/0000-0001-5628-4506
Giovanni Vimercati https://orcid.org/0000-0002-2419-8088
Anna F. Probert https://orcid.org/0000-0003-4288-4716
Sven Bacher https://orcid.org/0000-0001-5147-7165
Christian A. Kull https://orcid.org/0000-0002-7516-7898
Ana Novoa https://orcid.org/0000-0001-7092-3917

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.