

Diverse views among scientists on non-native species

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Abstract

Conservation scientists have traditionally viewed non-native species (NNS) as potential threats to native biodiversity. Here, we question whether alternative views of NNS exist in the scientific community that stand in contrast to the dominant narrative that emerges from the literature. We asked researchers from the biological, social, and environmental sciences to participate in an anonymous poll regarding the perceived values and threats of NNS. Some 314 individuals responded, approximately half of whom were biologists and half were social or environmental scientists. We grouped responses into three statistical clusters defined by shared responses. We then analyzed the correlation of responses to individual questions and membership of clusters with predictor variables age, gender, and field of work. Overall, a majority of respondents in our sample supported statements that the species-component of biodiversity should include all species (55%) or some types of non-native species (an additional 32%), which contrasts with the manner in which major biodiversity assessments and indicators are constructed. A majority of respondents in our sample (65%) also supported that measurement of the impact of invasive species should be based on the net biological, social, and economic effects, which also represents a marked departure from current methods that focus only on the adverse effects of a subset of NNS considered as invasive. Field of work and age were correlated with clusters and numerous individual responses. For example, biologists were three-times more likely than non-biologists to support a definition of species richness that included only native species. Two clusters (Cluster 1 and Cluster 3), mainly composed of non-biologists and biologists, respectively, differed in their support for statements that NNS would provide useful ecosystem services in the future (66% and 40%, respectively). Thus, a key result of this study is that a variety of normative stances regarding NNS is present within the scientific community. Current international indicators of progress (e.g., Aichi Targets) capture only a “nativist” set of values, which, if our sample is representative of the scientific community, appears to be a minority view. Therefore, we argue that indicators should be modified to integrate the diversity of views that exist within the scientific community.

Keywords

conservation ethics, exotic species, invasive species, nativism, values

Introduction

There is a consensus among scientists that humanity is experiencing a sixth mass extinction of species, which is resulting in an alarming decline of biodiversity (Barrett et al. 2018; Ceballos and Ehrlich 2018; Ceballos et al. 2015; Ceballos et al. 2017; Mayhew et al. 2007). Species considered as invasive are regarded to be one of the main direct drivers of biodiversity loss and recent extinctions (Bellard et al. 2016; Butchart et al. 2010; McGeoch et al. 2010). Although scientists largely agree on the biodiversity crisis and potential negative effects of invasive species, the debate is just emerging about the potential risks and contributions that should be attributed to the bulk of non-native species (NNS) that are not currently considered to be invasive.

Ambiguities in the definitions and understanding of terms such as “biodiversity” and “invasive species” have contributed to confusion among scientists, policy-makers, and the public. They may also contribute to opposing positions around NNS. Indeed, the term “biodiversity” can have both scientific and cultural meanings. Scientifically, biodiversity (biological diversity) refers to the variability among all living organisms and the ecological systems of which they are a part; this includes variation at the genetic, species, and ecosystem levels [Convention on Biological Diversity (CBD), Article 2]. Culturally, biodiversity refers to the dimensions of nature that we cherish and wish to conserve, wherein individual species have been categorized as more or less desirable in particular places (Fall 2014). For example, a large number of assessments and reports use the word “biodiversity” when in practice only the status, richness and abundance of native species are assessed (Schlaepfer 2018b). In such examples NNS are implicitly - and sometimes explicitly - given either no value or a negative value.

In a similar vein, the term “invasive species” is conceptualized differently across policy contexts. Primarily, species considered as invasive refer to NNS (also referred to as “alien species”) whose ancestors were introduced deliberately or unintentionally outside their natural habitats and which become established, proliferate, and spread in ways that cause damage to a range of interests, including biological diversity (Daisie-database; Shine 2007). The term “invasive species” is used in this sense in an international and political context (e.g. CBD, IUCN) and by government and intergovernmental organizations (e.g. the European Commission). A broader definition is used by some researchers and practitioners (landscape managers, botanists, conservationists, horticulturists, etc.) who refer to species “considered as invasive” as native species and NNS that are over abundant, even without any proven adverse effects on the environment (Colautti and MacIsaac 2004). Finally, Richardson et al. (2000) proposed that the term “invasive” should be used without any inference to environmental or economic impact, but rather on the capacity of species to produce reproductive offspring, often in very large numbers, at considerable distances from the parent and thus have the potential to spread over a considerable area.

The versatile meanings of “biodiversity” and “invasive species” highlight the ambiguous thinking on NNS within conservation scientists. This raises some fundamental questions: *What do we wish to conserve? And for whom?* (Mace 2014). Currently, NNS are not considered as (positive) contributions to biodiversity. For example, indices and metrics used to measure progress towards biodiversity conservation and sustainability goals focus solely on the “native” component of biodiversity (Schlaepfer 2018b). Thus, current indicators may capture only a limited range of values that exist in the conservation community and across society.

In practice, the justifications for conserving nature have changed over time, and the current conservation frame is a mix of different conservation models (Mace 2014; Sandbrook et al. 2019), with each model receiving attention from different groups of people depending on their personal values and expertise. These differences in knowledge and values may be contributing factors to the differing views between invasion biologists and the public (Genovesi 2008). Beyond the expertise and influence of the former group (invasion biologists), the importance of the opinion of the latter is increasingly recognized. Indeed, there is a call to include greater input from the public in an attempt to seek greater public support for the conservation goal and reduce the rate of biodiversity loss. In this context, an important aspect that could contribute to a constructive debate surrounding the importance of NNS in conservation is an awareness of the range of views regarding NNS within the conservation community and greater care to consider alternative views in conservation discourse and decision-making (Sandbrook et al. 2019).

Here, we enquired whether a variety of values exists within the scientific community regarding NNS. We also investigated different positions on the debate and to what extent they were associated with the demographic (age, gender) and professional (field of study) factors of participants. The existing perspectives on NNS among scientists (Guiaşu 2016; Guiaşu and Tindale 2018; Schlaepfer 2018b; Simberloff 2003), including among invasion biologists (Humair et al. 2014; Young and Larson 2011), suggest the existence of factors (personal values, diverging conceptual understandings, knowledge gaps, etc.) likely to determine or influence attitudes towards NNS. Considering the evolution of conservation paradigms (Mace 2014), and knowing that individual attributes influence people’s perception of invasive alien species (Shackleton et al. 2019), we hypothesize that socio-demographic factors and field of work can potentially shape the opinions of scientists. Also, based on our personal experiences at workshops and conferences, we considered age and gender as potential explanatory factors.

This survey differs from previous opinion surveys, which focused mainly on invasive species issues (Andreu et al. 2009; Bardsley and Edwards-Jones 2007; Fischer et al. 2014; Guiaşu and Tindale 2018; Humair et al. 2014; Young and Larson 2011) and contributes to the broader question of how to value and manage NNS (including those considered as invasive). Bringing more diverse voices into our understanding of NNS and the debate on “*conserving what and for whom*” (Mace 2014) can help to inform policy and research directions in the current context of preparation for the post-2020 Strategic Plan for the Convention on Biological Diversity.

Methods

Survey planning and data collection

We designed a poll to query a sample of individuals from the research community on their views and values regarding the role of NNS in the field of conservation science. We designed 13 multiple choice questions (Table 1) that covered the following three areas: (i) individual values associated with biodiversity and NNS, (ii) the perceived threats associated with NNS, and (iii) the most appropriate approaches for assessing the value of NNS. An additional, open-ended question allowed respondents to provide comments and to nuance their responses. The survey was anonymous, although we did ask for age category, gender, and field of work.

The survey used a “snowball” sampling approach, wherein the invitation to complete the survey form was shared through various outlets, including social media platforms (Twitter, Facebook, LinkedIn), the journal of PLOS Biology (in the comments section associated with Schlaepfer (2018b) on the website of PLOS Biology), and five email lists for different fields of research: Eanth-l (official listserv of the Anthropology & Environment Society of the American Anthropological Association; roughly 2000 subscribers), Aliens (researchers interested in biological invasions; 1,505 members); CESG (Cultural and Political Ecology Specialty Group of the Association of American Geographers; no information available on the number of subscribers), the Swiss Biodiversity Forum (researchers and practitioners interested in biodiversity in Switzerland; 1,870 subscribers) and Biodiversity-l (an international list, with 7,970 members). Researchers were also invited to share the invitation within their respective networks.

Using international email lists and social media (Twitter, Facebook, LinkedIn, etc.) with wide global reach, we expected to reach the global community of scientists. We have no information on the country of origin, but we assume that respondents came predominantly from North America and Europe, and we knew through spontaneous feedback that at least a few responses came from Africa. Responses were recorded during 131 days (April 26 – September 04, 2018). The raw results of the survey are available in Suppl. materials 1, 2.

Statistical analyses

Results were analyzed using two approaches. First, responses to questions were analyzed and visualized according to a priori hypotheses regarding independent predictors such as age, gender, and field of work. Sometimes, we pooled together the “strongly support” and “somewhat support” responses to indicate the magnitude of agreement (or, conversely, disagreement). Pearson’s Chi-square tests were used to test whether each response variable was independent of the predictor variables. Age, gender, and field of work were used in multiple binary logistic (for binary responses) or ordinal logistic (for ordinal responses) models to test their effect on respondents’ opinions and perceptions. After specifying the full model (i.e. including all main effects of each factor), the full model was compared to

the null model (a model without any of the factors) to test whether it was globally significant (Crawley 2012). We then identified the most parsimonious model using backward elimination (Crawley 2012). Only the summary of the final model was reported. For binary responses, we reported the odds ratio (OR) and confidence interval. OR expresses the relative chance of an event happening under two different conditions (Szumilas 2010). Here, for a factor with two levels (e.g. gender), it expressed the relative chance of a male respondent agreeing with a statement compared to that of a female respondent. For a factor with more than two levels (e.g. academic background), OR expressed the relative chance of a respondent from a given background (e.g. non-biologist) agreeing with a statement compared to that of a respondent from a reference group (e.g. biologists).

In a second analytical approach, we analyzed responses using a clustering tool, independently of predictor variables. This allowed us to group respondents into relatively homogeneous classes irrespective of their age, gender, and field of work. A multiple correspondence analysis (MCA) was first performed on individual answers, and then the factorial axes from the MCA were used in a hierarchical clustering on principal component analysis (HCPC). HCPC is a multivariate descriptive method that, in addition to assigning individuals into groups, provides information on which of the initial variables submitted to the MCA best describes each cluster (Le et al. 2008). A Chi-square test was used to test independence between clusters and age, gender, and field of work of respondents. Fourteen further independent Chi-square tests were performed to examine the association between clusters and each of the 14 statements. Because conclusions from these multiple independent tests are prone to type I error, a more conservative p-value was obtained using the correction method of Benjamini and Hochberg (1995). This correction method reduces type I error, but also minimizes type II error (Jafari and Ansari-Pour 2019). As an additional step, we reconsidered the dataset without responses to methodological questions (survey questions 10 through 14), which were likely less relevant to the core questions of this study. The reduced and full dataset yielded results that did not differ significantly. For both datasets, the level of three clusters was sufficient to reveal general trends, and retaining a greater number of clusters would have led to complex analyses without any significant added value.

All statistical analyses were performed in R software version 3.5.0 (R Core Team 2018). MCA and HCPC were run using packages *ade4* (Dray and Dufour 2007), *FactomineR* (Lê et al. 2008), and *Factoextra* (Kassambara and Mundt 2016). Binary logistic models and the correction method of Benjamini and Hochberg (1995) were run in R Basics, whereas the ordinal logistic models were implemented in package *ordinal* (Christensen 2018).

Results

Respondents' characteristics

The internet-based survey form was completed by 314 respondents. The majority of responses (251/314) were recorded within the first 30 days following the inception of the survey. The response rate for closed questions ranged from 99% to 100%. For the

unique open question, the response rate was 89.17%. The typical time to complete the survey was 8.47 ± 5.49 min.

The reported fields of work included biology (44.05%) social science (31.19%), and environmental science (14.15%). The remaining respondents (10.61%) came from fields of work such as engineering, sustainable development, law, education, and information technology. Hereafter, respondents reporting a field of work other than biology are grouped into the non-biologist category. Respondents were nearly gender balanced (53.07% males and 46.93% females) and covered a wide range of ages, with about half of respondents (50.48%) aged between 34 and 55 years.

Responses to individual questions on places, values, and threats associated with inclusion of non-native species as part of biodiversity, and appropriate methods for measuring their desirability

We found that responses to individual questions/statements were significantly associated with the socio-demographic features (age, gender) and field of work (called professional background on the survey form) in 8 of 14 cases (Table 1). Field of work and age were more likely to be associated with responses than gender (Table 1, Suppl. material 3). In the next section, we illustrate the detailed responses to each group of questions, emphasizing cases with significant associations.

Values associated with non-native species

Responses to the five values-based questions/statements illustrated a range of opinions regarding the current and future values of NNS. Hereafter, all reported results refer to the percentages of respondents in our sample.

More than half of respondents (55.41%) reported that in their view, biodiversity is composed of all species - including NNS, domesticated species, and invasive species (Statement 1, Table 1). The other respondents (44.59%) excluded one or several groups of species based on historical, social, or economic criteria, preconditioning the inclusion of NNS in biodiversity due to their invasiveness, naturalization (being in place for >100 years), or social appreciation. Some rare respondents (8.20%) restricted the notion of species richness to native species only. Respondents were ambivalent about attributing any future value to NNS. Whereas some of the respondents (40.19%) were neutral (Figure 1b), others agreed or disagreed with the statement in roughly equal proportions (Statement 2, Table 1). In addition, about half of respondents (53.55%) felt that it was useful to maintain a distinction between native species and NNS (Statement 3, Table 1). Finally, a majority of respondents (65.07%) agreed that evaluating the invasiveness of NNS should be based on the net impacts (Statement 4, Table 1) or on at least one documented undesirable impact (72.02%, Statement 5, Table 1).

Opinions on the inclusion of NNS as part of biodiversity were primarily associated with the fields of work of the respondents ($\chi^2 = 23.751$, $p < 0.05$) and to a lesser extent

with age. Biologists were more likely than non-biologists to restrict biodiversity to native species (Figure 1a) and to attribute no future value to NNS (Figure 1b). Finally, biologists and older respondents were more likely to support maintaining a distinction between native species and NNS than both non-biologists and younger respondents (respectively, $\chi^2 = 27.986$, $p < 0.01$ and $\chi^2 = 16.28$, $p < 0.05$ for field of work and age; Figure 1c, d). Gender, in general, was rarely associated with particular responses ($\chi^2 = 2.7993$, $p > 0.05$; Table 1).

Threats from non-native species

Responses to the four questions/statements related to the perceived threats associated with NNS also showed a large variety of opinions among respondents. All reported results refer to the percentages of respondents in our sample.

More than half of respondents (about 58%) agreed that NNS represent a potential threat to native species (Statement 6, Table 1), whereas about 23% were undecided. About half of respondents (about 49%) disagreed that NNS represent a threat to human well-being (Statement 7, Table 1). Respondents were divided on the statement "*Non-native species should all be considered as potentially invasive species*", with 43% of respondents in agreement and 46% in disagreement (Statement 8, Table 1). Finally, respondents were also divided on the statement "*Including non-native species as part of biodiversity lowers conservation standards* (the "*shifting baseline*" effect) for society", with a quarter of respondents in disagreement with the statement.

Differences in perceptions of the threats from NNS were also associated with the field of work. Non-biologists were more likely than biologists to view NNS as a threat to human well-being (Figure 2a), whereas non-biologists were more likely than biologists to perceive the inclusion of NNS as part of the biodiversity as a lowering of conservation standards (Figure 2b).

Appropriate approaches for measuring whether a non-native species is desirable or not

Statements 10–14 explored different methods for assessing the values and impacts of NNS. The most commonly favored approach was to measure the impact of NNS on ecological functions, followed by approaches that measure the net effect of NNS on native species richness and their net impact on ecosystem services (Table 1).

Field of work influenced the responses on methodological approaches. Biologists generally supported a method in which the impact of NNS on native biodiversity is measured (Table 1). By contrast, non-biologists generally supported an approach in which the net impact of NNS on total species richness is measured (Table 1).

Younger respondents were more likely than older respondents to favor approaches that conduct an evaluation of ecosystem services gained and lost through the addition of the NNS and approaches that measure the effects of the NNS on ecological functions.

Table I. Survey statements, summary of responses, and statistical tests of correlation with predictor variables.

N°	Statements	Proportion of responses (%)					Logistic regression		
		All species	Exclude invasive	Useful NNS	Exclude recent	Native only	Age	Gender	Field of work
Values associated with non-native species									
1	"Which group(s) of species should be considered when quantifying the "species" dimension of biodiversity?"	55.41	17.70	4.26	14.43	8.20			
2	Non-native species should be conserved because they may provide useful functions ("ecosystem services") in the future.	N/A	Strongly agree	Agree	Neutral	Disagree	Strongly disagree		*
3	The distinction between native and non-native species is artificial and counter-productive.	0	8.04	23.79	40.19	21.22	6.75		*
4	The definition of an invasive species should be based on an evaluation of all its desirable and undesirable impacts ¹ .	0	7.74	19.35	19.35	29.03	24.52	*	*
5	The definition of an invasive species should be based on at least one documented undesirable impact.	1.28	30.13	34.94	12.82	14.42	6.41		
Threats from non-native species									
6	Non-native species, on average, represent a potential threat to the survival of native biodiversity.	10.5	17.25	40.58	14.38	22.04	4.47		
7	Non-native species, on average, represent a potential threat to human well-being.	2.89	6.43	19.29	23.15	31.19	17.04		*
8	Non-native species should all be considered as potentially invasive species.	0.96	10.86	32.27	10.22	28.12	17.57		
9	Inclusion of non-native species as part of biodiversity lowers conservation standards (the "shifting baseline" effect) for society.	0	11.29	28.71	25.81	26.13	8.06		*
What methodological approach is most appropriate for measuring whether a given non-native species is desirable or not?									
10	Measure the effect of the non-native species on native species richness.	—	—	42.04	—	57.96	—		*
11	Measure the net effect of the non-native species on total species richness.	—	—	22.93	—	77.07	—		*
12	Conduct an economic cost-benefit analysis of the addition of the non-native species.	—	—	15.92	—	84.08	—		
13	Conduct an evaluation of ecosystem services gained and lost through the addition of the non-native species.	—	—	42.68	—	57.32	—	*	
14	Measure the effects of the non-native species on ecological functions.	—	—	53.50	—	46.50	—	*	

¹ on native biodiversity, economy, or human health, social; All species=all species, including non-native species, domesticated species, and invasive species; exclude invasive=native and most non-native species, but excluding invasive species; Useful NNS=native species and socially appreciated non-native species; exclude recent=native species and non-native species that have been present for a "long time" (e.g. >100 years); Native only=only native. *-significant in determining the opinion.

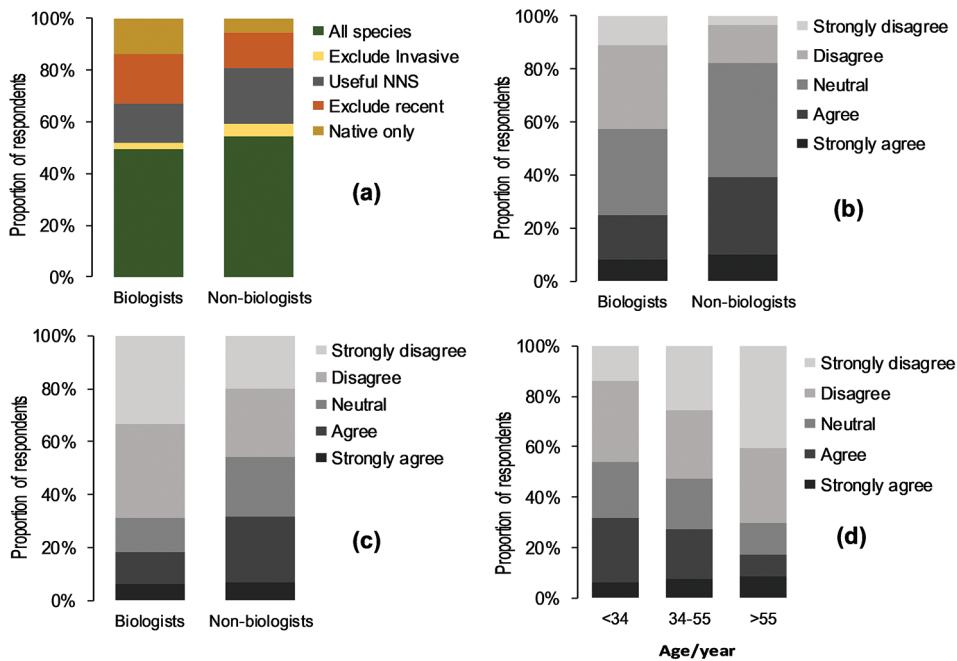


Figure 1. Proportion of responses to statements on values with significant associations to at least one predictor variable. Field of work was associated with the respondents' definitions of biodiversity (Statement 1, panel **a**) and “*NNS should be conserved for potential future value*” (Statement 2, panel **b**), and the distinction between native species and NNS was artificial (Statement 3, panel **c**). Age (years) was associated with responses to Statement 3 (panel **d**). **All species**=all species, including non-native species, domesticated species and invasive species; **Exclude invasive**=native and most non-native species, but excluding invasive species; **Useful NNS**=native species and socially appreciated non-native species; **Exclude recent**=native species and non-native species that have been present for a “long time” (e.g. >100 years); **Native only** = only native. <34 = 34 years and younger, 34–55 = between 34 and 55 years, and >55 = 55 years and older.

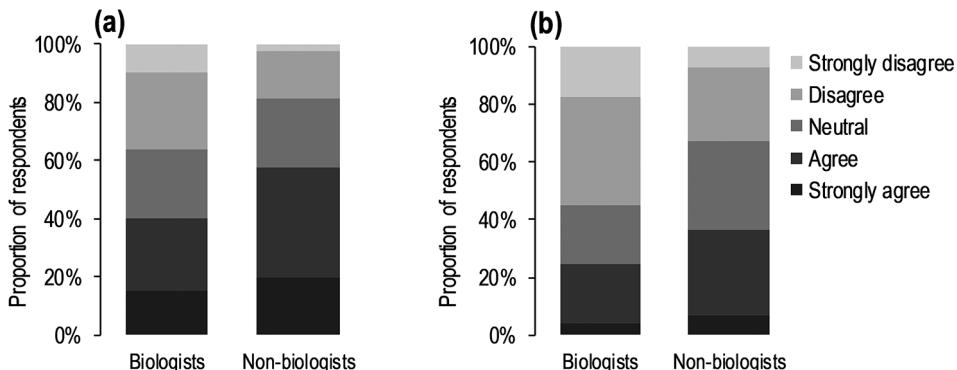


Figure 2. Proportion of responses to statements on perceived threats with significant associations and at least one predictor variable. Field of work was associated with the perception that NNS represent a threat to human-well-being (Statement 7, panel **a**) and that including NNS as part of the biodiversity leads to a lowering of conservation standards (Statement 8, panel **b**).

Statistically-independent groups of opinions on biodiversity and non-native species issues

The MCA performed on the dataset of 314 respondents and 15 variables (which corresponded to the responses to questions) followed by HCPC distinguished three distinct clusters of respondents (Figure 3). Each cluster represents a generally shared opinion across the poll and can be thought of as analogous to political parties. The three clusters captured 18.05%, 66.43%, and 15.52% of respondents, respectively.

Here, we report the statistical associations between predictor variables and clusters. We also describe how clusters were positioned with regard to values associated with NNS, threats perceived from NNS, and the most appropriate methods for evaluating NNS.

A significant association was found between field of work and the clusters ($\chi^2 = 14.889$; $p < 0.05$; Figure 4a). Cluster 1 was composed primarily of non-biologists (66%) whereas Cluster 3 was composed mostly of biologists (62.79%). The three clusters were statistically independent from age and gender ($\chi^2 = 5.5518$; $p > 0.05$), although Cluster 3 was composed of more males and older respondents (Figure 4b, c) than the other two clusters.

As with the individual responses, the three clusters differed with regard to the respondents' opinions on values associated with NNS, perceived threats, and methodologies to measure the impact of NNS (Suppl. material 3). Cluster 1 was generally the most distinct from Cluster 3, with Cluster 2 being intermediary. Differences between Cluster 1 and Cluster 3 were marked for at least one statement or for questions pertaining to values, perceived risks, and methods for evaluating NNS (Table 2; Suppl. material 3).

Relative to the other two clusters, members of Cluster 1 were more inclined to agree that NNS have the potential to become invasive and represent a potential threat to native biodiversity and human well-being. However, they mostly agree that an evaluation of the net impacts of NNS should be undertaken before considering a species as invasive. Similarly, they mostly agreed that the decision to label an NNS as invasive or not should be driven by an evaluation of its net effect on total species richness. Respondents from this cluster mostly agreed that the distinction between native species and NNS is artificial and counter-productive and were likely to accept that NNS should be conserved in the future. However, they mostly thought that inclusion of NNS as part of biodiversity may lower conservation standards (Table 2, Suppl. material 3).

Collectively, these responses showed concern for the potential negative impacts of NNS, but also an open-mindedness towards their potential future contributions and a desire to measure both their positive and negative impacts. We coined this cluster as "liberal".

Relative to the other two clusters, members of Cluster 2 were more inclined to agree that biodiversity should include both native species and NNS but not invasive species. According to those respondents, NNS represent a potential threat to the survival of native biodiversity. They are mostly undecided on the potential invasiveness of NNS and were likely to think that the net impact of an NNS should be evaluated before considering a species as invasive. Similarly, they were undecided on whether NNS could potentially threaten human well-being and whether their inclusion as part of biodiversity

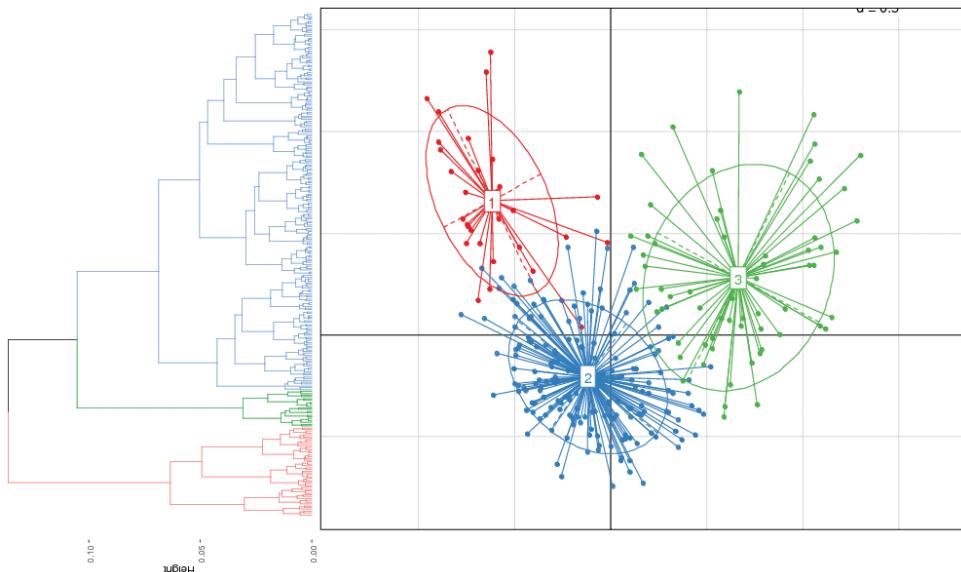


Figure 3. Clustergram showing the three independent groups of respondents.

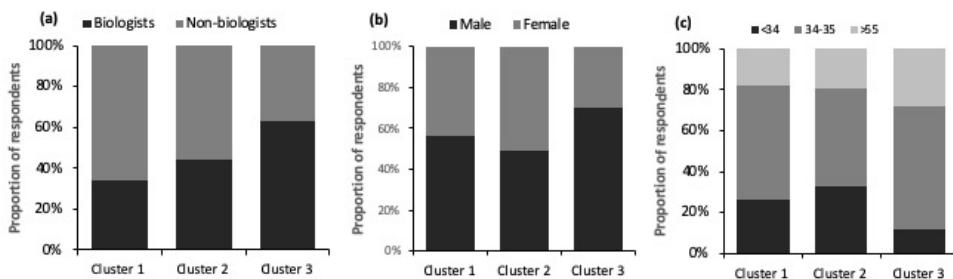


Figure 4. Distribution of the fields work (a), gender (b), and age (c) of respondents across the three clusters.

would lower the conservation standards. They also remained undecided on whether the distinction between native species and NNS is artificial and counter-productive and on the need to conserve NNS in the future (Table 2, Suppl. material 3).

Collectively, these responses were ambivalent and intermediate between Cluster 1 and Cluster 3. As a result, we coined this cluster as “agnostic” based on the assumption that as more data become available (e.g. about the dangers of NNS or their positive contributions) that values of this group could change.

Finally, relative to the other two clusters, members of Cluster 3 were more inclined to support the idea of restricting biodiversity to only native species even though they strongly disagreed that all NNS are potentially invasive and that there is no risk of lowering the conservation standards if NNS are included as part of the biodiversity.

Table 2. Statistically significant associations (+ positive; - negative) between the responses to questions/statements and the three clusters.

N°	Statements	Opinions					
		All species C1(+)	Exclude invasive C2(+)	Useful NNS C3(-)	Exclude recent C2(-)	Native only C3(+)	
Values associated with non-native species							
1	“Which group(s) of species should be considered when quantifying the “species” dimension of biodiversity?”	Strongly agree C1(+), C2(-) C1(+), C2(+) C3(-)	Agree C1(-), C2(+) C2(+), C3(-)	Neutral C1(-), C2(+) C2(+), C3(+)	Disagree C1(-), C2(+) C2(+), C3(-)	Strongly disagree C1(-), C2(+) C2(+), C3(-)	Native only C2(-), C3(+)
2	Non-native species should be conserved because they may provide useful functions (“ecosystem services”) in the future.	Strongly agree C1(+), C2(-) C1(+), C2(+) C3(-)	Agree C1(-), C2(+) C2(+), C3(-)	Neutral C1(-), C2(+) C2(+), C3(+)	Disagree C1(-), C2(+) C2(+), C3(-)	Strongly disagree C1(-), C2(+) C2(+), C3(-)	Native only C2(-), C3(+)
3	The distinction between native and non-native species is artificial and counter-productive.	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C1(-), C2(+) C2(+), C3(-)	Neutral C1(-), C2(+) C2(+), C3(+)	Disagree C1(-), C2(+) C2(+), C3(-)	Strongly disagree C1(-), C2(+) C2(+), C3(-)	Native only C2(-), C3(+)
4	The definition of an invasive species should be based on an evaluation of all its desirable and undesirable impacts ² .	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C2(+), C3(-)	Neutral C2(+), C3(+)	Disagree C2(+), C3(-)	Strongly disagree C2(+), C3(+)	Native only C2(-), C3(+)
5	The definition of an invasive species should be based on at least one documented undesirable impact.	Strongly agree C2(-), C3(+)	Agree C2(+)	Neutral C3(-)	Disagree C2(-), C3(+)	Strongly disagree C2(-), C3(+)	Native only C2(-), C3(+)
Threats from non-native species							
6	Non-native species, on average, represent a potential threat to the survival of native biodiversity.	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C1(+), C2(-) C2(+), C3(-)	Neutral C1(-), C2(+), C3(-)	Disagree C1(-), C2(+), C3(-)	Strongly disagree C1(-), C2(+), C3(-)	Native only C1(-), C2(+), C3(+)
7	Non-native species, on average, represent a potential threat to human well-being.	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C1(-), C2(+), C3(-)	Neutral C1(-), C2(+), C3(-)	Disagree C1(-), C2(+), C3(+)	Strongly disagree C1(-), C2(+), C2(-), C3(+)	Native only C2(-), C3(+)
8	Non-native species should all be considered as potentially invasive species	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C1(-), C2(+), C3(-)	Neutral C2(+), C3(-)	Disagree C2(+), C3(+)	Strongly disagree C2(+), C3(+)	Native only C2(-), C3(+)
9	Including non-native species as part of biodiversity lowers conservation standards (“the shifting baseline” effect) for society.	Strongly agree C1(+), C2(-) C1(+), C2(+)	Agree C2(+), C3(-)	Neutral C2(+), C3(+)	Disagree C1(-), C3(+)	Strongly disagree C1(-), C2(+), C3(+)	Native only C1(-), C2(+), C3(+)
What methodological approach is most appropriate for measuring whether a given NNS is desirable or not?							
10	Measure the effect of the non-native species on native species richness.		Strongly agree C1(-)	Agree C1(+)	Neutral C1(-)	Disagree C1(+), C3(-)	Native only C1(-), C3(+)
11	Measure the net effect of the non-native species on total species richness.		Strongly agree C1(-)	Agree C1(+)	Neutral C1(-)	Disagree C1(+), C3(-)	Native only C1(-), C3(+)
12	Conduct an economic cost-benefit analysis of the addition of the non-native species.						
13	Conduct an evaluation of ecosystem services gained and lost through the addition of NNS						
14	Measure the effects of the non-native species on ecological functions.						

² on native biodiversity, economy, or human health, social

All species=all species, including non-native species, domesticated species, and invasive species; exclude invasive=native and most non-native species, but excluding invasive species; Useful NNS=native species and socially appreciated non-native species; exclude recent=native species and non-native species that have been present for a “long time” (e.g. >100 years); Native only=native; C1=Cluster 1; C2=Cluster 2; C3=Cluster 3. (+)=Highly represented; (-)=Less represented.

They mostly agreed that the distinction between native species and NNS is useful. According to those respondents, there is no need to evaluate the net impact of NNS nor to document at least one undesirable impact before considering a species as invasive. They mostly disagreed that NNS can potentially threaten native biodiversity and human well-being. They also disagreed that NNS may provide useful functions in the future (Table 2, Suppl. material 3).

Collectively, these responses matched the current dominant value system, whereby native species are valued and NNS are viewed as potential threats with little or no potential value. We, therefore, coined this cluster as “nativist” to capture the strong preference for “native” species.

Discussion

The primary aim of this study was to investigate whether a variety of perceptions and values regarding NNS exists amongst scientists. Further, we investigated whether a person's opinions were correlated with their age, gender, or field of work (e.g. biologist or non-biologist). An important result of this survey is the demonstration that a great variety of normative positions exist beyond the nativist position, which currently dominates the scientific literature and the operationalization of biodiversity programs.

From the perspective of the scientific community, should NNS be considered as part of biodiversity along with native species? A key result from our study is that in our sample there was a poor consensus on which types of species belong to what is called “biodiversity” (Table 1, Statement 1). First, the fact that some respondents excluded NNS from biodiversity or conditioned its inclusion to some features stands in contradiction to the definition of biodiversity stated in Article 2 of the CBD agreement (CBD 1992). Second, this may indicate that some scientists perceive NNS species to have less value outside of their historic ranges. Yet, recent studies have documented that some NNS do have a positive contribution to biodiversity and human-well-being (Guiaşu 2016; Schlaepfer 2018a; Schlaepfer 2018b; Schlaepfer et al. 2011). According to some respondents, the risk of accepting NNS as part of biodiversity will be that “*Non-native species will be seen as normal. This is not the case.*” (*Respondent #45, Biologist, male, 45–54 years old*) or “*People turn their backs on native species if both native and non-native are seen as of equal value*” (*Respondent #26, Biologist, female, 35–44 years*). Such attitudes of re-conceptualization and operationalization of the term “biodiversity” at the level of the scientific community may reflect a shift from a scientific to more vernacular or cultural meaning of the term biodiversity that increasingly takes into account the desirability of the public and the political vision. This attempt to re-conceptualize and operationalize the term biodiversity may also reflect the different aspects of biodiversity being emphasized (Russell and Kueffer 2019).

Nevertheless, we were surprised to note that responses in our sample tended to be at odds with the current practices of assessing progress in biodiversity conservation, which use metrics focused only on native species. For example, the vast majority of

respondents did not support the statement that species richness is defined by only native species. Instead, they favor notions of species richness that also included some other NNS and – more surprisingly – a notion of species richness based on all species, including invasive species (Figure 1, Table 1). Scientists in our sample mostly find the distinction between NNS and native species as artificial and counterproductive. In practice, the distinction between which species are native to a region or not is a matter of uncertainty on the origin of the species and therefore impacts management options. Species whose geographic origins cannot be determined based on the available evidence are now referred to as “cryptogenic” species, a much less stigmatizing expression than “invasive” (Carlton 1996; Guiașu and Tindale 2018).

Does the origin of a species really matter? In the field, both native species and NNS are identified as drivers of species’ extinction and, therefore, the theoretical or practical usefulness and importance of a distinction between native species and NNS to conservation may be questioned (Davis et al. 2011; Guiașu 2016; Venter et al. 2006). However, recent evidence indicated that the biogeographic origin of species is likely to worsen the ecological impact (Blackburn et al. 2019), suggesting that the distinction may be justified, especially in an island context.

Does the scientific community consider NNS as a threat to native species and human well-being? Respondents in our sample mostly believed that NNS represent a threat to the survival of native biodiversity and to human well-being and should be considered as potentially invasive, which is congruent with the position of many invasion biologists (Richardson and Ricciardi 2013; Simberloff 2003). This opinion indicates a leeringness towards NNS and may reflect the magnitude of an “*a priori*” negative association to NNS in the collective consciousness (Guiașu 2016), even though evidence shows that only a small percent of established NNS ever become problematic (IUCN 2019; Moore 2005; Primack 2012; Seebens et al. 2018; Vander Zanden 2005). Interestingly, the fact that some respondents thought that NNS do not, on average, represent a threat to native species reveals a shift in how NNS are viewed within the field of conservation.

The views of respondents in our sample on how to define an invasive species were also at odds with current practices. An introduced species for instance can be considered as invasive if “at least” one undesirable economic, biological, social, or human-health effect is reported (Daisie-database; Shine 2007). By contrast, Schlaepfer (2018a) defined a species as “invasive” if the negative effects exceed the positive effects. The finding that respondents mostly supported such an approach acknowledges a need to account for the net impact of NNS, including invasive ones (Young and Larson 2011) and to call for more realism and transparency in communication on NNS and invasive species to curb the social anxiety regarding NNS (Ernwein and Fall 2015).

How best to decide whether an NNS is desirable or not? Most of the respondents in our sample agreed on the importance of taking into account the effects of NNS on ecological functions, evaluating the net ecosystem services provided by NNS, and taking into account the effect of NNS on native species richness. This observation suggests that the scientists surveyed were therefore aware of the variety of positive and negative effects of NNS, similar to those of native species (Davis et al. 2011). However, they were frequently neutral on the opportunities to conserve NNS that may provide useful functions (“ecosys-

tem services") in the future. Such an attitude confirms the hesitancy about NNS but also suggests the versatility of this position, which may evolve with more information about the importance and contribution of NNS to biodiversity and sustainable development.

The scientific community is heterogeneous and our results indicate that the perceptions of NNS may be influenced by the demographic features and professional training of scientists, among others factors established to influence people's perceptions of NNS, especially the invasive subset (Shackleton et al. 2019). More generally, the opinions on NNS were not significantly associated with gender. However, unlike non-biologists, biologists (mainly older ones) were more likely to distinguish NNS from native species and were more likely to exclude NNS from biodiversity. However, both groups (biologists and non-biologists) showed a great deal of heterogeneity, generating the lack of consensus on some aspects of NNS even among biologists (Young and Larson 2011). Curiously, non-biologists were more likely than biologists to associate NNS with potential threats to the survival of native biodiversity and to human well-being, and thus – by extension – to consider them as invasive. This trend in the opinion of non-biologists may have reflected a "fear of the unknown" maintained by communication around NNS to influence the opinions, perceptions, and actions of the public (McNeeley 2012; Larson 2008). Beyond demographic and professional factors, scientists' perceptions of NNS may also be influenced by other individual factors (i.e., knowledge and value systems, relationship), the species itself, the effect of the species, the socio-cultural context, the landscape context, the institutional and policy context (Shackleton et al. 2019).

Overall, the mapping of opinions on NNS within our sample indicated three main groups of scientists in our sample corresponding to three leading opinions: two minority, extreme positions and one dominant, intermediate position. Scientists, practitioners, and policymakers within the "nativist" position are likely to focus excessively on the potential negative effects of NNS, declaring them as harmful or potentially harmful even in the absence of evidence (Ricciardi and Simberloff 2009). In opposition to this group, the group that we characterized as "liberal" was represented mainly by non-biologists, and its respondents were more open to the potential benefits of NNS. This position reflects the belief that NNS should be considered "innocent until proven guilty". Between these two opposing opinions was the group characterized as "agnostic", in which scientists were undecided towards the values associated with and perceived threats from NNS as well as the opportunities for their conservation. Their prevalence may be symptomatic of a transition process, suggesting a possible shift in opinions on NNS issues in the future. This observed trend of the debate is reflexive of the middle-ground approach on the perception and management of NNS proposed by Shackelford et al. (2013), in which the authors suggested a stepwise consideration when analyzing the situation of NNS. Although a cautious approach is recommended especially in the initial stages of the introduction and establishment of NNS (Shackelford et al. 2013), our results indicate that the net impact and the desirability of a species, not its origin, were what mattered most to scientists in our sample (see also Lindemann-Matthies 2016; Van Der Wal et al. 2015).

This study also aimed to describe and explain the views of scientists on the importance and contribution of NNS to biodiversity. We speculate that the above-mentioned diverse views indicated an evolution of the views of biodiversity and the values

associated with NNS. This diversity of views may reflect a transitional period during which the primary motives for protecting nature are called into question (Mace 2014; Sandbrook et al. 2019). In this sense, instead of the simplifying and leveling of values to match the views of a single group of biologists, the policy commitments and indicators used to measure progress in conservation may need to account for this diversity of views. Because NNS are also of importance and interest to the public, their conservation value should be captured by indicators of progress in biodiversity conservation.

A second important implication of this study derives from the observed “leading opinions groups” and points to a need to question the use of an apparent consensus to define policy instruments and biodiversity indicators. While being consistent with the traditional positions of invasion biologists, our results revealed the emergence of two other groups of opinions, reflecting a lack of consensus on the concepts, opportunities, and risks associated with NNS. This lack of consensus in values observed both among experts and non-experts (Humair et al. 2014; Young and Larson 2011) clearly showed that positions on the debate were not just a matter of diverging conceptual understandings and knowledge gaps but also reflected underlying personal values and/or alignments to social norms and group ideologies (Essl et al. 2017; Humair et al. 2014). Although divergence in concepts could be fixed and knowledge gaps bridged with more education, convergence of personal values, motivations, and emotions would be a much greater task.

This study was based on the opinions of 314 scientists, whom we presume were located primarily in Western countries (Europe, USA, and Canada) based on participation patterns in other studies. We do not know to what extent our sample was representative of the global community. Thus, as in any study of this nature, the precise percentage of respondents that we reported should be treated with caution and should not be extrapolated to represent the wider scientific community. Nevertheless, our study provides the best estimate to date of the relative importance of different value systems found within the scientific community and our findings clearly revealed a diversity of views regarding NNS. As such, results from our study call for a shift in how we collectively think about and define priorities for the conservation of biodiversity in its broadest sense. Here, we addressed a small subset of the interdisciplinary challenges that are linked to NNS and we look forward to other researchers exploring these questions in alternative ways and from different angles (importance of ethics, different types of intrinsic values, a regional focus, etc.). We believe that such efforts will be both timely and welcome in the context of the preparation for the post-2020 Strategic Plan for the Convention on Biological Diversity.

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Supplementary material 1

Raw data of the survey on perception and valuation of non-native species

Authors: Rodrigue C. Gbedomon, Valère K. Salako, Martin A. Schlaepfer

Explanation note: This material is the raw data file as downloaded from surveymonkey.

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Link: <https://doi.org/10.3897/neobiota.54.38741.suppl1>

Supplementary material 2

Perception and valuation of non-native species

Authors: Rodrigue C. Gbedomon, Valère K. Salako, Martin A. Schlaepfer

Data type: Opinion

Explanation note: This material is the survey report as generated by surveymonkey.

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Link: <https://doi.org/10.3897/neobiota.54.38741.suppl2>

Supplementary material 3

Distribution of respondents across the clusters regarding their opinions on values associated to non-native species

Authors: Rodrigue C. Gbedomon, Valère K. Salako, Martin A. Schlaepfer

Data type: Multimedia

Explanation note: This figure shows the distribution of respondents across the cluster clusters regarding their opinions on values associated to NNS, threats perceived from NNS and most appropriate methods for measuring whether a given non-native species is desirable or not.

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