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CONTRIBUTED PAPERS

Bibliometric investigation of the integration of animal personality in conservation contexts

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Article impact statement: Studies integrating animal personality and conservation are exponentially increasing and reveal ways to improve future conservation efforts.

Abstract

Consistent individual differences in behavior, commonly termed *animal personality*, are a widespread phenomenon across taxa that have important consequences for fitness, natural selection, and trophic interactions. Animal personality research may prove useful in several conservation contexts, but which contexts remains to be determined. We conducted a structured literature review of 654 studies identified by combining search terms for animal personality and various conservation subfields. We scored the relevance of personality and conservation issues for each study to identify which studies meaningfully integrated the 2 fields as opposed to surface-level connections or vague allusions. We found a taxonomic bias toward mammals (29% of all studies). Very few amphibian or reptile studies applied personality research to conservation issues (6% each). Climate change (21%), invasive species (15%), and captive breeding and reintroduction (13%) were the most abundant conservation subfields that occurred in our search, though a substantial proportion of these papers weakly integrated conservation and animal personality (climate change 54%, invasive species 51%, captive breeding and reintroduction 40%). Based on our results, we recommend that researchers strive for consistent and broadly applicable terminology when describing consistent behavioral differences to minimize confusion and improve the searchability of research. We identify several gaps in the literature that appear to be promising and fruitful avenues for future research, such as disease transmission as a function of sociability or exploration as a driver of space use in protected areas. Practitioners can begin informing future conservation efforts with knowledge gained from animal personality research.

KEYWORDS
climate change, individual differences, invasive species, population management, reintroduction, temperament

Investigación bibliométrica sobre la integración de la personalidad animal a los contextos de conservación

Resumen: Las diferencias individuales y constantes en el comportamiento, comúnmente llamadas *personalidad animal*, son un fenómeno generalizado en los taxones con con-

secuencias importantes para la aptitud, selección natural e interacciones tróficas. Las investigaciones sobre la personalidad animal pueden ser útiles en varios contextos de conservación, aunque falta determinar cuáles son estos contextos. Realizamos una revisión literaria estructurada de 654 estudios identificados mediante la combinación de los términos de búsqueda para la personalidad animal y varios subcampos de la conservación. Puntuamos la relevancia de la personalidad y los temas de conservación en cada estudio para identificar cuáles de estos integraron significativamente a ambos campos, contrario a las conexiones a nivel superficial o alusiones vagas. Descubrimos un sesgo taxonómico por los mamíferos (29% de todos los estudios). Pocos estudios enfocados en anfibios o reptiles aplicaron un estudio de personalidad a los temas de conservación (6% para cada uno). El cambio climático (21%), las especies invasoras (15%) y la reproducción en cautiverio y las reintroducciones (13%) fueron los subcampos de conservación más abundantes que aparecieron en nuestra búsqueda, aunque una proporción significativa de estos artículos integraron muy poco a la conservación y la personalidad animal (cambio climático 54%, especies invasoras 51%, reproducción en cautiverio y reintroducciones 40%). Con base en nuestros resultados, recomendamos que los investigadores procuren tener terminologías consistentes y de aplicación generalizada cuando describan las diferencias conductuales para así minimizar las confusiones y facilitar la búsqueda durante la investigación. Identificamos varios vacíos en la literatura que prometen ser vías fructíferas para las investigaciones en el futuro, como la transmisión de enfermedades como una función sociable o la exploración como un impulsor del uso del espacio en las áreas protegidas. Los practicantes pueden comenzar por guiar los siguientes esfuerzos de conservación con el conocimiento obtenido de las investigaciones sobre la personalidad animal.

PALABRAS CLAVE
cambio climático, diferencias individuales, especie invasora, manejo poblacional, reintroducción, temperamento

【摘要】
个体在行为上一致的差异, 通常被称为动物个性, 这是一种跨类群的普遍现象, 对适合度、自然选择和营养级互作有重要影响。在一些保护背景下, 动物个性研究可能是有用的, 但仍有待确定具体的保护背景。我们通过结合动物个性和各种保护子领域的搜索词, 确定了654项相关研究, 并进行了结构化的文献综述。我们对每项研究中动物个性和保护问题的相关性进行打分, 以确定哪些研究有意义地整合了这两个领域, 而不只是表面的联系或模糊的暗示。我们发现, 这些研究在类群上偏向哺乳动物(占所有研究的29%)。很少有两栖动物或爬行动物研究将动物个性应用于保护问题(各占6%)。气候变化(21%)、入侵物种(15%)、圈养繁殖与重引入(13%)是搜索结果中最常见的保护子领域, 尽管其中相当一部分论文中保护和动物个性的联系很弱(气候变化54%, 入侵物种51%, 圈养繁殖与重引入40%)。基于我们的结果, 我们建议研究人员在描述一致的行为差异时, 尽量采用一致的、广泛适用的术语, 以减少混淆, 并提高研究的可搜索性。我们还确定了几项研究空缺, 可能是未来进行有希望和有成果的研究的机遇, 如基于社会性的疾病传播或以探索为驱动力的保护区空间利用。保护实践者可以开始将动物个性研究中获得的知识用于指导未来的保护工作。**【翻译:胡怡思;审校:聂永刚】**

气质: 气候变化, 入侵物种, 重引入, 个体

INTRODUCTION

Traditional conservation strategies focus on conservation at the population level and may conserve a nonrandom or biased subset of the population based on inherent phenotypic differences (Kelleher et al., 2018; Smith & Blumstein, 2013). Recent studies demonstrate that individual animals respond differently to environmental variation, including anthropogenic disturbances, based on intrinsic behavioral differences (e.g., Collins et al., 2019; Sih, 2013; Turner et al., 2020; Wolf & Weissing, 2012). Known as animal personality, these behavioral differences are consistent within individuals across time or context, relatively easy to measure, and often have a genetic basis (Dubuc-Messier et al., 2018; Karlsson Green et al., 2016; Moran et al., 2017; Réale et al., 2007). Animal personality has been linked to fitness traits such as reproductive success and annual survival (Boon et al., 2007; Collins et al., 2019; Santicchia et al., 2018), which can be used to assess conservation goals, suggesting a direct

association between personality and conservation. Animal personality may, therefore, be a promising tool to help improve conservation techniques to conserve a larger proportion of each population (MacKinlay & Shaw, 2022; Sih, 2013).

Despite its potential for use in developing management strategies, animal personality appears to be understudied and underutilized in conservation. The intersection between conservation and behavioral subfields was documented by Berger-Tal et al. (2016) and MacKinlay and Shaw (2022) with a bibliometric approach. Berger-Tal et al. (2016) used a set of search terms corresponding to 10 behavioral (e.g., animal personality, dispersal, communication) and 16 conservation subfields to investigate how behavioral ecology was used in conservation. They identified articles published up to mid-2014 at the intersection of each pair of conservation and behavioral subfields (n intersections = 160) and found that some intersections are far more commonly studied than others. For example, they identified 7031 conservation papers concerning foraging, but only 212 studies involving animal personality. MacKinlay and Shaw (2022) examined animal personality papers identified based on the more general search term *conservation* and also found a relatively small number of papers (92) that made a strong link.

Berger-Tal et al.'s (2016) broader review constituted primarily a bibliographic summary of the number of papers at each intersection. A deeper investigation of how behavioral ecology was applied in every subfield was beyond the scope of their review. It remains to be seen whether the lack of studies in certain behavioral subfields reflect important gaps in our knowledge meriting further research or if these intersections represent effective dead ends of research where behavior has limited potential to affect conservation or management of a species. MacKinlay and Shaw's (2022) detailed review investigated the personality traits and methods of a subset of studies in detail, but we were interested in a broader scale and looking at the representation of animal personality within individual conservation subfields as in Berger-Tal et al. (2016).

To address this gap, we explored the role of personality in conservation using methods adapted from those described by Berger-Tal et al. (2016). We examined the literature, searching for intersections between 16 conservation fields and personality research, and rated the strength of integration for papers in our database by independently ranking each paper's relevance to the animal personality literature and the literature of the conservation subfield (Appendix S1). Papers with a high rank in both animal personality and conservation represent strong integration. Our objectives were as follows. First, we updated findings from Berger-Tal et al. (2016) regarding animal personality and identify conservation subfields (Appendix S1) with which it intersects. We predicted a substantial increase in the number of papers at the intersections of these fields in the 4 years following this initial investigation. Second, we sought to highlight areas where personality can contribute to conservation research and areas where it may not. Distinguishing meaningful integration from specious connections may help develop animal personality research as a useful conservation tool. Conservation priorities and the changing climate are pressing issues for policy makers and consequently may be mentioned in personality literature that is not directly related to conservation issues. We predicted that the integration of personality in conservation will be weak, with few studies actually demonstrating an applied link. Third, in cases for which the intersection between animal personality and conservation shows promise, we devised recommendations for future research and for policy makers to better integrate animal personality in conservation efforts.

METHODS

Literature search

Our first goal was to update the findings of Berger-Tal et al. (2016) relating to animal personality. We followed their methods with some updates to include changes in the field since mid-2014. A literature search was conducted on the Web of Science for 1900–2018. Given the lack of consistency in usage of terms related to animal personality (Sánchez-Tójar et al., 2022), we used multiple search terms to capture as many articles as possible. The personality search terms were as follows: *personalit** OR *temperament** OR "*individual variation**" OR "*behav* type**" OR "*behav* syndrome**" OR "*behav* variation**" OR "*behav* consisten**" OR "*consisten* behav**" OR "*behave*consistent**" OR "*consisten**." The final 4 terms are additions to the terms used by Berger-Tal et al. (2016).

All conservation subfields used by Berger-Tal et al. (2016) were replicated here, and no additional themes were added. These subfields included nuisance disturbances, overexploitation, invasive species, habitat loss, fragmentation, pollution, climate change, captive breeding and reintroduction, population modeling, wildlife disease management, prevention and control of invasive species, reserve design, connectivity, habitat restoration, managing harvesting and poaching, and human–wildlife conflict management (Appendix S1). We used the same search terms and exclusions for the conservation subfields as in Berger-Tal et al. (2016) (Appendices S1 & S2).

Analyses of papers

Seventeen animal behavior researchers analyzed 654 total papers. Some papers appeared 2 (n = 68 unique papers) or 3 (n = 9 unique papers) times in the data set because they were identified in multiple conservation subfields in the initial search. Extensive biweekly group workshops for development of methods and analysis of papers as well as assessments of interrater reliability (IRR) (see below) ensured consistency in our analyses. We considered only empirical studies of nonhuman animals (n = 508), omitting reviews (n = 96), human and plant studies (n = 44), and otherwise inaccessible studies (n = 7) from all analyses. We then collected data on 7 additional criteria: taxonomy, data collection method, behavioral response, personality traits measured, whether the study measured each trait multiple times, repeatability, and conservation importance (see below) of the link between personality and the threat of interest.

We recorded the species and taxa examined in each study as 1 or more of mammals, birds, amphibians, reptiles, fish, invertebrates, and other taxa. Invertebrates made up only 17% of studies, so we grouped them together because classes would

have been too small to consider individually. The other category included studies on plants and humans ($n = 44$), which were excluded from subsequent analyses. We then determined whether the study used animals from the wild, from captivity, or both. Several simulation studies did not study a specific taxa ($n = 18$) but were included in the data set if they met the remaining inclusion criteria.

We categorized the data collection method for each study as 1 or more of manipulative, observational, remotely sensed, or simulation. Only 1 study could not be classified in any of these categories and was omitted from the data set. Manipulation studies included those in which there was direct interaction with the study animals. For example, the subjects were placed in a box or arena to measure behavior, the subjects were presented with a novel object, or the authors approached the subjects as part of the behavioral assessment. Observational studies included those in which the authors directly observed the subjects and recorded the animals behaving naturally without intervention. Remote sensing studies included those in which individuals were observed indirectly with technology such as global position systems (GPS), telemetry, camera traps, or collars. Simulation studies included those in which no live animals were studied and instead computer modeling was conducted.

We recorded the behavioral response the authors of the articles reported in their study verbatim without interpretation or categorization. These included numerous behaviors, such as flight initiation distance, exploration, and space use. If the authors did not measure any behavior in their study, the paper was excluded from subsequent analyses ($n = 138$).

We recorded the personality traits measured in each study as a binary response (measured or not measured) for each of the following traits as outlined and defined in Réale et al. (2007): boldness, exploration, aggressiveness, sociability, and activity (hereafter Big 5). If the authors used 1 of the Big 5 terms for the behavior they measured, this was recorded as measured, regardless of the authors' definition or the behavioral assessment methods used in the paper. Although there is considerable inconsistency in the definitions and ways of measuring the Big 5 personality traits (Réale et al., 2007; Sánchez-Tójar et al., 2022; White et al., 2013), we did not assess the specificity of these terms in each paper. If the authors described the measured behavioral response as a personality or individual trait but did not use 1 of the Big 5 terms, we recorded the term used by the authors. Some authors reported several of the Big 5 traits in addition to other terms. Other traits included, but were not limited to, agreeableness, cognition, and neophobia or neophilia (Appendix S3). Although individual differences in parental behavior are commonly observed, we did not include terms relating to parental behavior.

We recorded if there were multiple measures of each behavior for each individual. For our purposes, multiple tests included the repetition of the same test ≥2 times to quantify the same trait or the use of different tests explicitly stated in the paper to measure the same trait. For GPS data, the authors needed to explicitly state that the data were blocked into multiple temporal units to measure a behavior or personality trait.

Animal personality is commonly defined as consistent individual differences in behavior, and most personality researchers agree that behavior must be repeatable to be considered personality (Bell et al., 2009; Sánchez-Tójar et al., 2022). We therefore assessed whether the authors measured and reported repeatability in their paper. If the authors did not include multiple measures (above), we scored repeatability as no. Reviewers looked for keywords in each paper including mixed-effects model, intraclass coefficient, and other repeatability coefficients (e.g., a correlation coefficient, Kendall's coefficient of concordance). We also searched for R packages commonly used to assess repeatabilities, including rptR, MCMCglmm, glmer, lmer, and nlme (Bates et al., 2015; Hadfield, 2010; Pinheiro et al., 2020; Stoffel et al., 2017). Random effects of individual identity or random slopes from individual identities are not sufficient as repeatability measures on their own, and papers that included only these were scored as no for repeatability.

The classification of conservation importance was adapted from the strength of linkage classification in Berger-Tal et al. (2016). We defined conservation importance based on how well the paper connected to or built off the specific conservation subfield under which it was identified. Some papers appeared in search results of 2 ($n = 68$) or 3 ($n = 9$) different subfields, so although all other information would be identical for each of these papers, the conservation importance could differ (i.e., the paper focused on climate change, but mentioned habitat fragmentation only in passing). The conservation importance of papers was ordinal, ranked from none to high. Papers ranked as none were found in our original search but were not about the conservation subfield (i.e., studies of animal personality with no mention of conservation or studies not relevant to either field). Papers ranked as low mentioned the conservation subfield briefly in the introduction or discussion, but no meaningful connections were made, or the conservation subfield received a token mention. Papers ranked as medium made a link to the conservation subfield that was clear and important in the rationale for the study or had clear and important consequences or interpretation of findings in the discussion in the context of conservation. Medium-ranked papers included more than just a passing reference but did not make specific policy or management recommendations. Finally, papers ranked as having high conservation importance had the conservation subfield strongly integrated into the research and writing and made specific recommendations for future studies, policy, or management based on conservation concepts.

Personality relevance assessment

We determined the relevance of each paper to personality after data collection based on the outcome of the multiple measures, repeatability, and Big 5 variables. Papers were scored as yes in the Big 5 column if the authors explicitly stated that they measured activity, aggression, boldness, exploration, or sociability; if the authors used a term that is a common measure of 1 of the Big 5 (e.g., using the term *risk-taking* for boldness

or *space use* for activity); or if the authors measured cognition, decision-making, problem-solving, or inhibition (Appendix S3). The classification of personality relevance was based on specific criteria: none, authors did not measure 1 of the Big 5, did not perform multiple measures, and did not report repeatability; low, there were multiple measures for each individual, but the authors did not report repeatability or the authors measured 1 of the Big 5 but did not have multiple measures or report repeatability; medium, there were multiple measures and the authors reported repeatability but did not measure 1 of the Big 5 or the authors measured 1 of the Big 5 or another relevant personality trait and there were multiple measures but did not report repeatability; high, there were multiple measures, the authors reported repeatability, and the authors measured 1 of the Big 5 or another relevant personality trait.

Data analyses

Data were sorted, cleaned, and analyzed using R 4.0.1 (R Core Team, 2020). Data files and R code are available on Zenodo (https://doi.org/10.5281/zenodo.7258459; https://zenodo.org/record/7257981#.Y1qvLHZKg2w). We measured IRR to ensure that data collection was consistent across observers with the package irr (Gamer et al., 2019). For most variables, IRR was assessed for the subset of papers that appeared twice in the data set ($n = 68$). An exception was for the conservation importance variable because this variable inherently differed for each paper, depending on the conservation subfield with which it was associated (see above). A new subset of 100 papers was randomly selected and reassessed for the conservation importance value by reviewers who had not previously read that paper. Our conservation importance data were ordinally ranked, so we used the weighted Cohen's kappa (κ) with a linear weight for our measure of IRR. This method accounts for the ordinal ranking when evaluating agreement among observers (rewarding closeness in values), so a paper that was ranked high by 1 reviewer and medium by another contributes to a higher IRR than a paper ranked high and none by different reviewers (Cohen, 1968).

The IRR for conservation importance was statistically significant ($\kappa = 0.316$, $z = 4.82$, $p < 0.001$, agreement 54.9%), but agreement was lower than desired. Upon investigation of cases with the greatest discrepancy between observers, the majority of these were initially, and incorrectly, scored as none. In light of this, we rescored all papers that were given a conservation importance score of none. The percent agreement was used for all other variables and exceeded 80% except for the data collection method and multiple measures (Appendix S4).

Plots were made with the package ggplot2 (Wickham, 2016). Because our data set contained duplicate studies that differed only by conservation subfield and conservation importance score, duplicates were removed for all analyses not relating to conservation subfield or importance.

To determine whether conservation importance changed over time, we scored papers from 1 to 4 (1, none; 2, low; 3, medium; 4, high) and calculated the average score per year. Given that these scores were calculated for all papers with at least low relevance to animal personality, this score represented the strength of integration of animal personality in conservation for the papers in each year. We tested for changes in conservation importance over time with a linear model with year as an integer predictor. A Pearson's chi-square test was used to determine whether the ranking of conservation importance was independent of the ranking of personality relevance. Assumptions of both analyses were met.

In the interest of describing the diversity in behaviors measured and terminology used by personality researchers, we created a complete list of all terms recorded in the behavioral response definition column and counted the number of unique terms. Using this list, we made a word cloud with the package wordcloud (Fellows, 2018). Prior to counting, quantifying words or phrases, such as *number of*, *amount of*, *maximum*, *minimum*, *mean*, and *total*, and unnecessary words, such as *and* and *the*, were removed. Big 5 terms and terms very similar to the Big 5 were removed from the word cloud. Terms that were very similar to each other (e.g., *flight initiation distance* vs. *flight response distance*) were combined as a common term to better represent the use of that behavior in papers in the data set (Appendix S5).

RESULTS

The original data set contained 654 papers (Appendix S6). After removing reviews, papers that studied humans or plants, and papers that did not study any behavior, the sample size was 370 papers published in 108 unique journals (Appendix S7). After classification of personality relevance, removal of papers with a personality relevance score of none ($n = 87$), and removal of papers with incomplete data ($n = 8$), the final sample size was 275 papers (249 unique papers) (Appendix S8). We used this final sample, hereafter referred to as relevant studies, for all analyses and data summaries.

Data summary

The number of studies increased substantially with time (Figure 1). Overall, 65% of the relevant personality papers were published after 2014 when data collection for Berger-Tal et al. (2016) ceased. There was no significant change in average conservation importance score over time ($F_{1, 17} = 1.92$, $p = 0.18$, $r^2 = 0.10$) (Appendix S9).

Most studies were conducted on mammals (28.7%), birds (21.1%), fish (20.6%), and invertebrates (17.8%). Reptiles (5.7%) and amphibians (6.1%) were poorly represented in the data set (Appendix S10). Mammals were the most commonly studied taxa overall and in most conservation subfields; they were absent only from reserve design and invasive control (Appendix S10). Climate change and invasive species contained studies of all taxonomic groups, but human–wildlife conflict, invasive control, managing harvesting and poaching, and reserve design each had studies on only 1 taxonomic group (Appendix S10).

The majority of relevant studies were conducted on wild animals (wild, 70.8%; captive, 24.3%; both, 4.9%) and used

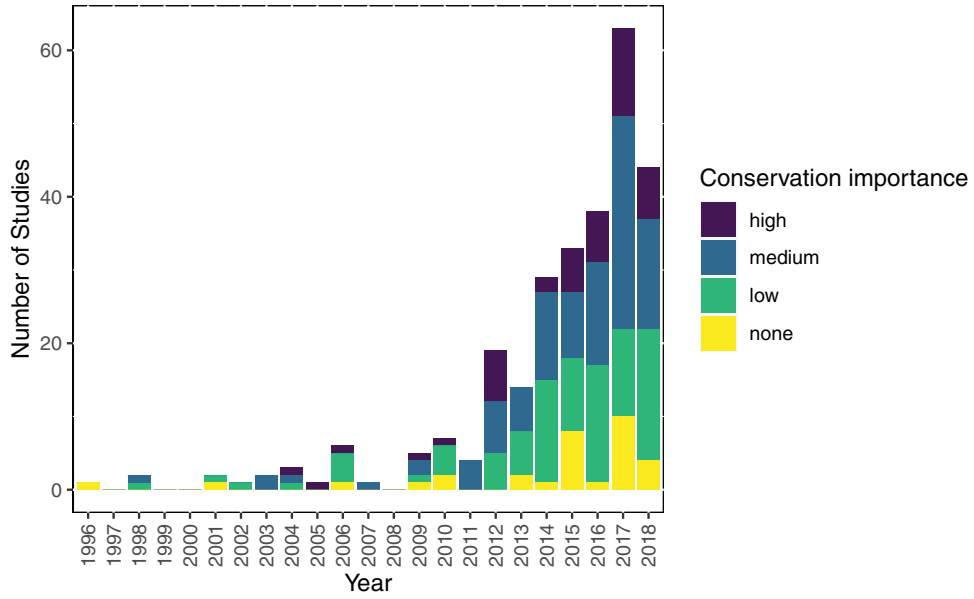

FIGURE 1 Change over time in the number of animal personality articles relative to conservation importance

manipulative methods (61.4%) either exclusively or in combination with other data collection methods. Observational methods were used in 22.5% of papers, remote sensing in 18.9%, and simulation in 5.6% either exclusively or in combination with other data collection methods. The majority of relevant studies (73.5%) measured the personality trait of interest at least twice per individual, but only 46.6% of studies explicitly stated the repeatability.

Climate change, invasive species, and captive breeding and reintroduction subfields made up over half of the studies in the final data set (Figure 2). About one-half of the studies scored either medium (37.5%) or high (16.7%) conservation importance, one-third scored low (34.2%), and the remainder scored none (11.6%).

Integration of personality in conservation subfields

There was no association between a paper's conservation importance and personality relevance ($\chi^2 = 5.2$, df = 9, $p = 0.82$). Invasive species, captive breeding and reintroduction, and climate change had the most papers that were categorized as medium or high conservation importance (Figure 3). Wildlife disease, reserve design, managing harvesting and poaching, invasive control, and habitat restoration each had at most 2 papers that were relevant to both animal personality and the conservation subfield, suggesting that these intersections are either understudied or that these are conservation subfields in which personality is not particularly relevant.

Personality traits studied

In total, 816 unique terms were used by authors to describe the behavior measured (Appendix S11). Of these 816, the Big 5 terms (boldness, activity, exploration, aggression, sociability) were the most frequently used. The other most common terms generally referred to movement and space use, such as *dispersal*, *foraging*, *space use*, *home range*, *habitat selection*, and *movement*, or were behaviors related to risk-taking including *flight initiation distance* and *neophobia* (Figure 4).

For our analysis of which personality traits were measured in each conservation subfield, we considered only studies relevant to personality with medium or high conservation relevance ($n = 149$). Among these studies, although the Big 5 terms were the 5 most frequently used overall (79.9% of studies included at least 1 of the 5), a majority (56.4%) of papers also used a term outside of the Big 5 to refer to a personality trait (collectively referred to as other in Figure 5). Boldness (40.9%), activity (41.6%), and exploration (32.9%) were the most commonly measured Big 5 traits in relevant papers. Sociability (12.8%) was the least studied Big 5 trait among personality–conservation intersection papers. Aggression was moderately represented overall (18.8%), but occurred in more than one-third of papers in the conservation subfields of captive breeding and reintroduction, invasive species, and wildlife disease. The use of all Big 5 traits were best represented in the conservation subfields of wildlife disease, invasive species, and captive breeding and reintroduction.

DISCUSSION

In the 4.5 years since Berger-Tal et al.'s (2016) initial review, the number of studies that empirically demonstrated the intersection between animal personality and conservation more than doubled (Figure 1). More than one-half of the studies in our database were relevant to both animal personality and to at least 1 of 16 conservation subfields, but there was no general trend in the strength of the integration over time (Appendix S9). Some

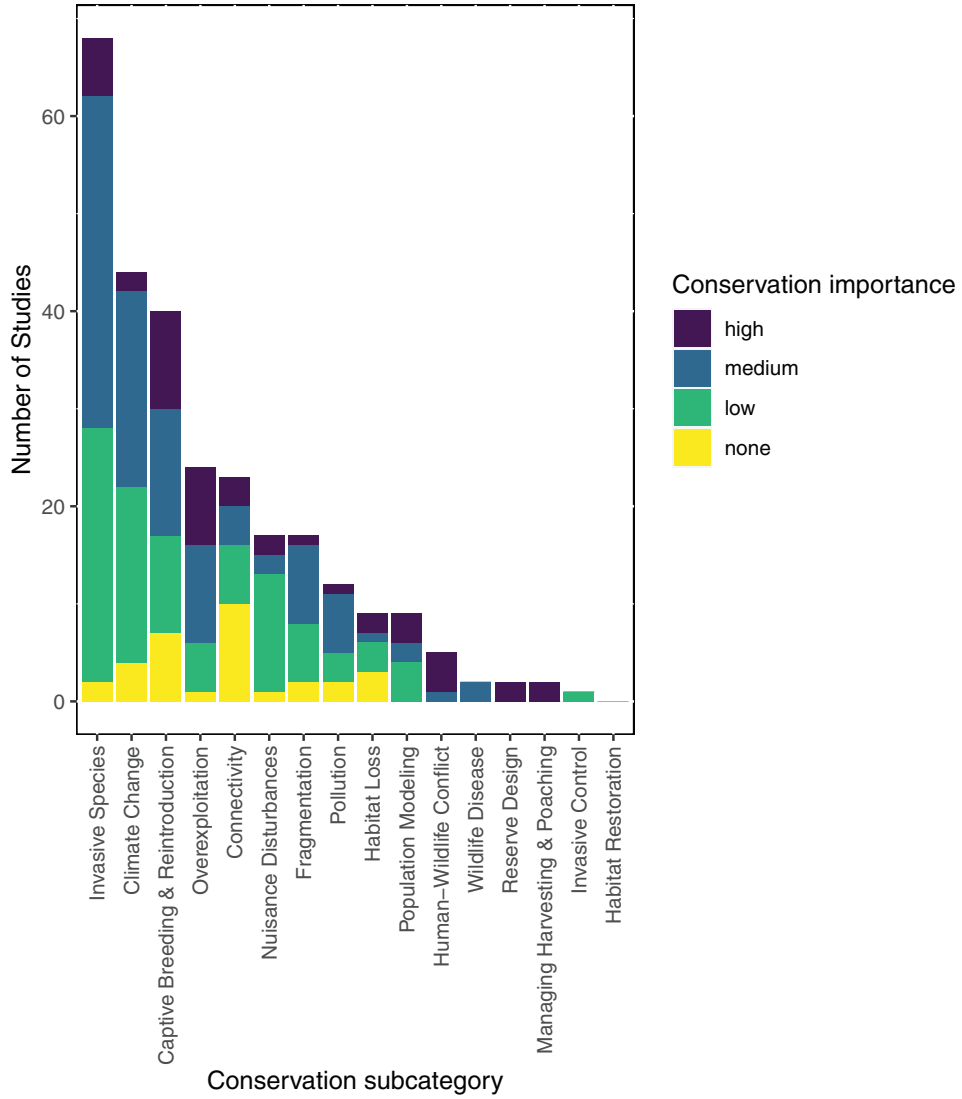

FIGURE 2 The number of studies on animal personality in each conservation subfield included in the final data set divided by conservation importance. Studies assessed as having no relevance to animal personality and reviews and studies of humans and plants were not included

subfields have, overall, a much larger body of literature than others (e.g., climate change vs. reserve design). We considered our findings in light of the total number of papers in each intersection and of the proportion of studies in a subfield when the distinction was relevant. Overall, we found that animal personality is relevant to multiple subfields of conservation, and we believe the lack of knowledge in other subfields warrants further investigation.

Meaningfulness of integration

The integration of animal personality and conservation was most abundantly represented in the conservation subfields of climate change, captive breeding and reintroduction, invasive species, and overexploitation (Figure 3). These subfields represent areas in which animal personality has already been adopted and applied to some extent. We reviewed some of these existing applications below and encourage the continued use of animal personality in these subfields.

The implications of animal personality for captive breeding and reintroduction have been reviewed on numerous occasions (de Azevedo & Young, 2021; Powell & Gartner, 2011), and practical applications have been recommended and successfully implemented in some cases. Personality traits, such as boldness, can be used to predict the survival of reintroduced species (Baker et al., 2016; Bremner-Harrison et al., 2004; Dutra et al., 2016; Germano et al., 2017; Lopes et al., 2017) and can therefore be used as a selection criteria for which individuals to reintroduce (Bremner-Harrison et al., 2004). Personality traits can also inform practices for enhancing enrichment for captive animals (Coelho et al., 2012) and can enhance captive breeding programs through, for example, personality-based assessments of compatibility (Martin-Wintle

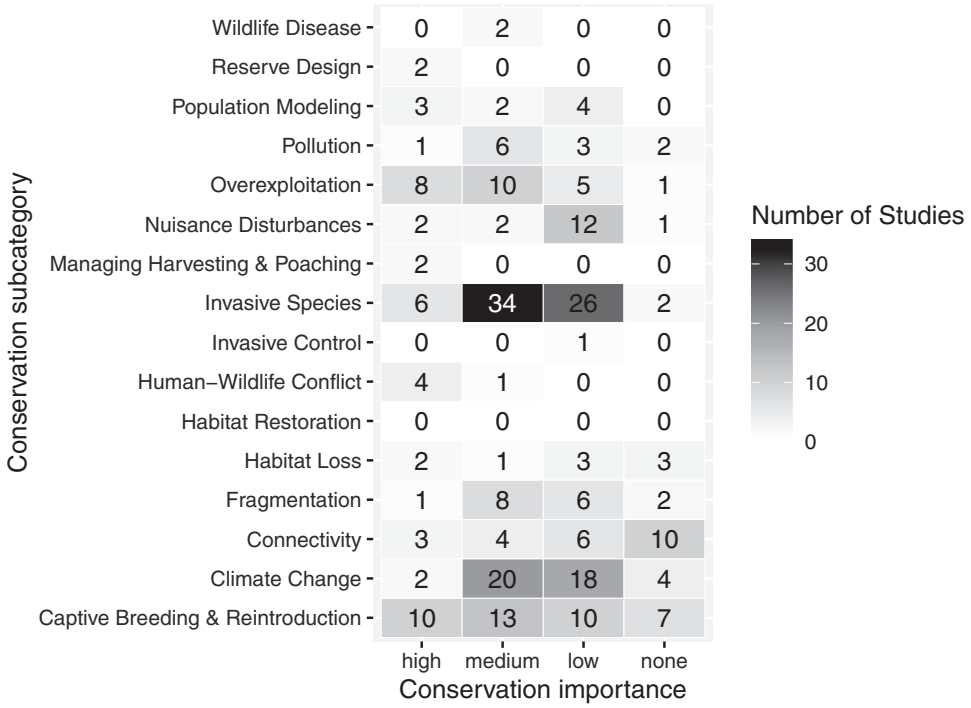

FIGURE 3 Number of articles relevant to animal personality that had high, medium, low, or no conservation importance for each conservation subfield

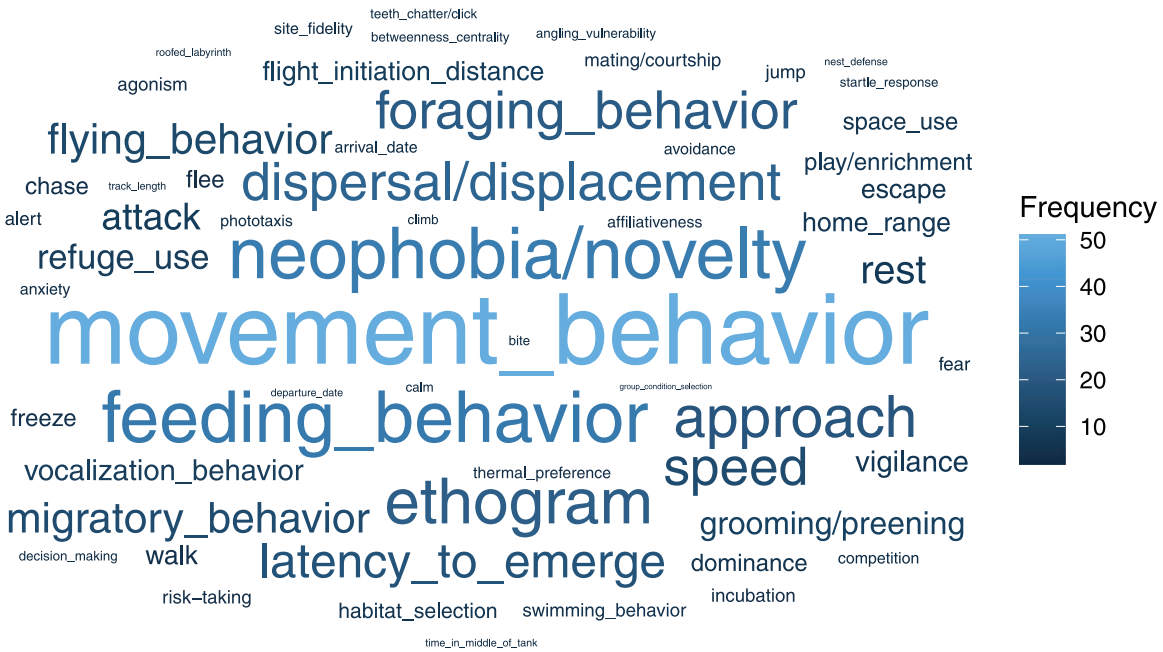

FIGURE 4 Most common words or phrases used by authors to describe behavior associated with animal personality, excluding the most used terms (the Big 5): *boldness*, *exploration*, *aggressiveness*, *sociability*, and *activity*

et al., 2017). These studies aim to bridge the gap between animal personality and animal management by providing a methodology to apply personality testing to established management practices.

The literature surrounding animal personality and climate change is less applied and tends to focus on how individuals will respond to the changing environment through behavioral plasticity, habitat use, or range shifts (Stanley et al., 2012; van Beest

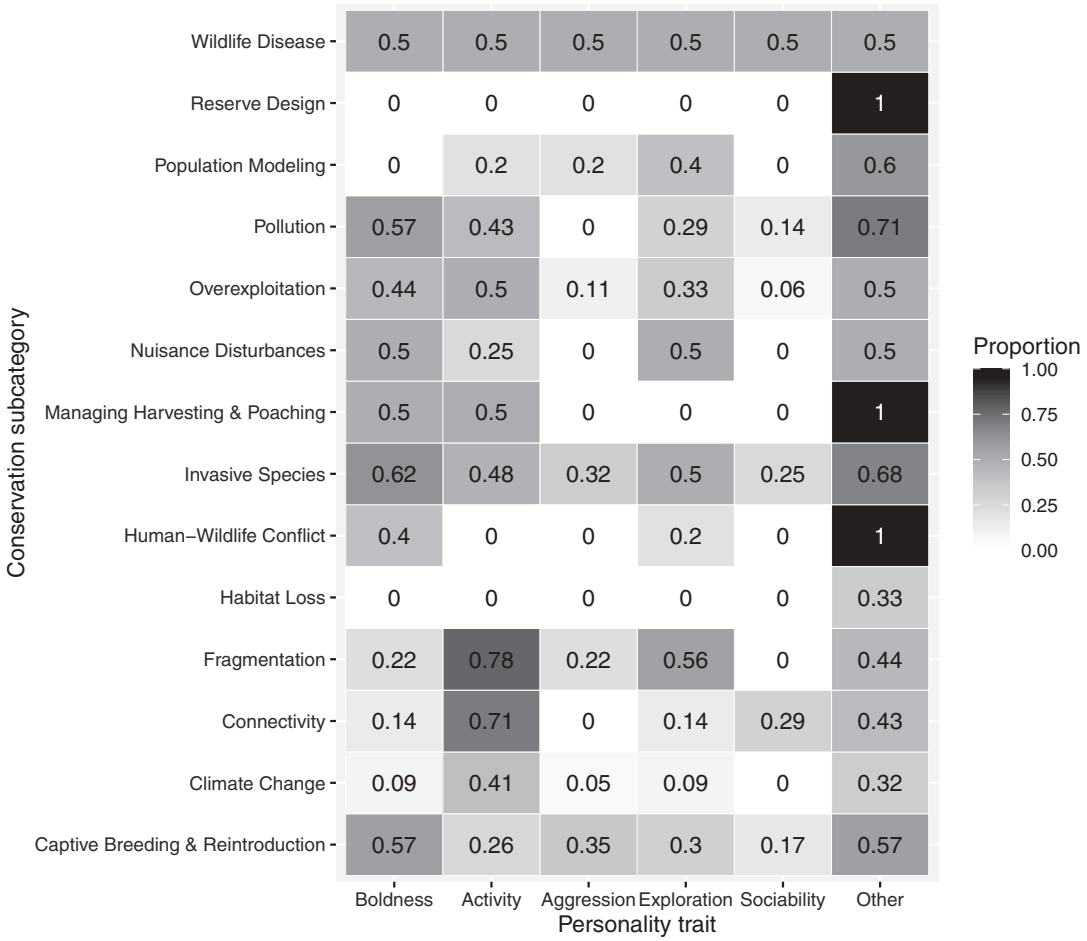

FIGURE 5 Proportion of animal personality studies in each conservation subfield that measured boldness, exploration, aggressiveness, sociability, and activity or other. Traits measured in studies relevant to animal personality and the respective conservation subfield (medium or high conservation importance). Some studies measured more than 1 personality trait and so may be represented more than once

& Milner, 2013) and on how environmental conditions alter personality traits (Frost et al., 2013). Animal personality is therefore useful for predicting adaptability and survival of individuals in warming environments (Moran et al., 2016).

For invasive species, animal personality studies reveal that individuals at the forefront of invasion tend to have specific personality traits that enable them to disperse (Cote et al., 2011), dominate resources or outcompete native species (Galbraith et al., 2017), and persist in non-native environments (Lapiedra et al., 2017). In addition, changes in the personality of native species exposed to invasive species, such as increased wariness when living with an invasive predator, can inform how native species adapt to changing communities (West et al., 2018). Animal personality can also influence ease of capture or recapture of individuals (Carroll et al., 2016; Johnstone et al., 2021), which could have important implications for management of invasive species. Attempted eradication via trapping may only select for individuals with certain personality traits, thus creating a population of individuals with biased personality traits that are more difficult to trap or manage (e.g., Johnstone et al., 2021). Conversely, deliberate targeting of individuals with certain personality traits could mitigate future impacts and spread of an invasive species if personality is known to be linked to dispersal or competitive ability. Overall, animal personality is useful for predicting the impacts that invasive species will have on ecosystems (Brodin & Drotz, 2014).

The intersection of animal personality and overexploitation by humans is well studied, particularly for marine ecosystems and fishing (Brooker et al., 2016). Personality traits influence which individuals are most susceptible to being caught (Alós et al., 2016). Various fishing gears are known to select for different traits (Claireaux et al., 2018), and changes in the behaviors of populations due to overexploitation of specific individuals have been observed (Uusi-Heikkilä et al., 2015).

Although valuable insights can be gleaned from the intersection of animal personality with captive breeding and reintroduction, climate change, invasive species, and overexploitation, these conservation subfields are overrepresented in the data set. Each of these subfields, with the exception of overexploitation, had over 40% of papers with conservation importance ranked as low or none. Although a few papers highlighted applied insights, there was an abundance of captive breeding and reintroduction

papers that either focused on conservation with weak or no integration with personality (e.g., Bergvall et al., 2017; McPhee & Silverman, 2004) or focused on personality with low conservation relevance (e.g., Boulton et al., 2014; Madden & Whiteside, 2013). In climate change papers, many made token mention of climate change without any real connection to the topic. Climate change is an urgent threat to many species and attracts broad public interest; authors may be more likely to allude to climate change in their research to illustrate its relevance without further developing these ideas. For both climate change and invasive species, very few papers used their results to recommend future studies or conservation actions. The prevention and control of invasive species was a separate conservation subfield in our review from studies of invasive species themselves, and so many of the studies in the invasive species category were less directly relevant for conservation practices and more focused on identifying personality traits that may predict invasion potential. Only 1 paper was identified in the invasive control subfield, so the application of animal personality to invasive control needs further development.

Animal personality should not be considered irrelevant to subfields with fewer papers detected by our search because they may simply be understudied overall and still have valuable information to discover. Although wildlife disease, human–wildlife conflict, and reserve design each had among the fewest papers intersecting with personality (Figure 3), the papers that were included had high relevance to personality and to the conservation subfield and provided valuable insights, suggesting these subfields have not yet been exhausted of fruitful research questions. For example, Olsen et al. (2012) demonstrated that consistent individual differences in migratory behavior in Atlantic cod (*Gadus morhua*) correlated with their harvest susceptibility, and the authors used this information to recommend improvements to marine reserves. Similarly, boldness, exploration, and neophobia varied among juvenile spotted hyenas (*Crocuta crocuta*) in association with human disturbance, predicting their likelihood of surviving to adulthood (Greenberg & Holekamp, 2017). This study was among the first to investigate the relationship between human disturbance and personality in species other than birds and small mammals, which suggests that the intersections between animal personality and certain conservation subfields may be underrepresented due to the previously limited ability of researchers to test these questions due to constraints on observability, time, and resources. Given that the number of studies in our data set increased over time, none of these intersections are likely exhausted as of yet.

Taxa studied

Amphibians and reptiles were poorly represented in the data set overall and within each subfield; these taxa were studied in 20% or fewer papers in all subfields. Mammals were well represented in the data set; they were studied in all but 2 conservation subfields, reflective of the taxonomic bias toward mammals and charismatic megafauna in the broader conservation field (Donaldson et al., 2016). Although invertebrates as a whole may not appear underrepresented relative to reptiles and amphibians, the 18% of studies that looked at invertebrates were spread across a vast range of taxa. Of these papers, 47% involved various insect taxa across 7 orders (Lepidoptera and Coleoptera each 11%). Crustaceans made up 31% of invertebrate studies, and the rest consisted of molluscs (10%), arachnids (8%), and echinoids (6%).

Some taxa were far more likely to occur in specific subfields (e.g., fishes in the pollution category). Although some of this variation may be attributed to ecological differences among species (i.e., aquatic systems are more conducive to pollution research), further research effort could be devoted to various taxa in specific subfields for which animal personality is understudied despite its highly relevant nature. For example, amphibians were entirely absent from studies of wildlife disease and pollution, despite the ongoing global chytrid fungal crisis and the susceptibility of amphibians to waterborne pollutants (Bosch et al., 2021).

Personality measurements

According to a recent self-report study, most animal personality researchers agree that multiple measurements per individual are required in a study of animal personality (Sánchez-Tójar et al., 2022). It is therefore surprising that many studies investigating consistent individual differences in behavior did not measure individuals more than once, a finding consistent with the findings of the systematic reviews conducted by Sánchez-Tójar et al. (2022) and MacKinlay and Shaw (2022). In our study, 66 papers (26.5%) used 1 of the Big 5 terms without performing multiple measures per individual. In some cases, papers used data from populations that had been studied for many years, and the repeatability of certain personality traits had been well established. In other cases, however, the authors did not attempt to measure individuals more than once or had a very small subsample of individuals with repeated measures. In any study that does not conduct multiple measures per individual, the interpretation of these behaviors as animal personality should be considered with caution (Sánchez-Tójar et al., 2022).

In papers that had multiple measures of individual behavior, 36.6% did not report the repeatability coefficient. These studies either did not mention repeatability at all or they stated that the behavior was repeatable without providing the statistical values. We contend that it is important to provide an estimate of repeatability for the sake of transparency.

A wide range of language was used to describe the behaviors measured among the papers in our data set. Although the Big 5 terms were most common, we identified more than 800 other terms used to describe the behaviors measured. Many of the common terms used are synonymous with Big 5 terms. For example, risk-taking and flight initiation distance are measured to gauge boldness. Migratory, foraging, and resting behaviors are often measured as part of activity, and refuge use and open field trials are common measurements of exploration (Réale et al., 2007). Contrastingly, some terms can be associated with

numerous personality traits. For example, the personality trait measured using novel object trials has been called neophobia–neophilia, shyness–boldness, or exploration–avoidance. The lack of consistent terminology has been identified as a possible reason to question the animal personality literature (MacKinlay & Shaw, 2022; Réale et al., 2007; Sánchez-Tójar et al., 2022) and may discourage the use of animal personality in the development of conservation tactics (Takola et al., 2021). The methods used to measure a trait, such as boldness, will inevitably differ among species and ecological contexts, but greater clarity and transparency of both the test used and what the researchers consider the trait being measured would allow for better interpretation across studies. For example, it is better to say, "We used a novel object test to measure boldness in this population, as the species commonly encounters unfamiliar objects in its urban habitat" than to say "We used an aerial predator simulation to measure boldness of this prey species." Better agreement within the animal personality field on what and how personality traits are measured will enable researchers and practitioners who do not specialize in personality testing to integrate it into their work.

Recommendations

Based on our findings, we propose a set of recommendations for integrating animal personality into conservation. First, as previously recommended (e.g., MacKinlay & Shaw, 2022; Réale et al., 2007; Sánchez-Tójar et al., 2022), we recommend a consistent set of terms be used to describe measurable personality traits. Preparation, wide-spread dissemination, and use of a glossary would be helpful to make the field of animal personality more accessible to researchers from other disciplines.

Second, we recommend researchers focus research efforts on the underrepresented conservation subfields, taxa, and Big 5 personality traits we identified in our review. Certain conservation subfields that are underrepresented in our data set, including wildlife disease, human–wildlife conflict, and reserve design, have clear paths forward where animal personality could be usefully applied to research questions: disease transmission as a function of sociability, boldness as a mediator of interactions between humans and wildlife, and exploration and activity as drivers of space use in protected areas, to name a few. Other subfields do not have as immediately apparent fruitful intersections, but we assert that none of the intersections that are currently scarcely populated have been sufficiently investigated to dismiss them outright as not meriting further work. A broader exploration of taxa is required in most fields to better understand the intersection of animal personality with conservation. In particular, all subfields need more studies on reptiles and amphibians to broaden understanding of the relevance of reptile and amphibian personality to conservation. The use of personality traits in conservation is currently biased toward boldness, exploration, and activity, each of which has clear relevance in several conservation contexts. Sociability in particular merits further work, given how important social interactions and relationships have been shown to be (Vander Wal et al., 2015) even for species typically thought of as solitary or asocial (Siracusa et al., 2021).

Third, researchers should consider the ecological and social factors that influence behavioral variation. Given that individual variation in behavior is more likely than not to occur across most species that have been studied, we maintain that the demonstration of the existence of animal personality in a given species is no longer sufficient for current research. Personality researchers should close the gap between low and high conservation importance by drawing more concrete connections between the causes and consequences of individual behavioral variation in a population-level ecological context.

Fourth, practitioners should consider individual variation in management strategies. Animal personality influences how individuals respond to environmental change and anthropogenic disturbance. Personality traits should therefore be used in environmental assessments and population modeling to predict survival of individuals with different traits and evolution of populations facing environmental change and anthropogenic pressure. Individual differences in behavior should also be considered when developing applied management techniques, including, but not limited to, traps, harvest gear types, ecological reserves, enclosures, and translocation and reintroduction programs. Certain methods will not effectively conserve individuals with disparate personalities, so multiple methods may need to be developed and applied simultaneously to accommodate a greater proportion of the population. Our results indicate that animal personality shows a particularly promising intersection with climate change, captive breeding and reintroduction, overexploitation, and invasive species. We encourage integration of animal personality into current and future mitigation strategies dealing with these subfields.

Overall, strong integrations exist between animal personality and conservation across topics and taxa, but there is still opportunity for growth and further development. The field has progressed enough that personality research in conservation measures can be used to improve management of diverse populations. As a first step, managers could search the literature for individual differences in behaviors with fitness consequences in their system, and researchers should investigate links between fitness and personality in species in which only the existence of personality has been demonstrated. Although personality traits may not have important fitness consequences in every context, the widespread relevance we found suggests that the investigation of personality as a potentially important consideration in managed populations should be a fundamental part of the conservation process. As a goal, this should provide mutually beneficial collaborations for both academics and management agencies.

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the territory in which we gather as the ancestral homelands of the Beothuk, and the island of Newfoundland as the ancestral homelands of the Mi'kmaq and Beothuk. This acknowledgement is just a small step in working toward reconciliation.

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