Received: 6 July 2021 | Revised: 0 xxxx 0000 | Accepted: 26 April 2022

DOI: 10.1111/cobi.13935

Conservation Biology

REVIEW

# A systematic review of animal personality in conservation science

**Regan D. MacKinlay** | **Rachael C. Shaw**

School of Biological Sciences, Victoria University of Wellington, Wellington, New Zealand

**Correspondence**
Regan David MacKinlay, School of Biological Sciences, Victoria University of Wellington, PO Box 600, Wellington 6140, New Zealand.
Email: regan.d.mackinlay@gmail.com

**Article impact statement**: Most animal personality studies in conservation do not follow best practice for personality research; those that do offer guidance.

**Funding information**
Faculty of Science, Victoria University of Wellington, Grant/Award Number: Doctoral Scholarship; Royal Society Te Apārangi: NZ, Grant/Award Number: RDF-VUW1604

## Abstract

Although animal personality research may have applied uses, this suggestion has yet to be evaluated by assessing empirical studies examining animal personality and conservation. To address this knowledge gap, we performed a systematic review of the peer-reviewed literature relating to conservation science and animal personality. Criteria for inclusion in our review included access to full text, primary research articles, and relevant animal conservation or personality focus (i.e., not human personality studies). Ninety-two articles met these criteria. We summarized the conservation contexts, testing procedures (including species and sample size), analytical approach, claimed personality traits (activity, aggression, boldness, exploration, and sociability), and each report's key findings and conservation-focused suggestions. Although providing evidence for repeatability in behavior is crucial for personality studies, repeatability quantification was implemented in only half of the reports. Nonetheless, each of the 5 personality traits were investigated to some extent in a range of conservations contexts. The most robust studies in the field showed variance in how personality relates to other ecologically important variables across species and contexts. Moreover, many studies were first attempts at using personality for conservation purposes in a given study system. Overall, it appears personality is not yet a fully realized tool for conservation. To apply personality research to conservation problems, we suggest researchers think about where individual differences in behavior may affect conservation outcomes in their system, assess where there are opportunities for repeated measures, and follow the most current methodological guides on quantifying personality.

**KEYWORDS**
applied animal behavior, behavioral traits, wildlife management

## Resumen

Aunque la investigación sobre la personalidad animal puede tener usos aplicados, esta propuesta aún no ha sido evaluada mediante el análisis de estudios empíricos que examinan la personalidad animal y la conservación. Realizamos una revisión sistemática de la literatura revisada por pares relacionada con las ciencias de la conservación y la personalidad animal para abordar este vacío en el conocimiento. Los criterios para la inclusión dentro de nuestra revisión incluyen el acceso al texto completo, artículos de investigación primaria y un enfoque relevante en la conservación animal o en la personalidad (es decir, no estudios sobre la personalidad humana). Noventa y dos artículos cumplieron con estos criterios y de ellos resumimos los contextos de conservación, procedimientos de análisis (incluyendo el tamaño de la muestra y de la especie), estrategia analítica, características declaradas de la personalidad (actividad, agresión, audacia, exploración y sociabilidad) y los hallazgos más importantes de cada reporte y sus sugerencias enfocadas en la conservación. Aunque proporcionar evidencias para la repetitividad en el comportamiento es crucial para los estudios

de personalidad, la cuantificación de la repetitividad sólo se implementó en la mitad de los reportes. Sin embargo, cada una de las cinco características de la personalidad se investigaron hasta cierto punto dentro de una gama de contextos de la conservación. Los estudios más sólidos en el campo mostraron varianza en cómo la personalidad se relaciona con otras variables de importancia ecológica a través de las especies y los contextos. Además, muchos estudios fueron los primeros intentos del uso de la personalidad con propósitos de conservación en un sistema dado de estudios. En general, parece que la personalidad todavía no es una herramienta completamente realizada para la conservación. Para poder aplicar la investigación sobre la personalidad a los problemas de conservación, sugerimos que los investigadores piensen en dónde pueden afectar las diferencias individuales en el comportamiento a los resultados de la conservación dentro de su sistema, evalúen en dónde hay oportunidades para repetir medidas y sigan las guías metodológicas más actuales sobre la cuantificación de la personalidad.

**PALABRAS CLAVE**
características conductuales, comportamiento animal aplicado, manejo de fauna

**【摘要】**
尽管研究动物的个性可能具有应用价值, 但这一提议尚未得到动物个性与保护的实证研究的评估。为了弥补这一知识空缺, 我们对与保护科学和动物个性有关的同行评议文献进行了系统性综述。纳入综述的标准包括可获取全文、初级研究文章, 以及关注动物保护或个性(即不是人类个性研究)。有92篇文章符合这些标准。我们总结了保护背景、检验程序(包括物种和样本量)、分析方法、研究分析的个性特征(活动性、攻击性、大胆性、探索性和社交性), 以及每篇报告的主要发现和以保护为重点的建议。虽然行为可重复性的证据对于个性研究至关重要, 但只有一半的报告对可重复性进行了量化。尽管如此, 这5种性格特征中都在一系列保护背景下得到了一定程度的研究。该领域最有力的研究表明, 在不同物种和环境中, 个性与其他重要生态学变量的关系存在变异。此外, 许多研究都是首次尝试在特定的研究系统中利用动物个性来进行保护。总的来说, 动物个性似乎还不是一个能完全实现的保护工具。为了将个性研究应用于保护问题, 我们建议研究人员思考在他们的系统中个体行为的差异如何影响保护结果, 评估是否有重复测量的机会, 并遵循最新的个性量化方法指南。**【翻译:胡怡思;审校:聂永刚】**

**关键词**: 行为特征, 野生动物管理, 应用动物行为学

## INTRODUCTION

After an initial focus on understanding animal behavior from evolutionary perspectives at the species and population levels (Tinbergen, 2005), there is growing interest in investigating animal behaviors at an individual level (Dall et al., 2004; Réale et al., 2007; Roche et al., 2016; Sih et al., 2004), particularly the consistency of behaviors and the ecological and evolutionary causes and consequences of such consistency, commonly understood as animal personality (Bell, 2007; Gosling, 2008; Wolf & Weissing, 2012). In contrast to human personality studies, animal personality can only be inferred from behavior (Carter & Feeney, 2012). This difference has led to the study of animal personality applying many synonyms over time, including temperament, coping style, behavioral syndrome, behavioral type, and individuality (Carter et al., 2013; Gherardi et al., 2012; MacKay & Haskell, 2015; Réale et al., 2007; Roche et al., 2016).

The multitude of terms used in early studies of personality, alongside methodological inconsistencies, contributed to an initially confused discipline, particularly for researchers outside the field. (Beekman & Jordan [2017] critiqued these historical issues, and other authors outlined [e.g., Briffa, 2017; Dingemanse, 2017; Sih, 2017; Bell, 2017] how they have been resolved in response.) However, the field of animal personality research has recently become more clearly defined (Dingemanse & Wright, 2020; Roche et al., 2016). A seminal review by Carter et al. (2013) describes best practices for conducting personality research and presents a framework built on an earlier review of animal personality research by Réale et al. (2007). Réale et al.'s (2007) review is an essential contribution to the development of the field, providing definitions of key personality traits (Table 1) and a list of tests used to determine personality (reproduced in Appendix S1). Carter et al. (2013) expand on this work by emphasizing how to measure personality and examine a personality study for its ecological, convergent, and discriminant validity (Table 2) and highlights potential pitfalls. Simultaneously, several statisticians reviewed and developed statistical methodologies for investigating personality in animals (Cleasby et al., 2015; Dingemanse & Dochtermann, 2013; Garamszegi, 2016; Nakagawa & Schielzeth, 2010). This body of work

**TABLE 1** Definitions of animal personality traits originally described as temperament traits in Réale et al. (2007)

| Personality trait | Definition |
|---|---|
| Activity | General level of activity of an individual |
| Aggressiveness | Individual's agonistic reaction toward conspecifics |
| Boldness | Individual's reaction to any risky situation, but not new situations; includes reaction to risky situations, such as predators and humans |
| Exploration | Individual's reaction to a new situation; includes behavior toward a new habitat, new food, or novel objects |
| Sociability | Individual's reaction to the presence or absence of conspecifics (excluding aggressive behavior) |

**TABLE 2** Criteria for determining whether repeatability and validity were assessed in studies of applying personality in conservation science, as defined by best research practice (details in Carter et al., 2013)

| Validity | Criteria |
|---|---|
| Repeatability | There is an estimate of the repeatability of the trait or traits. |
| Convergent validity | There is a positive correlation between performance in 2 tests that are hypothesized to measure the same trait. |
| Discriminant validity | There is a negative or no correlation between performance in 2 tests that are hypothesized to measure different traits. |
| Ecological, physiological validity | There is a test of the relationship between the behavioral trait and physiological or ecological traits and contexts. Physiological and ecological traits fit into 5 defined types: reproduction, growth, health, survival, and other. |

crystalized the idea that repeated measures of behaviors are necessary for animal personality studies.

Personality diversity can have implications for the ecology and evolution of species (Biro & Stamps, 2008; Moiron et al., 2020; Wolf & Weissing, 2012). There is evidence that personality influences key ecological variables, such as survival, movement, disease, reproduction, sampling, anthropogenic disturbance, habitat use, species interactions, ecological invasions, human–wildlife conflicts, and response to environmental change (Merrick & Koprowski, 2017; Wolf & Weissing, 2012). Incorporating personality into experimental biology may improve understanding of trait evolution and ecology, as well as help conservationists use differences in individual variation to predict, maintain, and adapt population responses to environmental changes (Roche et al., 2016; Wolf & Weissing, 2012).

Conservation may benefit from incorporating animal personality, due to its focus on mitigating threats to vulnerable populations (Conrad et al., 2011; McDougall et al., 2006; Merrick & Koprowski, 2017; Soulé, 1985). For example, in reviews of animal personality research, an often-cited application is to help limit bias in conservation programs that trap or capture animals because there is evidence that bolder animals are more accessible for trapping than shyer ones (Brooker et al., 2016; Merrick & Koprowski, 2017; Mittelbach et al., 2014; Roche et al., 2016). Another frequently suggested application is quantifying the personalities of conservation-dependent species prior to their release into the wild because personalities can be related to dispersal (Biro & Stamps, 2008; Kelleher et al., 2018; Merrick & Koprowski, 2017; Mittelbach et al., 2014; Smith; West et al., 2019 & Blumstein, 2008). In their review Merrick and Koprowslki (2017) make detailed suggestions of how personality can be applied to a multitude of different conservation contexts, including detection probability and capture success, stress response, movement and space use, habitat selection, mate choice and reproductive success, parasite infections, harvest success, anthropogenic disturbance, wildlife control, invasive species ecology, reintroductions and translocations, and captive conservation programs. However, in these reviews many suggestions for how personality can be applied to conservation are based on inferences from broader personality literature, rather than actual conservation contexts. Moreover, these suggestions for applying animal personality to management build on earlier debates surrounding conservation behavior that predate modern understanding of best-practice animal personality research (Buchholz, 2007; Caro, 2007; McDougall et al., 2006).

Conservation is a multidisciplinary science that includes species-specific breeding programs, population biology, international law, and community group organization (Griffiths & Dos Santos, 2012) (Appendix S2). Conservation practitioners often have a minimal margin of error in designing and implementing interventions (Snyder et al., 1995; Soulé, 1985). Any diversion of resources into a strategy with unknown outcomes could have devastating consequences, risking detrimental impacts on intended conservation goals, stakeholder involvement, continued funding, or even economic and political support (Catalano et al., 2019; Shaw et al., 2021; Soulé, 1985). Conservationists considering incorporating animal personality in management interventions could easily take a misstep if they have access only to outdated terminology and methodological approaches (Buchholz, 2007; Caro, 2007; Carter et al., 2013; McDougall et al., 2006; Réale et al., 2007). The initial lack of a unified framework or terminology in animal personality research may have made the field inaccessible to some (Beekman & Jordan, 2017; Jungwirth et al., 2017). A recent editorial in *Ethology* by Dingemanse and Wright (2020) provides a consensus on

measuring personality; thus, the state of previous personality research remains questionable. Exacerbating all the problems, the extent to which animal personality has been incorporated into conservation has yet to be quantified. Instead, most reviews highlight only a handful of positive examples (Brooker et al., 2016; Kelleher et al., 2018; Mittelbach et al., 2014; Roche et al., 2016; Wolf & Weissing, 2012). To ensure that conservationists looking to incorporate personality in their practice make the most of the resources at their disposal, it is imperative to evaluate the extent to which animal personality and conservation have already been integrated and to define best practices for such studies.

To evaluate how animal personality has been incorporated into conservation biology and provide a practical entry point for conservationists interested in incorporating personality in their management decisions, we performed a systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodological guidelines (Page et al., 2021). The PRISMA systematic review protocols provide an objective and transparent way to summarize literature in a reproducible way and are particularly valuable in this case because they can overcome selective reporting and research biases that may be present in previous reviews of the use of animal personality in conservation.

We used PRISMA to summarize primary research articles to determine how personality has been incorporated in conservation biology so far. We aimed to answer this question by detailing the breadth of methodological techniques used in each article. To evaluate the rigor of the research from a personality perspective, we assessed each research article based on the Carter et al. (2013) guidelines for personality studies (summarized in Table 2). We also categorized articles based on the conservation contexts in which personality tests have been used and summarized the reasons personality was investigated and the key findings and authors' suggestions concerning personality as a conservation tool. Finally, we used this information to create a shortlist of the articles in which animal personality and conservation were successfully integrated in terms of the methodology used to evaluate personality and the degree of focus on conservation application. This list is intended as a resource for conservationists who may be unfamiliar with personality but are interested in its potential conservation applications.

## METHODS

We used the PRISMA framework with the ecology and evolutionary biology extension (O'Dea et al., 2021). Before conducting the literature search, several lists of definitions and criteria were made based on Carter et al.'s (2013) review to ensure that when categorizing and reporting information from each journal article we interpreted it based on a single set of definitions and criteria (Table 3). For example, if the authors described a trait as excitability, but in the definition guidelines, it fits within the definition of *boldness*, we reported it in the review as boldness. This approach allows a more reproducible methodology for future reviews and limits potential biases arising from the somewhat confused state of the animal personality literature. However, it should also be noted that all assessments were made by R.D.M. alone and therefore subject to this author's ability to interpret the original authors' work and this author's understanding and knowledge of statistical analyses. However, using a predetermined guide for all categorizations and summarizing the literature (Table 3) should help eliminate objective bias to some extent (O'Dea et al., 2021).

We used the Web of Science search engine to access databases of articles available to Victoria University of Wellington, New Zealand. We were only interested in primary research articles that integrated animal personality and conservation science. To focus on personality studies in the field of animal conservation, we used the following single string of Boolean operators that we modified from a previous review of the publication of personality studies across taxa (Gherardi et al., 2012): TS = ((*conservation* AND *animal**) AND (*personalit** OR ((*behavior** OR *behaviour**) AND *syndrome**) OR *temperament** OR (*coping* AND *style**) OR *individualit**))). These terms were further refined by document type (article or proceedings paper or early access) and Web of Science indexes (SCI-expanded, SSCI, A&HCI, CPCI-S, CPCI-SSH, ESCI, CCR-EXPANDED, IC time span was all years) to complete the search query.

This search was conducted on May 5, 2021 and initially returned 174 journal articles (hereafter referred to as reports following the definition by Page et al. [2021]), all of which were sought for retrieval and assessed for eligibility. This process was performed manually for each article (flow diagram detailing retrieval process in Appendix S3). Five reports in this search could not be accessed and were excluded. The 169 remaining reports were read in their entirety, and a further 31 reports that were literature reviews were excluded. A further 25 exclusions were made for reports that were not directly related to animal personality or conservation because they were focused on human personality ($n = 10$), repeatability in animal vocalization ($n = 8$), genetics without personality testing ($n = 5$), technical veterinary research ($n = 1$), or plant biology ($n = 1$).

After these exclusions, 113 reports remained, and data were extracted from the text of each report. First, objective variables were summarized, including authors names, journal name, year of publication, country where the study took place, species studied, condition of testing (wild or captive), test sample size, and whether there was an assessment of repeatability. Next, the slightly more subjective categorizations of the articles were made using the definitions and criteria established prior to beginning the literature search (Table 3). Further exclusions were made for reports that did not include material aligning with any of the objective or subjective categories ($n = 21$) and reports that did not include any form of repeatability assessment ($n = 44$).

The remaining 48 reports that included an attempt to quantify repeatability were further summarized. This summary included the statistical method used for estimating repeatability; the personality traits identified; the ecological or physiological traits that personality was compared with; the relationships

**TABLE 3** Report (i.e., a document supplying information about a particular study) assessment categorization guide for the systematic review of studies applying personality in conservation science

| Report component | Category | Criteria for inclusion in a category |
|---|---|---|
| Conservation context | List of 13 conservation contexts in Appendix S2 | Where the report met definitions for >1 of the contexts in Appendix S2, the most extensively discussed context was assigned. |
| Personality test | List of 18 test categories in Appendix S1 | Assigned based on meeting the description for a test type given in Appendix S1, regardless of name given to test in the original article. |
| Repeatability and validity | Repeatability, convergent validity, discriminant validity, ecological or physiological validity or both | If the definitions in Table 2 were met, the report was marked as yes for that category. If there was evidence for ecological or physiological validity, we assigned type by assessing the ecological and physiological context that personality was compared with. |
| Personality trait | Activity, aggressiveness boldness, exploration, sociability | If a report met the repeatability criterion, this was assigned based on criteria described in table 1, regardless of the label for the trait that was used in original article. |
| Relationship between personality and ecological or physiological traits or both | None, N | Articles in which authors indicated there was no statistically significant relationship found. |
| | Positive, Y(+) | Article in which authors reported a statistically significant relationship with higher degrees of the personality trait meaning higher ecological or physiological trait (e.g., boldness increased survival). |
| | Negative, Y(–) | Authors reported a statistically significant relationship that higher degrees of the personality trait meant lower ecological and physiological traits (e.g., boldness decreased survival) |
| | Other Y | There was a relationship that could not be described using positive or negative terms. |
| Conservation content | Low | There was less than a paragraph in the discussion. |
| | Medium | There was approximately a paragraph in the discussion. |
| | High | There was a specific conservation section or specific recommendations for conservationists. |

found in those comparisons; whether the report confirmed ecological, convergent, or discriminant validity or all 3 or none of these; and the amount of conservation content in the report (details in Table 3). We categorized reports as high quality if they showed ecological validity alongside convergent or discriminant validity for the personality traits assessed. The discussion section of reports with either or both convergent or discriminant validity testing was examined. The reason for investigating personality, the study's key findings, the suggestions of reasons for findings, and suggestions for future use of findings concerning conservation were summarized. Finally, we categorized reports as highly relevant to conservation based on the amount of conservation content they included. Reports were identified as the highest quality examples of research interfacing animal personality and conservation science if they scored both the highest in terms of personality study quality and had the most conservation relevance.

After summarizing the literature, we examined the patterns in publication year, sample size, taxa examined, testing condition, type of personality test, and conservation context of reports that included repeatability assessment with those that did not. We collated the types of personality tests for reports that assessed repeatability and organized them by testing condition and conservation context. We separately collated each ecological and physiological trait measured against personality trait.

To investigate why so many reports did not have repeatability measures, we performed row-wise Fishers exact tests to determine whether there was a difference in the proportions of reports that assessed repeatability versus those that did not across time, by taxonomic class, conservation context, or personality test. To determine whether there was a difference in the proportion of captive to wild testing conditions in reports that assessed repeatability and those that did not, we performed the chi-square goodness-of-fit test. Finally, we performed a 2-sample Wilcoxon test and calculated the Wilcoxon effect size of the difference in sample sizes between reports that assessed repeatability and those that did not. All significance tests were calculated with an alpha of 0.05.

The initial summaries were made using Google sheets, data cleaning, and error checking in Microsoft Excel. Statistical tests were conducted and figures created with RStudio (RStudio Team, 2021) packages reshape2 (Wickham, 2007) and rstatix (Kassambara, 2021) for tests and ggplot2 (Wickham, 2016) and cowplot for figures (Wilke, 2020). Tables were produced in Microsoft Word. The entire data set of 174 articles, together with their inclusion–exclusion status and categorization, is in Appendix S4 and a complete reference list is in Appendix S5.

## RESULTS

Our search resulted in 174 total returns, but only 92 met our eligibility criteria and were assessed by this review. Publication of reports increased slowly from 1999 to 2014, peaking

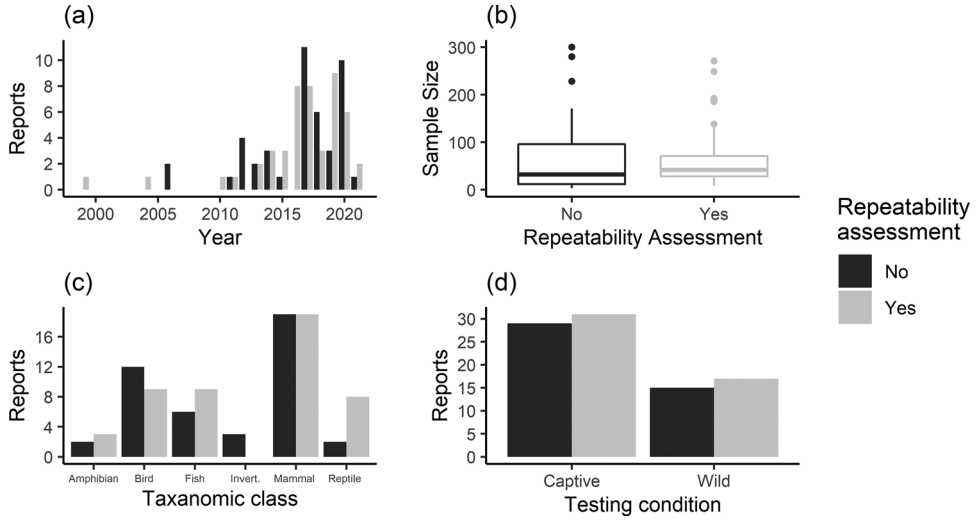


**FIGURE 1** (a) Number of articles (i.e., a document supplying information about a particular study) published over time on animal personality and conservation (black, no attempt to assess repeatability of behavioral measures in reports; gray, reports where assessment of repeatability of behavioral measures was attempted); (b) difference in sample sizes of reports that dealt with animal personality and conservation and those that assessed repeatability and those that did not (dots, outliers); (c) number of reports that dealt with animal personality and conservation published across different animal taxa; and (d) differences in reports on animal personality and conservation between those that performed tests in captivity and those that performed tests in the wild

in 2015. Over half the reports were published from 2015 to 2021 (Figure 1a). Study sample sizes ranged from 3 to 1748 (median = 41, mode = 20, mean [SD] = 100 [208]). Most reports in this review had sample sizes of <100 (Figure 1b). The species studied ranged across all classes of vertebrates and 2 classes of invertebrates (Insecta, Chromadorea). The most frequently studied group, mammals, made up over one third of the reports (Figure 1c). Testing personality in captivity was the most common testing condition (Figure 1d).

When examining the rates of wild testing within each taxonomic class, birds were the only class to have more wild testing ($n_{captive}$ = 9, $n_{wild}$ = 12). In contrast, remarkably more captive testing was performed with mammals ($n_{captive}$ = 23, $n_{wild}$ = 15), fish ($n_{captive}$ = 13, $n_{wild}$ = 2), and reptiles ($n_{captive}$ = 7, $n_{wild}$ = 3). There was no wild testing of amphibians ($n_{captive}$ = 5, $n_{wild}$ = 0) or invertebrates ($n_{captive}$ = 3, $n_{wild}$ = 0). The most common test performed was the novel object test, followed closely by movement tracking and novel environment tests; these tests made up over one third of all tests used across the reports (Figure 2a). Tonic immobility, separation, and proximity to conspecific tests were not used in any of the reports. The most common conservation context cited in one third of the reports was population biology, with community-based conservation, conservation education, economics, habitat management, wildlife law and policy, and wildlife trade not appearing in any report (Figure 2b).

## Repeatability assessment in reports

Of the 92 reports that met our overall eligibility criteria, 48 assessed the repeatability of behaviors (listed in Appendix S6), meeting the minimum criteria for measuring personality (Carter et al., 2013). The proportion of reports with repeatability assessments did not significantly differ from those without in any year, taxonomic class, conservation context, or personality test (Appendix S7). The proportion of reports with repeatability assessment did not significantly differ from those without in wild or captive testing condition ($\chi^2$ = 0.018, $df$ = 1, $n$ = 92, $p$ = 0.984) (Figure 1d). The sample sizes of reports that assessed repeatability (median = 46, range: 8–1748) did not differ from those that did not (median = 34, range: 3–340; $W$ = 905.5, $p$ = 0.241, $n$ = 92; Wilcoxon effect size = 0.123) (Figure 1b).

## Repeatability of behavior assessments

Correlation-based methods were the most common method of determining repeatability across reports ($n_{reports}$ = 22), followed by mixed-effects modeling ($n_{reports}$ = 12) and intraclass correlation coefficients ($n_{reports}$ = 9). The rest used other methods, such as Bayesian modeling ($n_{reports}$ = 5). In terms of evaluating repeatability, boldness was the most common personality trait investigated ($n_{instance}$ = 27), followed by activity ($n_{instance}$ = 16), exploration ($n_{instance}$ = 13), sociability ($n_{instance}$ = 5), and aggression ($n_{instance}$ = 3). All but 3 of the reports that assessed repeatability compared the personality trait investigated with some ecological or physiological traits, meeting the definition of ecological validity (Carter et al., 2013). A list of tests used in reports that assessed repeatability sorted by testing condition and conservation context is in Appendix S8. The most common ecological and physiological trait category was other behavior ($n_{instances}$ = 57), followed by reproduction ($n_{instances}$ = 33), growth ($n_{instances}$ = 23), survival ($n_{instances}$ = 20), and health ($n_{instances}$ = 8). All specific ecological and physiological traits investigated and their relationships with personality traits are reported in Appendix S9 for reports that assessed repeatability. Twenty-eight out of these 45 ecologically valid reports

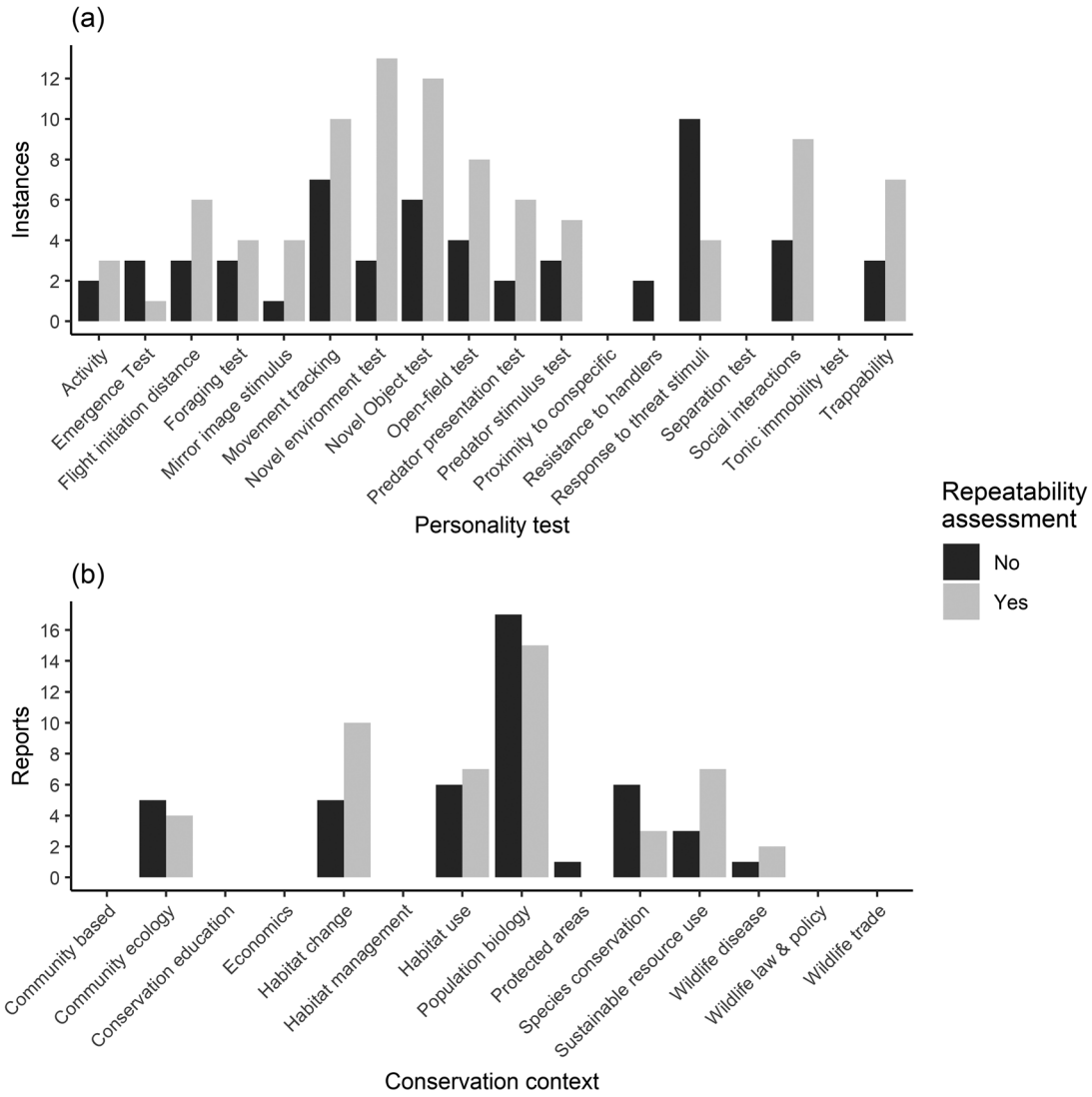


**FIGURE 2** Instances of (a) personality tests used across reports dealing with animal personality and conservation (1 report may have had >1 type of personality test) and (b) conservation contexts cited in reports on animal personality and conservation

confirmed convergent or discriminant or both validities in their reporting. Their key findings and conservation applications are summarized in Table 4. Nineteen of these 45 valid reports were also in the highest category of conservation content. Overall, 18 reports had the highest possible scores in terms of both conservation content and personality assessment (studies listed and summarized in Table 5).

## DISCUSSION

Little more than half of the reports included in our systematic review accurately assessed personality by assessing repeatability of behavior in their personality test. Of the 48 reports that reported personality correctly, 28 also confirmed their personality measures using discriminant or convergent techniques. Of these 28, 18 had a high degree of information specifically for conservationists. We believe these 18 reports represent the best introduction to integrating animal personality and conservation.

Many included reports claimed to measure personality and incorporate it within some conservation context, most of which were published after 2014. This is notable because, in theory, most already had access to Carter et al.'s (2013) seminal review on animal personality. Therefore, a best practice in terms of methodological and statistical approaches to studying personality had already been established prior to the publication of most reports included in our review, provided they had access to the journals that published this research. Furthermore, authors of reports published after 2017 could have accessed the Beekman and Jordan (2017) discussion. These post-2017 studies, therefore, have a distinct advantage because the field of personality research had had the opportunity to tailor their research following the best practice guidelines set out in the responses.

**TABLE 4** Summary of key findings and suggestions or interpretations of the use of personality in conservation from the 28 validated reports (i.e., a document supplying information about a particular study)

| Report | Species | Reason for investigating personality | Key personality finding | Conservation application |
|---|---|---|---|---|
| Allard et al., 2019 | Blanding's turtles (*Emydoidea blandingii*) | Use in a reintroduction program | Survival positively correlated with exploration but no correlation with boldness or aggression. Body mass and travel distance positively correlated with exploration but no correlation with boldness or aggression. Detectability was not correlated with any personality type. Evidence of personality-dependent habitat selection based on level of boldness or exploration, which may have affected survival. | Personality-based selection protocols could be important for reintroduction programs and habitat matching. |
| Andersson et al., 2014 | Domestic rabbit (*Oryctolagus cuniculus domesticus*) | Use in captivity and relation to observer ratings | Exploration and activity were more prominent in males and juveniles. | Individuals can be screened for behavioral types. |
| Arroyo et al., 2017 | Montagu's harrier (*Circus pygargus*) | Relationship to human disturbance and reproduction | Shyer individuals had more reproductive failures. Evidence of selection for bolder individuals from human disturbance | Minimizing human contact in conservation programs should be considered, but the risks should be weighed by practitioners. Human disturbance could lead to population level changes in behavior. |
| Baker et al. 2016 | Kangaroo rat (*Dipodomys stephensi)* | Relationship to social behavior and predation | Exploration negatively correlated with fecal cortisol concentration | Personality-based screenings might be useful for translocation procedures and may enable maintenance of behavioral diversity in a population and improvement to captive conditions. |
| Bremner-Harrison et al., 2017 | San Joaquin kit fox (*Vulpes macrotis mutica*) | Testing methods for measuring personality in free ranging animals and assessing value to managers | Boldness varied across familial groups. Each test able to quantify personality, but tests differed in their required resource intensity. | Quantifying personality in free ranging animals can be done through different methods but decisions on which test to use should be made based on available resources, specific questions, and goal of conservation program. |
| Castanheira et al., 2016 | Gilthead seabream (*Sparus aurata*) | Effect of social group on personality | Boldness is mediated by social context. | Personality could be used to develop different rearing conditions in aquaculture or breeding and selection programs to increase sustainability and welfare. |
| Dutra et al., 2016 | Saffron finch (*Sicalis flaveola*) | Use in antipredator training (captive-reared and captured individuals) | No relationship between boldness and antipredator response or sex. | Captive-reared and captured individuals may be biased in their personality expression and not representative of wild populations. |
| Germano et al., 2017 | Desert tortoises (*Gopherus agassizii*) | Use in translocation | More exploratory individuals had higher survival and used refugia more. Exploration dependent on body size. | Targeted personality assessment prior to translocation could improve initial survival but may bottleneck the population. |
| Haage, Maran, et al., 2017 | European mink (*Mustela lutreola*) | Use in reintroduction programs | Survival postrelease was positivity related to boldness. | Selection for reintroduction based on personality types may be useful but may decrease genetic variation in the population. Incorporating antipredator training that focuses on shyer individuals may improve translocation and reintroduction programs. |
| Hammond et al., 2020 | Mountain yellow-legged frog (*Rana muscosa*) | Use in translocation and monitoring | Activity and exploration positively associated with visual detection postrelease. | Quantifying personality differences prior to release may be important for species that cannot accommodate tracking devices. If detection is biased by personality type, it may lead to underestimates of survival postrelease for less active or less exploratory individuals. |

(Continues)

**TABLE 4** (Continued)

| Report | Species | Reason for investigating personality | Key personality finding | Conservation application |
|---|---|---|---|---|
| Heinen-Kay et al., 2016 | Bahamas mosquitofish (*Gambusia hubbsi*) | Relationship to group wide predation level | Exploration is higher in low-predation populations and appears to be heritable. Exploration positively correlates with detection. | Personality may be important for understanding responses to environmental stressors such as human-induced climate change. Selection on complex behaviors may lead to evolutionary divergences. |
| Kowalski et al., 2019 | Common vole (*Microtus arvalis*) | Relationship to movement behaviors (wildlife corridors) | Movement through corridors was not explained by exploration score. | Landscape features are potentially more important than individual behavior regarding movement, particularly in wildlife corridors. |
| Madden & Whiteside, 2014 | Pheasant (*Phasianus colchicus*) | Relationship to selection by hunters | Bolder individuals were less likely to survive. No relationship between boldness and body condition. | Shooting may impose selection for increased shyness, which could affect other aspects of the population and make shooting more difficult. |
| Maes et al., 2012 | Natterjack toad (*Bufo calamita*) | Relationship to movement, habitat use. comparison between captive and natural populations | Faster moving individuals had higher activity. No correlation with feeding latency and activity. Captive-raised individuals more active than wild raised. | Wild animals may differ from captive-reared individuals, so should be incorporated in personality testing. Personality does not exclusively explain movement behaviors so be cautious in interpretation. |
| Martin-Wintle et al., 2017 | Giant panda (*Ailuropoda melanoleuca*) | Use in captive breeding | Disassortative mating for activity associated with better reproductive outcomes. Assortative mating for boldness associated with better reproductive outcomes. If both partners were bold, a pair was more likely to mate and produce offspring when the male was more aggressive than the female. | Personality pairing can be useful in captive breeding programs and authors provide guide for optimal pairings. |
| May et al., 2016 | Brushtail possum (*Trichosurus vulpecula*) | Use in translocation | Increased boldness associated with riskier sleeping habitat and body mass gains. | Shyness is selected against in captive breeding which may influence postrelease survival. Personality screening could be useful in future translocations. |
| Michelangeli et al.,2015 | Delicate skink (*Lampropholis delicata*) | Testing the trapping bias hypothesis | No relationship between 3 different trapping methods and personality traits of boldness, activity, exploration, and sociability. | Trapping bias may be only relevant for passive trapping methods. |
| Nogueira et al., 2017 | Collared peccary (*Pecari tajacu*) White-lipped peccary (*Tayassu pecari*) | Relationship to hormones comparison between related species | Positive correlation between exploration and plasma glucocorticoid concentrations. White lipped peccary more explorative than collared peccary. | Human selection and environmental change may favor certain personality traits that could reduce behavioral variability in populations. This may contribute to the variation in conservation status of collared and white-lipped peccary as white-lipped peccary are more explorative. |
| Nogueira et al., 2021 | Paca (*Cuniculus paca*) | Use in captivity and relationship to observer ratings | More active individuals displayed more abnormal behaviors. | Targeted hunting may select for certain personality types in the population. |
| Schwarz et al., 2021 | Galápagos sea lion (*Zalophus wollebaeki*) | Movement and foraging | Activity was not correlated with age, body condition or body mass. Activity type related to habitat preference. | Habitat use and grouping may be mediated by activity type. As habitats change, individuals with differing personalities may vary in their ability to adapt. |
| Silva et al., 2014 | Nile tilapia (*Oreochromis niloticus*) | Relation to hormonal activity | Activity negatively correlated with serotonergic activity in the hypothalamus | Selection programs aimed at improving feeding motivation may benefit from personality assessment. |

(Continues)

**TABLE 4** (Continued)

| Report | Species | Reason for investigating personality | Key personality finding | Conservation application |
|---|---|---|---|---|
| Turner et al., 2020 | Spotted hyena (*Crocuta crocuta*) | Relationship to anthropogenic disturbance | Individuals from low-disturbance areas were bolder. Shyer individuals had greater survival. No effect of social rank or sex on boldness. | Anthropogenic disturbance may favor shyer individuals. |
| Villegas-Ríos et al., 2017 | Atlantic cod (*Gadus morhua*) | Comparison between populations | Activity and boldness differed between populations. Boldness negatively correlated with body condition. | Personality differences are due to environmental variation and findings may be important for understanding population responses to natural and human-induced selection. |
| Ward-Fear et al., 2020 | Yellow-spotted monitor (*Varanus panoptes*) | Use in conditioned taste aversion training protocol | Boldness predicted response to training protocol and subsequent survival. Shyer individuals more likely to survive. | There may be selection on behavioral type due to invasive species and from the use of conditioned taste aversion training protocols. |
| Webber & Willis, 2020 | Little brown bat (*Myotis lucifugus*) | Relationship to social behaviors | Individuals with similar activity scores roosted together. | Personality may influence disease transmission as individuals with similar activity congregate more. This could lead to population-level change if disease spreads by contact. |
| Wielebnowski, 1999 | Cheetah (*Acinonyx jubatus*) | Use in captivity and relationship to keeper ratings | Ratings correlated to behavioral measures. Nonbreeding cheetahs shyer than breeders and female cheetahs shyer than males. | Understanding personality may be important for coping in captive environments and improving breeding programs. |
| Williams et al., 2019 | African elephant (*Loxodonta africana*)<br>Asian elephant (*Elephas maximus*) | Use in captive social groups and relationship to keeper ratings | Keeper scores matched behavioral ratings. Sociability not related to individual origin, sex, species, or relatedness to others. Sociability positively correlated with positive social interactions. | Changes to species-specific captive management guidelines based on personality. |
| Wong et al., 2017 | Wide-band anemone fish (*Amphiprion latezonatus*) | Comparison between related species | Personality was present in one species but not the other. | Personality could explain interspecific differences in ability to respond to environmental change. |

*Note*: Reports are organized alphabetically by author.

**TABLE 5** Reports (i.e., a document supplying information about a particular study) identified as having both high-quality personality methodologies and high content conservation information

| Article | Species | Conservation context | Personality test | No. of individuals examined | Personality trait |
|---|---|---|---|---|---|
| Allard et al., 2019 | Blanding's turtles *Emydoidea blandingii* | Population biology | Mirror image stimulus, predator stimulus test, open-field test | 23 | Aggression, boldness, exploration |
| Andersson et al., 2014 | Domestic rabbit *Oryctolagus cuniculus domesticus* | Sustainable resource use | Trappability | 61 | Activity, exploration |
| Arroyo et al., 2017 | Montagu's harrier *Circus pygargus* | Habitat change | Activity, movement tracking | 30 | Boldness |
| Baker et al., 2016 | Kangaroo rat *Dipodomys stephensi* | Population biology | Movement tracking | 46 | Exploration |
| Germano et al., 2017 | Desert tortoise *Gopherus agassizii* | Population biology | Trappability, resistance to handlers | 59 | Exploration |
| Haage, Maran, et al., 2017 | European mink *Mustela lutreola* | Population biology | Novel environment, threat stimulus, predator presentation foraging, flight initiation distance | 10 | Boldness |
| Hammond et al., 2020 | Mountain yellow-legged frog *Rana muscosa* | Population biology | Movement tracking | 185 | Activity, exploration |
| Heinen-Kay et al., 2016 | Bahamas mosquitofish *Gambusia hubbsi* | Habitat change | Trappability | 249 | Exploration |
| Madden & Whiteside, 2014 | Pheasant *Phasianus colchicus* | Sustainable resource use | Foraging, novel object, predator presentation | 21 | Boldness |
| May et al., 2016 | Brushtail possum *Trichosurus vulpecula* | Population biology | Conspecific interaction, response to threat stimuli, movement tracking, novel environment, flight initiation distance | 20 | Boldness |
| Martin-Wintle et al., 2017 | Giant panda *Ailuropoda melanoleuca* | Species conservation | Open-field | 29 | Activity, aggression, boldness, sociability |
| Michelangeli et al., 2015 | Delicate skink *Lampropholis delicata* | Community ecology | Movement tracking | 63 | Activity, boldness, exploration, sociability |
| Nogueira et al., 2017 | Collared peccary *Pecari tajacu*<br>White lipped peccary *Tayassu pecari* | Habitat change | Novel object, novel environment, predator presentation | 20 | Exploration |
| Villegas-Ríos et al., 2017 | Atlantic cod *Gadus morhua* | Sustainable resource use | Response to threat stimuli, flight initiation distance | 303 | Activity, boldness |
| Ward-Fear et al., 2020 | Yellow-spotted monitor *Varanus panoptes* | Community ecology | Response to threat stimuli, flight initiation distance | 46 | Boldness |
| Webber & Willis, 2020 | Little brown bats *Myotis lucifugus* | Wildlife disease | Movement tracking | 34 | Activity |
| Wielebnowski, 1999 | Cheetah *Acinonyx jubatus* | Species conservation | Open-field test | 8 | Boldness |
| Williams et al., 2019 | African elephant *Loxodonta africana*<br>Asian elephant *Elephas maximus* | Species conservation | Movement tracking | 29 | Sociability |

Therefore, it is somewhat astonishing that nearly half of the included reports did not assess repeatability.

## Reasons for lack of repeatability quantification

We attempted to pinpoint why there was such a dearth of reports that assessed repeatability. Our literature summary revealed no clear pattern of repeatability assessment being included more frequently (i.e., in more than half of all papers published) in the most recent years, as one might expect. Moreover, we found no difference in the proportion of repeatability assessment between years, taxonomic class, conservation context, personality tests, or testing conditions. Although there was a slightly higher minimum sample size in studies that included repeatability estimates, there was no difference in sample sizes between reports that assessed repeatability and those that did not. Some authors may not have included repeatability because they investigated animals that were rare or nonterritorial or that travel long distances (handling of such animals is limited for ethical or practical reasons), which may explain why most threat stimuli and handling tests did not include repeatability (Richardson et al., 2019). Furthermore, some reports were at the population level and did not consider the individual level (Tudorache et al., 2015; Turner et al., 2015; White et al., 2017). However, several reports managed to assess personality at the individual level and then compare differences in the population (Castanheira et al., 2016; Villegas-Ríos et al., 2017; Wong et al., 2017). It appears that the difference between those that did repeatability testing and those that did not came down to the authors' decision. However, if there is no evidence for repeatability in behavior, then personality terminology should not be used (Dingemanse & Wright, 2020), as acknowledged by at least 1 report in which authors referred to "personality proxy" rather than outright personality (Richardson et al., 2019).

It is possible that our methodology for gathering reports biased our findings toward more outdated or misguided work because our search terms included older synonyms for personality. Additionally, the search terms we used may have failed to capture some studies that investigated personality as it was defined in our methodology. For example, an overlooked study could have used terms such as *neophobia* instead of *exploration*, without directly referencing personality. Furthermore, our search may not have encompassed all possible conservation contexts due to the broad interdisciplinary nature of the field, or we may have undersampled relevant studies because we used only 1 indexing system for our search. Nonetheless, our search terms were sufficiently broad to return several studies that ultimately did not meet our inclusion criteria. Moreover, we used standardized terms and definitions when evaluating each report. As such, we are confident that our method did not overly bias our assessment toward finding studies that did not assess repeatability, and we are confident we gathered a representative sample of the relevant literature. Instead, we suggest that it is more likely that some authors followed older or alternative guides when defining personality in their studies due to the confusing nature of the animal personality field or following inappropriate methodology from previous studies. Furthermore, as discussed by Dingemanse and Wright. (2020), many authors appear to cite Réale et al. (2007) inappropriately, defining personality as a class of behaviors, irrespective of repeated measures of each distinct behavior. Because so many reports in our review did not assess repeatability, we considered in detail only those that met this minimum criterion for assessing personality to ensure that any conservationist wanting to understand what has so far been incorporated from animal personality has access to best practice examples.

## Incorporation of personality in conservation science

Our search revealed the widespread use of personality tests across several conservation contexts that focus on animal biology in the wild and captivity. However, captive testing was the dominant testing condition across reports, mirroring other disciplines within animal behavior research (Greggor et al., 2014, 2016; McDougall et al., 2006; Roche et al., 2016; Sih et al., 2015) and personality generally (Bell et al., 2009; Roche et al., 2016). The issues with overreliance on captive testing and the need to understand animal behavior in situ have been discussed extensively elsewhere (Greggor et al., 2014, 2016; Pritchard et al., 2016), but wild testing is of particular importance to animal personality. For example, Bell et al. (2009) found that repeatability estimates were higher in field-based studies than in the lab. Repeatability of behavior is at the core of animal personality (Dingemanse & Wright, 2020), so quantifying repeatability in wild contexts, where there may be more room for between individual variance to be expressed (Bell et al., 2009), will likely improve the applicability of personality research to conservation. Despite this, we recognize that in many cases species of conservation concern are often limited in population size, accessibility, or are in a crisis state (Soulé, 1985). This, alongside the difficulties performing experiments with wild animals (Dawkins, 2007; Pritchard et al., 2016), may also contribute to captive testing being more frequent in the reports in our review.

The most prevalent personality test was the novel object test; it was used in every conservation context except species conservation, captive community ecology, and wild wildlife disease. This was closely followed by the novel environment test. This pattern is unsurprising because these are among the best-defined and most used tests across the broader personality literature (Carter et al., 2013; Merrick & Koprowski, 2017; Roche et al., 2016). Both tests are relatively simple to implement repeatedly and are the only way to measure boldness and exploration as personality traits (Carter et al., 2013; Réale et al., 2007). Furthermore, both can be conducted at short, medium, and long-time scales through direct observation, video recordings, or electronic tracking, making them ideal for implementation in conservation contexts in the wild and in captivity (Réale et al., 2007). Due to the widespread implementation and flexibility of novel object and environment tests, they should be a top priority for future studies attempting to measure personality in conservation contexts.

Perhaps one of the most interesting findings of our review is that there was no evidence that a specific personality trait has the same relationship across species and contexts. As a case study that highlights this phenomenon, boldness was investigated in reports within each ecological and physiological category and was found to have either positive, negative, or no relationships to the ecological or physiological trait in question (Appendix S9). For example, boldness was not related to survival in desert tortoises (*Gopherus agassizii*) or Blanding's turtles (*Emydoidea blandingii*), yet was positively related to survival in European mink (*Mustela lutreola*) and negatively related to survival in swift fox (*Vulpes velox*), pheasants (*Phasianus colchicus*), spotted hyenas (*Crocuta crocuta*), yellow-spotted monitors (*Varanus panoptes*), and brushtail possums (*Trichosurus vulpecula*) (Allard et al., 2019; Bremner-Harrison et al., 2004; Germano et al., 2017; Haage, Maran, et al., 2017; Madden & Whiteside, 2014; May et al., 2016; Turner et al., 2020; Ward-Fear et al., 2019, 2020) (Table 4). Similar variation in the nature of ecological links to personality measures was apparent for boldness and body condition measures with no relationship in Blanding's turtles and pheasants, positive relationships in desert tortoises and brushtail possums, and negative relationships in Atlantic cod (*Gadus morhua*) (Allard et al., 2019; Germano et al., 2017; May et al., 2016; Villegas-Ríos et al., 2017). This suggests that personality's role in conservation is more complicated than the traditional unidirectional relationship suggestions made by reviewers, such as shyer individuals will always have lower rates of capture (Brooker et al., 2016; Mittelbach et al., 2014; Roche et al., 2016). However, boldness was the only personality trait that had several examples of the same or similar ecological variables being tested across species with methodological and statistical rigor. Further investigation under recently outlined methodological and statistical frameworks will, we hope, further enhance the understanding of these conflicting results (Dingemanse & Wright, 2020). Ultimately, personality associations found for a particular conservation context may not necessarily be reproducible in other contexts, populations, or species. Perhaps this is an obvious conclusion, but it is something that both personality researchers interested in applying their research and conservationists looking to incorporate personality should be aware of.

## Advice for conservation practitioners

Despite the breadth of research at the interface of animal personality and conservation, interpreting the implications that personality could have for conservation is not possible without carefully examining the methodology and statistics used to support a report's conclusion. An important outcome of our review is the identification of reports that meet all of Carter et al.'s (2013) recommendations for personality research while also having substantial conservation content. In this context, Tables 4 and 5 provide a preliminary reading list for conservation practitioners considering applying personality to their work. These relatively few studies set a benchmark for best practice in personality measurement in a conservation context. Among these reports, the most common motivations for studying personality were for use in translocation or reintroduction programs or to improve captive management and behavioral training programs. These studies provide evidence from actual conservation contexts that there are important ecological consequences dependent on personality type. Examples include survival, detection, and habitat use after translocation, as well as mate paring and social structures in captivity. However, because each study investigated personality in slightly different contexts and compared different behaviors, there is no consensus yet on what to expect for specific personality traits. Overall, the authors of these studies share the view that personality may be helpful in conservation programs to select individuals that will be optimized to specific environmental conditions or pairing with certain conspecifics. Furthermore, among these reports there are multiple suggestions that as the environment is changed or there is human interference (i.e., hunting, monitoring), there is the potential for certain personality types to be selected for, and this may have severe consequences for conservation-dependent species. However, we identified only 18 reports that were highly relevant to conservation and that also followed best practice for measuring personality; thus, more research is necessary to reveal the full extent of how personality can contribute to conservation. Ultimately, before embarking on any new research, the feasibility of incorporating personality should be assessed to ensure that accurate and valuable information can be obtained without negatively affecting ongoing conservation. Therefore, we provide final recommendations for conservationists interested in incorporating personality into their project.

First, we recommend that conservation practitioners and researchers follow the guidelines of Wolak et al. (2012) when designing their personality research to achieve the optimal combination of sample size and tests per individual within their study system. Additionally, Garamszegi (2016) provides an excellent guide and resources on what to do if the analysis of behavior is constrained due to practical or ethical reasons. Conservationists may want to quantify and record behavior as part of procedures already at the core of their work. For example, conducting visual observation measures with novel space testing is a relatively simple and effective way of quantifying personality, particularly if the species is kept in captivity for any period (e.g., during a translocation event). Two excellent examples of how this may be implemented are Allard et al.'s (2019) study of Blanding's turtles and Hammond et al.'s (2020) study of Mountain yellow-legged frogs (*Rana muscosa*).

We also advise looking for opportunities to record behaviors repeatedly across time and contexts without altering what would already be occurring because this is one of the easiest and most cost-effective ways for conservationists to incorporate personality into their programs. Many of the reports in our review tested animals as part of ongoing conservation programs, such as an ongoing reintroduction program for European mink (Haage, Angerbjörn, et al., 2017), conditioned taste aversion training with yellow-spotted monitors (Ward-Fear et al., 2019, 2020), and regular breeding-season monitoring of Montagu's harrier (*Circus pygargus*) nesting (Mougeot & Arroyo, 2017). Due to the longitudinal nature of these projects, multiple measures of

individuals were able to be made over time and the repeatability of behaviors could be examined easily. However, depending on what personality trait and species are being tested, incorporating behavioral measures in this way may not be the most robust method (Carter et al., 2013). Yet if study species are held in captivity as part of a conservation intervention (e.g., captive breeding or translocation), it may create the opportunity to collect personality information with multiple tests. Once the repeatability of a personality trait has been sufficiently quantified, it may then be possible to establish more straightforward behavioral measures that can be used as a proxy for personality (e.g., Ward-Fear et al., 2019). These simple measures could then be added to existing protocols to screen animals, allowing for management decisions to be made without entire personality testing protocols needing to be implemented. However, this type of proxy establishment should only come after appropriately quantifying personality in the managed population; our results highlight that personality traits do not always show the same ecological relationships across conservation contexts and species.

In terms of statistical methodologies, most included reports followed the protocols of Nakagawa and Schielzeth (2010) in their use of correlational, mixed modeling, or intraclass correlation coefficient tests. It may not be possible in all conservation contexts to meet the assumptions of such tests (Wolak et al., 2012), but other approaches are valid and may carry less strict assumptions (Allegue et al., 2017; Cleasby et al., 2015; Garamszegi, 2016). Alternatively, Bayesian approaches are available for those who shy away from frequentist statistics (see Villegas-Ríos et al., 2017). Whatever statistical approach is chosen, there must be some form of repeated measures testing and analyses to meet the Carter et al. (2013) guidelines. Establishing the validity of tests is an essential aspect of personality quantification (definitions in Table 2) but not as critical as repeatability testing. A standard methodology used for convergent and discriminant validity testing is factor analysis, with which it is possible to examine the relationships between repeatable traits. However, correlation analysis can be sufficient (Carter et al., 2013). In summary, for those conservationists interested in exploring the interface of conservation and personality in their practice, we suggest starting by reading Carter et al. (2013), drawing on the examples in the best practice reports identified by this review (Table 4, 5) and following the statistical guides mentioned above.

Our systematic review revealed that personality has been broadly applied to conservation, with personality tests used in many conservation contexts. However, in most cases personality has not been very well incorporated into conservation science; very few examples met the requirements of personality research. Nevertheless, we were able to identify several rigorous integrated personality reports, and we used these as the basis for providing recommendations on how conservationists might integrate personality into a conservation program. We hope any conservationist who follows these recommendations will be well prepared to quantify personality, ultimately improving understanding of how integrating animal personality may benefit conservation science.

## ACKNOWLEDGMENTS

We are very grateful to T. Dawes, J. Fischer, O. Lennon, E. Irwin, and C. Woolley for their input and discussion during the conception of this review. We are also extremely grateful to D. Abraham, I. Armstrong, O. Hartshorne, L. McAuliffe, E. McCallum, and T. Vámos for their reviews and comments on several versions of this manuscript. R.D.M. was supported by a PhD Student Scholarship at the University of Victoria, Wellington, New Zealand. R.C.S. was supported by a Rutherford Discovery Fellowship from The Royal Society Te Āparangi.

Open access publishing facilitated by Victoria University of Wellington, as part of the Wiley - Victoria University of Wellington agreement via the Council of Australian University Librarians.

## ORCID

*Regan D. MacKinlay* https://orcid.org/0000-0002-6322-4509
*Rachael C. Shaw* https://orcid.org/0000-0002-4831-8283

## REFERENCES

Allard, S., Fuller, G., Torgerson-White, L., Starking, M. D., & Yoder-Nowak, T. (2019). Personality in zoo-hatched Blanding's turtles affects behavior and survival after reintroduction into the wild. *Frontiers in Psychology*, *10*, 2324. https://doi.org/10.3389/fpsyg.2019.02324

Allegue, H., Araya-Ajoy, Y. G., Dingemanse, N. J., Dochtermann, N. A., Garamszegi, L. Z., Nakagawa, S., Réale, D., Schielzeth, H., & Westneat, D. F. (2017). Statistical Quantification of Individual Differences (SQuID): An educational and statistical tool for understanding multilevel phenotypic data in linear mixed models. *Methods in Ecology and Evolution*, *8*(2), 257–267.

Andersson, A., Laikre, L., & Bergvall, U. A. (2014). Two shades of boldness: novel object and anti-predator behavior reflect different personality dimensions in domestic rabbits. *Journal of Ethology*, *32*(3), 123–136. https://doi.org/10.1007/s10164-014-0401-9

Arroyo, B., Mougeot, F., & Bretagnolle, V. (2017). Individual variation in behavioural responsiveness to humans leads to differences in breeding success and long-term population phenotypic changes. *Ecology Letters*, *20*(3), 317–325. https://doi.org/10.1111/ele.12729

Baker, L., Lawrence, M. S., Toews, M., Kuling, S., & Fraser, D. (2016). Personality differences in a translocated population of endangered kangaroo rats (Dipodomys stephensi) and implications for conservation success. *Behaviour*, *153*(13–14), 1795–1816. https://doi.org/10.1163/1568539x-00003380

Beekman, M., & Jordan, L. A. (2017). Does the field of animal personality provide any new insights for behavioral ecology? *Behavioral Ecology*, *28*(3), 617–623.

Bell, A. M. (2007). Animal personalities. *Nature*, *447*(7144), 539–540.

Bell, A. M. (2017). There is no special sauce: A comment on Beekman and Jordan. *Behavioral Ecology*, *28*(3), 626–627.

Bell, A. M., Hankison, S. J., & Laskowski, K. L. (2009). The repeatability of behaviour: A meta-analysis. *Animal Behaviour*, *77*(4), 771–783.

Biro, P. A., & Stamps, J. A. (2008). Are animal personality traits linked to life-history productivity? *Trends in Ecology & Evolution*, *23*(7), 361–368.

Bremner-Harrison, S., Cypher, B. L., Van Horn Job, C., & Harrison, S. W. R. (2017). Assessing personality in San Joaquin kit fox in situ: efficacy of field-based experimental methods and implications for conservation management. *Journal of Ethology*, *36*(1), 23–33. https://doi.org/10.1007/s10164-017-0525-9

Bremner-Harrison, S., Prodohl, P. A., & Elwood, R. W. (2004). Behavioural trait assessment as a release criterion: Boldness predicts early death in a reintroduction programme of captive-bred swift fox (*Vulpes velox*). *Animal Conservation*, *7*(3), 313–320.

Briffa, M. (2017). Abandoning animal personality would cause obfuscation: A comment on Beekman and Jordan. *Behavioral Ecology*, *28*(3), 625–626.

Brooker, R. M., Feeney, W. E., White, J. R., Manassa, R. P., Johansen, J. L., & Dixson, D. L. (2016). Using insights from animal behaviour and behavioural ecology to inform marine conservation initiatives. *Animal Behaviour*, *120*, 211–221.

Buchholz, R. (2007). Behavioural biology: An effective and relevant conservation tool. *Trends in Ecology & Evolution*, *22*(8), 401–407.

Caro, T. (2007). Behavior and conservation: A bridge too far? *Trends in Ecology & Evolution*, *22*(8), 394–400.

Carter, A. J., & Feeney, W. E. (2012). Taking a comparative approach: Analysing personality as a multivariate behavioural response across species. *PLoS ONE*, *7*(7), e42440. https://doi.org/10.1371/journal.pone.0042440

Carter, A. J., Feeney, W. E., Marshall, H. H., Cowlishaw, G., & Heinsohn, R. (2013). Animal personality: What are behavioural ecologists measuring? *Biological Reviews*, *88*(2), 465–475.

Castanheira, M. F., Cerqueira, M., Millot, S., Gonçalves, R. A., Oliveira, C. C. V., Conceição, L. E. C., & Martins, C. I. M. (2016). Are personality traits consistent in fish?—The influence of social context. *Applied Animal Behaviour Science*, *178*, 96–101.

Catalano, A. S., Lyons-White, J., Mills, M. M., & Knight, A. T. (2019). Learning from published project failures in conservation. *Biological Conservation*, *238*, 108223. https://doi.org/10.1016/j.biocon.2019.108223

Cleasby, I. R., Nakagawa, S., & Schielzeth, H. (2015). Quantifying the predictability of behaviour: Statistical approaches for the study of between-individual variation in the within-individual variance. *Methods in Ecology and Evolution*, *6*(1), 27–37.

Conrad, J. L., Weinersmith, K. L., Brodin, T., Saltz, J. B., & Sih, A. (2011). Behavioural syndromes in fishes: A review with implications for ecology and fisheries management. *Journal of Fish Biology*, *78*(2), 395–435.

Dall, S. R. X., Houston, A. I., & McNamara, J. M. (2004). The behavioural ecology of personality: Consistent individual differences from an adaptive perspective. *Ecology Letters*, *7*(8), 734–739.

Dawkins, M. S. (2007). *Observing animal behavior: Design and analysis of quantitative data*. Oxford University Press. https://books.google.co.nz/books?id=4HJYAwAAQBAJ

Dingemanse, N. J. (2017). The role of personality research in contemporary behavioral ecology: A comment on Beekman and Jordan. *Behavioral Ecology*, *28*(3), 624–625.

Dingemanse, N. J., & Dochtermann, N. A. (2013). Quantifying individual variation in behaviour: Mixed-effect modelling approaches. *Journal of Animal Ecology*, *82*(1), 39–54.

Dingemanse, N. J., & Wright, J. (2020). Criteria for acceptable studies of animal personality and behavioural syndromes. *Ethology*, *126*(9), 865–869.

Dutra, L. M. L., Young, R. J., Galdino, C. A. B., Vasconcellos, A., & da, S. (2016). Do apprehended saffron finches know how to survive predators? A careful look at reintroduction candidates. *Behavioural Processes*, *125*, 6–12. https://doi.org/10.1016/j.beproc.2016.01.007

Garamszegi, L. Z. (2016). A simple statistical guide for the analysis of behaviour when data are constrained due to practical or ethical reasons. *Animal Behaviour*, *120*, 223–234.

Germano, J. M., Nafus, M. G., Perry, J. A., Hall, D. B., & Swaisgood, R. R. (2017). Predicting translocation outcomes with personality for desert tortoises. *Behavioral Ecology*, *28*(4), 1075–1084.

Gherardi, F., Aquiloni, L., & Tricarico, E. (2012). Behavioral plasticity, behavioral syndromes and animal personality in crustacean decapods: An imperfect map is better than no map. *Current Zoology*, *58*(4), 567–579.

Gosling, S. D. (2008). Personality in non-human animals. *Social and Personality Psychology Compass*, *2*(2), 985–1001.

Greggor, A. L., Berger-Tal, O., Blumstein, D. T., Angeloni, L., Bessa-Gomes, C., Blackwell, B. F., St Clair, C. C., Crooks, K., de Silva, S., Fernández-Juricic, E., Goldenberg, S. Z., Mesnick, S. L., Owen, M., Price, C. J., Saltz, D., Schell, C. J., Suarez, A. V., Swaisgood, R. R., Winchell, C. S., & Sutherland, W. J. (2016). Research priorities from animal behaviour for maximising conservation progress. *Trends in Ecology & Evolution*, *31*(12), 953–964.

Greggor, A. L., Clayton, N. S., Phalan, B., & Thornton, A. (2014). Comparative cognition for conservationists. *Trends in Ecology & Evolution*, *29*(9), 489–495.

Griffiths, R. A., & Dos Santos, M. (2012). Trends in conservation biology: Progress or procrastination in a new millennium? *Biological Conservation*, *153*, 153–158.

Haage, M., Angerbjörn, A., Elmhagen, B., & Maran, T. (2017). An experimental approach to the formation of diet preferences and individual specialisation in European mink. *European Journal of Wildlife Research*, *63*(2), 34.

Haage, M., Maran, T., Bergvall, U. A., Elmhagen, B., & Angerbjörn, A. (2017). The influence of spatiotemporal conditions and personality on survival in reintroductions–evolutionary implications. *Oecologia*, *183*(1), 45–56.

Hammond, T. T., Curtis, M. J., Jacobs, L. E., Tobler, M. W., Swaisgood, R. R., & Shier, D. M. (2020). Behavior and detection method influence detection probability of a translocated, endangered amphibian. *Animal Conservation*, *24*(3), 401–411. https://doi.org/10.1111/acv.12645

Heinen-Kay, J. L., Schmidt, D. A., Stafford, A. T., Costa, M. T., Peterson, M. N., Kern, E. M. A., & Langerhans, R. B. (2016). Predicting multifarious behavioural divergence in the wild. *Animal Behaviour*, *121*, 3–10. https://doi.org/10.1016/j.anbehav.2016.08.016

Jungwirth, A., Wedell, N., Bshary, R., & Milinski, M. (2017). Animal personalities: An empty placeholder feigning understanding: A comment on Beekman and Jordan. *Behavioral Ecology*, *28*(3), 629–630.

Kassambara, A. (2021). *rstatix: Pipe-friendly framework for basic statistical tests*. R package version 0.7.0. https://cran.r-project.org/package=rstatix

Kelleher, S. R., Silla, A. J., & Byrne, P. G. (2018). Animal personality and behavioral syndromes in amphibians: A review of the evidence, experimental approaches, and implications for conservation. *Behavioral Ecology and Sociobiology*, *72*(5), 79.

Kowalski, G. J., Grimm, V., Herde, A., Guenther, A., & Eccard, J. A. (2019). Does Animal Personality Affect Movement in Habitat Corridors? Experiments with Common Voles (Microtus arvalis) Using Different Corridor Widths. *Animals*, *9*(6), 291. https://doi.org/10.3390/ani9060291

MacKay, J., & Haskell, M. (2015). Consistent individual behavioral variation: The difference between temperament, personality and behavioral syndromes. *Animals*, *5*(3), 455–478.

Madden, J. R., & Whiteside, M. A. (2014). Selection on behavioural traits during 'unselective' harvesting means that shy pheasants better survive a hunting season. *Animal Behaviour*, *87*, 129–135.

Martin-Wintle, M. S., Shepherdson, D., Zhang, G., Huang, Y., Luo, B., & Swaisgood, R. R. (2017). Do opposites attract? Effects of personality matching in breeding pairs of captive giant pandas on reproductive success. *Biological Conservation*, *207*, 27–37. https://doi.org/10.1016/j.biocon.2017.01.010

Maes, J., Van Damme, R., & Matthysen, E. (2012). Individual and among-population variation in dispersal-related traits in Natterjack toads. *Behavioral Ecology*, *24*(2), 521–531. https://doi.org/10.1093/beheco/ars193

May, T. M., Page, M. J., & Fleming, P. A. (2016). Predicting survivors: Animal temperament and translocation. *Behavioral Ecology*, *27*(4), 969–977.

McDougall, P. T., Réale, D., Sol, D., & Reader, S. M. (2006). Wildlife conservation and animal temperament: Causes and consequences of evolutionary change for captive, reintroduced, and wild populations. *Animal Conservation*, *9*(1), 39–48.

Merrick, M. J., & Koprowski, J. L. (2017). Should we consider individual behavior differences in applied wildlife conservation studies? *Biological Conservation*, *209*, 34–44.

Michelangeli, M., Wong, B. B. M., & Chapple, D. G. (2015). It's a trap: sampling bias due to animal personality is not always inevitable. *Behavioral Ecology*, *27*(1), 62–67. https://doi.org/10.1093/beheco/arv123

Mittelbach, G. G., Ballew, N. G., & Kjelvik, M. K. (2014). Fish behavioral types and their ecological consequences. *Canadian Journal of Fisheries and Aquatic Sciences*, *71*(6), 927–944.

Moiron, M., Laskowski, K. L., & Niemelä, P. T. (2020). Individual differences in behaviour explain variation in survival: A meta-analysis. *Ecology Letters*, *23*(2), 399–408.

Mougeot, F., & Arroyo, B. (2017). Behavioural responses to human activities and implications for conservation. *Ecosistemas*, *26*(3), 5–12.

Nogueira, S. S. C., Reis, A. M., Marsaro, S. G., Duarte, J. M. B., Moreto, V., Lima, S. G. C., Costa, T. S. O., & Nogueira-Filho, S. L. G. (2017). The defensive behavioral patterns of captive white-lipped and collared peccary (Mammalia, Tayassuidae): an approach for conservation of the species. *Acta Ethologica*, *20*(2), 127–136. https://doi.org/10.1007/s10211-017-0256-5

Nakagawa, S., & Schielzeth, H. (2010). Repeatability for Gaussian and non-Gaussian data: A practical guide for biologists. *Biological Reviews*, *85*(4), 935–956.

Nogueira, S. S. C., Nogueira-Filho, S. L. G., Duarte, J. M. B., & Mendl, M. (2021). Temperament, Plasticity, and Emotions in Defensive Behaviour of Paca (Mammalia, Hystricognatha). *Animals*, *11*(2), 293. https://doi.org/10.3390/ani11020293

O'Dea, R. E., Lagisz, M., Jennions, M. D., Koricheva, J., Noble, D. W. A., Parker, T. H., Gurevitch, J., Page, M. J., Stewart, G., Moher, D., & Nakagawa, S. (2021). Preferred reporting items for systematic reviews and meta-analyses in ecology and evolutionary biology: A PRISMA extension. *Biological Reviews*, *96*(5), 1695–1722.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *PLoS Medicine*, *18*(3), e1003583. https://doi.org/10.1371/journal.pmed.1003583

Pritchard, D. J., Hurly, T. A., Tello-Ramos, M. C., & Healy, S. D. (2016). Why study cognition in the wild (and how to test it)? *Journal of the Experimental Analysis of Behavior*, *105*(1), 41–55.

Réale, D., Reader, S. M., Sol, D., McDougall, P. T., & Dingemanse, N. J. (2007). Integrating animal temperament within ecology and evolution. *Biological Reviews*, *82*(2), 291–318.

Richardson, K. M., Parlato, E. H., Walker, L. K., Parker, K. A., Ewen, J. G., & Armstrong, D. P. (2019). Links between personality, early natal nutrition and survival of a threatened bird. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374*(1781), 20190373. https://doi.org/10.1098/rstb.2019.0373

Roche, D. G., Careau, V., & Binning, S. A. (2016). Demystifying animal 'personality' (or not): Why individual variation matters to experimental biologists. *Journal of Experimental Biology*, *219*(24), 3832–3843.

RStudio Team. (2021). *RStudio: Integrated development environment for R (1.4.1106)*. RStudio, PBC. http://www.rstudio.com/

Schwarz, J. F. L., Mews, S., DeRango, E. J., Langrock, R., Piedrahita, P., Páez-Rosas, D., & Krüger, O. (2021). Individuality counts: A new comprehensive approach to foraging strategies of a tropical marine predator. *Oecologia*, *195*(2), 313–325. https://doi.org/10.1007/s00442-021-04850-w

Shaw, R. C., Greggor, A. L., & Plotnik, J. M. (2021). The challenges of replicating research on endangered species. *Animal Behavior and Cognition*, *8*(2), 240–246. https://doi.org/10.26451/abc.08.02.10.2021

Sih, A. (2017). Insights for behavioral ecology from behavioral syndromes: A comment on Beekman and Jordan. *Behavioral Ecology*, *28*(3), 627–628.

Sih, A., Bell, A., & Johnson, J. C. (2004). Behavioral syndromes: An ecological and evolutionary overview. *Trends in Ecology & Evolution*, *19*(7), 372–378.

Sih, A., Mathot, K. J., Moirón, M., Montiglio, P.-O., Wolf, M., & Dingemanse, N. J. (2015). Animal personality and state–behaviour feedbacks: A review and guide for empiricists. *Trends in Ecology & Evolution*, *30*(1), 50–60.

Silva, P. I. M., Martins, C. I. M., Höglund, E., Gjøen, H. M., & Øverli, Ø. (2014). Feeding motivation as a personality trait in Nile tilapia (Oreochromis niloticus): role of serotonergic neurotransmission. *Fish Physiology and Biochemistry*, *40*(5), 1547–1557. https://doi.org/10.1007/s10695-014-9947-2

Smith, B. R., & Blumstein, D. T. (2008). Fitness consequences of personality: A meta-analysis. *Behavioral Ecology*, *19*(2), 448–455.

Snyder, N. F. R., Derrickson, S. R., Beissinger, S. R., Wiley, J. W., Smith, T. B., Toone, W. D., & Miller, B. (1995). Limitations of captive breeding in endangered species recovery. *Conservation Biology*, *10*(2), 338–348.

Soulé, M. E. (1985). What is Conservation Biology? A new synthetic discipline addresses the dynamics and problems of perturbed species, communities, and ecosystems. *Bioscience*, *35*(11), 727–734.

Tinbergen, N. (2005). On aims and methods of ethology. *Animal Biology*, *55*(4), 297–321.

Tudorache, C., ter Braake, A., Tromp, M., Slabbekoorn, H., & Schaaf, M. J. M. (2015). Behavioral and physiological indicators of stress coping styles in larval zebrafish. *Stress*, *18*(1), 121–128.

Turner, J. M., Warnecke, L., Wilcox, A., Baloun, D., Bollinger, T. K., Misra, V., & Willis, C. K. R. (2015). Conspecific disturbance contributes to altered hibernation patterns in bats with white-nose syndrome. *Physiology & Behavior*, *140*, 71–78.

Turner, J. W., LaFleur, R. M., Richardson, A. T., & Holekamp, K. E. (2020). Risk-taking in free-living spotted hyenas is associated with anthropogenic disturbance, predicts survivorship, and is consistent across experimental contexts. *Ethology*, *126*(1), 97–110.

Villegas-Ríos, D., Réale, D., Freitas, C., Moland, E., & Olsen, E. M. (2017). Individual level consistency and correlations of fish spatial behaviour assessed from aquatic animal telemetry. *Animal Behaviour*, *124*, 83–94.

Ward-Fear, G., Brown, G. P., & Shine, R. (2020). Predators learning to avoid toxic invasive prey: A study on individual variation among free-ranging lizards. *Behaviour*, *157*(14–15), 1153–1172.

Ward-Fear, G., Rangers, B., Pearson, D., Bruton, M., & Shine, R. (2019). Sharper eyes see shyer lizards: Collaboration with indigenous peoples can alter the outcomes of conservation research. *Conservation Letters*, *12*(4), e12643. https://doi.org/10.1111/conl.12643

West, R. S., Blumstein, D. T., Letnic, M., & Moseby, K. E. (2019). Searching for an effective pre-release screening tool for translocations: Can trap temperament predict behaviour and survival in the wild? *Biodiversity and Conservation*, *28*(1), 229–243.

White, S. L., Wagner, T., Gowan, C., & Braithwaite, V. A. (2017). Can personality predict individual differences in brook trout spatial learning ability? *Behavioural Processes*, *141*, 220–228.

Wickham, H. (2007). Reshaping data with the {reshape} package. *Journal of Statistical Software*, *21*(12), 1–20. http://www.jstatsoft.org/v21/i12/

Wickham, H. (2016). *ggplot2: Elegant graphics for data analysis*. Springer-Verlag. https://ggplot2.tidyverse.org

Wilke, C. O. (2020). *cowplot: Streamlined plot theme and plot annotations for 'ggplot2*. R package version 1.1.1. https://cran.r-project.org/package=cowplot

Wolak, M. E., Fairbairn, D. J., & Paulsen, Y. R. (2012). Guidelines for estimating repeatability. *Methods in Ecology and Evolution*, *3*(1), 129–137.

Wolf, M., & Weissing, F. J. (2012). Animal personalities: Consequences for ecology and evolution. *Trends in Ecology & Evolution*, *27*(8), 452–461.

Wong, M. Y. L., Beasley, A. L., Douglass, T., Whalan, S., & Scott, A. (2017). Some anemonefish lack personality: A comparative assessment of behavioral variation and repeatability in relation to environmental and social factors. *Coral Reefs*, *36*(4), 1307–1316.

Webber, Q. M. R., & Willis, C. K. R. (2020). Correlations between personality traits and roosting behaviours suggest a behavioural syndrome in little brown bats. *Behaviour*, *157*(2), 143–183. https://doi.org/10.1163/1568539x-00003585

Wielebnowski, N. C. (1999). Behavioral differences as predictors of breeding status in captive cheetahs. *Zoo Biology*, *18*(4), 335–349. https://doi.org/10.1002/(SICI)1098-2361(1999)18:4⟨335::AID-ZOO8⟩3.0.CO;2-X

Williams, E., Carter, A., Hall, C., & Bremner-Harrison, S. (2019). Exploring the relationship between personality and social interactions in zoo-housed elephants: Incorporation of keeper expertise. *Applied Animal Behaviour Science*, *221*, 104876. https://doi.org/10.1016/j.applanim.2019.104876

## SUPPORTING INFORMATION

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

**How to cite this article:** MacKinlay, R. D., & Shaw, R. C. (2023). A systematic review of animal personality in conservation science. *Conservation Biology*, *37,* e13935. https://doi.org/10.1111/cobi.13935