Citation for published version

Dos Santos, Marcileida M. and Griffiths, Richard A. and Jowett, Tim and Rock, Jennifer and Bishop, Phillip J. (2019) A comparison of understanding of the amphibian crisis by zoo visitors across three countries. Zoo Biology . ISSN 0733-3188.

DOI

https://doi.org/10.1002/zoo.21516

Document Version

Author's Accepted Manuscript

A comparison of understanding of the amphibian crisis by zoo visitors across three countries

Authors: Marcileida M. Dos Santos[1], Richard A. Griffiths[2], Tim Jowett[3], Jennifer Rock[4], Phillip J. Bishop[1],

[1] Department of Zoology, University of Otago, PO Box 56, Dunedin, 9054, New Zealand

[2]Durrell Institute of Conservation and Ecology, School of Anthropology and Conservation, University of Kent, Marlowe Building, Canterbury, Kent CT2 7NR, United Kingdom
http//orcid.org/0000-0002-5533-1013

[3] Department of Mathematics & Statistics, University of Otago, PO Box 56, Dunedin, 9054, New Zealand

[4] Center for Science Communication, University of Otago, PO Box 56, Dunedin, 9016

Corresponding author: Marcileida M. Dos Santos (https://orcid.org/0000-0003-4070-6692)

University of Otago

Department of Zoology

PO Box 56, Dunedin, 9054, New Zealand

Phone: +64 3-479 7986

Fax: +64 3479 7584

Email: ldossantos@amphibians.org

Abstract

Despite the rate of global amphibian declines, evaluation of public understanding of the crisis has not yet been carried out. We surveyed visitors (n = 1293) at 15 zoos in Brazil, New Zealand, and the United Kingdom, using a certainty-based assessment method to compare visitor knowledge of the global amphibian crisis. We further analyzed zoo educational material about amphibians to explore its potential to raise awareness through amphibian-focused environmental education. Visitors in the three countries had relatively little understanding of amphibians and the global amphibian crisis. When the degree of confidence in answering the questions (high, medium, low) is accounted for, correct answers varied between 28-39%. This compared to scores of between 58-73% when the degree of confidence in responding was not accounted for. However, specific areas of knowledge (e.g. biology, conservation, biogeography and conceptual ideas) varied significantly across the countries. Visitors had a weaker grasp of biogeographical and conservation issues than general amphibian biology. Zoo visitors in Brazil knew less about amphibian conservation than those in New Zealand or the United Kingdom. There was less amphibian-focused content in educational materials in zoos in Brazil than there was in the United Kingdom. Improving information about the global amphibian crisis may increase support for future conservation actions. Outreach education is one of the most important approaches in any strategic planning for conservation of species. Amphibian-focused environmental education at institutions such as zoos and aquaria can be a crucial intervention to support amphibian conservation worldwide.

Key words: Environmental education, science communication, public awareness, knowledge, amphibian declines.

Introduction

Living collection-based institutions such as zoos and aquariums have an important role in conservation and in connecting people with nature (Miller et al., 2004; Patrick et al., 2007). With current figures showing that 52 % of vertebrate species have experienced population declines in the past 40 years (McLellan et al., 2014), and with most threats linked to anthropogenic factors (Purvis, Gittleman, Cowlishaw, & Mace, 2000), modern zoos can be catalysts for conservation and public engagement in the 21st century (Hutchins, 2003; Rabb & Saunders, 2005; Zimmermann et al., 2007). In many countries they have been increasingly fulfilling this educational role (Consorte-McCrea et al., 2017; Conway, 2003; Mony & Heimlich, 2008; Jacobson, McDuff, & Monroe, 2015, Moss et al., 2015, Ballantyne and Packer, 2016). Although there has been an increase in the number of zoos holding amphibians (Dawson, Patel, Griffiths, & Young, 2016), zoos still typically focus on highly charismatic megafauna such as large mammals (Balmford, 2000; Melfi, 2009; Ward, Mosberger, Kistler, & Fischer, 1998) with relatively little attention paid to amphibians or amphibian conservation (Reid & Zippel, 2008). This is despite the fact that amphibians are more threatened than mammals or birds (IUCN, 2012), and have experienced dramatic declines and extinctions for over 30 years (Beebee & Griffiths, 2005; Bishop et al., 2012; Blaustein, Wake, & Sousa, 1994).

Tackling amphibian declines has been challenging, as it appears that there is not a single cause for the phenomenon, but rather an interaction of multiple stressors (Bishop et al., 2012; Catenazzi, 2015; Hayes, Falso, Gallipeau, & Stice, 2010). However, many initiatives have been put in place including the IUCN Global Amphibian Assessment (GAA) in 2004 (Stuart et al., 2004); the creation of the Amphibian Ark and the IUCN SSC Amphibian Specialist Group in 2006; the production of the Amphibian Conservation Action Plan (ACAP) in 2007 (Gascon, 2007); and the formation of the Amphibian Survival Alliance in 2011 (Bishop et al., 2012). Nevertheless, a multidisciplinary approach including public engagement is necessary to reverse on-going population declines and extinctions (Meredith, VanBuren, & Antwis, 2016).

As defined by the Tbilisi Declaration in 1977, Environmental Education (EE) has explicit goals to increase awareness/sensitivity, knowledge, attitudes, skills and participation in environmental issues and associated problems, and educational programs should include these goals (UNESCO, 1978). Knowledge is considered a strong catalyst to bring about pro-environmental changes, as has been shown in models of Environmentally Responsible Behavior (ERB) as early as 1970 (Hines, Hungerford, & Tomera, 1987; Hungerford, & Volk, 1990; Moon & Blackman, 2014). Knowledge improvement has been shown to support active participation in environmental issues, preventing the escalation of crises such as the extinction of species (Hines et al., 1987). There is a need for interdisciplinary collaboration to tackle the lack of knowledge, values, and active involvement in environmental issues by the general public (Disinger & Roth, 1992; Steg & Vlek, 2009, Curtin & Papworth, 2018).

Zoo associations such as the World Association of Zoos and Aquariums (WAZA) encourage their members to ensure a breadth of knowledge is used to engage the wider community in conservation (WAZA, 2005; EAZA, 2008). Focusing on specific taxa may provide an effective mechanism to enhance the understanding of higher level ecosystem processes. A lack of knowledge of specific taxa can affect how people perceive and respond to concepts such as extinction (Hunt, 2003; Meyer, 2015).

Although zoos have contributed extensively to environmental education, and some studies have reported the long-term conservation knowledge gained (Mallapur et al., 2008), few studies have evaluated the knowledge of visitors on specific taxa. Learning about amphibians, specifically in a zoo setting, has been shown to improve the achievement of schoolchildren (Randler et al., 2005; Wünschmann et al., 2017). In this study, we seek to understand more about what visitors to zoos understand about the global amphibian extinction crisis, and what zoos are doing to raise visitor awareness of this issue around the world.

The three countries were chosen due to their differences in biodiversity and differences in educational ranking. For example, Brazil is one of the world's biodiversity hotspots (Myers et al., 2000), and is the country with the highest number of amphibian species in the world, with at least 1080 described native species (AmphibiaWeb, 2018, Segalla et al., 2012, 2016). In contrast, the UK has just seven native species of amphibians and several naturalized species (Arnold, 1995). New Zealand has only four native species belonging to the worlds' rarest and most ancient family of frogs: the Leiopelmatidae (Bell, 1994; Daugherty, Patterson, & Hitchmough, 1994). These countries also vary in their educational ranking; the United Nations Development Programme 'Human Development Reports Office' of 2013 showed New Zealand ranking 7th on the educational index, while the UK is placed as 13th and Brazil 79th (UNDP, 2016).

This study investigates public knowledge of amphibians and amphibian declines by surveying visitors to living collections of animals (i.e. zoos, aquaria, vivaria, hereafter collectively referred to as 'zoos'), in three countries (Brazil [BR], New Zealand [NZ] and the United Kingdom [UK]), as well as assessing how these institutions use amphibians in their environmental education outreach programs, to deliver messages about amphibian conservation.

Methods

We conducted a survey comprising thirteen questions in a self-administered questionnaire over a period of eight months involving fifteen zoos, across three countries - Brazil (BR, n = 6) , New Zealand (NZ, n = 4) and the United Kingdom (UK, n = 5). These zoos were those that responded positively to an initial request to participate in the survey that was sent to 48 institutions. A total of 1293 participants sampled randomly completed the surveys (BR = 501; NZ = 509; and UK = 283). Because we were interested in general knowledge about amphibians, no questions regarding their science background or prior knowledge about amphibians was asked. To comply with the human ethics restrictions in Brazil, only zoo visitors of 18 years old and over took part in the survey (see Appendix S1 for data summary, Table S1.1 and S1.2).

Data collection

The self-administered questionnaire (via Apple iPad) included 13 closed-format questions with multiple choices. Three questions were related to visitor demographics, and the remaining ten tested knowledge about amphibians that could be grouped into four categories: biology, general concepts, conservation and biogeography (See Appendix S1 Table S1.3 for category definitions). We designed the questions to reflect each country's culture and amphibian diversity while still allowing comparisons between countries. For example, in questions that required identification of an amphibian we used a common or widespread species. However, as Brazil has over 1080 species of amphibians, we added a different biological question reflecting the same weight (see Appendix S1 Table 1a-1d for questionnaire design). Questionnaires used in Brazil were translated into Portuguese and reviewed by a Brazilian Portuguese speaker. The questionnaires were peer-reviewed by experts in the field and piloted by similar age groups to check survey design; see Appendix S1 Table 1a-1d for questionnaire design. The structure of the questions was as simple as possible to aid understanding and avoid any misinterpretation or ambiguities (Newing, Eagle, Puri, & Watson, 2011); see Appendix S1, Table S1a-1c for the structure of the questions). We asked participants to state their country of residence and any data from non-residents were excluded. We conducted the survey in picnic or café areas so as not to interfere with visitors viewing exhibits. Although we sampled participants randomly, we asked if they had toured the zoo prior to answering the questions. If visitors were in groups or pairs, we advised that the survey was to be recorded individually and not as a group response.

We employed a certainty based marking (CBM) method, modified from Gardner-Medwin & Curtin (2007, p. 29-31), such that respondents were asked to moderate each answer by indicating their level of confidence in their knowledge on a three point scale (low, medium and high). This method not only provides a more accurate overview of the knowledge but also helps to eliminate less reliable answers (Hunt, 2003). For example, after each question respondents indicated the degree of certainty with which they answered the question. Our CBM model differed from Gardner-Medwin & Curtin (2007, p. 29-31) in not penalizing incorrect answers but filtering correct responses with different degrees of certainty (CBM): high level of confidence = 100% sure; medium level of confidence = know the answer but cannot be sure; low level of confidence = respondent has a vague idea of the answer, or might have guessed, therefore it was considered incorrect. We also compared the proportion of correct and incorrect responses with and without the level of confidence to further investigate utility of CBM (Hunt 2003).

We administered a second questionnaire of closed-format questions (n = 6), to each zoo's education manager to determine how much amphibian-specific educational material was used in their environmental education program. This was defined as any educational activity running on a daily basis, and involving either formal (i.e. related to a curriculum); non-formal (i.e. out-of-school learning, but with a structured and systematic approach); or informal (i.e. indirect education related to a lifelong process of acquiring and accumulating knowledge [La Belle, 1982]). Each response to the questions was awarded one (1) mark if it included amphibians, and zero (0) if it did not (see Appendix S1, Table S1. d for questionnaire description).

Statistical analysis

Multiple models were used with the statistical software R to compare knowledge between the countries and zoos (R Core Team, 2014). We fitted generalized linear mixed models (GLMMs) using the MASS package (Venables & Dichmont, 2004; Zuur, 2009) to analyze all responses by using a binomial error structure with a logit link function (correct = 1, incorrect = 0), except the level of certainty (CBM; high, medium, low). The models were fitted with predictor variables: question categories, country, gender, and if the zoo had an amphibian exhibit (AmpEx), determining the effects of each response (1 or 0) as a fixed factor. We considered the fixed factors as non-significant at a $p > 0.05$. We used a random intercept ZooID and individual respondent ID) to control for the assumption that responses were correlated between participants from the same zoo, across zoos and countries. The models were fitted using the "glmer" and "lmer" function from the package "lme4" to determine the maximum likelihood (ML) estimate of the parameters (Bates, Maechler, Bolker, Walker, & Hayward, 2015; Bolker et al., 2009). Additionally, parameter estimates were computed, as were the associated variances from the 95% confidence interval (CI) using the 'R' package Lsmean (Lenth, 2016). Model selection and model averaging, for both random (ZooID/ID) and fixed effects (question categories, gender and amphibian Exhibit) were implemented using a multi-model inference approach based on the Akaike's Information Criterion (AIC_c) (Burnham & Anderson, 2002) in the "MuMIn" R package, (Bartòn, 2016). We reported the results of GLMM after model averaging using the parameter estimates (b), unconditional standard errors (SE), and upper and lower confidence intervals (CI).

Multinomial logistic regression (MLR) models were used to analyze the level of certainty with which each respondent answered the questions (high, medium and low: Agresti, 2002; Agresti & Kateri, 2011). Models were fitted using the "nnet" package. Models in which all independent variables were significant at the 5% level were chosen and considered as the best explanatory models. For the fixed effect factors (degree of certainty; high, medium and low) we also calculated the parameter estimates for correct answers for all fixed effects (question categories, country and gender) and the associated variances from the 95% confidence interval (CI) and considered the effect of one variable as having an important predictive value only when the 95% CI did not include zero (Garamszegi et al., 2009).

For the questionnaires completed by zoo educators, we performed a chi-square test of independence as the small sample size caused the generalized linear mixed model to inadequately converge producing unreliable estimates of the adjusted ORs. We carried out descriptive analysis to determine the proportion of amphibian-specific content in the educational provision at each zoo. For each question that fulfilled the criteria (the use of amphibians in the education enrichment content), each response was given a score (1 = met the criteria, 0 = did not meet the criteria).

Results

General knowledge

A total of 12,930 responses from 1293 respondents were obtained across the three countries. Using unmoderated responses, the average percentage of correct answers was 67% (n = 8650). Visitors at NZ zoos had lower scores (mean = 58%, SD = 0.49, n = 5090) than the UK (mean = 72.1%, SD = 0.45, n = 2080) and BR (mean = 72.9%, SD = 0.44, n = 5010) (GLMM: $\chi^2_{(2,\, n = 12930)} = 46.3$, $p < 0.001$; Appendix S2, Figure S1, Table S2.1 for model selection parameters, and Table S1.2 for model output). Post-hoc pairwise comparisons showed no significant difference between the responses from BR and UK (z = -1.67, SE = 0.09, $p > 0.05$), but significant difference in responses between BR and NZ (z = 8.42, SE = 0.08, $p < 0.0001$) and NZ and UK (z = -8969, SE = 0.09, $p < 0.0001$; Appendix S2, Table S2.3).

When correct answers were moderated with CBM, 34% of the correct answers were answered with a high degree of certainty, with once again NZ (27.5%) scoring lower than the UK (36.3%) or BR (38.9%) (MLR: $\chi2_{(4,\, n = 12930)} = 14.88$, $p < 0.001$; Figure 1; see Appendix S3 Table S3.1 for model selection parameters).

(Figure 1 here)

Specific knowledge

Knowledge in each question category (i.e. Biology, General Concepts, Conservation, Biogeography) varied between the countries, with unmoderated scores ranging from 18 to 81% (GLMM: $\chi^2_{(6,\, n = 12930)} = 568.6$, $p < 0.001$). Post-hoc comparisons showed knowledge of Biology differed between BR (81%) and NZ (73%) (Est. = 0.48, z = 4.76, *SE* = 0.10, $p < 0.001$); but not between BR (81%) and the UK (85%) (Est. = -0.34, z = -2.55, *SE* = 0.13, $p > 0.05$). Biogeography knowledge did not differ between BR (59%) and NZ (58%) (Est. = 0.03, z = 0.23, *SE* = 0.12, $p > 0.05$) but did differ between BR (56%) and UK (44%) (Est. = 0.64, z = 4.40, *SE* = 0.15, $p < 0.001$) and between NZ (58%) and UK (44%) (Est. = 0.61, z = 4.97, *SE* = 0.12, $p < 0.001$). Conceptual knowledge also differed between BR (59%) and NZ (17%) (Est. = 2.10, z = 16.98, SE = 0.12, $p < 0.001$); between BR (59%) and UK (76%) (Est. = -0.88, z = -7.04, *SE* = 0.12, $p < 0.001$); and between NZ (17%) and the UK (76%) (Est. z = -21.67, *SE* = 0.14, $p < 0.001$). No significant differences were detected for conservation knowledge between BR and the other countries.

Moderated answers with high CBM also differed between categories and across countries with moderated scores ranging from 8 to 49% (MLR: $\chi^2_{(12,\, n = 12930)} = 111.50$, $p < 0.001$). Across all zoos, biology questions had a higher proportion of correct answers (33 %), and biogeography the lowest (12 %). Across the countries, visitors from BR were most certain about their answers regarding biology (Est = 0.55), followed by those in the UK (Est = 0.53) and NZ with the lowest (Est = 0.43) (Figure 2). General conceptual knowledge about amphibians was highest for those in the UK (Est = 0.52), followed by those in NZ (Est = 0.49), and BR (Est = 0.45) (Figure 2). Respondents in NZ were more certain about conservation-related answers (Est = 0.49), followed by those in BR (Est = 0.47) and the UK (Est = 0.38). Knowledge of biogeography was highest in NZ (Est = 0.46), followed by the UK (Est = 0.43) and BR (Est = 0.35) (Figure 2).

(Figure 2 here)

Global amphibian declines

We analyzed knowledge about global amphibian declines separately. When answers were not moderated, on average 72.1% of responses (n = 1293) were correct with some degree of certainty. However, the best fitting model showed no significant difference between countries (GLMM: $\chi^2_{(2,\, n = 1293)} = 4.53$, $p > 0.05$).

Answers moderated by CBM showed no difference between countries, therefore the data were pooled and revealed that 33.6% of respondents across the countries were aware of global amphibian declines (MLR: $\chi^2_{(2,\, n = 1293)} = 12.93$, $p < 0.001$; Figure 3).

(Figure 3 here

Amphibian conservation educational content in different countries

A chi-square test of independence showed a significant difference between countries in education material about amphibians ($\chi^2_{(2,\ n = 1)} = 8.24$, $p = 0.01$). Of the zoos surveyed (n = 15), 56% provided content about amphibians, and the zoos in the UK showed proportionally more amphibian content in their education programs (mean = 0.77 ± 0.08) than those in NZ (mean = 0.50 ± 0.10) or BR (mean = 0.42 ± 0.08). The majority of the zoos visited had an amphibian exhibit (mean proportion in the countries = 0.73 ± 0.12) and most had animal interpretation (mean = 0.68 ± 0.13), with BR zoos having the lowest frequency. Zoos generally included amphibians in educational programs (mean = 0.60 ± 0.13). Across zoos amphibian specific ‘animal encounter’ experiences (visitors have a chance to meet animals face to face) occurred in less than half the zoos (mean = 0.40 ± 0.13), and zoos in NZ and BR had the lowest. Additionally, amphibian educational programs linked to the school curriculum was also relatively low (mean = 0.40 ± 0.13) in all countries, with BR having the lowest frequency (Table 1).

Table 1 here

Discussion

The major threats to amphibian populations are mainly caused by anthropogenic landscape changes (Gallant, Klaver, Casper, & Lannoo, 2007). On their own, site-specific conservation efforts to reduce the rate of biodiversity loss are insufficient (Hoffmann et al., 2010). As knowledge and values are strong predictors of behavioral intentions (Kaiser, Oerke, & Bogner, 2007), raising awareness of issues facing amphibians and increasing interest in their conservation is urgently needed (Mendelson et al., 2006). Our results suggest that conservation messages about global amphibian declines are largely failing to reach the public who visit zoos, a finding consistent with another recent study (e.g. Meredith et al., 2016). This is despite the fact that visitors to zoos are not necessarily representative of the wider general public, being more likely to have an affinity with animals and wildlife than other members of the public (Fraser & Sickler, 2009). Our results suggest there is room for improvement in all three countries studied, regarding communication and education about amphibian conservation.

How much do zoo visitors know about amphibians and the current global amphibian extinction crisis?

As global initiatives have been introduced to combat amphibian declines (e.g. Barber & Poole, 2014; Bishop et al., 2012; Pavajeau et al., 2008), many conservationists might feel that the issue has been well publicized. However, our results show that an understanding of amphibians and the extinction crisis can be improved. On average, across three different countries and continents, respondents answered correctly only 33% of the total questions with a high degree of certainty. Visitor knowledge may also be directly linked to the value placed on amphibians and their conservation within each country’s cultural and educational systems. This finding matches previous studies that show that learning is intrinsically connected to social context for the visitor (Falk, 2002; Falk & Adelman, 2003). Visitors to New Zealand zoos showed the highest level of confidence in their answers to conservation questions, and it is possible that this is attributable to how the New Zealand public value conservation and conservation education. Because of its isolation, New Zealand is extra vigilant about threats to its unique flora and fauna. This created conservation policies that extend beyond regulation to embrace conservation education for pro-conservation behavior (Moss, Jensen, & Gusset, 2016; Towns, Daugherty, & Atkinson, 1990).

Brazil has the highest amphibian species richness in the world (1080 species; Segalla et al., 2012; 2016), with 294 endemic species (Mittermeier et al., 1998). Tremendous efforts have been made in Brazil since the 1980s to implement environmental education at all education levels (Dias, 2008). Nevertheless, visitors to Brazilian zoos showed the highest percentage of incorrect answers with respect to amphibian conservation. Although Brazil was a signatory to the United Nations Conference on the Human Environment held in Stockholm in 1972, it was not until 1998 that environmental protection became a specific component of the constitution (Clayton, 2011).

Although significant efforts have been put in place since to protect habitats, and the herpetological research community is steadily growing (Mittermeier, Da Fonseca, Rylands, & Brandon, 2005), 39% of Brazilian amphibian species are threatened (Haddad, Machado, Drummond & Paglia, 2008) and many species are still classed as ‘Data Deficient’ (IUCN, 2008). Clearly, environmental education is needed to increase public awareness of the threats that amphibian populations are facing and the importance that these animals play in our ecosystems. Increasing public awareness of threats posed to species can then stimulate media pressure, political debates and policy change (Gozlan, Burnard, Andreou & Britton, 2013).

In the UK, visitors had the second-highest percentage of correct answers overall, although this was still only 40%. Environmental education in zoos in the UK has developed since the 1990s (IUDZG/CBSG, 1993; Tunnicliffe, 1995). The UK also has a long history of protecting native amphibian species going back over 40 years (Beebee, 2014). Despite this, initiatives to inform the public about the global amphibian extinction crisis need to be improved. Reinforcing knowledge through educational interventions and evaluating public awareness is critical to motivate positive behavior change towards conservation (Howe, Obgenova, & Milner-Gulland, 2012).

What specific knowledge do zoo visitors have regarding amphibians?

Knowledge across the four categories of questions (Biology, General Concepts, Conservation and Biogeography) was strongly biased towards basic amphibian biology, including their life cycle, physiology, and habitats and may reflect the area of emphasis that schools put on amphibians. The category of local biogeographical questions, such as recognizing a native species, was one of the least understood categories, a finding seen across all countries. In contrast, conservation knowledge was relatively high, although still only 40% responded with a high degree of confidence. The lack of knowledge regarding global amphibian declines was particularly concerning, with only 33% of all zoo visitors being aware of the phenomenon. Species-focused environmental education has been successfully put into effect in the past. For example, the Lion Tamarin (*Leontopithecus rosalia*) recovery project was implemented in Brazil in 1983 (Dietz, Dietz, & Nagagata, 1994) to address specific knowledge gaps within the local communities, prompting scientists to work more closely with the public (Engels & Jacobson, 2007). Another successful campaign is exemplified in the conservation of the axolotl (*Ambystoma mexicanum*) in Mexico, where environmental interpretation programs improved knowledge and awareness of visitors (Bride, Griffiths, Meléndez-Herrada, & McKay, 2008). There is evidence that animals kept in zoos can act as ambassadors for their species in the wild, encouraging stakeholder interest to support conservation and enhancing public knowledge about conservation around the world (Conway, 2011; Hutchins, 2003; Reid & Zippel, 2008). Zoos and aquaria are in unique positions to be able to conduct species-focused programs that can educate about amphibian conservation. Evaluating the specific knowledge that the public might have about a species can support the development of targeted educational programs and break down barriers to achieving successful species-focused environmental education (Devictor, Whittaker, & Beltrame, 2010).

How much amphibian conservation material is contained in zoo education programs?

The use of amphibians and amphibian-related content in environmental education programs was not evenly distributed across the countries. Institutions in the United Kingdom showed a higher proportion of amphibian content in their educational programs than Brazil or New Zealand. However, activities such as the frequency of keeper talks and the use of amphibians as case studies were present in six of the fifteen zoos studied. When visitor knowledge is enhanced by interactive conservation education, rather than relying on the passive observation of animal exhibits and associated interpretation, there is often higher motivation to support conservation (Andersen, 2003; Rommel, Crump, & Packard, 2016; Tribe & Booth, 2003).

Improving education about amphibian conservation in zoos

Little attention has been given to amphibian-focused environmental education in zoos, and increasing awareness has the potential to narrow the knowledge gap between the public, scientific researchers and practitioners (Kellert & Berry, 1980). Previous studies have found that reinforcing knowledge, direct exposure to different forms of knowledge and intensive conservation interventions have a positive influence on the public's behavior and attitudes (Howe et al., 2012; Loyau & Schmeller, 2017). Evaluating public knowledge, reinforcing and expanding knowledge through education is crucial to motivate positive behavior change towards conservation (Howe et al., 2012). However, improving 'knowledge' will not translate into behavior change on its own, but should be used in combination with enhancing cognitive skills such as thinking, remembering and reasoning (Hines et al., 1987). For environmentally responsible behavior to be achieved, a carefully designed targeted program with systematic evaluation of desired goals should take place (Mckenzie-Mohr, 2000; Steg & Vlek, 2009).

Zoos are well-placed to provide a balanced portfolio of educational activities and amphibians resonate strongly in different cultures around the world and zoos have yet to fully capitalize on this. We suggest that educational managers of zoos refocus the messages included in their environmental programs, to ensure that information about the conservation of amphibians and the global issues affecting amphibians are highlighted. If environmental education efforts are combined globally, we can make faster progress towards halting amphibian declines and minimize the likelihood of future extinctions.

Acknowledgments

We are thankful to Moacir Tinoco for supporting the project in Brazil and to the ethics committee from Catholic University (UCSAL), Bahia, Brazil, for providing ethical clearance so the work could be carried out in Brazil. We are thankful to Nick Meek from the Department of Computer Science at the University of Otago, that gave his full support to the design of the online questionnaire. We are also thankful to all zoos and institutions involved and the people that made this research possible in Brazil (Humberto Melo - Jardim Zoológico da Fundação de Parques Municipais e Zoobotânica - BH, Minas Gerais, Felipe Garcia - Zooparque Itatiba, Itatiba, SP, Cybele Lisboa, Fundação Parque Zoológico de São Paulo, Cecilia Pessuti, Zoo de Sorocaba - SP, Gerson Norberto - Parque Zoologico de Salvador, Bahia) in the UK (Ben Tapley ZSL - London, Andrew Gray - The Vivarium, Manchester, Mike Bungard - Paignton Zoo, Devon, Jeff Dawson - Jersey Zoo) in New Zealand (Carol Larson – National Aquarium, Stephen Stanley and Ken Milwood - Hamilton Zoo, Kevin Buley - Auckland Zoo, Toby Johnson - Orana Wildlife Park). We would like to thank Luke Easton and Scott Jarvie for assistance with the data analysis. This work was mainly funded by the Department of Zoology at the University of Otago, Mohamed bin Zayed Species Conservation Fund and the British Herpetological Society (BHS). The research received ethics approval from the University of Otago Human Ethics Committee and from the ethics committee at the Catholic University of Salvador Bahia (UCSAL), Brazil.

Supporting information

Additional information (appendices S1-S4) contain questionnaires applied to institutions in the three countries (Brazil, New Zealand and the United Kingdom), summary of the data used, model selection parameters for all GLMMs used, tables and additional model estimate. The authors are solely responsible for the contents and functionality of the material. Queries (other than absence of the material) should be directed to the correspondent author.

References

Agresti, A. (2002). Logit models for multinomial responses. *Categorical Data Analysis* (2nd ed., vol. 44, 267-313). John Wiley & Sons, Inc., New York.

Agresti, A., & Kateri, M. (2011). *Categorical Data Analysis*. In: Lovric M.. (eds) International Encyclopedia of Statistical Science. (pp. 206-208).Heidelberg, Berlin, Germany: Springer.

AmphibiaWeb. (2018, March 20th),. University of California, Berkeley, CA, USA. Retrieve from https://amphibiaweb.org

Andersen, L. (2003). Zoo education: from formal school programmes to exhibit design and interpretation. *International Zoo Yearbook*, *38*, 75-81.

Arnold H.R., (1995). *Atlas of amphibians and Reptiles in Britain*. ITE research publication no. 10, (pp 40). London, England: HMSO. Retrieved from http://www.seh-herpetology.org/node/62

Ballantyne, R., & Packer, J. (2016). Visitors' perceptions of the conservation education role of zoos and aquariums: implications for the provision of learning experiences. *Visitor Studies*, *19*, 193-210.

Balmford, A. (2000). Priorities for captive breeding-which mammals should board the ark? *Conservation Biology Series*, (pp. 291-308). *Cambridge, England*: Cambridge University Press.

Barber, D. & Poole, V. (2014). *Association of Zoos and Aquariums - Amphibian Taxon Advisory Group, Regional Collection Plan*. Retrieved from https://www.aza.org/taxon-advisory-groups

Bartoń, K. (2016). MuMIn: Multi-model Inference. R package version 1. 15. 1. 2016. *The Comprehensive R Archive Network (CRAN), Vienna, Austria*.

Bates, D., Maechler, M., Bolker, B., Walker, S., & Hayward, A. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical Software, 67*, 1-48.

Beebee, T. J., & Griffiths, R. A. (2005). The amphibian decline crisis: A watershed for conservation biology? *Biological Conservation, 125*, 271-285.

Beebee, T. J. C. (2014). Amphibian conservation in Britain: A 40-year history. *Journal of Herpetology*, *48*, 2–12.

Bell, B. D. (1994). A review of the status of New Zealand *Leiopelma* species (Anura: Leiopelmatidae), including a summary of demographic studies in Coromandel and on Maud Island. *New Zealand journal of zoology*, *21*, 341-349.

Bishop, P., Angulo, A., Lewis, J., Moore, R., Rabb, G., & Moreno, J. G. (2012). The amphibian extinction crisis-what will it take to put the action into the Amphibian Conservation Action Plan? *SAPI EN. S. Surveys and Perspectives Integrating Environment and Society, 5*, 96-111. Retrieved from http://journals.openedition.org/sapiens/1406

Blaustein, A. R., Wake, D. B., & Sousa, W. P. (1994). Amphibian declines: judging stability, persistence, and susceptibility of populations to local and global extinctions. *Conservation Biology, 8*, 60-71.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., & White, J.-S. S. (2009). Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in Ecology & Evolution, 24*, 127-135.

Bride, I. G., Griffiths, R. A., Meléndez-Herrada, A., & McKay, J. E. (2008). Flying an amphibian flagship: conservation of the Axolotl *Ambystoma mexicanum* through nature tourism at Lake Xochimilco, Mexico. *International Zoo Yearbook, 42*, 116-124.

Burnham, K., & Anderson, D. (2002). Model Selection and Multimodal Inference: A practical information-theoretic approach (2nd ed.) Springer-Verlag. *New York, NY*.

Catenazzi, A. (2015). State of the World's amphibians. *Annual review of environment and resources, 40*, 91-119.

Clayton, L. A. (2011, Jan). Overview of Brazil's legal structure for animal issues. Retrieved from https://www.animallaw.info/article/overview-brazils-legal-structure-animal-issues

Consorte-McCrea A. et al. (2017) Understanding Attitudes Towards Native Wildlife and Biodiversity in the UK: The Role of Zoos. In: Leal Filho W. (eds) Sustainable Development Research at Universities in the United Kingdom. World Sustainability Series. Springer, Cham

Conway, W. (2003). The role of zoos in the 21st century. *International Zoo Yearbook, 38*, 7-13.

Conway, W. G. (2011). Buying time for wild animals with zoos. *Zoo Biology*, *30*, 1–8.

Curtin, P., & Papworth, S. (2018). Increased information and marketing to specific individuals could shift conservation support to less popular species. *Marine Policy*, *88*, 101–107. https://doi.org/10.1016/j.marpol.2017.11.006

Daugherty, C. H., Patterson, G. B., & Hitchmough, R. A. (1994). Taxonomic and conservation review of the New Zealand herpetofauna. *New Zealand Journal of Zoology*, *21*, 317-323.

Dawson, J., Patel, F., Griffiths, R. A., & Young, R. P. (2016). Assessing the global zoo response to the amphibian crisis through 20-year trends in captive collections. *Conservation Biology, 30*, 82-91.

Devictor, V., Whittaker, R. J., & Beltrame, C. (2010). Beyond scarcity: citizen science programmes as useful tools for conservation biogeography. *Diversity and Distributions, 16*, 354-362.

Dias, G. F. (2008). Os quinze anos da educação ambiental no Brasil: um depoimento. *Em Aberto. [*Dias, G. F. (2008). The fifteen years of environmental education in Brazil: a testimony. *In Open*, 10, 3-12].

Dietz, J. M., Dietz, L. A., & Nagagata, E. Y. (1994). The effective use of flagship species for conservation of biodiversity: the example of lion tamarins in Brazil. In *Creative conservation* (pp. 32–49). Springer.

Disinger, J. F., & Roth, C. E. (1992). Environmental literacy. ERIC/CSMEE Digest. ERIC Publication. Office of Educational Research and Improvement (ED), Washington, DC. Retrieved from https://eric.ed.gov/?id=ED351201

EAZA. (2008). European Association of Zoos and Aquaria. Education in zoos and aquaria. In: *European aquaria and zoo association strategy*. Retrieved from http://www.eaza.net/education/education_strategy.html

Engels, C. A., & Jacobson, S. K. (2007). Evaluating long-term effects of the golden lion tamarin environmental education program in Brazil. *The Journal of Environmental Education, 38*, 3-14.

Falk, J. H. (2002). The contribution of free-choice learning to public understanding of science. *Interciencia, 27*, 62-65.

Falk, J. H., & Adelman, L. M. (2003). Investigating the impact of prior knowledge and interest on aquarium visitor learning. *Journal of Research in Science Teaching, 40*, 163-176.

Fraser, J., & Sickler, J. (2009). Measuring the cultural impact of zoos and aquariums. *International Zoo Yearbook*, *43*, 103-112.

Gallant, A. L., Klaver, R. W., Casper, G. S., & Lannoo, M. J. (2007). Global rates of habitat loss and implications for amphibian conservation. *Copeia, 2007*, 967-979.

Garamszegi, L. Z., Calhim, S., Dochtermann, N., Hegyi, G., Hurd, P. L., Jørgensen, C., Kutsukake, N., Lajeunesse, Marc J., Pollard, K. A., Schielzeth, H. (2009). Changing philosophies and tools for statistical inferences in behavioral ecology. *Behavioral Ecology, 20*, 1363-1375.

Gardner-Medwin, T., & Curtin, N. (2007). Certainty-based marking (CBM) for reflective learning and proper knowledge assessment. In *Proceedings of the REAP International Online Conference: Assessment Design for Learner Responsibility. Glasgow: University of Strathclyde*.

Gascon, C. (2007). *Amphibian conservation action plan: proceedings IUCN/SSC Amphibian Conservation Summit 2005*: IUCN.

Gozlan, R. E., Burnard, D., Andreou, D., & Britton, J. R. (2013). Understanding the threats posed by non-native species: public vs. conservation managers. *PloS One, 8*, e53200.

Haddad, C. F., Machado, A., Drummond, G., & Paglia, A. (2008). Uma análise da lista brasileira de anfíbios ameaçados de extinção. *Livro Vermelho da Fauna Brasileira Ameaçada de Extinçã*o.[An analysis of the Brazilian list of endangered amphibians. *Red Book of the Brazilian Fauna Threatened with Extinction*]. *(Machado, ABM; Drummond, GM and AP Paglia, eds.. MMA e Fundação Biodiversitas, Brasília e Belo Horizonte*, 286-325.

Hayes, T., Falso, P., Gallipeau, S., & Stice, M. (2010). The cause of global amphibian declines: a developmental endocrinologist's perspective. *Journal of Experimental Biology, 213*, 921-933.

Hines, J. M., Hungerford, H. R., Tomera, A. N. (1987). Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *Journal of Environmental Education*, *18*, 1-8.

Hoffmann, M., Hilton-Taylor, C., Angulo, A., Böhm, M., Brooks, T. M., Butchart, S. H., Carpenter, K. E., Chanson, J., Collen, B., Cox, N. A. (2010). The impact of conservation on the status of the world’s vertebrates. *Science, 330*, 1503-1509.

Howe, C., Obgenova, O., & Milner-Gulland, E. (2012). Evaluating the effectiveness of a public awareness campaign as a conservation intervention: The saiga antelope *Saiga tatarica* in Kalmykia, Russia. *Oryx, 46*, 269-277.

Hungerford, H. R., & Volk, T. L. (1990). Changing learner behavior through environmental education. *The Journal of Environmental Education, 21*, 8-21.

Hunt, D. P. (2003). The concept of knowledge and how to measure it. *Journal of Intellectual Capital, 4*, 100-113.

Hutchins, M. (2003). Zoo and aquarium animal management and conservation: current trends and future challenges. *International Zoo Yearbook, 38*, 14-28.

IUDZG/CBSG. (1993). Internation Union of Directors of Zoological Gardens ans IUCN Species Survival Commission, Captive Breeding Specialist Group (CBSG). The Role of the Zoos and Aquaria of World in Global Conservation. Chicago Zoological Soc..

IUCN, International Union for Conservation of Nature and Natural Resources (2008). An analysis of amphibians on the 2008 IUCN Red List. Retrieved from www.iucnredlist.org/amphibians

IUCN, International Union for Conservation of Nature and Natural Resources (2012). Amphibians patterns of endemism. Retrieved from http://www.iucnredlist.org/initiatives/amphibians/analysis/geographic-patterns

Jacobson, S. K., McDuff, M. D., & Monroe, M. C. (2015). *Conservation education and outreach techniques*. UK: Oxford University Press.

Kaiser, F. G., Oerke, B., & Bogner, F. X. (2007). Behavior-based environmental attitude: Development of an instrument for adolescents. *Journal of Environmental Psychology, 27*, 242-251.

Kellert, S. R., & Berry, J. K. (1980). Knowledge, affection and basic attitudes toward animals in American society: Phase III. Washington. *DC: United States Department of the Interior-Fish and Wildlife Service*.

La Belle, T. J. (1982). Formal, nonformal and informal education: A holistic perspective on lifelong learning. *International review of education, 28*, 159-175.

Lenth, R.V. (2016). Least-Squares Means: The R Package lsmeans. Journal of Statistical Software, 69, 1-33.

Loyau, A., & Schmeller, D. S. (2017). Positive sentiment and knowledge increase tolerance towards conservation actions. *Biodiversity and Conservation, 26*, 461-478.

Mallapur, A., Waran, N., & Sinha, A. (2008). The captive audience: the educative influence of zoos on their visitors in India. *International Zoo Yearbook, 42*, 214-224.

Mckenzie-Mohr, D. (2000). New ways to promote proenvironmental behavior: Promoting sustainable behavior: an introduction to community-based social marketing. *Journal of Social Issues*, *56*, 543–554.

McLellan, R., Iyengar, L., Jeffries, B., & Oerlemans, N. (2014). *Living planet report 2014: species and spaces, people and places*. WWF International.

Melfi, V. (2009). There are big gaps in our knowledge, and thus approach, to zoo animal welfare: a case for evidence-based zoo animal management. *Zoo Biology, 28,* 574-588.

Mendelson, J. R., Lips, K. R., Gagliardo, R. W., Rabb, G. B., Collins, J. P., Diffendorfer, J. E., Diffendorfer, J., Daszak, P., Ibáñez, R., Zippel, K., Lawson, D. P. (2006). Confronting amphibian declines and extinctions. *Science, 313,* 48-48.

Meredith, H. M., VanBuren, C. S., & Antwis, R. E. (2016). Making amphibian conservation more effective. *Conservation Evidence, 13*, 1-6.

Meyer, A. (2015). Does education increase pro-environmental behavior? Evidence from Europe. *Ecological Economics*, *116*, 108-121.

Miller, B., Conway, W., Reading, R. P., Wemmer, C., Wildt, D., Kleiman, D., Hutchins, M. (2004). Evaluating the conservation mission of zoos, aquariums, botanical gardens, and natural history museums. *Conservation Biology, 18*, 86-93.

Mittermeier, R. A., Myers, N., Thomsen, J. B., Da Fonseca, G. A., & Olivieri, S. (1998). Biodiversity hotspots and major tropical wilderness areas: approaches to setting conservation priorities. *Conservation Biology, 12,* 516-520.

Mittermeier, R. A., Da Fonseca, G. A., Rylands, A. B., & Brandon, K. (2005). A brief history of biodiversity conservation in Brazil. *Conservation Biology, 19*, 601-607.

Mony, P. R., & Heimlich, J. E. (2008). Talking to visitors about conservation: Exploring message communication through docent–visitor interactions at zoos. *Visitor Studies, 11*, 151-162.

Moon, K., & Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation Biology, 28*, 1167-1177.

Moss, A., Jensen, E., & Gusset, M. (2015). Evaluating the contribution of zoos and aquariums to Aichi Biodiversity Target 1. *Conservation Biology, 29,* 537-544.

Moss, A., Jensen, E., & Gusset, M. (2016). Probing the link between biodiversity-related knowledge and self-reported proconservation behavior in a global survey of zoo visitors. *Conservation Letters,10, 33-40*.

Myers, N., Mittermeier, R. A., Mittermeier, C. G., Da Fonseca, G. A., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, *403*, 853-858.

Newing, H., Eagle, C., Puri, R., & Watson, C. (2011). Conducting research in conservation: A social science perspective. *London and New York: Routledge*.

Patrick, P. G., Matthews, C. E., Ayers, D. F., & Tunnicliffe, S. D. (2007). Conservation and education: Prominent themes in zoo mission statements. *Journal of Environmental Education*, *38*, 53-60.

Pavajeau, L., Zippel, K. C., Gibson, R., & Johnson, K. (2008). Amphibian ark and the 2008 year of the frog campaign. *International Zoo Yearbook*, *42*, 24-29.

Purvis, A., Gittleman, J. L., Cowlishaw, G., & Mace, G. M. (2000). Predicting extinction risk in declining species. *Proceedings of the Royal Society of London B: Biological Sciences*, *267*, 1947-1952.

Rabb, G. B., & Saunders, C. D. (2005). The future of zoos and aquariums: conservation and caring. *International Zoo Yearbook*, *39*, 1–26.

Randler, C., Ilg, A., & Kern, J. (2005). Cognitive and emotional evaluation of an amphibian conservation program for elementary school students. *Journal of Environmental Education*, *37*, 43-52.

Reid, G. M., Zippel, K. C., McGregor, R., & Zippel, K. C. (2008). Can zoos and aquariums ensure the survival of amphibians in the 21st century? *International Zoo Yearbook*, *42*, 1–6. https://doi.org/10.1111/j.1748-1090.2007.00035.x

Rommel, R. E., Crump, P. S., & Packard, J. M. (2016). Leaping from awareness to action: impacts of an amphibian educator workshop. *Journal of Herpetology,50, 12-16.*

R Core Team (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Retrieve from http://www.R-project.org/

Segalla, M. V., Caramaschi, U., Cruz, C. A., Garcia, P. C. A., Grant, T., Haddad, C. F. B., & Langone, J. (2012). Brazilian amphibians–List of species. Retrieve from http://www.sbherpetologia. org. br

Segalla, M. V., Caramaschi, U., Cruz, C. A., Grant, T., Haddad, C. F. B., Garcia, P. C. A., Langone, J. (2016). Brazilian amphibians-list of species. *Herpetologia Brasileira, 3*, 37-48.

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*, 309-317.

Stuart, S. N., *et al*. (2004). Status and trends of amphibian declines and extinctions worldwide. *Science*, *306*, 1783-1786.

Towns, D.R, Daugherty, CH., and Atkinson, I.A.E. (Eds), 1990. *Ecological restoration of New Zealand islands*. Conservation Sciences Publication No. Z. pp (iii-iv), (pp 261-271). Wellington, New Zealand: Department of Conservation.

Tribe, A., & Booth, R. (2003). Assessing the role of zoos in wildlife conservation. *Human Dimensions of Wildlife, 8*, 65-74.

Tunnicliffe, S.D. (1995). *Talking about animals: studies of young children visiting zoos, a museum and a farm.* (Unpublished Doctoral dissertation, King's College, London, England). Retrieved from https://files.eric.ed.gov/fulltext/ED409171.pdf

UNDP. (2016). United Nations Development Programme. Human development reports, education Index. Retrieved from http://hdr.undp.org/en/content/education-index

UNESCO, T. D. (1978). United Nations Educational, Scientific, and Cultural Organization, Paris (France). *Intergovernmental Conference on Environmental Education Organized By Unesco in Co-Operation with Unep (Tbilisi, Ussr, 14-26 October 1977). Final Report*. UNIPUB.

Venables, W. N., & Ripley, B. D. (2002). Random and mixed effects. *Modern Applied Statistics with S* (pp. 271-300): Springer, New York, NY, USA.

Ward, P. I., Mosberger, N., Kistler, C., & Fischer, O. (1998). The relationship between popularity and body size in zoo animals. *Conservation Biology, 12,* 1408-1411.

WAZA (World Association of Zoos and Aquariums) (2005). Building a future for wildlife: The world zoo and aquarium conservation strategy. Bern, Switzerland: WAZA Executive Office. Retrieve from http://www.waza.org/en/site/conservation

Wünschmann, S., Wüst-Ackermann, P., Randler, C., Vollmer, C., & Itzek-Greulich, H. (2017). Learning achievement and motivation in an out-of-school setting—visiting amphibians and reptiles in a zoo is more effective than a lesson at school. *Research in Science Education, 47,* 497-518.

Zimmermann, A., Hatchwell, M., Dickie, L. A., & West, C. (2007). Zoos in the 21st century: catalysts for conservation?, (pp. 303-321). *Cambridge, England : Cambridge University Press.*

Zuur, A., Ieno, E., Walker, N., Savilev, A., & Smith, G. (2009). Mixed effects models and extensions in ecology with R, Gail M, Krickeberg K, Samet JM, Tsiatis A, Wong W, editors. *New York, NY: Spring Science and Business Media*.

Table legends

Table 1

Table 1. Proportion of amphibian content in zoo (n = 15) educational programs, across the countries (n = 3). Questions referred to the use of amphibians in Communication & education (C&E), Animal encounter (Enc), Amphibian exhibit (Exb), Interpretation (Interp) and Keeper talk (K. talk). Total = number of questions answered "yes" for zoos in each country. Brazil (n = 6), New Zealand (n = 4), United Kingdom (n = 5). Total = total number of questions answered per country. Freq = frequency of answers per country. *M* = mean proportion of responses, SE = Standard error

Figure legends

Figure 1

Figure 1: Multinomial logistic regression model (MLR) probability estimates and 95% confidence intervals of answers being correct and incorrect (n = 12930) with CBM (low [black], medium [grey], and high [white], for each country (n = 3). Results were averaged over the levels of: gender, question category and country.

Figure 2

Figure 2: Multinomial logistic regression model (MLR) probability estimates and 95% confidence intervals of correct responses with CBM (low [black], medium [grey], and high [white], for each country (n = 3). Results were averaged over the levels of: gender, question category and country. Questions

categories (B = Biology, Cc = Concepts, Cs = Conservation, G = Biogeography), for each country (n = 3). Results were averaged over the levels of: responses, gender, country and question category.

Figure 3

Figure 3: Multinomial logistic regression model (MLR) probability estimates and 95% confidence intervals of correct and incorrect responses (n = 1293) regarding global amphibian decline knowledge only. CBM (low [black], medium [grey], and high [white], for each country (n = 3). Results were averaged across the levels of gender, country and question category.