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Original Contribution

Attitudes and Behavioral Intentions of Pet Amphibian Owners About Biosecurity Practices

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Abstract: Global trade has been linked with the emergence of novel pathogens and declines in amphibian populations worldwide. The potential for pathogen transmission within and between collections of captive amphibians and spillover to wild populations makes it important to understand the motivations, knowledge, attitudes and behaviors of pet amphibian owners. We surveyed US pet amphibian owners to understand their characteristics and evaluated whether and how they were associated with behavioral intentions to adopt biosecurity practices. We found that the majority of pet amphibian owners are aware of the threat of emerging pathogens, concerned about potential spillover of pathogens from captive to wild populations and willing to adopt biosecurity practices to mitigate pathogen threats. Intentions to adopt such practices were driven more by psychosocial constructs such as attitudes, perceptions and beliefs than demographic characteristics. Pet amphibian owners also expressed a strong interest in acquiring, and willingness to pay a price premium for, certified disease-free animals. These findings advance our understanding of the characteristics, motivations and behaviors of pet owners, a key stakeholder in global amphibian trade, which could help to inform new policies and outreach strategies to engage them in mitigating pathogen threats. Moreover, our results imply the economic viability of a market-based program to promote pathogen-free, sustainable trade of amphibians.

Keywords: Consumers, Pet industry, Disease, Certification, Wildlife, Clean trade

Introduction

Rapid declines in natural populations of amphibian species have become a matter of conservation concern worldwide. Nearly half of the over 6000 known species of amphibians are believed to be experiencing some type of population

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declines (Stuart et al. 2004), and almost a third are threatened, making them one of the most imperiled classes of vertebrates (Stuart et al. 2008). Research has consistently shown that ranaviral disease (*Rv*) and chytridiomycosis, caused by the zoosporic fungi *Batrachochytrium dendrobatidis (Bd)* and *B. salamandrivorans* (*Bsal*), are associated with regional amphibian declines and species extinctions (e.g., Berger et al. 1998; Lips et al. 2006; Mendelson et al. 2006; Schloegel et al. 2009; Brunner et al. 2015; Stegen et al. 2017; Yap et al. 2018; Scheele et al. 2019; Martel et al. 2020). Evidence suggests that anthropogenic trade in, and the introduction of, amphibians is partly responsible for the global spread of these pathogens (e.g., Fisher and Garner 2007; Schloegel et al. 2009).

Between 2008 and 2018, 27 million live amphibians were imported into the USA (Drinkwater et al. 2021). Few US diagnostics laboratories have the resources necessary to support routine testing for amphibian pathogens, making robust surveillance efforts relatively inaccessible or cost-prohibitive for most pet owners and dealers. Of particular concern is the potential for spillover of harmful pathogens from captive to wild populations. These pathogens might move from captive to wild amphibian populations (Peel et al. 2012) including the introduction or release of infected animals, as has been inferred in spread of *Bd* and *Rv* in Europe, Asia and the Americas (Fisher and Garner 2007; Picco and Collins 2008). Indeed, the recent emergence of *Bsal* in Europe is presumed to have occurred due to release of unwanted pet salamanders (Martel et al. 2014).

Mounting evidence that the commercial amphibian trade facilitates the regional and global spread of pathogens (Fisher and Garner 2007; Picco and Collins 2008; Schloegel et al. 2009; Kolby et al. 2014) has led to increased interest in the husbandry and biosecurity practices of pet amphibian owners, as well as their knowledge, attitudes and perceptions toward pathogen threats. Social science literature on the US amphibian pet trade has generally focused on understanding the attitudes and perceptions of the general public regarding risks associated with the live animal trade (e.g., Episcopio-Sturgeon and Pienaar 2020; Steele and Pienaar 2021; Pienaar et al. 2022). There is a lack of study on the awareness, attitudes, perceptions of individual pet owners, in particular regarding pathogen threats and biosecurity, and the extent to which these characteristics may affect their behavior. Through a partnership with members of the US pet amphibian trade industry, this study used a semi-structured online survey of US pet amphibian owners to characterize their knowledge, attitudes and behaviors, including awareness of emerging amphibian pathogens,[1] experience with amphibian health, attitudes and values toward acquiring certified pathogen-free amphibians and intention to adopt biosecurity practices.

The specific objectives of this study were to understand: (1) the awareness, attitudes, perceptions and behaviors of pet amphibian owners regarding pathogen threats and the value they place on acquiring pathogen-free amphibians and (2) the factors associated with pet amphibian owners' behavioral intentions to engage in preventative biosecurity practices. The findings from this study can be used to identify potential opportunities and barriers to developing policies and outreach strategies targeting pet amphibian owners and assess the potential economic viability of a healthy trade program that reduces disease-related financial losses for businesses, increases customer satisfaction and mitigates the threat of pathogen spillover to native populations.

Methods

We designed a survey questionnaire containing questions (S1) regarding experience with amphibian health, awareness and knowledge of amphibian pathogens, attitudes toward pathogen spillover and level of agreement with statements regarding biosecurity practices. The anonymous and voluntary survey instrument and protocols were approved by the University of Tennessee Institutional Review Board for Human Subjects' Research (approval#: UTK-IRB-21-06494-XM). Similar to Morrisey et al. (2011), we established a collaboration with members of the pet care community to assist us with study design, ensure relevance of survey questions and increase survey participation. Collaborators included the Pet Advocacy Network (formerly the Pet Industry Joint Advisory Council), a national pet care community advocacy organization that promotes animal well-being and responsible pet ownership, and two respected US amphibian dealers (Josh's Frogs and Reptiles by Mack). The survey, administered through the Qualtrics online survey platform, was launched in summer of 2021 with an email message from our industry partners to individuals in their membership lists. The survey was also promoted via a link on the project website located in the

[1]Throughout the manuscript, "the pathogens" and "amphibian pathogens" refer to *Bd*, *Bsal* and *Rv*.

public web domain of the investigators' institution and at several pet industry trade shows using flyers containing a QR code and web link to the survey. During a period of approximately 7 weeks when we actively recruited participants, a total of 393 respondents completed the survey.

Development of survey questions assessing attitudes, perceptions and intentions was generally based on Ajzen's Theory of Planned Behavior (TPB) (Ajzen 1991), which has been used widely in studies to predict and explain human behavior in relation to companion animals and their care (e.g., Rohlf et al. 2010; Toukhsati et al. 2012; Gunaseelan et al. 2013). According to the theory, the most proximate predictors of an individual's behavior are their behavioral intentions, which are anteceded by (1) their attitude toward the behavior (ATB), (2) the extent to which they perceive the behavior to be within their personal control (i.e., perceived behavioral control, PBC) and (3) their perceptions of the norms and conventions regarding the behavior (i.e., subjective norms, SN) (Ajzen 1991).

Respondents' intention to adopt biosecurity practices to prevent transmission of pathogens and protect populations of native amphibians (Intention to Adopt) was elicited by asking the likelihood of their engaging in seven actions aimed at minimizing pathogen threats (Table 2) rated on a five-point scale from 1 = Extremely unlikely to 5 = Extremely likely. Respondents' ATB was elicited with three statements addressing their attitudes regarding biosecurity practices and protection of natural populations of amphibians and their PBC with three statements addressing their own perceived ability to prevent transmission of pathogens and protect populations of native amphibians. Perceived SN were elicited with the statement "People important to me (e.g., family, friends) expect me to adopt biosecurity practices to prevent transmission of *Rv*, *Bd* and *Bsal*." Responses on ATB, PBC and SN regarding biosecurity practices were rated on a five-point Likert scale (1 = Strongly disagree, 5 = Strongly agree).

Respondents' knowledge of amphibians (Knowledge) was elicited with the question "Before reading this survey, how familiar were you with general knowledge about amphibians?", rated on a five-point Likert scale of familiarity (1 = Not at all familiar, 5 = Extremely familiar), and perceptions of risk regarding the transmission of pathogens from pets to native populations (Risk) was elicited with the statement "The threat of transmission of *Rv*, *Bd* and *Bsal* pathogens from pets to natural areas is serious" ranked on a Likert scale of agreement. Awareness of amphibian pathogens (Awareness) was elicited with the question "Before reading this survey, were you aware that the pathogens (*Rv*, *Bd*, *Bsal*) can be transmitted through pet trade?". The frequency with which respondents seek veterinary care for their pet amphibians (Veterinary) was elicited with the question "How frequently does your amphibian receive veterinary care or diagnostic tests?". Potential responses included "never," "as needed," "occasionally" and "regularly." We also asked for demographic characteristics including respondent age (Age), and whether the respondent was female (Female), white (White), or had completed a college degree (College).

In human dimension studies involving survey responses, many psychological concepts (i.e., latent constructs) are unobserved but measured by utilizing responses to survey questions (i.e. observed variables) that are designed to measure the latent concept (Vaske 2019). Researcher, based on established theory in social science, knows in advance which observed variables are associated with which unobserved psychological concepts. Moreover, some psychological constructs such as behavioral control are complex and require combining responses to multiple survey questions for complete and accurate measurement. Since responses to multiple questions that are similar could be correlated, some multivariate statistical tools such as factor analysis are used to derive unique factors (latent constructs) from a given number of observed variables (Vaske 2019). Latent constructs are the predicted score from a linear regression of all observed variables (Thurstone 1935; Devlieger et al. 2016). As we did not directly observe ATB, PBC and Intention to Adopt (the dependent variable in our linear regression model), we extracted factors representing these latent variables from their respective survey questions with factor analysis using the principal factor method, orthogonal rotation (DiStefano et al. 2009). Similar to principal component analysis (PCA), factor analysis consolidates a dataset into a smaller number of latent variables, or factors, assuming that each of the measured variables captures a part of one or more of those factors. Rotating the axis of the factors orthogonally within the multidimensional variable space minimizes the number of variables that have high loadings on each factor and simplifies the interpretation of the extracted factors (Abdi 2003). In our study, we hypothesized the existence of two latent factors, PBC and ATB, as antecedents to respondents' behavioral intentions to adopt preventative biosecurity practices, which was represented by a third latent factor. We evaluated the sampling adequacy and suitability of our data for factor analysis using the Kaiser–Meyer–Olkin

(KMO) test, which is a measure of the proportion of variance among variables that might be correlated; the higher the value, the more the variables share in common. Values less than 0.5 indicate the sampling is not adequate and the data are not suited for factor analysis (Kaiser and Rice 1974).

From the factor analysis, factor scores for the latent constructs (Intention to Adopt biosecurity practices, ATB, PBC) were predicted. Using the variables described above, we evaluated and compared the results of four multiple linear regression models using Intention to Adopt as the dependent variable in every model. Models 1 and 2 contained only demographic and TPB variables, respectively, as independent variables. Model 3 contained only knowledge, awareness and risk perception variables, while model 4 was comprised of a combination of the independent variables evaluated in models 1–3. For all the significant variables in the final model, marginal effects (i.e., partial derivatives) were calculated in STATA 16.1 (www.stata.com). We hypothesized that ATB, PBC and SN regarding biosecurity would be significantly and positively associated with intention to engage in preventive biosecurity practices. We had no a priori expectations of whether and how knowledge of amphibians, perceptions of risk and demographic characteristics would relate to behavioral intentions. Finally, respondents were asked to indicate their willingness to pay a premium for a certified animal compared to a non-certified animal. As is typical in willingness to pay studies (Carson and Hanemann 2005), the question presented a randomly selected amount from a range ($1, $2, $3, $5, $7, $10, $20, $30, $50) and asked whether the respondent will be willing to pay the presented amount.

Results

Amphibian Acquisition and Ownership

Ninety-five percent of respondents reported owning or having owned a frog (i.e., Anura), 38% a newt/salamander (i.e., Caudata; Table 1). Eighty-one percent of respondents reported a history of also owning reptile(s), followed by dogs (75%), fish (68%) and cats (62%). Nearly half (42%) of respondents indicated they had owned amphibian(s) for 4 years or less, while more than a third (35%) reported owning amphibians for more than 10 years. Only 9% of respondents reported owning a single amphibian, while more than a third (37%) reported owning more than ten amphibians.

Most respondents (92%) reported purchasing an amphibian, 24% indicated having rescued/found an amphibian, and 19% reported having collected an amphibian from the wild. Among those who purchased, 58% reported acquiring amphibians from an in-store retailer/pet store, 49% online retailer, 37% pet show and 29% acquiring amphibians from hobbyists. Almost half (49%) of respondents indicated paying between $26 and 75 for their most recently acquired amphibian, whereas 8% reported paying over $125. In terms of monthly care expense, 50% reported paying $1–25 per animal, while another 39% reported paying $26–75 (Table 1).

Knowledge of, and Motivations for, Owning Amphibians

In terms of factors motivating the decision to own their most recent pet amphibian, scientific or educational value (mean score 3.31), sense of companionship (mean score 3.00) and esthetic and environmental values (mean score 2.97) were rated relatively more important than family favorite (mean score 2.20), cultural significance (mean score 1.50) and religious significance (mean score 1.17; Fig. 1). In general, most respondents indicated being at least moderately familiar with amphibian biology (96%) and the role of amphibians in the environment (93%).

Experience with Amphibian Health

When asked whether they had ever become unable to keep a pet amphibian or been forced to get rid of a pet amphibian for any reason, 9% of respondents had, while the remaining 91% indicated "never." Most (59%) of those who had been unable to keep an amphibian indicated they had given away or sold their animal, 8% each indicated they had taken their animal to a rescue facility/pet amnesty event or returned to where it was acquired, while 5% reported euthanizing the animal. All of the respondents that had become unable to keep a pet amphibian or been forced to get rid of a pet amphibian reported their animal had not been released into nature.

Sixty-three percent of respondents indicated their amphibian(s) receive veterinary care or diagnostic tests as needed, while 30% indicated their pet amphibian(s) never receive veterinary care or tests. Nearly 80% of respondents reported having had a pet amphibian die. Disposal techniques included burying outdoors (61%), placing in the garbage (21%), flushing down the toilet (3%) and leaving the animal outdoors (3%).

Table 1. Characteristics of survey participants.

Variable	%	Variable	%
*Types of amphibians owned (n = 393)		Amount paid for most recently acquired amphibian (US $) ($n$ = 388)	
Frog/Toad	95	0	10
Newt/Salamander	38	1–25	21
Other	5	26–75	49
Caecilian	3	76–125	12
		Over 125	8
*Other type(s) of pet(s) in household (n = 386)		*Sources of amphibian care information (n = 387)	
Reptile	81	Websites	92
Dog	75	Self-learning/personal experience	87
Fish	68	Scientific journals	61
Cat	62	Social media	44
Other	33	Magazines	37
Bird	28	Formal training	16
Number of years owned amphibians (n = 394)		*Mode of acquisition of amphibians (n = 393)	
1–4	42	Purchased	92
5–7	15	Rescued/found	24
8–10	7	Collected from the wild	19
> 10	35	Received as a gift	18
		Inherited	7
Total number of amphibians owned (n = 394)		*Where amphibians were acquired (n = 388)	
1	9	In-store retailer/pet store	59
2–4	27	Online retailer	49
5–7	18	Pet show	37
8–10	10	Hobbyist	29
> 10	37	Friend/relative	16
Race/Ethnicity (n = 354)		Education level attained (n = 356)	
White	88	Some college	38
Other	8	Bachelor's degree completed	31
Black or African American	1	Graduate degree completed	18
Asian	1	High school completed	12
American Indian or Alaska Native	1	Less than high school	2
Native Hawaiian or Pacific Islander	0		
Age (n = 357)		Gender (n = 353)	
18–24	19	Male	40
25–34	29	Female	50
35–44	18	Non-binary/third gender	6
45–54	16	Prefer not to say	3
55–64	10		
65 or older	7		

*Sum of percentages may exceed 100% as respondents may have selected multiple responses.

Familiarity and Experience with Harmful Pathogens and Beneficial Microbes

Seventy percent of respondents indicated they were aware that the pathogens can be transmitted through pet trade. Approximately two-thirds (64%) reported when acquiring their most recent amphibian they were not at all concerned that the animal may have been infected with the pathogens, whereas nearly one-third (30%) were slightly concerned and the remaining 6% very concerned. Nearly all (96%)

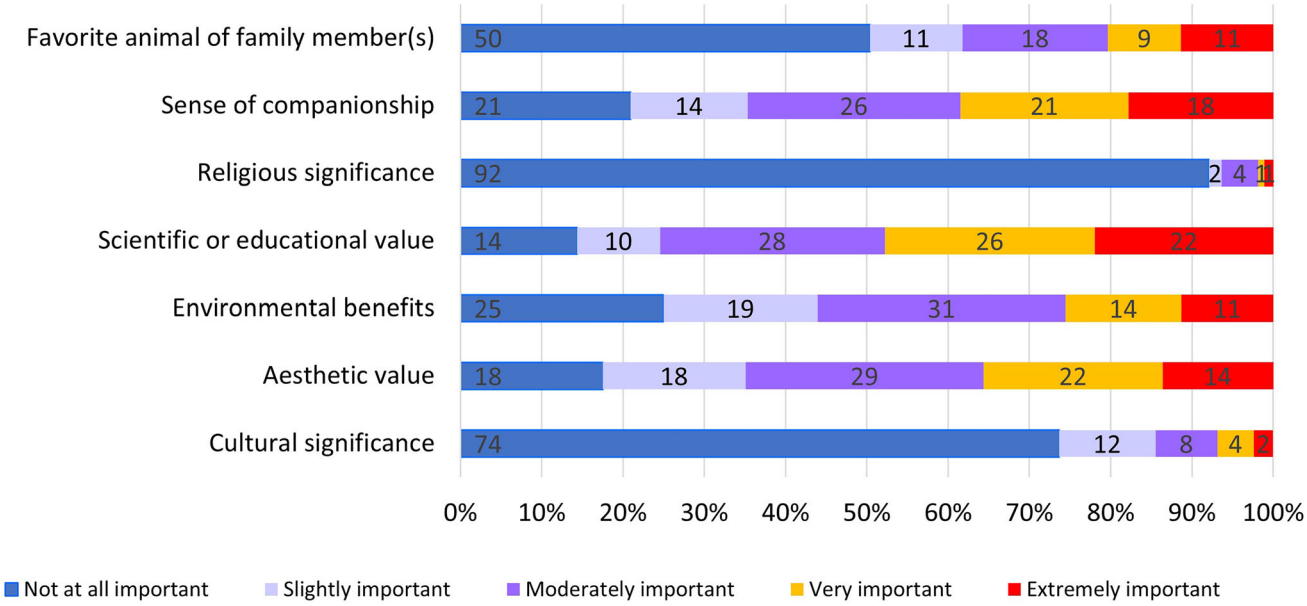

Figure 1. Importance of various factors in amphibian pet ownership (from top: $n1 = 380$, $n2 = 382$, $n3 = 380$, $n4 = 383$, $n5 = 379$, $n6 = 383$, $n7 = 379$).

respondents reported having never detected any pathogens in their pet amphibian(s); however, whether owners tested their amphibians for pathogens routinely or if they appeared sick or had died was not asked. No consumers reported having detected *Bd*, and less than 1% of consumers reported having detected either *Rv* or *Bsal*. Although about 3% of respondents responded "other" pathogens had been detected in their pet amphibians, only three respondents specified actual illnesses or disease. Most (63%) respondents reported being unaware of *Bacillus mycoides*, or other beneficial microbes and their ability to kill harmful microbes. Forty percent of respondents indicated they would consider administering treatment to their pet amphibian using "probiotics" such as *Bacillus mycoides*, while 60% reported needing more information to decide.

Willingness to Pay for Certified Pathogen-Free Amphibian

Three-quarters of respondents indicated that if they were to acquire another pet amphibian in the future, it would either be extremely important (52%) or very important (27%) the animal is free of the pathogens. A similar proportion (76%) of the respondents indicated that they would be willing to pay more for an animal that is certified free of the pathogens, while ~ 20% indicated they were not sure about paying more, and the remaining 4% were unwilling to pay more. In response to a follow-up question, 90% of respondents indicated they were willing to pay a premium (randomly presented from among the nine amounts: $1, $2, $3, $5, $7, $10, $20, $30, $50), for a certified animal compared to a non-certified animal. Among those 10% unwilling to pay extra for a certified animal, 38% indicated that they cannot afford to pay the amount presented in the survey question, 40% indicated they do not think they should be responsible for this expense, and the remaining 22% indicated it is not worth paying.

Attitudes Toward Pathogen Transmission and Intention To Adopt Biosecurity Practices

Respondents were asked to report their level of agreement with a series of statements pertaining to pathogen transmission in the pet trade (Fig. 2). Most indicated they believed the threat of transmission of harmful pathogens from pets to natural areas is serious (83.5%), protecting natural populations is important (92.1%), and that they have a role to play in protecting natural populations (88.8%). When asked about the likelihood of taking various biosecurity measures to mitigate the spread of harmful pathogens, most respondents indicated they were extremely likely to take the steps listed (Fig. 3).

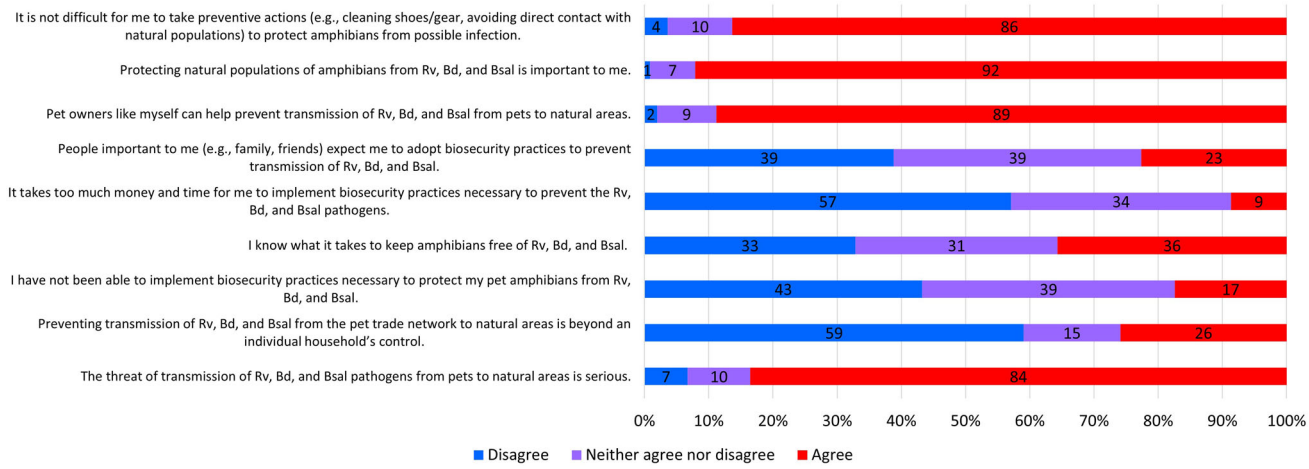

Figure 2. Level of agreement and disagreement with statements related to *Bd*, *Bsal* and *Rv* transmission. Somewhat agree and Strongly disagree responses were combined into Disagree category and somewhat agree and Strongly agree responses were combined into Agree (from top: $n1 = 358$, $n2 = 359$, $n3 = 356$, $n4 = 359$, $n5 = 359$, $n6 = 358$, $n7 = 358$, $n8 = 355$, $n9 = 359$).

Factor Analysis

The factors PBC, ATB and Intention to Adopt derived from the individual survey questionnaire statements are presented in Table 2. The overall KMO statistics for the three variables were 0.57, 0.55 and 0.84, respectively, indicating an acceptable level of correlation between variables (Kaiser 1974). With the exception of one variable (i.e., preventing transmission of *Rv*, *Bd* and *Bsal* from the pet trade network to natural areas is beyond an individual household's control; − 0.279), the rotated loadings of the variables used to extract the three factors exceeded 0.30, which is considered an acceptable threshold for the sample size of this study (Meyers et al. 2013).

Factors Influencing Pet Amphibian Owners Intention to Adopt Biosecurity Practices

Of the four multiple regression models predicting the Intention to Adopt biosecurity practices, no single category

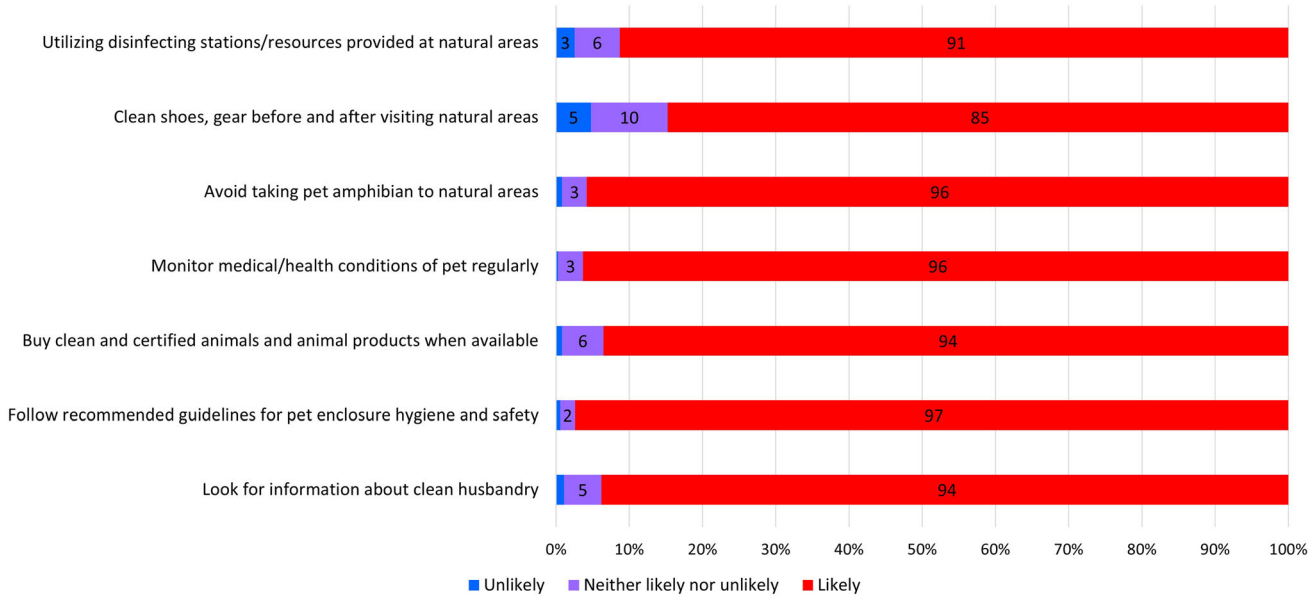

Figure 3. Likelihood of taking various steps to limit the spread of harmful pathogens. Extremely unlikely and Somewhat unlikely responses were combined into Unlikely category and Somewhat likely and Extremely likely responses were combined into Likely category (from top: $n1 = 354$, $n2 = 350$, $n3 = 355$, $n4 = 353$, $n5 = 357$, $n6 = 356$).

Table 2. Socio-psychological constructs included in regression analyses of pet amphibian owners' intention to adopt preventative biosecurity practices.

Factor	Survey question	Mean	Eigenvalue	Factor Loading
*Behavioral control**				
	It takes too much money and time for me to implement biosecurity practices necessary to prevent the *Rv*, *Bd* and *Bsal* pathogens	2.21	0.473	−0.449
	I know what it takes to keep amphibians free of *Rv*, *Bd* and *Bsal*	3.00		0.354
	It is not difficult for me to take preventive actions (e.g., cleaning shoes/gear, avoiding direct contact with natural populations) to protect amphibians from possible infection	4.43		0.382
*Attitudes toward behavior**				
	Pet owners like myself can help prevent transmission of *Rv*, *Bd* and *Bsal* from pets to natural areas	4.46	0.900	0.633
	Protecting natural populations of amphibians from *Rv*, *Bd* and *Bsal* is important to me	4.66		0.649
	Preventing transmission of *Rv*, *Bd* and *Bsal* from the pet trade network to natural areas is beyond an individual household's control	2.47		−0.279
*Subjective norms**				
	People important to me (e.g., family, friends) expect me to adopt biosecurity practices to prevent transmission of *Rv*, *Bd* and *Bsal*	2.65		
*Intention to Adopt-Dependent Variable***				
How likely are you to take the following actions?			3.35	
	Look for information about clean husbandry	4.61		0.740
	Follow recommended guidelines for pet enclosure hygiene and safety	4.74		0.761
	Buy clean and certified animals and animal products when available	4.66		0.689
	Monitor medical/health conditions of pet regularly	4.80		0.727
	Avoid taking pet amphibian to natural areas	4.85		0.626
	Clean shoes, gear before and after visiting natural areas	4.36		0.614
	Utilizing disinfecting stations/resources provided at natural areas	4.59		0.675

*1 = Strongly disagree, 5 = Strongly agree; **1 = Extremely unlikely, 5 = Extremely likely. Eigenvalues and factor loadings derived with factor analysis using the principal factor method, orthogonal rotation.

of predictors (Demography, TPB or Knowledge, Risk, and Awareness; models 1–3) was even close to the models that incorporated multiple categories of predictors (model 4). Model 4 also resulted in the lowest AIC and BIC scores and was retained for further examination (Table 3). The variance inflation factor (VIF) was below the critical threshold of 5 (Vaske 2019), suggesting that multicollinearity is not an issue in the model. As hypothesized, the constructs of ATB and PBC were both positively and significantly ($p < 0.001$)) related to the respondents' intentions to adopt preventative biosecurity practices. Estimates of marginal effects indicated that one unit increase in measure of ATP and PBC was associated with an increase in intention to adopt biosecurity practices by 0.36 (95% CI: 0.22, 0.50) and 0.28 (95% CI: 0.11, 0.46). However, SN had no significant ($p = 0.85$) relationship with Intention to Adopt. Knowledge about amphibians was significantly ($p < 0.001$) and positively associated with Intention to Adopt, as was the perceived risk of transmission of pathogens from pets to natural areas. Estimated marginal effects indicated that a one unit increase in measure of knowledge of amphibians increased their intention to adopt biosecurity practices by 0.14 (95% CI: 0.03, 0.25). Counterintuitively, awareness that amphibian pathogens can be transmitted through pet trade was significantly ($p < 0.001$) and negatively associated with Intention to Adopt biosecurity practices. The marginal effect of − 0.30 (95% CI: − 0.49, − 0.10) suggested that respondents intention to adopt biosecurity practices decreased by 0.30 if they were aware, prior to reading this survey, that the pathogen can be transmitted through the trade. Frequency of receiving veterinary care was significantly ($p < 0.001$) and

Table 3. Regression estimates from alternative models explaining US amphibian pet owners' Intention to Adopt preventative biosecurity practices.

		Model 1 Demography Coefficients (standard error)	Model 2 TPB Coefficients (standard error)	Model 3 KRA Coefficients (standard error)	Model 4 TPB, KRA demography Coefficients (Standard error)	Model 4 Marginal effects (95% CI)
Theory of planned behavior (TBD)	Attitude toward behavior		0.488***		0.359***	0.359
			(0.071)		(0.072)	(0.217, 0.500)
	Perceived behavioral control		0.322***		0.285***	0.285
			(0.091)		(0.089)	(0.109, 461)
	Subjective norms		0.030		−0.015	−0.007
			(0.036)		(0.035)	0.035
Knowledge, risk & awareness (KRA)	Knowledge			0.228***	0.145***	0.145
				(0.055)	(0.054)	(0.038, 252)
	Risk			0.335***	0.216***	0.216
				(0.045)	(0.046)	(0.125, 0.308)
	Awareness			−0.304***	−0.301***	−0.301
				(0.105)	(0.099)	(−0.497, −0.105)
	Veterinary			0.289***	0.245***	
				(0.068)	(0.063)	
Demography	White	−0.243			−0.230*	0.230
		(0.167)			(0.137)	(−0.498, 0.038)
	Age	−0.002			0.018	
		(0.035)			(0.029)	
	College	−0.010			−0.136	
		(0.105)			(0.087)	
	Female	0.113			0.083	
		(0.104)			(0.087)	
	R-squared	0.01	0.27	0.24	0.38	
	AIC	911.88	809.75	832.98	754.87	
	ΔAIC	143.32	41.19	64.42	0	
	BIC	930.97	825.01	852.11	800.35	
	Mean VIF	1.04	1.29	1.08	1.21	

Standard error in parentheses; ***$p \leq 0.01$,**$p \leq 0.05$,*$p \leq 0.10$.

positively related with the intention of adopting biosecurity practices. The estimated marginal effect suggested that one unit increase in measured frequency of veterinary care for amphibian was associated with 0.24 (95% CI: 0.12, 0.37) increase in the intention. In terms of demographic variables, the variable indicating the respondent's race/ethnicity as white (White) was negatively, but not significantly associated with intention to adopt biosecurity practices ($p = 0.11$).

Discussion

Similar to previous studies examining the motivations of pet owners, participants in this study reported sense of companionship as a key factor in their decision to acquire their most recent amphibian (Harris 1983; Endenburg et al. 1994; Hirschman 1994). Scientific or educational value and esthetic and environmental values were more important to the participants of this study than has been reported by owners of more traditional pets such as dogs, cats, birds and fish (e.g., Gates et al. 2019). These findings are corroborated by evidence that suggests captive amphibians are sought after because they afford their owners opportunities to observe behaviors that are not easily seen in nature (Measey et al. 2019). While animals are acquired from a variety of sources, purchasing from an instore or online business is the most common. Interestingly, 19% of consumers reported acquiring their amphibians from the wild, which is illegal without a scientific collection permit or license in many states. Although no pet amphibian owners reported releasing unwanted amphibians into the wild, some indicated that they returned the amphibian to where it was acquired. Release of amphibians into the wild is a pathway to pathogen spillover, even if the amphibian is a native species. Education outreach or pet amnesty programs are strategies that could be used to reduce the likelihood of the release of live unwanted animals. Additionally, a large percent of owners disposed of dead amphibians outdoors (61% buried, 3% surface), which is another spillover pathway.

The percentage of respondents reporting taking their amphibians in as needed for veterinary care or diagnostic tests was comparable to the findings of similar studies of traditional pet owners suggesting the majority take their pets in for annual check-ups/vaccinations or when health issues arise (e.g., Gates et al. 2019; Bir et al. 2020). Only 4% of respondents reported having detected a pathogen in their pet amphibian(s), while less than 1% reported detecting *Rv, Bd* or *Bsal.* This reported rate of detection is lower than previous reports for *Rv* and *Bd* surveillance in US trade, albeit for amphibians not in the pet trade (Picco and Collins, 2008; Schloegel et al. 2009); however, we did not ask whether pet owners routinely tested their collections or tested sick or dead animals. Future research needs to focus on pathogen surveillance in private collections because these data are lacking for the USA. Interestingly, one respondent indicated positive detection of *Bsal*, which is unknown to occur in the USA. Collectively, we feel this data entry was likely an error, because: (1) only a limited number of US laboratories are known to be testing for *Bsal* infection (using quantitative PCR) and have the capacity to confirm the disease *Bsal* chytridiomycosis (via histopathology), (2) it is best-practice for laboratories that record positive results for a novel pathogen to have a second laboratory confirm a positive *Bsal* result to minimize uncertainty and (3) known *Bsal* testing laboratories have been instructed to report results to the North American *Bsal* Task Force, which has not occurred to date. Given our survey was anonymous, we did not have the opportunity to follow-up with the respondent, which emphasizes the need to include the option for confidential disclosure of personal information in future surveys if a consumer or business believes *Bsal* has been detected in their collection.

Most amphibian owners indicated they believe the threat of transmission of harmful pathogens from pets to natural areas is serious, protecting natural populations is important, and they have a role to play in protecting natural populations. This is consistent with similar studies that have found the public places importance on protecting the health of native wildlife and the natural environment from pathogens transmitted through the herpetological trade (Pienaar et al. 2022) and that public support for most interventions related to invasive species is positively correlated with concern about impacts on the environment (Episcopio and Pienaar 2020). Moreover, Hanisch-Kirkbride et al. (2013) found many stakeholders to be more concerned about the effects of disease on wildlife than on themselves personally.

Knowledge may be a barrier preventing further adoption of biosecurity practices—only about a third of owners reported they know what it takes to keep their amphibians free of pathogens. This result suggests pet amphibian owners may be receptive to engaging in, or improving, biosecurity practices; however, education and outreach campaigns should be comprehensive in terms of the

information, resources and support offered. Such campaigns should demonstrate scientific evidences to help them understand the facts and understand the risk involved. Moreover, they should include practical solutions such as what owners themselves could do with the resources they have and what external resources (e.g., training, materials, testing toolkits, incentives) they can receive from government or other agencies to engage in preventive behavior. Manuals or publications with biosecurity protocols exist (Gray et al. 2017; Pessier and Mendelson 2017), however, may not be easily accessible to consumers. The Disease Task Team of the Partners in Amphibian and Reptile Conservation is one organization that can help with developing outreach educational materials for amphibian and reptile conservation.

Most owners indicated it was extremely likely that they will buy clean and certified animals and animal products when available and an overwhelming majority reported a willingness to pay a price premium for certified pathogen-free amphibians. These findings correspond to those of other studies in which pet owners have demonstrated a substantial willingness to pay for preventative care (e.g., Bir et al. 2020) and suggest the economic viability of an industry-wide clean-trade program whereby business costs for enhanced biosecurity and product certification and are offset by increased prices paid by consumers. Such a program ensuring disease-free animals could potentially benefit amphibian suppliers through increased demand for their product and consumers through overall lower expenditures from reduced pet fatalities. Importantly, 40% of the 10% US consumers who are currently unwilling to pay more for certified animals felt it was not their responsibility to incur the full cost of an amphibian clean-trade program; hence, government support to subsidize clean trade may be necessary. While any government supported program would not be free of criticism and controversy, this may still be necessary for the government to consider from public interest perspective. In other words, if the government realizes that the public places significant value on promoting a sustainable pet industry and considers prevention of pathogen transmission to be a public health issue, then some level of public funding may be necessary. It should be noted that federal programs, subsidies and incentives already exist to promote cooperation and healthy trade in other industries. For example, the US Department of Agriculture (USDA) works with a wide-ranging network of private and public sector partners to conduct, provide and facilitate a variety of laboratory services, including animal disease testing, to ensure the health, quality and marketability of the nation's animals (including various wildlife) and animal products. Leveraging the resources of agencies like the USDA that are already engaged in disease surveillance for the protection of the nation's animal, public and environmental health may be a logical first step toward implementing pathogen-free certification in the pet amphibian trade.

Respondents' attitudes, perceptions and values played a key role in determining their behavioral intentions to engage in biosecurity practices. Significant positive relationships were found between intention to adopt preventative behaviors and two of the three socio-psychological constructs. The major factors affecting amphibian pet owners' intention to adopt preventative behaviors were Attitude Toward Behavior followed by Perceived Behavioral Control, suggesting strategies that increase the positive associations with and sense of efficacy of biosecurity practices are likely to increase their adoption. Subjective norms, which relates to how others we care about would feel about us engaging in a particular behavior, did not significantly influence respondents' intention to adopt preventative biosecurity practices. Other studies examining pet owners' intentions to engage in responsible ownership practices have similarly found PCB and ATB to be significant predictors of behavioral intentions, while subjective norms were insignificant (e.g., Gunaseelan et al. 2013; Sumarwan et al. 2019). While this is counter to our expectation, it is possible that others' preferences have no effect on how pet owners care for their pets and whether they adopt biosecurity practices. This result is supported by the fact that very few (33%) of the respondents indicated people important to them expect them to adopt biosecurity practices to mitigate pathogen threats. General knowledge of amphibians, awareness of the potential for pathogen spillover from the pet trade to natural areas and the belief that the threat of transmission of amphibian pathogens from pets to natural areas is serious were all highly significantly and positively associated with intention to adopt preventative behaviors. In terms of demographic factors, no variable, except for age were significantly associated with the intention to adopt preventative biosecurity practices. Collectively, these findings are consistent with those of previous studies that have found that the public's attitudes, beliefs and risk perceptions can be stronger determinants of their pet care behavior and support for managing risks associated with the live animal trade than their demographic characteristics. For example, Pienaar et al. (2022)

found the public's values and perceived susceptibility and sensitivity to pathogen threats were key drivers of their support for biosecurity. Although there is no preceding literature on amphibian ownership specifically, related studies on pet ownership have found that attitudes and pet–owner relationship variables predict compliance with pet management practices independently of demographic characteristics (e.g., Rohlf et al. 2010). Similarly, Episcopio-Sturgeon and Pienaar (2020) found that support for interventions was linked to individuals' concern regarding risks associated with the pet trade, trust in government, perceptions of the effectiveness of interventions and gender. While they found the effect of age to be significant, it was negligible and education was insignificant (Episcopio-Sturgeon and Pienaar 2020). The same study also found that support for interventions to address invasion risk associated with the pet trade as well as the perceived effectiveness of those interventions differ between pet owners and members of the general public. This highlights some of the differences in these groups and the need for targeted messaging to engage the various populations of stakeholders.

Conclusion

Amphibian pet owners, as a key part of the pet industry, can play an instrumental role in mitigating pathogen spread and spillover into nature. The results from this study have several important findings in understanding the risk perception, attitudes and behavioral intentions of pet owners. First, although pet amphibian owners are aware of emerging pathogens and recognize the potential threat of spillover from captive to wild populations, a sizeable proportion indicated they did not know what it takes to keep their amphibians free of *Rv*, *Bd* and *Bsal*. Thus, educational campaigns for dealing with these threats may be warranted. Second, pet owners expressed a responsibility to take action and indicated a strong intention to engage in preventative biosecurity practices. This finding can be useful in formulating targeted messaging and outreach and suggests emphasis on the ease, efficacy and importance of adopting biosecurity practices may improve buy-in and effectiveness of messaging campaigns. Third, psychosocial factors including knowledge, risk perception and behavioral control were generally stronger predictors of amphibian owners' intention to adopt biosecurity practices than their demographic characteristics.

Finally, as the government agencies and stakeholders interested in combating pathogens are looking for financially self-supporting mechanisms to promote clean trade, our finding lends support for establishment of a certification program, where expenses are in part incurred by consumers. However, given a notable percentage of consumers that are unwilling to pay more for certified animals felt supporting clean trade through commodity price increases was not entirely their responsibility, a government subsidized program to facilitate a pathogen-free amphibian certification program may have the greatest likelihood of success and help ensure animal well-being, reduced disease-related financial losses for businesses and increased customer satisfaction.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval This study was reviewed and approved by the University of Tennessee Institutional Review Board for Human Subjects' Research (approval # UTK-IRB-21-06494-XM).

Informed Consent Informed consent was obtained from the participants who chose to participate in this study.

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