Educators' and Visitors' Perceptions of Invasive Species Education in Zoos

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Abstract

Management of invasive alien species (IAS) depends on public awareness and cooperation, which may be increased by effective IAS education by zoos. We administered a questionnaire to visitors (n = 221) and educators (n = 44) at three Association of Zoos and Aquariums facilities in Florida to explore their perceptions of the content and effectiveness of IAS education at these facilities. Most visitors recalled seeing IAS on display, with 80% of visitors stating that they considered zoos to be a place to learn about IAS. Both visitors and educators agreed that minimal information on how IAS are introduced to Florida was presented. They also agreed that greater implementation of shows and presentations pertaining to IAS would be highly effective in educating the public about IAS and the need for actions to mitigate species invasions. Zoos may improve their educational effectiveness by making visitors aware of IAS citizen science programs and implementing interactive educational methods.

Keywords: Conservation messages; Florida; introduction pathways; management; non-native; outreach

Introduction

Species invasions are a global threat to biodiversity, ecosystem function, ecosystem services, economically and culturally important industries (e.g., agriculture, forestry, fisheries), and human health, well-being, and livelihoods (Pyšek et al., 2020). Invasive alien species (IAS) are species that have been accidentally or deliberately introduced to new regions through human actions, including recreational activities (e.g., scuba diving, boating) and trade in live animals (e.g., the pet trade; Pyšek et al., 2020). Despite scientists' warnings about the severe ecological, economic, and human welfare consequences of species invasions, the public is often unaware of the scale and impacts of species invasions, which results in disagreement about invasive species management (ISM; Estévez et al., 2015). Specifically, the public may not understand or may misinterpret the ecological risks (e.g., predation of native species by invasive species), economic risks (e.g., reduced economic returns from resource-based industries such as agriculture, fisheries, and recreation), and human welfare risks (e.g., human injury, spread of pathogens) associated with species invasions (Gozlan et al., 2013; Verbrugge et al., 2021). The public's lack of understanding of invasion risks and IAS denialism (Ricciardi & Ryan, 2018) is reinforced by inconsistent use of terminology pertaining to IAS (Iannone et al., 2020; Verbrugge et al., 2021) and differing interpretations of terminology by the public and scientists (Glass & Pienaar, 2021). Yet, the effectiveness of ISM depends on public support for, and voluntary compliance with, ISM interventions (Dayer et al., 2020; Steele & Pienaar, 2021). Improved education and outreach are needed to inform people about IAS and the consequences of species invasions, and to engage them in actions that mitigate the introduction and spread of

IAS (e.g., cleaning boats and recreational equipment to prevent accidental transport of organisms to new regions, adopting out non-native pets, rather than deliberately releasing them into parks, waterways or the wild, avoiding invasive landscaping plants; Waliczek et al., 2018; Verbrugge et al., 2021).

Environmental education has an important role to play in informing the public about IAS and engaging them in ISM (Dayer et al., 2020; Leicht et al., 2018; Verbrugge et al., 2021). The United Nations Educational, Scientific and Cultural Organization (UNESCO) has highlighted the need to include education about IAS in its larger international call for education for sustainable development, which is interactive, learner-centered education that facilitates changes in people's knowledge, skills, values, and attitudes to secure a more sustainable and just society (Leicht et al., 2018). UNESCO stressed the need for both physical and virtual delivery of exploratory, action-oriented, and transformative learning in formal, non-formal and informal education (Leicht et al., 2018). Zoos are uniquely placed to help attain these education goals, as recognized by the Association of Zoos and Aquariums (AZA). In its Policy on Non-Native Invasive Species, the AZA emphasized the need to educate the public about different IAS, the impacts of IAS, the need for ISM, and the pathways by which IAS are introduced, with special focus on how visitors (e.g., pet owners, anglers, and boat owners) may prevent species invasions (AZA, 2003). However, in common with informal education about climate change (Henry & Carter, 2021; Stylinski et al., 2017; Swim et al., 2017), designing and implementing invasion science education for the public is challenging because the science is imperfectly understood or disputed (Humair et al., 2014; Ricciardi & Ryan, 2018), and may be politically sensitive (e.g., disputes about trade bans for invasive species; Oficialdegui et al., 2020).

Both content (messages contained in educational programs) and form (delivery of messages) determine the effectiveness of these educational efforts (Verbrugge et al., 2021). AZA facilities most commonly use signage (typically next to an exhibit), conversations with educators, and educational shows or presentations to deliver content (Clayton et al., 2009). Although studies suggest that zoo visitors like exhibit signage that highlights quick facts (Ballantyne & Packer, 2016), visitors do not receive educational content when signs are poorly designed or placed (Pearson et al., 2013). Moreover, while most visitors recognize that zoos are educational facilities, their primary motivations for visiting zoos are often entertainment and leisure time with their family (Clayton et al., 2009; Tofield et al., 2003). Visitors who are socially driven prefer interactive content to signage (Clayton et al., 2009; Tofield et al., 2003). As such, zoo educators engage visitors through conversations to provide content that is often not included on signage. Conversations are likely to be more effective if educators receive training in invasion science, thereby increasing their confidence in their ability to convey information (Swim & Fraser, 2014). If content is emotionally or politically challenging, then training on how to message about IAS and ISM would benefit educators (Swim & Fraser, 2014). Conversations are particularly effective when educators create a personal connection between the visitor and the exhibit to convey conservation messages (Clayton et al., 2009). Visitors who attend zoos primarily for entertainment are also likely to be engaged through shows and presentations that provide stimulating and entertaining opportunities to learn about IAS and invasion risks (Pearson et al., 2013; Perdue et al., 2012). Storyline or narrative approaches that focus on three to four key messages that are clearly communicated in shows and presentations, and that combine solution- and behavior-oriented messages, informative messages, and improved understanding of invasion impacts and processes are most likely to improve the public's knowledge of IAS and engage them in ISM (Verbrugge et al., 2021). Shows or presentations are most effective when they provide simple take-home messages and appeal to

broad audiences with diverse motivations for visiting zoos (Perdue et al., 2012). Importantly, regardless of education methods used, invasion science education should communicate that the public can meaningfully assist in mitigating species invasions (Patterson et al., 2010; Prinbeck et al., 2011) by highlighting success stories (Clarke et al., 2020; Gozlan et al., 2013).

Effective communication of conservation messages and behavior change are most likely to occur when learning opportunities are delivered in an enjoyable manner that sparks discussion and reflection (Ballantyne et al., 2011), but previous research suggests that this occurs for only a small portion of zoo visitors (Ballantyne & Packer, 2016). Designing entertaining and interactive invasion science education requires substantial investments of time, expertise, and funding (Oele et al., 2015; Verbrugge et al., 2021; Waliczek et al., 2018). It is therefore important to ascertain whether educators and visitors concur on how invasion science education should be designed and delivered so that limited resources can be allocated most efficiently. Unfortunately, a disconnect may exist between educators and visitors, owing to educators' lack of understanding of visitors' learning agendas, the time they spend at exhibits, and the relative importance they place on different learning strategies (e.g., reading signs, viewing animals, listening to talks) (Roe & McConney, 2015; Stylinski et al., 2017; Brown et al., 2019). Similarly, differences in values and beliefs may exist between zoo educators and visitors leading to difficulties in developing appropriate messaging pertaining to IAS and ISM (Ballantyne et al., 2018; Estévez et al., 2015; Packer et al., 2022). Such disconnects are not limited to zoos but have also been documented for other informal education facilities like museums and national parks (Brown et al., 2019; Stylinski et al., 2017). Education is more likely to promote pro-environmental behavior change when educators understand their target audience and visitors' preferences for educational content and delivery (Packer et al., 2022; Roe et al., 2014). To investigate how AZA facilities may contribute to effective invasion science education, we conducted an exploratory study with both AZA educators and zoo visitors in Florida, United States. We investigated whether visitors and educators differed in their 1) recall of invasion science educational content and delivery at these facilities, and 2) perceptions of the most effective methods for communicating invasion science.

Methods

Study area

We conducted this study in Florida because, with three significant trade ports, a large volume of IAS flow into Florida every year (Hardin, 2007), and Florida residents actively engage in the non-native pet trade (Episcopio-Sturgeon & Pienaar, 2020). Florida contains over 123 established non-native species (Hardin, 2007), the majority of which were introduced by the live animal trade (Steele & Pienaar, 2021). The humid and subtropical climate of Florida increases the likelihood that IAS will survive and establish breeding populations if they are released (Hardin, 2007). Therefore, educating Florida residents about IAS is critical to limiting release events and garnering public support for ISM. Nineteen (8%) of the 238 AZA-accredited facilities are located in Florida, making it one of the states with the highest concentrations of AZA facilities (AZA, 2022) that may assist in invasion science education.

Selection of AZA facilities

We contacted eight Florida AZA facilities in May 2019 to elicit their interest in participating in this study. We invited these facilities based on:

1. Appropriate education staffing: We only contacted facilities with a large educational staff to avoid any potential sampling bias that may have occurred with the inclusion of smaller facilities with fewer educational resources.
2. The focus of the facility: We contacted facilities that offered Florida-specific educational programs, housed species invasive to Florida, and had previously organized or engaged in community-level ISM.

Six of the eight facilities (75%) responded to the study invitation, but scheduling conflicts only allowed us to conduct research at three facilities (the Central Florida Zoo & Botanical Gardens [CFZ], the Jacksonville Zoo and Gardens, and the Brevard Zoo). Henceforth, we refer to these facilities as Facility A, B, and C (in no specific order) in the interests of data confidentiality. These three facilities were comparable in size (300,000 to approximately 1 million visitors each year; average of 104 acres) to other facilities that were invited to participate in the study (300,000 to approximately 1 million visitors each year; average of 113 acres). We did not receive permission from any aquariums to conduct this research.

Questionnaire design

We designed two separate questionnaires for all three AZA facilities: 1) a questionnaire for educators (employees and volunteers associated with the facilities' educational department); and 2) a questionnaire for Florida residents visiting these facilities. We administered questionnaires to both visitors and educators to determine if educators and visitors differed in their perceptions of the content and effectiveness of invasion science education at each facility. We included both formal educators and volunteers in this study because many AZA facilities are heavily reliant on volunteers for providing education to visitors. For example, volunteers at the CFZ contributed 26,000 hours of service in 2018 (CFZ, 2019) and over 600 active volunteers at the Brevard Zoo contributed 100,000 hours in 2019 (Brevard Zoo, 2020), with many volunteers serving as docents.

We designed the questionnaires to 1) capture respondents' awareness of what IAS information was presented (e.g., what introduction pathways were highlighted) and the educational methods used (i.e., through signs, conversations, shows, presentations); 2) respondents' preferences for different educational methods; and 3) respondents' perceptions of how effectively information that is detailed in the AZA Policy on Non-Native Invasive Species was communicated (i.e., information about personal actions that guests can take to prevent species introductions and information about the negative impacts of species introductions). Survey questions are presented in Tables 1 and 2.

Table 1. Invasive species information presented by zoos, as identified by educators (E; n = 44) and visitors (V; n = 221).

Question	Response					
	Yes		No		I'm not sure	
	No.	%	No.	%	No.	%[†]
Educational methods	24	54.5	5	11.4	15	34.1
E: Does your zoo have species invasive to Florida on display?						
V: During your trip today, do you remember seeing any species invasive to Florida on exhibit?	123	55.7	40	18.1	57	25.8
E: Does your zoo have interpretive materials (e.g., signs and interactive displays) with information about species invasive to Florida?	12	27.3	13	29.5	19	43.2
V: During your visit to the zoo, did you see any signs or interactive displays with information on species invasive to Florida?	102	46.2	61	27.6	58	26.2
E: Does your zoo have shows or presentations with information about species invasive to Florida?	20	45.5	8	18.2	16	36.4
V: During your visit to the zoo, did you see any shows or presentations with information about species invasive to Florida?	31	14.0	177	80.1	12	5.4
V: During your visit to the zoo, did you speak with any employees or volunteers about species invasive to Florida?	31	14.0	177	80.1	12	5.4
Content on introduction pathways						
Does [this facility] present information on how…						
the pet trade can be an introduction pathway for non-native species?[‡]						
Educators	27	61.4	7	15.9	9	20.5
Visitors	39	17.6	141	63.8	34	15.4
research can be an introduction pathway for non-native species?						
Educators	9	20.5	15	34.1	18	40.9
Visitors	51	23.1	116	52.5	42	19.0
the food industry can be an introduction pathway for non-native species?						
Educators	13	29.5	12	27.3	17	38.6
Visitors	57	25.8	109	49.3	42	19.0
the live bait trade can be an introduction pathway for non-native species?						
Educators	2	4.5	16	36.4	24	54.5
Visitors	39	17.6	123	55.7	44	19.9
the medical industry can be an introduction pathway for non-native species?						
Educators	4	9.1	16	36.4	22	50.0
Visitors	37	16.7	122	55.2	45	20.4
the plant trade can be an introduction pathway for non-native species?						
Educators	13	29.5	10	22.7	17	38.6
Visitors	32	14.5	137	62.0	40	18.1
hiking can be an introduction pathway for non-native species?						
Educators	3	6.8	22	50.0	14	31.8
Visitors	29	13.1	128	57.9	48	21.7
scuba diving can be an introduction pathway for non-native species?						
Educators	2	4.5	23	52.3	14	31.8
Visitors	24	10.9	131	59.3	46	20.8
fishing can be an introduction pathway for non-native species?						
Educators	4	9.1	20	45.5	16	36.4
Visitors	37	16.7	127	57.5	45	20.4
boating can be an introduction pathway for non-native species?						
Educators	4	9.1	19	43.2	16	37.0
Visitors	29	13.1	128	57.9	46	20.8

[†]Some respondents did not answer all questions. Hence, the percentage of respondents who provided answers to questions may be less than 100%.

[‡]We summed responses about whether facilities presented information about how the pet trade, research industry, live food trade, live bait trade, medicinal industry, plant trade, and recreational activities may introduce IAS to new locations (yes = 1, no = 0, I'm not sure = 0) to generate the score 'information about introduction pathways' (see Appendix B). The score was skewed right for both educators (mean = 1.92; SD = 1.07; range: 0–10) and visitors (mean = 1.64; SD = 2.71; range: 0–10).

Table 2. Educators' (E; n = 44) and visitors' (V; n = 221) perceptions of the effectiveness of the zoo's invasion science education materials.

	Not at all effective		Slightly effective		Moderately effective		Very effective		Extremely effective	
	No.	%[†]	No.	%	No.	%	No.	%	No.	%
Educational methods										
[Is] seeing species invasive to Florida on exhibit [an effective way to learn] about invasive species?										
Educators	1	2.3	6	13.6	21	47.7	13	29.5	3	6.8
Visitors	13	5.9	24	10.9	44	19.9	33	14.9	9	4.1
[Are] signs and interactive displays about species invasive to Florida [an] effective way [to learn] about invasive species?										
Educators	2	4.5	4	9.1	17	38.6	18	40.9	3	6.8
Visitors	1	0.5	20	9.0	38	17.2	30	13.6	13	5.9
[Is] speaking with an employee or volunteer about species invasive to Florida [an effective way to learn] about invasive species?										
Educators	0	0.0	3	6.8	9	20.5	25	56.8	7	15.9
Visitors	1	0.5	2	0.9	16	7.2	28	12.7	16	7.2
[Is] attending a show or presentation with information about species invasive to Florida [an effective way to learn] about invasive species?										
Educators	0	0.0	4	9.1	9	20.5	25	56.8	5	11.4
Visitors	1	0.5	1	0.5	6	2.7	15	6.8	8	3.6
Content on actions people may take to prevent species invasions										
How effectively are the following actions that can help prevent the introduction of non-native species communicated by [this facility]?[‡]										
Selecting a pet that can be properly cared for throughout their lifetime										
Educators	2	4.5	2	4.5	13	29.5	12	27.3	9	20.5
Visitors	76	34.4	35	15.8	49	22.2	16	7.2	26	11.8
Identifying and reporting non-native species										
Educators	6	13.6	8	18.2	19	43.2	5	11.4	0	0.0
Visitors	72	32.6	36	16.3	55	24.9	16	7.2	19	8.6
Selecting the right plants for a yard and garden?										
Educators	6	13.6	11	25.0	10	22.7	7	15.9	3	6.8
Visitors	78	35.3	35	15.8	50	22.6	20	9.0	19	8.6
Cleaning recreational equipment (i.e., boats, hiking boots, fishing gear and dive gear)?										
Educators	21	47.7	9	20.5	7	15.9	1	2.3	0	0.0
Visitors	88	39.8	30	13.6	47	21.3	16	7.2	21	9.5
Avoiding purchases that can transport non-native species to Florida (i.e. live bait)										
Educators	16	36.4	8	18.2	6	13.6	8	18.2	0	0.0
Visitors	83	37.6	35	15.8	49	22.2	16	7.2	19	8.6
Content on invasion impacts										
How effective do you think [this facility] is at educating visitors about the ecological impacts of invasive species?[*]										
Educators	4	9.1	8	18.2	9	20.5	13	29.5	4	9.1
Visitors	50	22.6	47	21.3	70	31.7	23	10.4	18	8.1
How effective do you think [this facility] is at educating visitors about the economic impacts of invasive species?										
Educators	7	15.9	15	34.1	10	22.7	6	13.6	0	0.0
Visitors	61	27.6	40	18.1	66	29.9	25	11.3	13	5.9
How effective do you think [this facility] is at educating visitors about the human health and wellbeing impacts of invasive species?										
Educators	7	15.9	13	29.5	11	25.0	5	11.4	2	4.5
Visitors	65	29.4	44	19.9	57	25.8	27	12.2	12	5.4

[†]Some respondents did not answer all questions. If respondents had not participated in certain educational activities pertaining to IAS then they were not asked whether they considered those activities (as implemented by the zoo) to be effective. Hence, the percentage of respondents who provided answers to questions may be less than 100%.

[‡]We combined responses to these five items to generate a composite variable ('perceived effectiveness of communication about actions the public can take to prevent species invasions'; see Appendix B). This composite variable was normally distributed for educators (mean = 12.92; SD = 3.75; range: 5–25) and skewed right for visitors (mean = 11.61; SD = 6.393; range: 5–25), where for each survey item a response of 'not at all effective'=1, 'slightly effective'=2, 'moderately effective'=3, 'very effective'=4, and 'extremely effective'=5.

[*]We combined responses to these three items to generate a composite variable ('perceived effectiveness of communication about invasive species impacts'; see Appendix B). This composite variable was normally distributed for educators (mean = 8.05; SD = 2.98; range: 3–15) and skewed right for visitors (mean = 7.40; SD = 3.45; range: 3–15), where for each survey item a response of 'not at all effective'=1, 'slightly effective'=2, 'moderately effective'=3, 'very effective'=4, and 'extremely effective'=5.

To ensure that respondents understood terms as intended, we explained that non-native species are classified as any species that has been introduced by humans to an area where it has not been historically found. We explained that a non-native species is regarded as invasive if it causes adverse ecological, economic, or human welfare impacts (Steele & Pienaar, 2021). We provided these definitions at the beginning of the questionnaire. Prior to implementation, we thoroughly pre-tested questionnaires with experts within the research community (n = 4), current and former AZA educators (n = 5), and individuals who had recently visited Florida AZA facilities (n = 14). This research was approved on June 14th, 2019, by the University of Florida Institutional Review Board (IRB protocol #201901426).

Sample populations

We invited all members of the education team at each AZA facility to participate in this research. We determined that 375 visitors were the appropriate sample size after reviewing the visitor totals for all three participating AZA facilities over the past year (95% confidence level, 5% margin of error; based on an estimated 15,000 total visitors across 9 sampling days). Our visitor sample was a non-probability, intercept sample because we invited visitors to participate in the study as they exited each facility. We utilized this approach to maximize participation based on our limited funding and time at each facility.

Questionnaire implementation

We implemented the educator questionnaire online on June 28th, 2019, and the survey remained open for each facility until the completion of the visitor research at the facility. The questionnaire was distributed to a main contact at the facility (e.g., educator or programs coordinator) who then distributed the questionnaire to the education team. We collected visitor data over three days (Thursday-Saturday for consistency in sampling across facilities). We surveyed visitors to Facility A from July 11th to July 13th, 2019, visitors to Facility B from July 25th to July 27th, 2019, and visitors to Facility C from August 1st to August 3rd, 2019. We collected data from visitors using iPads at the exit to each facility. We collected data during summer months to maximize data collection during peak attendance.

Follow-up visits

We conducted follow-up visits to each facility immediately after data collection was completed to verify whether the educational materials that had been noted by respondents were present at the facility. This was not a formal assessment of the effectiveness of facilities' educational materials or methods, but rather a check to see if respondents' recall of educational materials was accurate.

Data analysis

We used statistical analysis software Stata/SE 15.0 and R studio/R version 3.6.1 to analyze questionnaire data. We pooled educator data and visitor data from all three facilities (see Appendix A). We ran principal factor analysis to test for the dimensionality of items intended to measure composite variables (e.g., perceived effectiveness of communication about preventing species invasions). We used Cronbach's alpha ($\geq$0.7) to test for the reliability and internal validity of composite variables (see Appendix B). We utilized independent t-tests and Mann-Whitney tests to test for differences in responses between visitors and educators. We used Kruskal-Wallis tests followed by the Dunn's test (if applicable) to determine if

respondents' perceptions of the effectiveness of IAS education differed based on the number of educational methods they were exposed to during their visit. We tested which educational content and methods influenced educators' and visitors' perceptions of the effectiveness of invasion science education using simple logistic regressions, Cramer's V coefficients, and Spearman correlation coefficients, depending on how data were measured (nominal, ordinal, or interval).

Results

We obtained a total of 44 completed questionnaires (12 from Facility A, 22 from Facility B, 10 from Facility C) from 67 questionnaires that were opened by educators (completion rate of 66%). We aimed to obtain a minimum sample of 30 educators based on previous studies (Roe & McConney, 2015; Zelak, 2018) and personal communications with AZA facilities that indicated that AZA facilities typically hire between 15 and 25 paid educational staff members, while supplementing the rest of the educational team with volunteers and interns. We exceeded this sample size. We obtained a total of 221 completed visitor questionnaires (95 from Facility A, 70 from Facility B, 56 from Facility C). Response rates for the visitor survey were similar at Facility A (32%) and Facility B (34%) but lower at Facility C (16%) owing to heavy rain that persisted for two of the three days of data collection.

Respondent characteristics and time spent at the zoo

Most educators were female (65.9%), identified as white (81.8%), and were employed at their facility (73%). On average, educators had earned a Bachelor's degree and had worked one to five years at their facility. Most visitors were female (60.2%) and identified as white (81%). On average, visitors were 35–44 years old, had earned a Bachelor's degree, had spent 3 hours at the facility, and had visited the facility twice (although 82 visitors, 37%, stated that this was their first visit to the facility). Visitors primarily attended the facility to spend time with their family (70%) and to see the animals (51%). Only 44 visitors (20%) attended the facility to learn. See Appendix C for more information about respondents.

Respondents' awareness of, and preferences for, IAS educational materials

Nearly 80% of visitors (n = 176) indicated that they considered zoos to be a place to learn about species invasive to Florida. Although 20 educators (45.5%) stated that their zoo presents information about the difference between non-native and invasive species, only 58 visitors (26.2%) agreed this was the case. Most educators (54.5%) and visitors (55.7%) agreed that the zoo had IAS on exhibit (Table 1). Most educators who indicated their facility had IAS on display (22 out of 24 educators) could identify an IAS that was currently on display, whereas only 30 visitors could correctly name an IAS they saw during their visit. The largest share of educators agreed the zoo had shows or presentations about IAS (45.5%) but were unsure if the zoo had interpretive (43.2%) or printed, take-home materials (50%) about IAS. By contrast, the largest share of visitors (46.2%) agreed that the zoo had interpretative materials but disagreed that the zoo had shows (80.1%) or printed, take-home materials about IAS (89.1%; follow-up visits confirmed that all three facilities did have shows or presentations with messages about IAS, but did not provide any printed, take-home materials). Most visitors (80.1%) had not spoken to an educator about IAS during their visit to the zoo, but educators stated they have approximately 15 conversations per day about IAS during the week (~19% of all conversations with guests) and approximately 20 conversations per day during the weekend (~23% of all conversations with guests). Most educators stated that they would like their

facility to provide more of all educational methods pertaining to IAS, whereas most visitors wanted to see more exhibits with species invasive to Florida (n = 134; 62%), signs and interactive displays about IAS (n = 118; 54%) and shows and presentations with messages about IAS (n = 116; 54%) in Florida zoos (Appendix D).

Both educators and visitors agreed that minimal information about introduction pathways for IAS was presented at the facility (Table 1). Whereas educators most frequently identified the pet trade (n = 27; 61.4%) as an invasion pathway featured in their facility's educational materials, visitors most frequently identified the food industry (n = 57; 25.8%) as a pathway highlighted by the zoo. Follow-up visits confirmed that information on different introduction pathways presented via signs and shows was limited to the invasion risks posed by two pathways, the pet and plant trades. These visits also revealed that multiple signs about IAS did not indicate how the species was introduced to Florida, the species range in Florida, or the adverse impacts associated with the species. Exhibits featuring recently introduced non-native species (that potentially may be established), such as the capybara (*Hydrochoerus hydrochaeris*) and pirapitinga (*Piaractus brachypomus*), often failed to present any information about these species being introduced to Florida.

Perceived effectiveness of educational methods

On average, educators and visitors considered conversations with educators and shows or presentations to be 'very effective' in conveying information about IAS, whereas they considered interpretive materials and exhibits of IAS to be 'moderately effective' (Table 2). We generated two composite variables that captured respondents' perceptions of how effectively the facility communicated 1) which actions the public can take to prevent species invasions and 2) invasion impacts (Appendix B; Table A1). Educators considered their facilities to be slightly to moderately effective in communicating what actions the public can take to prevent species invasions (weighted mean = 2.58, 'slightly effective'=2, 'moderately effective'=3) and the ecological, economic, and human welfare impacts of IAS (weighted mean = 2.68), an assessment with which visitors agreed (weighted mean = 2.32 for communication about actions to prevent species invasions; weighted mean = 2.47 for communication about IAS impacts). Educators' perceptions of how effectively the zoo communicated actions to prevent species invasions were positively correlated with the amount of information their facility provided about introduction pathways for IAS (r_s=0.474; p = 0.004; n = 35; Appendix E; Table A5), whereas visitors' perceptions were positively correlated with receiving information about different introduction pathways for IAS (r_s=0.457; p < 0.001; n = 180; Appendix E; Table A6). Educators' perceptions of how effectively their facility communicated IAS impacts was positively correlated with how often they discuss IAS with guests on a typical day during the workweek (r_s=0.341; p = 0.039; n = 37; Appendix E; Table A5). Visitors differed in their perceptions of how effectively the zoo had communicated actions to prevent species invasions and IAS impacts depending on the number and type of educational methods they recalled from their visit. Visitors who recalled more IAS educational methods stated that the zoo had been more effective in communicating actions to prevent species invasions (weighted mean of 2.33 for one educational method; weighted mean of 3.18 for four educational methods; $\chi^2(1)=30.81$; p < 0.001; n = 195; Appendix E; Table A9) and IAS impacts (weighted mean of 2.41 for one educational method; weighted mean of 3.70 for four educational methods; $\chi^2(1)=55.87$; p < 0.001; n = 195; Appendix E; Table A10). Regardless of educational method (exhibits, signs, conversations with educators, shows), visitors who had been exposed to an educational method during their visit scored the zoo more highly on the effectiveness of their invasion science education than visitors who had not been exposed to that

educational method (Appendix E; Table A11 and A12). Visitors who had spoken with educators and/or seen shows about IAS, in combination with reading signs about IAS, scored the zoo most highly on the effectiveness of their education about preventing species invasions ($\chi^2(1)=40.63$; $p < 0.001$; $n = 194$; Appendix E; Table A13) and IAS impacts ($\chi^2(1)=62.54$; $p < 0.001$; $n = 201$; Appendix E; Table A14). See Appendix E for full information on statistical tests.

Limitations

While this study aimed to gather at least 375 responses from visitors to Florida AZA facilities, we only obtained 221 responses. Data collection spanned only three days at each facility and relied on attendance numbers and weather events. These restrictions were particularly relevant to the data collection at Facility C ($n = 56$) because of heavy rain, particularly in the afternoon when most visitors left the facility. We caution that our findings are not broadly generalizable to all AZA facilities. Aquariums were excluded from our study despite our best efforts to recruit aquariums for our study.

Discussion

Although our study cannot be generalized to all AZA facilities, our findings provide useful insights on how invasion science education at zoos may be enhanced. The important role that zoos play in invasion science education was recognized by visitors, nearly 80% of whom stated that they view zoos as a place to learn about IAS. Given the critical need to engage the public in ISM (Dayer et al., 2020; Verbrugge et al., 2021), especially in states like Florida where the public is actively contributing to species invasions through pet ownership (Episcopio-Sturgeon & Pienaar, 2020), recreational activities, and landscaping (Steele & Pienaar, 2021), it was encouraging to see that all three zoos provided exhibits of species invasive to Florida (≥ 6 IAS at each facility). However, half the educators we surveyed were unable to identify an IAS their facility has on exhibit correctly, and more than half of educators were unaware that their facility has signs and interactive displays with information about IAS. Both visitors and educators agreed that little actionable information about introduction pathways and preventative actions that the public can take to reduce species invasions was presented at the facilities.

Educators' and visitors' perceptions that key invasion science content was missing may be partly attributable to the fact that most IAS exhibits were small and housed reptiles, a non-charismatic class of animals (Steele & Pienaar, 2021) that many visitors regard as boring because of their lack of movement (Tofield et al., 2003). People are more likely to engage with content about mammals and birds than amphibians, reptiles, or invertebrates, owing to the relative charisma of these species (i.e., body size, unique morphology, coloration, behavior, anthropomorphism, cultural or symbolic value; Jaríc et al., 2020). Studies also suggest that people are more likely to support ISM when they recognize and understand the invasive status of species (Cordeiro et al., 2020). However, our follow-up visits to zoos showed that many exhibits featuring IAS were missing critical information on how these IAS were introduced to Florida, the invasive and native range of the species, and the negative impacts associated with the species. Although the importance of the pet and plant trades in introducing IAS to Florida was highlighted, more information is needed on how recreational activities (fishing, boating, hiking, hunting, diving) may spread IAS and actions people can take to prevent species invasions (AZA, 2003; Ballantyne & Packer, 2016). Subject to budget constraints, zoos could improve their invasion science education by diversifying the collection of IAS exhibited to illustrate a broader assortment of IAS and to highlight that popular species (prevalent in the pet

and horticultural trades) are invasion threats. Visitors are more likely to recall educational content that highlights how IAS impact native and/or threatened species (Jaríc et al., 2020), especially if these species occur in Florida or are charismatic (e.g., the potential impacts on the Florida manatee [*Trichechus manatus latirostris*] by the invasive armored catfish [Loricariidae*: Pterygoplichthys*] that was introduced through the aquarium trade; Nico et al., 2009].

In contrast to previous research that suggests a disconnect between educators and visitors at informal education centers on how educational programs should be structured (Brown et al., 2019; Roe & McConney, 2015), the educators and visitors in our study largely agreed in their assessment of the effectiveness of different invasion education methods. Although both groups considered interactive education methods in the form of conversations with educators and shows or presentations to be highly effective in conveying invasion education content, they still considered interpretive materials and exhibits of IAS to be a moderately effective education method. Notably, we found that visitors who had received invasion education through both interactive methods (shows, conversations) and passive methods (exhibits, signs) scored the zoo more highly in its effectiveness in educating visitors about IAS impacts and preventing species invasions. Well-designed signs and exhibits have an important role to play in invasion education (Ballantyne & Packer, 2016).

Nonetheless, greater implementation of shows and presentations pertaining to IAS would be a highly effective means to educate the public about IAS and the need for actions to mitigate species invasions (see also Ballantyne et al., 2011; Oele et al., 2015; Prinbeck et al., 2011; Verbrugge et al., 2021). Visitors that are socially driven are more likely to engage in invasion science education if content is interactive (Clayton et al., 2009; Tofield et al., 2003; Verbrugge et al., 2021). Since most visitors spend 2 to 3 hours at the zoo, primarily to have fun, spend time with family and to see the animals (Clayton et al., 2009; Roe & McConney, 2015; Tofield et al., 2003), they are more likely to respond to narrative-based educational interventions that highlight potential personal risks from species introductions, such as risks to charismatic and symbolic species and economically- or culturally important activities (Jaríc et al., 2020; Steele & Pienaar, 2021). Repeat visits to the facility may then allow visitors to expand their knowledge of IAS and understanding of which actions they may take to prevent species invasions.

However, since shows and presentations are costly and time intensive to develop (Perdue et al., 2012), much of the burden of communicating information about IAS and educating guests about personal actions they can take to help prevent species introductions currently falls on the shoulders of educators due to budget and space constraints (Patterson et al., 2010). Both paid educators and volunteers would benefit from training in invasion science education, potentially through outreach programs (Patterson et al., 2010; Zelak, 2018). Such training would provide educators with the skills and confidence to engage visitors on invasion science, which is still imperfectly understood, disputed (Humair et al., 2014; Ricciardi & Ryan, 2018), and potentially politically sensitive (Oficialdegui et al., 2020). Similar efforts by informal education centers to train educators in climate change science improved educator confidence and visitor learning outcomes (Henry & Carter, 2021; Swim et al., 2017). Given the transparency and accuracy with which educators in this study assessed the successes and limitations of their facilities' invasion science education programs, educators are likely to be amenable to training in invasion science education content and delivery, potentially allowing for more shows and presentations with invasion science education.

In addition to the education methods we investigated in this study, zoos can improve invasion education at their facilities through the use of technology (e.g., smartphone applications, social media, open access educational resources), games (e.g., challenges to find all IAS at the facility) and take-home materials (Ballantyne & Packer, 2016; Verbrugge et al., 2021). Along with other informal education facilities, zoos may engage visitors in citizen science efforts to prevent the spread of IAS (Dayer et al., 2020; Patterson et al., 2010; Verbrugge et al., 2021), for example by making visitors aware of web-based mapping systems for documenting the distribution of IAS such as the Early Detection & Distribution Mapping System (EDDMapS [Early Detection & Distribution Mapping System], 2022) and Florida-specific smartphone applications (e.g., Ive Got 1). Zoos may further reinforce visitors' awareness and willingness to engage in ISM by hosting special events and community outreach events (Patterson et al., 2010), such as the Florida Fish and Wildlife Conservation Commission's Exotic Pet Amnesty program at which pet owners can safely surrender their non-native pets to pre-approved adopters to prevent potential release of IAS into the wild (FWC, n.d.).

Conclusion

Invasion education and communication of personal actions that the public can take to prevent the introduction and spread of IAS are crucial for successful ISM. Zoos can play a critical role in implementing invasion science education that engages the public in ISM. However, these facilities already have a range of conservation messages to convey with limited funding and resources. Zoos could benefit from partnerships with invasion science specialists and educators who can provide appropriate support in terms of educational content and delivery, including training and resources for educational staff. Increased funding from government or donor organizations may assist zoos in increasing and improving their shows and presentations, take-home materials, and exhibits of IAS to ensure that these educational materials are engaging, accurate, and provide clear guidance on actions the public can take to mitigate invasion risks. However, there are several interventions that zoos may implement to improve their invasion science education that would likely require minimal additional funding, such as making the public aware of citizen science programs, online resources and smartphone applications that would allow them to assist in ISM and implementing games for visitors that challenge them to locate all IAS in the facility. Such interventions would increase the interactive nature of zoos' invasion science education, while also helping zoos to attain their conservation mission.

Ethics approval

This research was approved on June 14th, 2019 by the University of Florida Institutional Review Board (IRB protocol #201901426).

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Disclosure statement

No potential conflict of interest was reported by the authors.

Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to their containing information that could compromise the privacy of research participants.

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