Integrating local perspectives into conservation could facilitate human–crocodile coexistence in the Ayeyarwady Delta, Myanmar

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Abstract Conservation will always fail when it does not address the drivers of biodiversity loss, which in many cases involves understanding human behaviours and the attitudes that underlie them. The saltwater crocodile *Crocodylus porosus* is a keystone species in mangrove wetlands but also a dangerous predator that affects people's safety and livelihoods. Although saltwater crocodiles are protected under the Myanmar Biodiversity and Protected Area Law, the government has not integrated local people's attitudes into conservation and management. As a consequence, saltwater crocodiles, although categorized as Least Concern on the IUCN Red List, are restricted to a single protected area, Meinmahlakyun Wildlife Sanctuary, in Myanmar. To examine local attitudes towards the species, we investigated local knowledge about the environment, crocodiles, habitats and threats, awareness of human–crocodile conflict, and perceptions of the benefits and impacts of saltwater crocodile conservation through questionnaires in 244 households in 17 villages. We found that people were highly knowledgeable about the local environment, saltwater crocodiles, and their habitats. People with seasonal livelihoods that rely on natural resources from Meinmahlakyun had negative attitudes towards crocodile conservation. People were likely to have negative attitudes if they perceived there were no benefits from conserving the species. Law enforcement through restricting resource access does not enhance conservation success and builds resentment towards the conservation of the species. Local people suggested that, as a basis for management, understanding risks posed by crocodiles was the best approach to facilitate human–crocodile coexistence in the Ayeyarwady delta region.

Introduction

The saltwater crocodile *Crocodylus porosus* is the most widely distributed crocodilian species, ranging across South-east Asia to Australia, and is categorized as Least Concern on the IUCN Red List. The species was once widespread and abundant in the wetland swamps of Myanmar, but is now limited to Meinmahlakyun Wildlife Sanctuary and adjacent reserved forests (Thorbjarnarson et al., 2000). The saltwater crocodile is a protected species under the Myanmar Biodiversity and Natural Areas Law of 2018 and killing or injury of crocodiles is punishable by a prison sentence, a fine or both (Rao et al., 2013). Since 1980, the population has declined as a result of illegal commercial hunting and habitat loss (Thorbjarnarson et al., 2000). The crocodile population size was estimated to be < 100 individuals in 1999 (Thorbjarnarson et al., 2000) and thus the species is in danger of extinction in the Ayeyarwady delta. Subsequent surveys have been conducted annually by Meinmahlakyun staff but these surveys are unreliable because of limited financial resources and lack of training. In 2017, a spotlight count detected 27 saltwater crocodiles (Forest Department, 2017) and, despite their unreliability, the annual surveys suggest the crocodile population is probably decreasing (Forest Department, 2017). Habitat loss from mangrove clearance (to boost agricultural productivity) is one of the greatest threats to this last remaining crocodile population in the Ayeyarwady delta (Thorbjarnarson et al., 2000; Webb et al., 2014).

The Ayeyarwady region is the second most populated area in Myanmar, with 86% of people living in rural areas. Rural livelihoods largely rely on natural resources, putting pressure on the ecosystem (Oo, 2002; Leimgruber et al., 2005; Giri et al., 2011; Webb et al., 2014; Feurer et al., 2018). After cyclone Nargis in 2008, only a small area of mangrove remained in Meinmahlakyun, which has continued to shrink as a result of illegal logging and lack of proper management (Wang, 2016). As the human population increases near protected

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areas, the probability of conflict is exacerbated when there is competition for limited resources between people and wildlife (Newmark et al., 1993; Madden, 2004; Wallace et al., 2011). Habitat loss is a major driver of human–crocodile conflict (Santiapillai & de Silva, 2001; Sivaperuman, 2015). Negative attitudes towards saltwater crocodiles are common in areas where people's livelihoods are affected by crocodiles. Addressing such attitudes and any potential conflict is an essential component of effective conservation strategies for saltwater crocodiles (Kaltenborn et al., 2006; Thomas, 2006; Wallace et al., 2011). However, attitudes towards wildlife are spatially heterogeneous, depending on cultural and demographic contexts (Naughton-Treves & Treves, 2003; Kaltenborn et al., 2006; Brackhane et al., 2019).

In South Africa, there were at least 214 records of injuries and fatal attacks on people by Nile crocodiles *Crocodylus niloticus*, and cattle loss and damage to fishing nets, during 1949–2016 (Aust et al., 2009; Wallace et al., 2011; Thomas, 2006; Pooley et al., 2020). The concerned authorities controlled the crocodiles by removing them, trapping and selling them to commercial farms, building protective structures (e.g. fences at some dams), licensing trophy hunters, and paying compensation for attacks (Pooley et al., 2020). In Sarawak, a strategic plan for crocodiles includes a state-wide crocodile inventory, the formation of a wildlife action team, an awareness programme and media engagement (Tisen et al., 2014). No comparable plan exists in Myanmar, although during 1996–2018, 25 fatal crocodile attacks were reported in the vicinity of Meinmahlakyun (Forest Department, 2018). Myanmar's biodiversity legislation and the Meinmahlakyun management plan do not address human–crocodile conflicts (Aung, 2007).

Unlike other coastal regions where saltwater crocodiles have been extirpated, Meinmahlakyun is legally protected. However, because of the environmental degradation of the Ayeyarwady region, local people heavily rely on Meinmahlakyun for their livelihoods, leading to encounters between people and wildlife in and around the Wildlife Sanctuary. Although saltwater crocodiles are legally protected in Myanmar, successful conservation in the Ayeyarwady delta requires interdisciplinary approaches that are able to promote human–crocodile coexistence. Here we (1) explore local people's knowledge, awareness and perceptions of, and attitudes towards, saltwater crocodile conservation, and how these factors vary demographically, (2) evaluate factors affecting attitudes towards the conservation of saltwater crocodiles in Meinmahlakyun and (3) develop measures to promote human–crocodile coexistence in the Ayeyarwady delta.

Study area

The 137 km² Meinmahlakyun Wildlife Sanctuary is an ASEAN Heritage Park and a Ramsar wetland of international importance (Ramsar, 2017) in Bogalae Township, Ayeyarwady Delta, Myanmar. Two Reserved Forests (Pyindayae and Kadonkani) neighbour the Sanctuary (Fig. 1). Meinmahlakyun was declared a Wildlife Sanctuary in 1986, corresponding to IUCN protected area category IV (Aung, 2007), and under the management of the Myanmar Forest Department. Development activities and resource extraction are strictly prohibited within the Sanctuary (Forest Law, 1992). Management activities include patrolling, forest inventory, enrichment planting, surveys of saltwater crocodiles and birds, and environmental education in nearby villages. There are c. 30 villages near Meinmahlakyun, with an average of 150 households per village (Meinmahlakyun Wildlife Sanctuary, 2018). Many local people use the mangrove forests for the collection of various natural products, including fuelwood for cooking and *Nypa fruticans* poles and leaves for house construction, and thus the protection of natural resources is important culturally and economically in the Ayeyarwady delta.

Methods

Questionnaire survey

We randomly selected 17 of 30 villages around Meinmahlakyun (Fig. 1, Supplementary Fig. 1), and 10% of households in each village. One adult resident ($>$18 years old) was interviewed per household, using a semi-structured questionnaire, during March–September 2018. The questionnaire used both open and fixed-response questions (Supplementary Material 1). Answers for the fixed-response questions were yes, no or don't know. For the open questions, we provided potential responses for the interviewers (KZT and ZZ) to match with respondents' answers. The interviewer noted answers not included in the list. These other answers were later coded as correct or incorrect, as appropriate.

The questions (Supplementary Table 1) included 11 variables: (1) environmental knowledge, (2) knowledge about saltwater crocodiles and their habitats, (3) knowledge about threats to saltwater crocodiles, (4) awareness of human–crocodile conflicts, (5) perceived benefits from saltwater crocodile conservation, (6) perceived impacts from saltwater crocodile conservation, (7) attitudes towards saltwater crocodile conservation in Meinmahlakyun, (8) age, (9) gender, (10) main source of livelihood and (11) educational level of the respondent (Xu et al., 2006; Leverington et al., 2010; Liu et al., 2010).

The first phase of analysis involved screening and coding answers to both sets of questions. We removed the 'don't know' answers in the fixed-response questions and incorrect answers in the open questions. For the former, answers were then coded as 0 and 1 for no and yes, respectively. For the
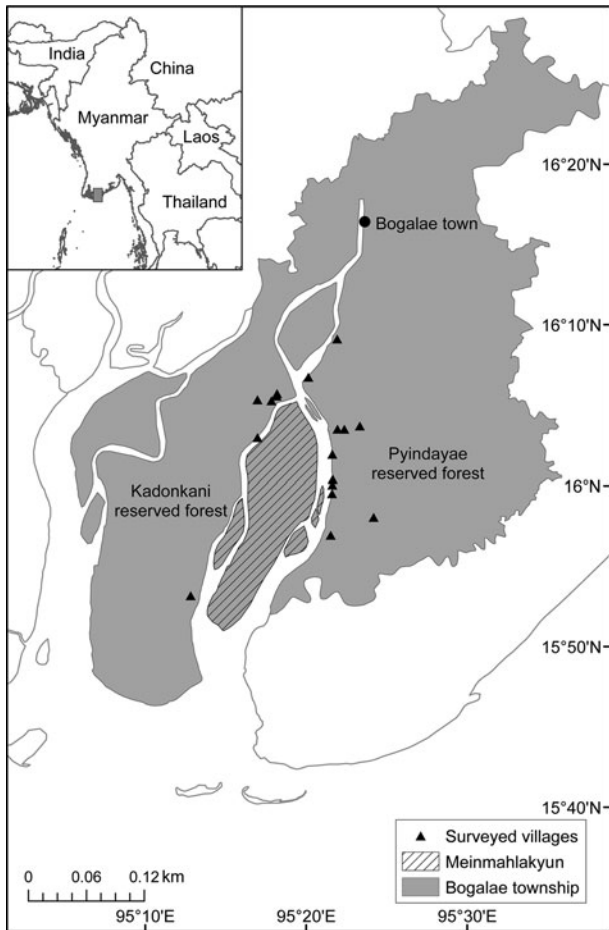
FIG. 1 The villages around Meinmahlakyun Wildlife Sanctuary, in Bogalae Township, Ayeyarwady Delta, Myanmar, where we conducted the questionnaire surveys. The Sanctuary comprises four islands.

open questions (except demographic variables), the score was 1 if the respondent gave one correct answer, 2 for two correct answers, and so on, and 0 for 'don't know' or incorrect answers (Kaczensky et al., 2004). Attitudes towards saltwater crocodile conservation in Meinmahlakyun was a dichotomous choice, with 1 for yes (positive attitude) and 0 for no (negative attitude) (Vincenot et al., 2015). The respondents were also asked to suggest measures to promote human–crocodile coexistence around Meinmahlakyun. Subsequently, we encouraged respondents to give the reasons why they suggested those measures (Supplementary Material 1; Question 28) and their suggestions were analysed separately from the 11 variables described in Supplementary Table 1.

Data analysis

The weighted average index value was calculated for variables with multiple questions (Leverington et al., 2010). Weights were based on a ranking of the importance of the questions within each of the 11 variables, allowing us to prioritize key questions depending on the local context. Weights were assigned by 10 Meinmahlakyun Wildlife Sanctuary staff using the compounded interval scale (Liu et al., 2010; Supplementary Table 2). For each variable, answer scores multiplied by the weights of the questions were averaged to derive the weighted average index value, which was then categorized as low, medium, high or very high. We then assessed the distribution of index values and removed outliers.

We used Pearson's χ^2 test to test if the numbers of respondents distributed within each level (low–very high) of variables were different than would be expected by chance, and multiple correspondence analysis to assess associations between variables. We used generalized linear models (GLMs) with binomial errors (binomial logistic regression) to examine the factors affecting attitudes towards saltwater crocodile conservation. Weighted average index values of the 11 variables were used in the GLMs. Attitudes towards saltwater crocodile conservation was the dependent variable and the other 10 variables were explanatory variables.

Using a saturated model with all potential interactions and main effects, we tested whether there were interactions among the explanatory variables. The simplified model was retained by removing interacting variables from a saturated model until the removal of further variables make no significant difference. Analysis of deviance statistics was used to compare the models and remove the non-significant interactions and main variables from the saturated model. Text mining analysis was used to conceptualize and visualize the words used in the respondents' suggestions and explore the emphasis of certain solutions, and similar themes were extracted and combined to provide recommendations to improve human–crocodile coexistence. All analyses were conducted in R 3.1.1 (R Core Team, 2018).

Results

Demographic characteristics

In total, we interviewed 64 women and 180 men, of whom 45.9% were 40–60 years old (Supplementary Table 3). As each respondent was selected based on who answered the door to the interviewer, men responded to the surveys more than women. In Myanmar, men are generally considered the head of the household and are therefore more likely to respond to a request for an interview. The majority of respondents had primary education (67.6%) and seasonal livelihoods (41%; Supplementary Table 3). People with seasonal livelihoods have no farmlands or fishing licences and hence they obtain income as labourers, and log and fish illegally in Meinmahlakyun. Their income-generating activities change

seasonally and they are therefore the most resource-dependent people living around the Sanctuary. The second-largest groups were fishers and farmers (with licences or land), comprising 23 and 27% of the total respondents, respectively (Supplementary Table 3).

Knowledge

The characterization of people's knowledge is summarized in Supplementary Table 4. Most respondents (96.7%) were aware of the degradation of local mangroves. Some respondents (32.4%) indicated wood exploitation was degrading the mangroves, and 38.5% of respondents mentioned the benefits of mangroves in providing protection from natural phenomena such as typhoons. Most (76.2%) respondents did not know why Meinmahlakyun was established. Many respondents (59.4%) had observed saltwater crocodiles in Meinmahlakyun, and 87.3% assumed the crocodile population was increasing in the Ayeyarwady delta. The importance of mangroves as suitable habitats for saltwater crocodiles was recognized by 84.8% of the respondents. Before saltwater crocodiles were legally protected, local people from the Ayeyarwady delta hunted crocodiles (Thorbjarnarson et al., 2000) but most respondents (94.3%) stated that hunting was no longer a threat to the saltwater crocodile because of strong legislation against poaching.

Awareness and perceptions

The awareness and perceptions of respondents are summarized in Supplementary Table 5. Circa 70% of respondents knew of 1–6 saltwater crocodile attacks. Most respondents (61.9%) reported receiving no benefits from the conservation of saltwater crocodiles in Meinmahlakyun but 34.8% perceived non-monetary benefits (i.e. ecosystem benefits or satisfaction in conserving saltwater crocodiles). Less than half of respondents (45.1%) suffered no impacts from the conservation of saltwater crocodiles but 40.2% were worried about the risk of attacks while fishing or washing in the river.

Association patterns between variables

The numbers of respondents with positive and negative attitudes were not significantly different (Table 1). Multiple correspondence analysis described association patterns of variables on two dimensions. Dimensions 1 and 2 explained only 8.7 and 7.4% of the variation in the data, respectively, showing that understanding factors associated with attitudes is challenging. On dimension 1 (Fig. 2), willingness to support saltwater crocodile conservation was strongly associated with perception of benefits. The knowledge/awareness levels (low–very high) of

variables with the largest squared correlations contribute the most to the multiple correspondence analysis plot (Supplementary Fig. 2). The association of the variables 'fishery' and 'have impacts' indicates that respondents who perceive they are affected by saltwater crocodile conservation were frequently associated with fishery livelihoods (Supplementary Fig. 2). Variables distant from the centre of the plot (e.g. 'livestock livelihood', 'high knowledge of threats to saltwater crocodiles') indicate these characteristics are uncommon. Conversely, variables near the centre of the plot indicate characteristics that are commonly associated (e.g. 'high environmental knowledge', 'high saltwater crocodile knowledge').

Factors influencing attitudes

The interaction and main variables retained from the saturated model are described in Supplementary Table 6. The interaction between age and livelihoods was significant (P < 0.01) in explaining the attitudes of local people towards the conservation of saltwater crocodiles (Supplementary Table 7). Older respondents (40–60 years old) were more likely to support the conservation of saltwater crocodiles than younger respondents (20–40 years old) although both groups were fishers (Supplementary Table 7). Levels of four variables (low level of knowledge about saltwater crocodiles, low level of perception of threats to saltwater crocodiles, no benefit of saltwater crocodile conservation, and seasonal livelihood) had significant main effects on the conservation attitudes of local people (Table 2). People who perceived no benefits from conservation activities had negative attitudes towards crocodile conservation. Respondents with seasonal livelihoods were more likely to have negative attitudes towards saltwater crocodile conservation compared to respondents with agricultural livelihoods. People who had a low level of knowledge about crocodiles and their habitats were unlikely to support saltwater crocodile conservation, but respondents who had a low level of knowledge about the threats to crocodiles were likely to have positive attitudes towards their conservation.

Suggestions for coexistence

The respondents suggested ways to facilitate human–crocodile coexistence in the Ayeyarwady delta (Fig. 3a). Some (15.5%) suggested awareness of the risks posed by saltwater crocodiles (Fig. 3b). Amongst the respondents' suggested solutions, 11% of all measures involved developing alternative livelihood options, especially for fishers, who are the most vulnerable group, to reduce exposure to crocodile attacks (Fig. 3b).

When crocodiles attacked pets, livestock and people outside Meinmahlakyun, respondents assumed they were

TABLE 1 An examination, using Pearson's χ^2, to test if the numbers of respondents distributed within each level of 11 variables that could influence human–crocodile coexistence were different than would be expected by chance.

Variable	Levels	P
Attitudes towards the conservation of saltwater crocodiles	Yes, No	0.800
Environmental knowledge	Normal, high, very high	< 0.001
Knowledge about saltwater crocodiles	Low, normal, high	< 0.001
Perceptions of threats to saltwater crocodiles	Low, normal, high	< 0.001
Human–crocodile conflict awareness	Low, normal, high	< 0.001
Perceptions of benefits of saltwater crocodile conservation	Have benefits, no benefits	< 0.001
Perceptions of impacts of saltwater crocodile conservation	No impacts, have impacts, have more impacts	< 0.001
Gender	Female, male	< 0.001
Livelihoods	Farm, fishery, livestock, seasonal, business, other	< 0.001
Age	$18 \leq 20, 20 \leq 40, 40 \leq 60, > 60$	< 0.001
Educational level of the respondents	Primary school, secondary school, high school	< 0.001

seeking prey outside the protected area as a result of the deforestation of mangroves in the Sanctuary. Consequently, 7.1% of measures suggested were the restoration and protection of mangroves in Meinmahlakyun, to provide prey for crocodiles (Fig. 3b). Some measures suggested were less practical, such as controlling crocodile movement outside Meinmahlakyun, preventing illegal fishing inside Meinmahlakyun, and delisting the Wildlife Sanctuary. These represented 22% of suggested measures but no supporting evidence was provided by the respondents to explain how these approaches would effectively manage human–crocodile interactions in the Ayeyarwady delta (Fig. 3b). Circa 6% of respondents assumed that numbers of saltwater crocodiles are increasing, and suggested population control (Fig. 3b).
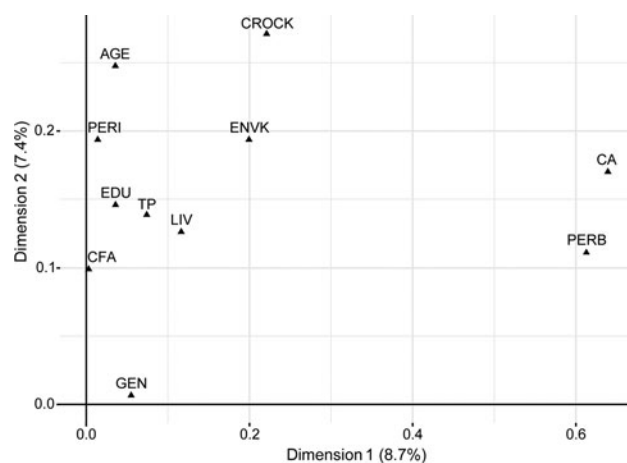

FIG. 2 Multiple correspondence analysis plot showing association patterns of the 11 variables (Table 1) on the first two dimensions and the per cent of variation in the data accounted for by each dimension: environmental knowledge (ENVK), knowledge about saltwater crocodiles (CROCK), perceptions of threats to saltwater crocodiles (TP), human–crocodile conflict awareness (CFA), perceptions of impacts (PERI) and benefits (PERB) of saltwater crocodiles, conservation attitudes of local people (CA), age (AGE), education (EDU), gender (GEN) and livelihoods (LIV).

Discussion

We found that knowledge about crocodiles, their habitats and threats to the species, perceptions of benefits, and people's livelihoods were the most significant factors influencing the attitudes of local people towards saltwater crocodile conservation in Meinmahlakyun Wildlife Sanctuary. We discuss how these factors could contribute to the conservation of saltwater crocodiles in the Ayeyarwady delta and, following suggestions made by local people we interviewed, we highlight how policy and management could be used to promote human–crocodile coexistence.

Knowledge

Circa 76% of local people living near Meinmahlakyun did not know why the Sanctuary was established. Limited knowledge about Meinmahlakyun implies poor community participation and a lack of information about the protected area. However, people were knowledgeable about the environment, saltwater crocodiles and their habitats, presumably from experience rather than from educational programmes (Dimitrakopoulos et al., 2010). Knowledge about the environment derived from experience or traditions is important for biodiversity conservation (Berkes et al., 2000; Liu et al., 2010). Researchers and natural resource managers need to integrate traditional ecological knowledge in developing conservation strategies and management approaches (Coreau et al., 2018). In Timor-Leste, the saltwater crocodile is regarded as an iconic and prestigious animal, and management strategies for the species are based on the cultural beliefs of local stakeholders (Brackhane et al., 2019).

Benefits and positive conservation attitudes

The perception that there are no benefits from Meinmahlakyun was a driver of negative attitudes. This corroborates previous findings demonstrating the link between

TABLE 2 Binomial logistic regression model used to examine whether conservation attitudes (the dependent variable) were influenced by 10 independent variables. Variables not listed in the Level column (Table 1) were used as the reference category in the model.

| Variable	Level	Exp(B)	SE	z	P
	(Intercept)	1.507	2.513	0.600	0.548
Environmental knowledge	Normal	0.095	0.742	0.128	0.897
	Very high	−0.372	0.618	−0.601	0.548
Knowledge about saltwater crocodiles	Low	−1.200	0.654	0.622	0.067
	Normal	−0.683	0.517	−1.322	0.186
Human–crocodile conflict awareness	Low	4.166	1.322	0.203	0.839
	Normal	0.138	1.283	0.107	0.915
Perceptions of threats to saltwater crocodiles	Low	5.039	1.871	2.226	0.026
	Normal	−15.714	1,493.346	−0.011	0.992
Perceptions of impacts of saltwater crocodiles	No impacts	0.628	0.486	1.310	0.190
	Have more impacts	0.055	0.480	0.070	0.944
Perceptions of benefits of saltwater crocodiles	No benefits	−5.694	0.860	−6.894	< 0.001
Age	> 1 ≤ 2 years	−0.054	2.062	−0.026	0.979
	> 4 ≤ 6 years	0.658	0.537	1.225	0.221
	> 60 years	0.752	0.736	1.023	0.306
Education	Primary	−0.644	0.900	−0.715	0.475
	Secondary	−0.467	0.932	−0.501	0.616
Gender	Male	−0.284	0.552	−1.473	0.607
Livelihoods	Business	−1.565	1.162	−1.347	0.178
	Fishery	−0.875	0.594	−1.473	0.141
	Livestock	−16.619	2,261.403	−0.007	0.994
	Others	0.431	1.769	0.244	0.806
	Seasonal jobs	−1.655	0.565	−2.931	0.003
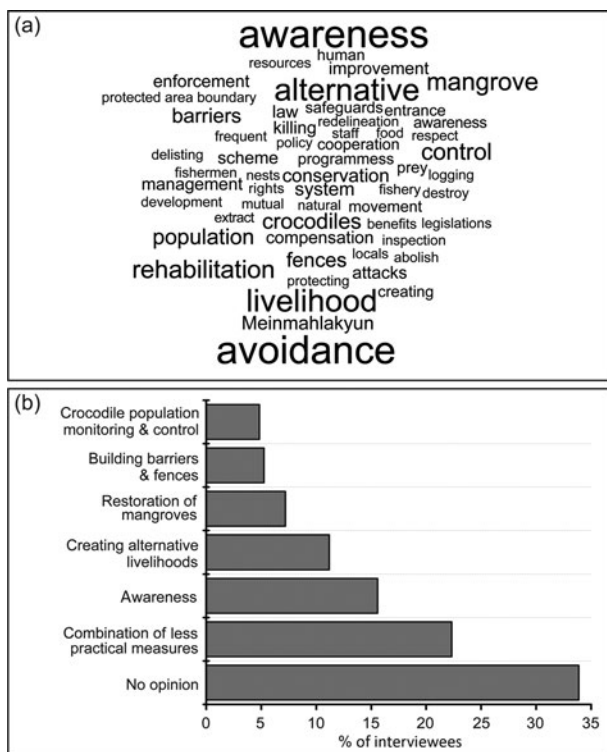
FIG. 3 (a) Words used by local people in their suggestions for human–crocodile coexistence (size of words reflects frequency of the words used in the suggestions). (b) The per cent of people interviewed who suggested various solutions to facilitate human–crocodile co-existence (some people suggested more than one measure).

sustainable conservation in protected areas and types of benefits secured for local people from those protected areas (Allendorf et al., 2006, 2012; Xu et al., 2006; Rahman et al., 2017). In China, people's perceptions of protected areas were affected by perceived costs and benefits, dependency on resources, and knowledge about protected area management (Xu et al., 2006). In the case of Chatthin Wildlife Sanctuary in Myanmar, the willingness of local communities to support conservation was related to the benefits of natural resource extraction (Allendorf et al., 2006, 2012). In Asian and African countries, conservation attitudes of people near protected areas were strongly influenced by receiving tangible benefits, particularly support for livelihoods and rights to co-manage natural resources (Newmark et al., 1993; Sekhar, 2003; Liu et al., 2010; Dewu & Roskaft, 2018). In contrast, local people in our study mentioned non-monetary benefits, including ecosystem service benefits and satisfaction in conserving saltwater crocodiles. Hence, we emphasize the potential to garner greater support for local protected area management and conservation of saltwater crocodiles through better engagement with local people, which could also provide conservation benefits to the people near the Wildlife Sanctuary.

Livelihood dependency and negative conservation attitudes

Visitation and use of natural resources are strictly controlled to ensure protection of species, associated ecosystems and

habitats in wildlife sanctuaries in Myanmar. We found there was no hunting of saltwater crocodiles because of strong legal enforcement against poaching. Factors such as educational level, gender and age did not explain differences in attitudes towards the conservation of saltwater crocodiles. Similarly, in the Philippines, local people's attitudes supportive of the conservation of the Philippine crocodile *Crocodylus mindorensis* were not explained by age, gender, livelihood, ethnicity or education (van der Ploeg & van Weerd, 2004; van der Ploeg et al., 2011a). However, in the Ayeyarwady delta, people with seasonal livelihoods were some of the most likely to have negative attitudes towards the conservation of saltwater crocodiles. Local people with seasonal livelihoods were normally dependent on Meinmahlakyun through illegal means.

As we did not detect any hunting of saltwater crocodiles, we assume law enforcement to protect them from poaching is effective in areas near the Wildlife Sanctuary. But local livelihoods and resource utilization near the sanctuary were not included in the Meinmahlakyun management plan, and hence issues regarding deforestation and other forms of illegal utilization of natural resources were prevalent. As reported by Deng et al. (2015), people who rely on resources from a protected area for income but have restricted access show negative attitudes and oppose reserve management. Our study highlights how dependency on natural resources for livelihoods is an underacknowledged challenge for wildlife sanctuary managers and should be integrated into protected area management plans. We recommend integrating sustainable measures in management strategies that recognize local people's dependencies and allow the extraction of natural resources in sustainable ways (Mukul et al., 2010).

Bridging management gaps to facilitate coexistence

Developing ways to promote human–crocodile coexistence is critical for improving saltwater crocodile conservation in Meinmahlakyun. People we interviewed suggested awareness as a measure for coexistence, which was explained by them as 'understanding and avoiding the attacks by being aware of the potential risks of crocodiles'. Local people recommended developing alternative livelihoods for fishers who cannot avoid exposure to crocodiles. Similarly, human–crocodile conflicts in Sri Lanka were associated with people with inland fishing livelihoods (Santiapillai & de Silva, 2001).

To support alternative livelihoods measures, Aust et al. (2009) suggested benefit-generating livelihood schemes for local communities who have to bear the costs of crocodile conservation. In our study, local people suggested building concrete barriers or fences around the waterways connected with the villages' boundaries, to limit the movement of crocodiles from Meinmahlakyun into the adjacent villages (Fig. 3b). Building fences around water sources near protected area boundaries has been used as a measure to prevent crocodile attacks in Africa (Thomas, 2006). Local people suggested crocodile monitoring to control the presumed increase in the numbers of saltwater crocodiles in Meinmahlakyun. Sustainable utilization practices (i.e. trophy hunting, egg and neonate collection for ranches) have been used to control the population of Nile crocodiles in Africa (Aust et al., 2009). But, for this approach to be effective in Meinmahlakyun better baseline data and careful management would be needed. Local people explained that food or prey scarcity linked with mangrove degradation in Meinmahlakyun increases human–crocodile conflict, and suggested strict law enforcement to prevent illegal logging and exploitation of resources. Unsurprisingly, local people had ecological knowledge about saltwater crocodiles and their habitats. They know that healthy mangrove forests in Meinmahlakyun could reduce the number of crocodiles foraging outside the protected area. Similarly, fostering interest in ecology and a sense of pride in the conservation of *C. mindorensis* provided a foundation for community-based conservation of crocodile species in the Philippines (van der Ploeg et al., 2011a,b). In the Philippines, environmental education programmes have been demonstrated to be effective for disseminating information about legislation, existing conservation activities, and the importance of crocodile ecology in wetland ecosystems. Such programmes could be implemented to foster improved attitudes as a foundation for community-based crocodile conservation in Myanmar.

Implications for conservation and management

As a result of the plethora of human pressures on Meinmahlakyun, the future of the only crocodilian population and its habitats in Myanmar remains uncertain. The success of conservation is not solely reliant on ecological information of the target species, but also on public awareness and perception of enforcement of protection programmes (Vincenot et al., 2015). Our study highlights the importance of local people's attitudes towards conservation of the saltwater crocodile in the Ayeyarwady delta, and ways to promote human–crocodile coexistence in this human-dominated landscape. Local people are knowledgeable about saltwater crocodiles, based on their experiences, but they have negative attitudes towards saltwater crocodile conservation because of their livelihood dependency on Meinmahlakyun and the lack of perceived benefits from crocodile conservation.

Therefore, we recommend awareness campaigns to engage and educate local people about conservation and management activities in Meinmahlakyun, to improve

their capacity for and knowledge of the protection and conservation of the fauna and flora of the Ayeyarwady delta region. Our study demonstrates that law enforcement effectively protects saltwater crocodiles from poaching but marginalizes local livelihoods and erodes local support for conservation. Despite law enforcement, illegal resource extraction affects the ability of Meinmahlakyun to support a healthy crocodile population. Unsustainable management practices in Meinmahlakyun undermine natural resource availability, leading to negative outcomes for both the Sanctuary and local people. To integrate local people's attitudes into the Meinmahlakyun management plan, we recommend developing ways to facilitate sustainable use of natural resources in the Sanctuary.

Our study also highlights the need for benefit-based approaches to foster local people's positive attitudes towards conservation. Ecotourism could be promoted as an alternative income source for local people, through creating tourism-related employment. Revenue from visitors can provide funds for conservation activities for saltwater crocodiles (Healy, 1994; Bookbinder et al., 1998; Spiteri & Nepal, 2008; DeFries et al., 2010; Karanth & Nepal, 2012). Law enforcement, as the traditional approach to protect saltwater crocodiles from poaching, will not enhance the sustainable conservation of saltwater crocodiles in the Ayeyarwady delta region as, although it may prevent poaching, it fails to protect habitats. Our findings indicate the need to integrate and promote the ecological knowledge of local people in the development of a management plan for the effective conservation of the saltwater crocodiles of the Ayeyarwady delta region. We also recommend that conservation managers consider the measures suggested by local people in this study to reduce human–crocodile conflicts in this region.

Author contributions Study design: all authors; fieldwork: KZT, ZZ; data analysis, writing: KZT, ACH.

Conflicts of interest None.

Ethical standards Experts from the Academy of Mathematics and Systems Science, University of Chinese Academy of Sciences and Xishuangbanna Tropical Botanical Garden, Chinese Academy of Sciences, reviewed and approved the survey questions; permission was secured from the Forest Department of Myanmar prior to carrying out the research; free, prior and informed consent of villages heads was secured with the assistance of staff from Meinmahlakyun Wildlife Sanctuary before the interviews; and this research otherwise abided by the *Oryx* guidelines on ethical standards.

References

ALLENDORF, T.D., AUNG, M. & SONGER, M. (2012) Using residents' perceptions to improve park–people relationships in Chatthin Wildlife Sanctuary, Myanmar. *Journal of Environmental Management*, 99, 36–43.

ALLENDORF, T.D., SWE, K.K., OO, T., HTUT, Y., AUNG, M., AUNG, M. et al. (2006) Community attitudes toward three protected areas in Upper Myanmar (Burma). *Environmental Conservation*, 33, 344–352.

AUNG, U.M. (2007) Policy and practice in Myanmar's protected area system. *Journal of Environmental Management*, 84, 188–203.

AUST, P., BOYLE, B., FERGUSSON, R. & COULSON, T. (2009) The impact of Nile crocodiles on rural livelihoods in northeastern Namibia. *South African Journal of Wildlife Research*, 39, 57–69.

BERKES, F., COLDING, J. & FOLKE, C. (2000) Rediscovery of traditional ecological knowledge as adaptive management. *Ecological Applications*, 10, 1251–1262.

BOOKBINDER, M.P., DINERSTEIN, E., RIJAL, A., CAULEY, H. & RAJOURIA, A. (1998) Ecotourism's support of biodiversity conservation. *Conservation Biology*, 12, 1399–1404.

BRACKHANE, S., WEBB, G., XAVIER, F.M., TRINDADE, J., GUSMAO, M. & PECHACEK, P. (2019) Crocodile management in Timor-Leste: drawing upon traditional ecological knowledge and cultural beliefs. *Human Dimensions of Wildlife*, 24, 314–331.

COREAU, A., GUILLET, F. & RABAUD, S. (2018) The influence of ecological knowledge on biodiversity conservation policies: a strategic challenge for knowledge producers. *Journal for Nature Conservation*, 46, 97–105.

DEFRIES, R., KARANTH, K.K. & PAREETH, S. (2010) Interactions between protected areas and their surroundings in human-dominated tropical landscapes. *Biological Conservation*, 143, 2870–2880.

DENG, H.B., CHEN, Z.F., CAO, H.M., SHEN, Y., WANG, Y.Y. & SHAN, P. (2015) Perceptions and attitudes of local residents on a nature reserve: a case study in Baimaxueshan National Nature Reserve. *International Journal of Sustainable Development and World Ecology*, 22, 165–170.

DEWU, S. & RØSKAFT, E. (2018) Community attitudes towards protected areas: insights from Ghana. *Oryx*, 52, 489–496.

DIMITRAKOPOULOS, P.G., JONES, N., IOSIFIDES, T., FLOROKAPI, I., LASDA, O., PALIOURAS, F. & EVANGELINOS, K.I. (2010) Local attitudes on protected areas: evidence from three Natura 2000 wetland sites in Greece. *Journal of Environmental Management*, 91, 1847–1854.

FEURER, M., GRITTEN, D. & THAN, M. (2018) Community forestry for livelihoods: benefiting from Myanmar's mangroves. *Forests*, 9, 150.

FOREST DEPARTMENT (2017) *Annual Crocodile Counting Report of Meinmahlakyun Wildlife Sanctuary*. Unpublished internal document. Forest Department, Nay Pyi Taw, Myanmar. [In Burmese].

FOREST DEPARTMENT (2018) *Report of Crocodiles' Attacks in Bogaly Township within 2017–2018 Year*. Unpublished report. Forest Department, Nay Pyi Taw, Myanmar. [In Burmese]

FOREST LAW (1992) *The State and Order Restoration Council, The Union of Myanmar*. monrec.gov.mm/?q=book/environmental-conservation [accessed 2 July 2020].

GIRI, C., OCHIENG, E., TIESZEN, L.L., ZHU, Z., SINGH, A., LOVELAND, T. et al. (2011) Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20, 154–159.

HEALY, R.G. (1994) Tourist merchandise' as a means of generating local benefits from ecotourism. *Journal of Sustainable Tourism*, 2, 137–151.

KACZENSKY, P., BLAZIC, M. & GOSSOW, H. (2004) Public attitudes towards brown bears (*Ursus arctos*) in Slovenia. *Biological Conservation*, 118, 661–674.

KALTENBORN, B.P., BJERKE, T., NYAHONGO, J.W. & WILLIAMS, D.R. (2006) Animal preferences and acceptability of wildlife management actions around Serengeti National Park, Tanzania. *Biodiversity and Conservation*, 15, 4633–4649.

KARANTH, K.K. & NEPAL, S.K. (2012) Local residents perception of benefits and losses from protected areas in India and Nepal. *Environmental Management*, 49, 372–386.

LEIMGRUBER, P., KELLY, D.S., STEININGER, M.K., BRUNNER, J., MULLER, T. & SONGER, M. (2005) Forest cover change patterns in Myanmar (Burma) 1990–2000. *Environmental Conservation*, 32, 356–364.

LEVERINGTON, F., COSTA, K.L., PAVESE, H., LISLE, A. & HOCKINGS, M. (2010) A global analysis of protected area management effectiveness. *Environmental Management*, 46, 685–698.

LIU, J., OUYANG, Z.Y. & MIAO, H. (2010) Environmental attitudes of stakeholders and their perceptions regarding protected area-community conflicts: a case study in China. *Journal of Environmental Management*, 91, 2254–2262.

MADDEN, F. (2004) Creating coexistence between humans and wildlife: global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife*, 9, 247–257.

MEINMAHLAKYUN WILDLIFE SANCTUARY (2018) *Population Census Field Report of the Villages Near the Boundary of Meinmahlakyun Wildlife Sanctuary, Bogalay Township.* Unpublished internal document in Myanmar language. Forest Department, Nay Pyi Taw, Myanmar.

MUKUL, S.A., UDDIN, M.B., RASHID, A.Z.M.M. & FOX, J. (2010) Integrating livelihoods and conservation in protected areas: understanding the role and stakeholder views on prospects for non-timber forest products, a Bangladesh case study. *International Journal of Sustainable Development and World Ecology*, 17, 180–188.

NAUGHTON-TREVES, L., GROSSBERG, R. & TREVES, A. (2003) Paying for tolerance: rural citizens' attitudes toward wolf depredation and compensation. *Conservation Biology*, 17, 1500–1511.

NEWMARK, W.D., LEONARD, N.L., SARIKO, H.I. & GAMASSA, D.G.M. (1993) Conservation attitudes of local people living adjacent to five protected areas in Tanzania. *Biological Conservation*, 63, 177–183.

OO, N.W. (2002) Present state and problems of mangrove management in Myanmar. *Trees-Structure and Function*, 16, 218–223.

POOLEY, S., BOTHA, H., COMBRINK, X. & POWELL, G. (2020) Synthesizing Nile crocodile *Crocodylus niloticus* attack data and historical context to inform mitigation efforts in South Africa and eSwatini (Swaziland). *Oryx*, 54, 629–638.

RAHMAN, M.M., AL MAHMUD, M.A. & SHAHIDULLAH, M. (2017) Socioeconomics of biodiversity conservation in the protected areas: a case study in Bangladesh. *International Journal of Sustainable Development and World Ecology*, 24, 65–72.

RAMSAR (2017) *Annotated List of Wetlands of International Importance.* Ramsar, Gland, Switzerland. rsis.ramsar.org [accessed 2 July 2020].

RAO, M., HTUN, S., PLATT, S.G., TIZARD, R., POOLE, C., MYINT, T. & WATSON, J.E.M. (2013) Biodiversity conservation in a changing climate: a review of threats and implications for conservation planning in Myanmar. *Ambio*, 42, 789–804.

SANTIAPILLAI, C. & DE SILVA, M. (2001) Status, distribution and conservation of saltwater crocodiles in Sri Lanka. *Biological Conservation*, 97, 305–318.

SEKHAR, N.U. (2003) Local people's attitudes towards conservation and wildlife tourism around Sariska Tiger Reserve, India. *Journal of Environmental Management*, 69, 339–347.

SIVAPERUMAN, C. (2015) Crocodiles in Andaman and Nicobar Islands, with special reference to human–crocodile conflict. In *Marine Faunal Diversity in India* (eds K. Venkataraman & C. Sivaperuman). pp. 453–460. Elsevier, Amsterdam, The Netherlands.

SPITERI, A. & NEPAL, S.K. (2008) Evaluating local benefits from conservation in Nepal's Annapurna conservation area. *Environmental Management*, 42, 391–401.

R CORE TEAM (2018) *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria.

THOMAS, G.D. (2006) *Human–crocodile conflict (Nile Crocodile: Crocodylus niloticus) in the Okavango Delta, Botswana.* MSc Thesis, Stellenbosch University, Stellenbosch, South Africa.

THORBJARNARSON, J., PLATT, S.G. & KHAING, U.S.T. (2000) A population survey of the estuarine crocodile in the Ayeyarwady Delta, Myanmar. *Oryx*, 34, 317–324.

TISEN, O.B., AHMAD, R.B., GOMBEK, F. & LADING, E. (2014) A roadmap for crocodile conservation in Sarawak. In *Proceedings of the 23rd Working Meeting of the Crocodile Specialist Group.* pp. 227–235. IUCN & The World Conservation Union, Gland, Switzerland and Cambridge, UK.

VAN DER PLOEG, J., ARAÑO, R.R. & VAN WEERD, M. (2011a) What local people think about crocodiles: challenging environmental policy narratives in the Philippines. *The Journal of Environment & Development*, 20, 303–328.

VAN DER PLOEG, J., CAUILAN-CUREG, M., VAN WEERD, M. & DE GROOT, W.T. (2011b) Assessing the effectiveness of environmental education: mobilizing public support for Philippine crocodile conservation. *Conservation Letters*, 4, 313–323.

VAN DER PLOEG, J. & VAN WEERD, M. (2004) Devolution of natural resource management and crocodile conservation: the case of San Mariano, Isabela. *Philippine Studies*, 52, 345–382.

VINCENOT, C.E., COLLAZO, A.M., WALLMO, K. & KOYAMA, L. (2015) Public awareness and perceptual factors in the conservation of elusive species: the case of the endangered Ryukyu flying fox. *Global Ecology and Conservation*, 3, 526–540.

WALLACE, K.M., LESLIE, A.J. & COULSON, T. (2011) Living with predators: a focus on the issues of human–crocodile conflict within the lower Zambezi valley. *Wildlife Research*, 38, 747–755.

WANG, A. (2016) In Myanmar's Irrawaddy Delta, a rapidly disintegrating mangrove forest. *Mongabay.* news.mongabay.com/2016/10/in-myanmars-irrawady-delta-a-rapidly-disintegrating-mangrove-forest [accessed 2 July 2020].

WEBB, E.L., JACHOWSKI, N.R.A., PHELPS, J., FRIESS, D.A., THAN, M.M. & ZIEGLER, A.D. (2014) Deforestation in the Ayeyarwady Delta and the conservation implications of an internationally-engaged Myanmar. *Global Environmental Change*, 24, 321–333.

XU, J., CHEN, L., LU, Y. & FU, B. (2006) Local people's perceptions as decision support for protected area management in Wolong Biosphere Reserve, China. *Journal of Environmental Management*, 78, 362–372.