Human-wildlife conflicts with freshwater piscivores

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Conservation of freshwater biodiversity and management of human-wildlife conflicts are major conservation challenges globally. Here we review the current literature on human conflicts with tropical and subtropical inland piscivores. We also present a new multispecies case study of conflicts with four large-vertebrate piscivores from the Western Amazon. Our review highlighted that documented conflicts occur with 30 piscivorous vertebrates including crocodilian, otter and cetacean species. Only 28.6% of the reviewed species have had conflicts well documented in the literature, with the saltwater crocodile the most studied species. We found a relationship between IUCN red list status and conflict severity, but no relationship between body mass and conflict severity. The saltwater crocodile accounted for most attacks on people between 2009 and 2019, but the Nile crocodile was responsible for the highest number of fatalities in the same period. Human-piscivore conflict occurs due to attacks on people, depredation of fisheries or livestock, damage to fishing equipment and entanglement in nets. This can be influenced by factors such as access to pumped water, population trends of piscivorous species and social beliefs or perceptions. We recommend future research should focus on poorly documented species, define conflicts in a quantifiable metric and document methods of effective conflict resolution

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Abstract

Conservation of freshwater biodiversity and management of human-wildlife conflicts are major conservation challenges globally. Here we review the current literature on human conflicts with tropical and subtropical inland piscivores. We also present a new multispecies case study of conflicts with four large-vertebrate piscivores from the Western Amazon. Our review highlighted that documented conflicts occur with 30 piscivorous vertebrates including crocodilian, otter and cetacean species. Only 28.6% of the reviewed species have had conflicts well documented in the literature, with the saltwater crocodile the most studied species. We found a relationship between IUCN red list status and conflict severity, but no relationship between body mass and conflict severity. The saltwater crocodile accounted for most attacks on people between 2009 and 2019, but the Nile crocodile was responsible for the highest number of fatalities in the same period. Human-piscivore conflict occurs due to attacks on people, depredation of fisheries or livestock, damage to fishing equipment and entanglement in nets. This can be influenced by factors such as access to pumped water, population trends of piscivorous species and social beliefs or perceptions. We recommend future research should focus on poorly documented species, define conflicts in a quantifiable metric and document methods of effective conflict resolution.

Introduction

Conflict between humans and wildlife poses a major challenge for biological conservation (Dickman, 2010). Conflicts arise as a result of recurring negative interactions and are frequently deep rooted in social beliefs (Pimm & Raven, 2000). Understanding the underlying factors driving conflicts is integral to successful management, due to the often-increasing proximity between humans and wildlife, driven by growing human populations and the recovery of rare conflict-generating species (Inskip & Zimmermann, 2009; Groenendijk *et al*., 2014). Increasing our knowledge of conflicts in freshwater ecosystems, between fisheries and piscivores, is especially important in the tropics and subtropics given the heavy exploitation pressure and continued decline of wildlife populations in freshwater ecosystems (He *et al*., 2019).

Freshwater habitats cover approximately 3% of the Earth's land surface area (Pekel, 2016), exposing freshwater vertebrates to potential conflicts with humans, as a result of overlapping distributions and utilisation of similar resources (Woodroffe & Ginsberg, 1998; Treves & Karanth, 2003; Dudgeon *et al*., 2006). Piscivores can impose significant impacts on human livelihoods in freshwater environments, including attacks on people and damage to fishing gear, in addition to co-depletion of fish stocks (Rosas-Ribeiro, Rosas & Zuanon, 2012; CrocBITE, 2013). The species involved in conflicts are usually large-bodied, low-fecundity, and their persistence can be directly or indirectly affected by the conflict (Alves *et al*., 2012; Huang *et al*., 2012; Groenendijk *et al*., 2014). Managing this conflict to ensure long-term persistence of populations is vital to maintaining ecosystem integrity (Rio *et al*., 2001) but is particularly challenging in tropical and subtropical regions where freshwater fisheries more often represent a critical component of the subsistence diets and commercial revenues of local people (Michalski *et al*., 2012).

Potential conflicts within marine fisheries have been well documented (Tixier *et al.*, 2021), and show negative impacts on both the conservation of large marine predators and the socio-economic viability of fishing activities. However, despite the importance of inland fisheries, a comparable review has not yet been undertaken of the conflicts reported in freshwater systems. Here, we address this deficit by reviewing conflicts between fisheries and tropical and subtropical freshwater piscivores worldwide. In addition, we also conduct a comprehensive assessment of conflicts between local communities and aquatic piscivorous vertebrates in western Brazilian Amazonia to elucidate how these conflicts arises at the frontline. Specific research questions investigated include: (1) which piscivores are implicated in conflicts?; (2) does species body mass, IUCN Red List status, proximity to human populations or percentage of seasonally flooded forest around communities influence severity of conflict?; (3) what are the key factors inducing human-piscivore conflicts?; and (4) what are the information gaps in the current literature?

Materials & Methods

Literature review

We conducted a literature review of human-wildlife conflicts, restricted to tropical and subtropical freshwater piscivores. Studies conducted outside the tropics and subtropics were excluded for species with a range that crosses into the temperate zone. Primary literature sources were collated from Google Scholar and Scopus using a Boolean search string search that included the common or scientific name of a species, together with the following keywords: attack, conflict, depredation, entanglement, perceptions and population. All keyword searches were conducted in English, which may have precluded some studies. For each piscivore species, Red List Status was assigned using IUCN (2020) and body mass in kilograms was attributed using the following categories ≤10 kg, 11-49 kg, ≥50kg adopted from Inskip & Zimmermann (2009). A category was designated for each species describing the severity and extent of knowledge concerning the conflict, based on criteria adapted from Inskip and Zimmermann (2009) (Table S1). In addition, we collated incidents of fatal and non-fatal crocodilian attacks on humans worldwide for 2009-2019 from the CrocBITE (2013) database.

Focal study area

Our focal landscape study was conducted in the state of Amazonas, Brazil along the mid-section of the Juruá River in two contiguous sustainable-use forest reserves: the Médio Juruá Extractive reserve (ResEx Médio Juruá), and the Uacari Sustainable Development Reserve (RDS Uacari) (Fig. 1). These two reserves are home to a combined total of approximately 4,000 rural Amazonians, living in 58 communities and employed in a diverse range of extractive livelihoods (Newton, Endo & Peres., 2012). Communities typically have access to extensive floodplains and are located along the main river channel or on oxbow lakes, which are embedded within forests that are seasonally flooded by nutrient-rich white-water, known as *várzea* (Hawes *et al.*, 2012).

Communities are therefore deeply entwined with their aquatic environment, and fishing represents both the principal source of protein in the subsistence diet of reserve residents (Endo, Peres & Haugaason, 2016), and one of the main sources of disposable income (Batista *et al*., 1998). Our focal study reserves represent an important site for globally significant community-based conservation arrangements (Campos-Silva & Peres, 2016; Campos-Silva *et al*., 2018) that benefit a wide range of freshwater piscivores, including the black caiman (*Melanosuchus niger*), giant otter (*Pteronura brasiliensis*), and two cetaceans: the Amazon river dolphin or boto (*Inia geoffrensis*) and the tucuxi (*Sotalia fluviatilis*) (Fig. 2).

Amazonian fishers interviews

We employed a semi-structured questionnaire design to investigate perceptions of human-piscivore conflict in the western Brazilian Amazon: black caiman, giant otter, boto and the tucuxi. We conducted a total of 49 interviews at 37 local communities located within two sustainable-use reserves in the Médio Juruá region (Fig. 1), during September-November 2014. We selected interviewees non-randomly, targeting the most experienced fishers in each community (either one individual or a small group of individuals). Interviews typically lasted 30 min and included eight objective yes/no questions regarding whether any potential ‘problem species’ cause problems, damages equipment, becomes entangled in nest, frightens away fish, or causes the interviewee to leave an area where the species has been sighted to fish elsewhere. Interviewees were also asked if the species had been hunted in the community, hunted in 2013 or 2014, or hunted within the informant’s lifetime. In addition, interviewees rank-ordered the potential problem of the conflict caused, with 1 being the greatest problem and 4 the least (Michalski *et al*., 2012). All fieldwork was authorised by the Ministério do Meio Ambiente/Instituto Chico Mendes de Conservação da Biodiversidade of the Brazilian government (45054-1). Individual participation in our interviews was voluntary and anonymous, and we attained verbal consent from all participants.

Data analysis

We used Spearman’s rank correlation to investigate the change in the number of reviewed studies over time. A Fisher’s exact test was implemented to determine if the severity of conflict differs between animal body mass categories (<10 kg, 10-49 kg, ≥50 kg) or the species

IUCN Red List category. In the Médio Juruá case study, we used a chi-squared test to determine if a difference occurred between the four species in terms of their ranking as a 'problem species', and a Mann-Whitney U test to determine which species were ranked as the highest problem. A chi-squared test was also used to determine if the response of fishers to aquatic animals entangled in fishing nets differed between species. We also calculated the nonlinear fluvial distance from the nearest urban centre of Carauari to each community, and the percentage of *várzea* floodplain forest within a 5-km buffer around each community, using ArcGIS v 10.2.2. We then examined the influence of distance to Carauari and percentage *várzea* forest cover on the eight binary interview questions using binary logistic regression. We used SPSS v 22 and R v 1.4.1106 for all statistical analyses.

Results

Literature review

We reviewed a total of 141 primary literature sources reporting conflicts with 30 freshwater piscivores, including crocodilians, cetaceans and otters. These studies covered 33 countries in the tropics and subtropics across Africa, Asia, Australia, North America and South America. Brazil was the country with the most studies undertaken (n = 24), followed by India (n = 20) and Australia (n = 19). All other countries hosted seven or fewer studies. Studies were published between 1977 and 2020 and the number of sources published per year increased over time (Spearman's: r_s=0.876, $p<0.001$; Fig. 3). Economic and livelihood reasons such as net damage or competition for fish accounted for 31.9% of studies, and attacks for 29.8% of studies. A total of 19.9% of studies focused on entanglement covering five species of crocodiles and six species of cetaceans, the latter accounting for 87.1% of all studies on entanglement. Management or resolution of conflict was the subject of only 10.6% of all studies covering five nations, notably Australia which accounted for 60.0% of management studies. Regarding conflict documentation, 28.6% of species were well documented, 42.9% poorly documented and 28.6% required further research (Table 1). The saltwater crocodile (*Crocodylus porosus*) had the highest number of conflict publications at 32.

The severity of conflict did not differ significantly between body mass categories (Fisher's: $p = 0.3047$) but did differ significantly between IUCN Red List categories ($p < 0.01$). From 2009-2019, 17 crocodilian species were documented to attack humans, 12 species fatally, with the saltwater crocodile responsible for the most attacks (1,327) and the Nile crocodile for most lethal attacks (734) (Fig. 4; CrocBITE, 2013). Four species, the Nile crocodile (*C. niloticus*), saltwater crocodile (*C. porosus*), mugger (*C. palustris*) and American crocodile (*C. acutus*) accounted for 96.7% of all lethal attacks between 2009 and 2019. The literature highlighted 42 studies with reference to sub-lethal or lethal attacks by crocodilians as a reason for conflict.

Amazonian case study

Interview responses in the Médio Juruá region showed a significant difference between the perception of black caiman, giant otters, botos and tucuxis as problem species (Chi-squared: $\chi^2 = 204.692$, $p < 0.001$). Black caiman was consistently regarded as the greatest source of conflicts (mean rank = 1.37, n = 49), followed by the boto (2.06, n = 49), giant otter (2.51, n = 45) and tucuxi (n = 2). The black caiman was ranked significantly higher as a 'problem species' than the boto (Mann-Whitney: U = 573.5, Z = -4.841, $p < 0.001$), and the boto was ranked significantly higher than the giant otter (U = 714.0, Z = -3.195, $p < 0.001$). Of the 49 interviews conducted, 100% of interviewees reported black caiman and boto as problem species, followed by 89.8% for the giant otter (Fig. 5). In the study area at least nine cases of lethal attacks involving both adults and children have been reported between 2007 and 2020, a rate of about 0.3 persons killed each decade per 1000 people (C Peres, 2021, pers. comm).

Fishers responses showed a significant difference between all species regarding the outcomes whenever found entangled in fishing nets ($\chi^2 = 152.123$, $p < 0.001$). Black caimans were reported to be killed by 93.0% of fishers (Fig. 6). In contrast, 79.0% of botos and 85.7% of tucuxi were released alive, and 40.0% of interviewees stated that giant otters could escape from gillnets without assistance (Fig. 6). Most interviewees reported that they could continue coexisting with these four species, ranging from 60.4% of interviewees considering coexistence with the black caiman is possible to 75.0% for the tucuxi (Fig. S2). With the exception of one variable, no interviewee responses showed a significant relationship with fluvial distance from the nearest urban centre of Carauari or the percentage of *várzea* floodplain forest found within a 5-km buffer area around each community (Table S2). The exception is the damage caused to gillnets by giant otters, which increased with fluvial distance from Carauari (B=0.007, p =0.009).

Discussion

Attacks on Humans

Crocodilians pose the greatest threat to human life amongst all vertebrate piscivores. Of the 26 recognised crocodilian species, 17 have been documented to attack humans, 12 of which were responsible for lethal attacks between 2009 and 2019 (Fig. 4; CrocBITE, 2013). Otters rarely attack humans, with 95.2% of documented cases linked to the North American river otter (*Lontra canadensis*) (Belanger *et al*., 2011). Our review found no relationship between body mass and conflict severity, contrary to the literature on crocodilians where larger-bodied species, particularly males, are associated with most attacks (Caldicott *et al*., 2015; Campbell *et al*., 2013; Fukuda *et al*., 2015). This result may reflect the use of average female crocodilian body mass for our analyses, rather than maximum reported body mass.

Globally, the saltwater crocodile accounted for the greatest number of attacks and the Nile crocodile for the highest number of fatalities between 2009 and 2019 (CrocBITE, 2013). Three main factors influence attacks. The first is victim:predator body size ratio, with small individuals such as children considered particularly vulnerable (Haddard & Fonseca, 2011; Fukuda *et al*., 2015; Pooley *et al*., 2020). The second factor is the location of the victim during the attack, with activities conducted in the water such as swimming, bathing or fishing increasing risk (Fukuda *et al*., 2015; Pooley *et al*., 2020). The third factor is seasonality, with species displaying more aggressive behaviour during the nesting season (Patro & Padhi, 2019). Interactions between humans and crocodiles can be reduced dramatically by access to pumped water, as highlighted by the difference in saltwater crocodile attacks between Australia and Asia (Jayson, Sivaperuman, & Padmanabhan, 2006; Gopi & Pandav, 2009; Brackhane *et al*., 2018). Calculating attack rates can be challenging with reports of authenticated attacks differing between areas, seasons and sometimes influenced by the local political and cultural context (Peres & Carkeek, 1993; Scott & Scott, 1994; McGregor, 2005). There is also likely to be a bias in the reporting of attacks depending on the country where the attacks occurred. For instance, attacks in Australia are well reported but in our study area in the mid-Juruá attacks are likely to be severely under-reported by official statistics.

Economic Loss, Entanglement and Retaliation

Freshwater piscivores come into conflict with subsistence and commercial fisheries causing damage to nets, depredating fish or livestock, causing competition for commercially valuable fish, displacing fish and becoming entangled in nets. Economic losses and entanglement are often cited in the literature but studies including quantifiable, standardised data and solutions to resolve these factors are limited compared to marine ecosystems or suggested practices to suppress felid depredation of livestock (Inskip & Zimmermann, 2009; Tixier *et al.*, 2021). Depredation of fish stocks and net damage by some piscivores and livestock in the case of crocodilians can be extensive and responses may include retaliatory killing (Jacque, Moutou & Alary., 2002; Aust *et al.*, 2009; Gopi & Pandav, 2009; Barbieri *et al.*, 2012). Riverine communities typically depend on fish for dietary protein and financial income so damage to nets severely impacts their livelihoods (Michalski *et al.*, 2012). In north-eastern Namibia approximately 71,500 nets are damaged annually by the Nile crocodile, and in the Amazon black caiman can damage up to 50.0% of commercially deployed gill nets (Peres & Carkeek, 1993; Aust *et al.*, 2009). Replacement of fishing nets may have major financial ramifications for fishers with limited resources since purchasing new nets can often exceed monthly income, as in Namibia (Aust *et al.*, 2009). To prevent damage, fishers may respond by guarding nets, which conversely could increase exposure to attacks (McGregor, 2005). Compared to crocodiles, depredation by otters is generally poorly documented although Barbieri *et al.* (2012) showed that depredation by the Neotropical otter can persistently damage nets (Alary, Moutou & Jacques, 2002; Hussain, Gupta & Da Silva, 2011; Fonseca & Marmontel, 2011). Similarly, for cetaceans there are consistent reports of the boto net raiding and damaging nets, with all interviewees in our study supporting findings from elsewhere in the Amazon (Alves, Zappes & Andriolo., 2012; Campbell *et al*; 2020; Fig. 5). This contrasts sharply with the sympatric tucuxi, where only 4.1% of interviewees reported damaged nets (Fig. 5).

Piscivores can be perceived to either reduce or displace stocks of commercially important fish (Fonseca & Marmontel, 2011). Conflicts with the giant otter occur in the western Amazon, particularly in relation to matrinxã (*Brycon cephalus*) fisheries, which are important for both subsistence and trade (Santos *et al.*, 2006; Rosas-Ribeiro, Rosas, Zuanon, 2012). In the Juruá, 50.0% of interviewees reported giant otters being responsible for a perceived decline in matrinxã, and 97.9% of interviewees stated that giant otters spatially displace fish (Fig. 5). Perceived competition can lead to retaliation and reduced population recovery (Brum *et al.*, 2021). Resource depletion by fisheries can intensify competition and conflict. In the Ganges river, competition for fish has intensified between fisheries and the South Asian river dolphin as commercial fisheries have reduced large fish abundance, increasing overlap between fisheries and the prey species profile targeted by dolphins (Kelkar *et al*., 2010).

Entanglement in fishing equipment threatens piscivores with impacts ranging from injury to death across crocodilians, otters and cetaceans (Platt & Thorbjarnarson, 2000; Choudhary *et al*., 2006; Alves*,* Zappes & Andriolo., 2012). Some net types may increase risk of fatality from entanglement, as found with otters and cetaceans (Leatherwood & Reeves, 1994; da Silva & Best, 1996; Lima, Marmontel & Bernard, 2014b). Certain species are better able to escape entanglement in nets. For instance, in our Juruá study the giant otter is rarely reported to become entangled, with 40.0% of interviewees stating that giant otters could escape (Fig. 6). This is higher than for the black caiman, boto or tucuxi, reflecting their ability to tear through nets with their teeth and dexterous paws. In extreme circumstances entanglement has been a fundamental driver of extinction such as for the Yangtze river dolphin (*Lipotes vexillifer*) where 40% of fatalities in the 1990s were attributed to this factor (Zhou *et al*., 1998; Zhang *et al*., 2003; Turvey *et al*., 2007). Entanglement is also cited as the primary source of conflict and a contributor to population declines of the boto and tucuxi (Campbell *et al*; 2020), the latter now listed as endangered on the (da Silva *et al*., 2018; IUCN, 2020; Brum *et al*., 2021). This has resulted in all river dolphin species now being listed as endangered, critically endangered or extinct (IUCN, 2020). In order to reduce entanglement acoustic deterrent pingers are currently being trialled in Peru for the species in line with trials in marine habitats (Waples *et al*., 2013; Snape *et al*., 2018; Zanon, 2021).

Human responses to economic loss and entanglement vary from release to retaliatory or assisted killing and are often influenced by local perceptions and economics (this study; Sinha, 2002; Alves*,* Zappes & Andriolo., 2012; Campbell *et al*., 2020). For instance, in the Central Amazon negative perceptions of river dolphins from economic losses results in intentional killing and retaliation for use as fishing bait for the piracatinga catfish (*Calophysus macropterus*) (Loch, Marmontel & Simoes-Lopes, 2009; Alves*,* Zappes & Andriolo., 2012). The situation in Peru is complex with most fishers releasing entangled botos and tucuxis, but some ports displaying a higher frequency of use for bait (Campbell *et al*., 2020). In contrast, both boto and tucuxi were always reported to be released in our Juruá waterscape, where piracatinga fisheries are not of commercial importance.

Community, Culture and Conflicts

Human-wildlife conflict is a multidisciplinary topic, but consideration of communities and culture is rarely considered in managing local conflicts. Community based approaches can be highly successful in achieving conservation outcomes (Campos-Silva & Peres, 2016; Campos-Silva *et al*., 2018), but this success is influenced by the understanding of societal beliefs, traditional practices and fisherfolk perspectives that can either reduce or enhance management objectives (Jones, Andriamarovololona & Hockley, 2008; D'Lima *et al*., 2014; Mgomo & Reed-Smith, 2020). Examples include reduced reporting of attacks to local authorities due to the association between African crocodilians and witchcraft, protective myths that historically protected the boto, and the misinterpretation of feeding and defence behaviour of the giant otter causing fear and retaliation (Scott & Scott, 1994; McGregor, 2005; Gravena *et al*., 2008; Lima, Marmontel & Bernard, 2014b). In some areas traditional protective beliefs are being challenged by expanding commercial fisheries (Alves, Zappes & Andriolo, 2012). For instance, the boto is strongly ostracised by fisherfolk in some regions of the Amazon, in stark comparison to the tucuxi (this study; Alves, Zappes & Andriolo, 2012). Managing these changing values through targeted education and integration of culture into management of conflict will be key to maintaining and enhancing positive attitudes towards piscivores (Mintzer *et al*., 2015; Mgomo & Reed-Smith, 2020). An area that requires much further research is community-based conflict resolution, which can prove highly successful as found with snow leopards (Jackson & Wanghcuk, 2004).

Population Recovery and Management

Human exploitation caused the historic decline of many piscivorous species (Smith, 1981; Mintzer *et al*., 2013). For instance, 4.5 million caiman hides were exported from Brazil between 1960 and 1969 and 40,663 giant otter pelts between 1960 and 1967 (Smith, 1981). Protection through CITES has allowed many species to successfully recolonise areas of their former ranges where human populations may now have increased (Groenendijk *et al*., 2014; Antunes *et al*., 2016). The growing spatial overlap between humans and piscivores has in some locations increased negative interactions, sometimes resulting in attacks on people, economic losses or coincidental declines in fish stocks, with piscivores potentially blamed even if overfishing is the driving factor (Gopi & Pandav, 2009; Recharte, Bowler & Bodmer, 2009; Fukuda, Manolis & Appel, 2014; Lima *et al*., 2014a).

Coexistence with apex predators can depend on population sizes and management strategies. For instance in the Juruá, where it is expected that black caiman and giant otter populations have increased in line with other localities since peak levels of hunting, 14.6% of interviewees reported that coexistence with these species depends on their future population trends (Lima, Marmontel & Bernard, 2014a; Pimenta *et al*., 2018; Marioni *et al*., 2021; Appendix A3). Currently such population trend data is limited in Amazonia, as with many other regions globally (Brum *et al*, 2021). Studies concerning the management and resolution of human-aquatic wildlife conflicts are poorly documented, except for the saltwater crocodile in Australia where methods trialled include population management and modelling, relocation and early detection using eDNA (Fukuda *et al*., 2019; Patro & Padhi *et al*., 2019; Fukuda *et al*., 2020; Rose, Fukuda & Campbell., 2020).

Conclusions

This study is the first comprehensive review of conflicts with freshwater piscivores in the tropical and subtropical regions. Conflict was found to occur with 30 piscivore species with conflict including attacks on people, depredation of fisheries or livestock, damage to fishing equipment and entanglement in nets. This can be influenced by factors such as access to pumped water, population trends of piscivorous species and social beliefs or perceptions. We found a relationship between IUCN red list status and conflict severity, but no relationship between body mass and conflict severity. We make three recommendations for future research. Firstly, there remains considerable gaps in our knowledge for many freshwater piscivores with only 28.6% of species well documented. Determining if conflict occurs, what the drivers of conflict are, and the severity of conflict remains a priority for species identified as poorly documented or requiring further research in Table 1. Many of these species are rare or cryptic, but some such as the mugger, black caiman and Morelet's crocodile are responsible for a considerable number of attacks on humans. Our second recommendation for future research is the need to report conflicts in a quantifiable and standardised manner to allow meta-analysis across studies. For instance, quantifying the number of nets damaged and financial costs of replacing nets in community questionnaires would improve the ability to understand the severity of conflicts. Questionnaire designs that report differences in fishing equipment used or whether fishers are commercial or subsistence add value to conflict detection (Campbell et al., 2020). Data are often lacking in remote tropical and subtropical areas, but the calculation of rates of attacks are also useful to determine if conflict severity is increasing or decreasing, particularly in relation to any management strategies. Our third recommendation is that for all conflict generating species, particularly those classified as well documented in Table 1 there is a need for future studies to focus on the resolution and management of conflicts. Currently, much of the literature concerning management is focused on population control of the saltwater crocodile in Australia. There remain considerable gaps in our knowledge regarding other species and on mitigation techniques such as community-based conflict resolution or lifestyle changes, including access to pumped water. Studies documenting reasons for increased vulnerability to attacks are particularly valuable for informing such mitigation strategies.

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Figure 1

Map showing the location of the focal study landscape in the Médio Juruá region of western Brazilian Amazonia.

Interviews were conducted in local communities (black dots) along the Juruá River (blue line) within two sustainable-use reserves (light green polygons).

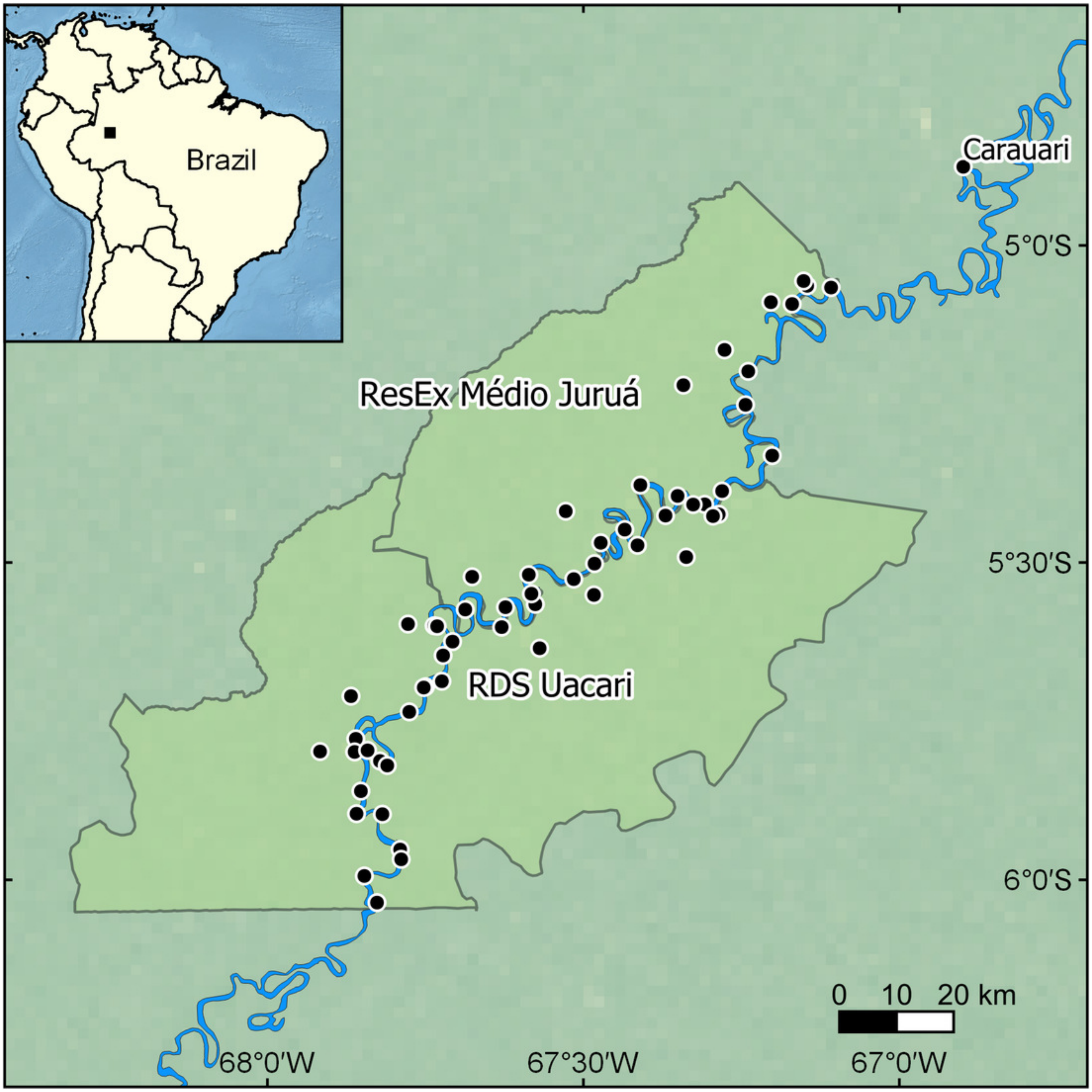
Brazil
Carauari
ResEx Médio Juruá
RDS Uacari
5°0′S
5°30′S
6°0′S
0 10 20 km
68°0′W
67°30′W
67°0′W

Figure 2

The four ‘problem species’ in the mid-Juruá.

A) black caiman, B) giant otter, C) boto and D) tucuxi. Photo credits: A and B) Jessica Groenendijk, C and D) Sannie Brum.

Figure 3

Number of human-wildlife conflict studies concerning freshwater mammals and reptiles over time (1977-2020).

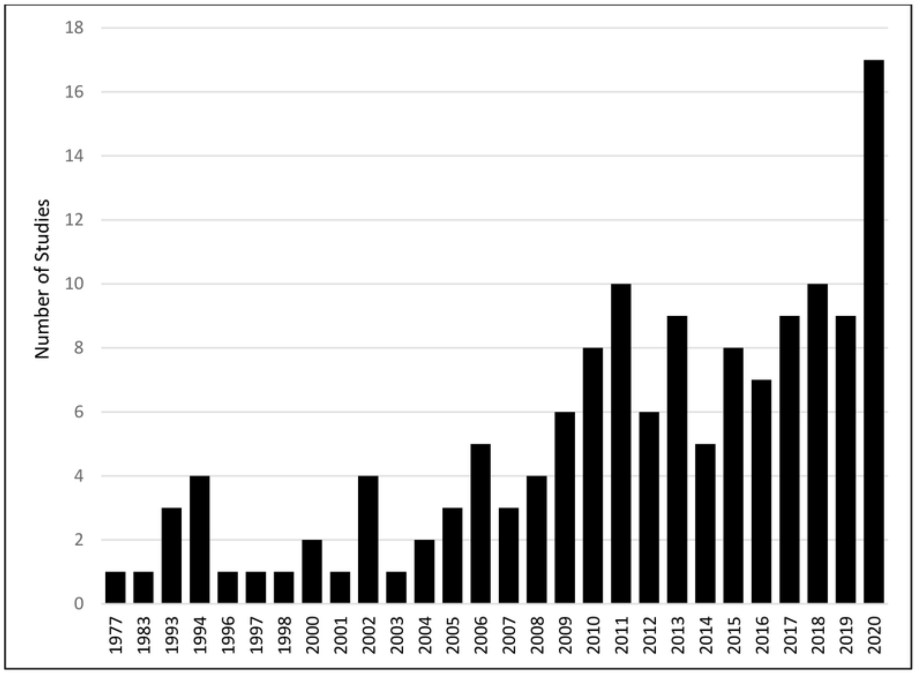
Number of Studies
18
16
14
12
10
8
6
4
2
0
1977
1983
1993
1994
1996
1997
1998
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020

Figure 4

Number of fatal (black bars) and non-fatal (white) attacks on humans by crocodilian species recorded by CrocBITE (2013) between 2009 and 2019.

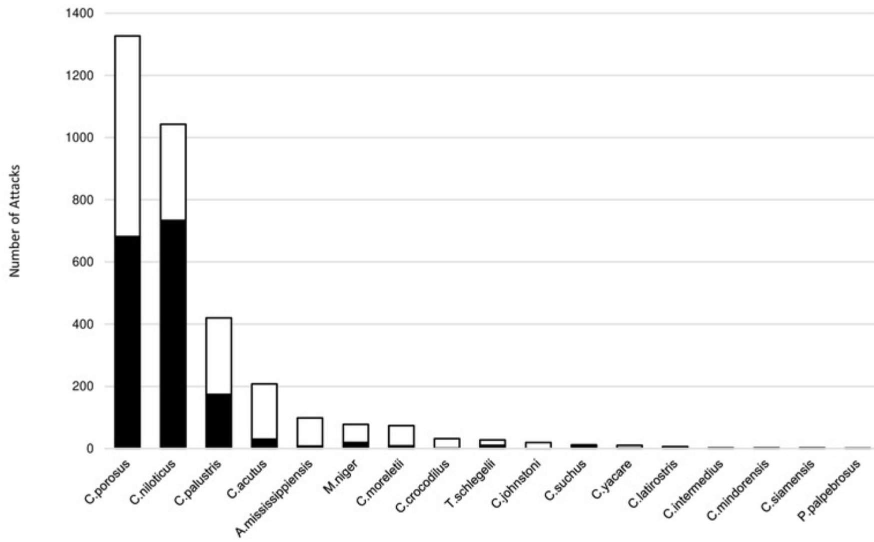
1400
1200
1000
800
600
400
200
0
Number of Attacks
C.porosus
C.niloticus
C.palustris
C.acutus
A.mississippiensis
M.niger
C.moreletii
C.crocodilus
T.schlegelii
C.johnstoni
C.suchus
C.yacare
C.latirostris
C.intermedius
C.mindorensis
C.siamensis
P.palpebrosus

Figure 5

Interviewee responses (%) to different categories of conflict.

Categories include whether the species (black caiman in black, giant otter in dark grey, boto in light grey and tucuxi in white) causes problems for fishing generally or specifically, by damaging equipment, frightening away fish or getting entangled in fishing nets.

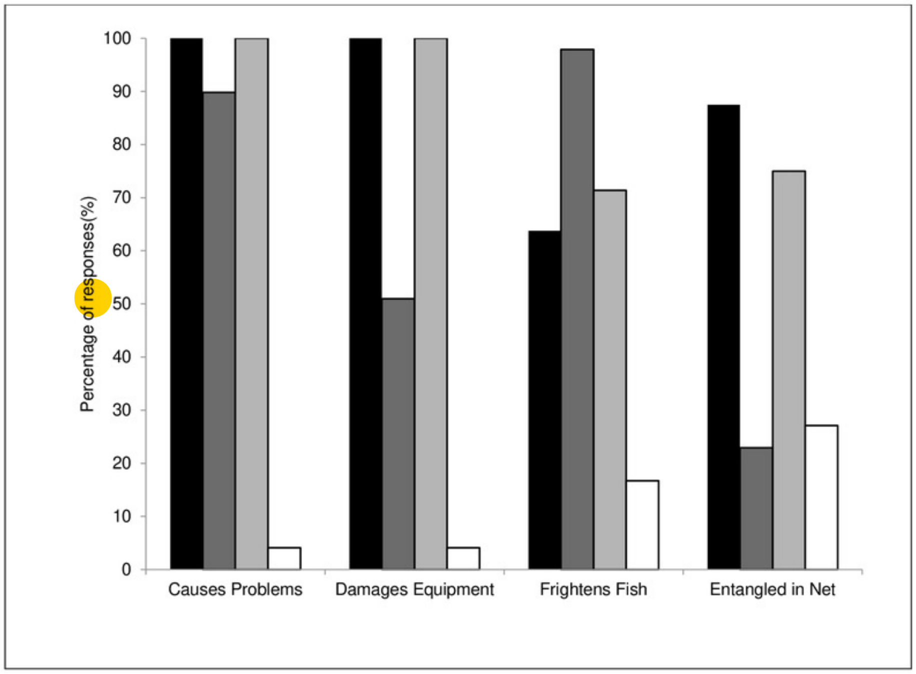
Percentage of responses(%)
100
90
80
70
60
50
40
30
20
10
0
Causes Problems
Damages Equipment
Frightens Fish
Entangled in Net

Figure 6

Interviewee responses (%) to black caiman, giant otter, boto, and tucuxi being entangled in nets.

Responses were categorised as killed (black), died (dark grey), released (light grey) and escaped (white). Death is defined as an animal found dead in a net without human assistance. Escaped means the animal worked its way free from the net.

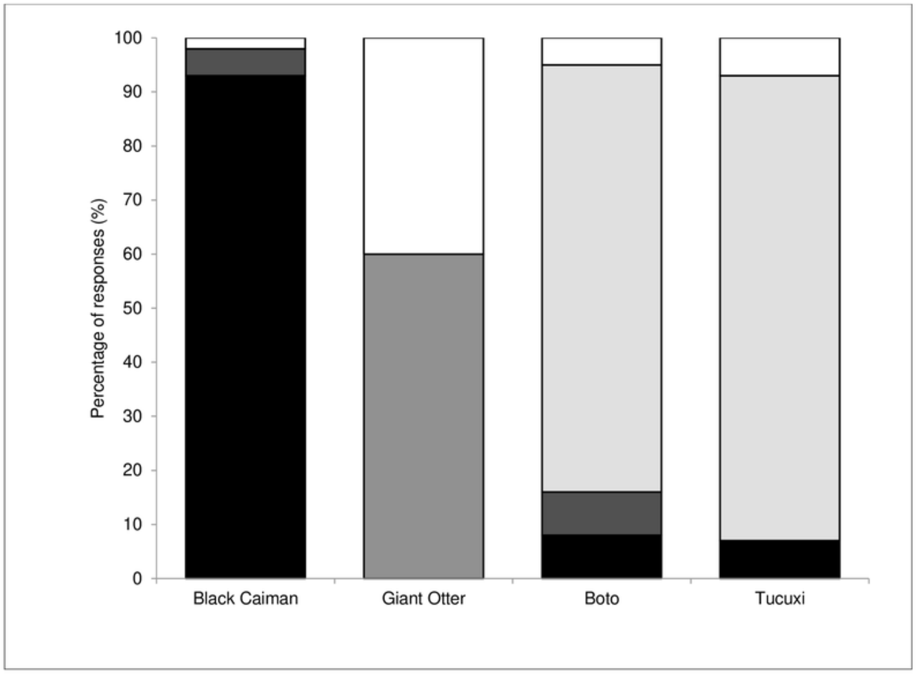
100
90
80
70
60
50
40
30
20
10
0
Percentage of responses (%)
Black Caiman
Giant Otter
Boto
Tucuxi

Table 1(on next page)

List of piscivore conflict species.

Columns show extent of knowledge for each species, severity of the human-wildlife conflict, body mass and IUCN Red List category.

Table 1. List of piscivore conflict species. Columns show extent of knowledge for each species, severity of the human-wildlife conflict, body mass and IUCN Red List category.

Species	Extent of Knowledge[1]	Scale of Conflict[2]	Body Mass Category (kg)	IUCN RED List Status
Crocodilians				
African Dwarf Crocodile (*Osteolaemus tetraspis*)	CPD	Data Deficient	10-49[3]	VU
American Alligator (*Alligator mississippiensis*)	CWD	High	≥50[3]	LC
American Crocodile (*Crocodylus acutus*)	CWD	Severe	≥50[3]	VU
Australian Freshwater Crocodile (*Crocodylus johnstoni*)	CPD	High	10-49[3]	LC
Black Caiman (*Melanosuchus niger*)	CPD	High	≥50[3]	LC
Broud-snouted Caiman (*Caiman latirostris*)	CPD	Moderate	10-49[3]	LC
Central African Slender-snouted Crocodile (*Mecistops leptorhynchus*)	RES	Data Deficient	Not available	Not assessed
Chinese Alligator (*Alligator sinensis*)	RES	Data Deficient	10-49[3]	CR
Cuban Crocodile (*Crocodylus rhombifer*)	RES	Data Deficient	≥50[3]	CR
Dwarf Caiman (*Paleosuchus palpebrosus*)	RES	Moderate	≤10[3]	LC
False Gharial (*Tomistoma schlegelii*)	RES	High	≥50[3]	VU
Gharial (*Gavialis gangeticus*)	CPD	Low	≥50[3]	CR
Hall's New Guinea crocodile	RES	Data	Not available	Not assessed

(*Crocodylus halli*)		Deficient		
Morelet's Crocodile (*Crocodylus moreletii*)	CPD	High	10-49[3]	LC
Mugger (*Crocodylus palustris*)	CPD	Severe	≥50[3]	VU
New Guinea Crocodile (*Crocodylus novaeguineae*)	RES	Data Deficient	10-49[3]	LC
Nile Crocodile (*Crocodylus niloticus*)	CWD	Severe	≥50[3]	LC
Orinoco Crocodile (*Crocodylus intermedius*)	RES	Moderate	≥50[3]	CR
Philippine Crocodile (*Crocodylus mindorensis*)	RES	Moderate	10-49[3]	CR
Saltwater Crocodile (*Crocodylus porosus*)	CWD	Severe	≥50[3]	LC
Siamese Crocodile (*Crocodylus siamensis*)	RES	Moderate	10-49[3]	CR
Slender-snouted Crocodile (*Mecistops cataphractus*)	CPD	Data Deficient	≥50[3]	CR
Smooth-fronted Caiman (*Paleosuchus trigonatus*)	CPD	Data Deficient	≤10[3]	LC
Spectacled Caiman (*Caiman crocodilus*)	CWD	High	10-49[3]	LC
West African Crocodile (*Crocodylus suchus*)	CPD	High	Not available	Not assessed
Yacaré (*Caiman yacare*)	CPD	High	10-49[3]	LC
Otters				
African Clawless Otter (*Aonyx capensis*)	CPD	Low	10-49[4]	NT
Asian Small-clawed Otter (*Aonyx cinereus*)	CPD	Low	≤10[4]	VU

Congo Clawless Otter (*Aonyx congicus*)	CPD	Low	10-49[4]	NT
Spotted-necked Otter (Hydrictis maculicollis)	CWD	Moderate	≤10[4]	NT
North American River Otter (*Lontra canadensis*)	CPD	Moderate	10-49[4]	LC
Neotropical River Otter (*Lontra longicaudis*)	CWD	Low	≤10[4]	NT
Eurasian Otter (*Lutra lutra*)	RES	Data Deficient	10-49[4]	NT
Hairy-nosed Otter (*Lutra sumatrana*)	RES	Data Deficient	≤10[4]	EN
Smooth-coated Otter (*Lutrogale perspicillata*)	CWD	Moderate	≤10[4]	VU
Giant Otter (*Pteronura brasiliensis*)	CWD	Moderate	10-49[4]	EN
Cetaceans				
Amazon River Dolphin (*Inia geoffrensis*)	CWD	Moderate	≥50[5]	EN
Baiji (*Lipotes vexillifer*)	CPD	Moderate	≥50[5]	CR
Yangtze Finless Porpoise (*Neophocaena asiaeorientalis ssp. asiaeorientalis*)	CPD	Moderate	≥50[5]	CR
Irrawaddy Dolphin (*Orcaella brevirostris*)	CPD	Moderate	≥50[5]	EN
South Asian River Dophin (*Platanista gangetica*)	CWD	Moderate	≥50[5]	EN
Tucuxi (*Sotalia fluviatilis*)	CWD	Low	10-49[5]	EN

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[1] CWD = Conflict Well Documented; CPD = Conflict Poorly Documented; FRR = Further Research Required (Table S1).

[2] Conflict categories (Table S1).

[3] Lakin *et al*. (2020)

[4] Hunter (2011)

[5] Macdonald (2009)