Human-wildlife conflicts with crocodilians, cetaceans and otters in the tropics and subtropics

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Human-Wildlife Conflicts with Crocodilians, Cetaceans and Otters in the Tropics and Subtropics

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Abstract

Conservation of freshwater biodiversity and management of human-wildlife conflicts are major conservation challenges globally. Human-wildlife conflict occurs due to attacks on people, depredation of fisheries, damage to fishing equipment and entanglement in nets. Here we review the current literature on human conflicts with tropical and subtropical crocodilians, cetaceans and otters in freshwater and brackish habitats. We also present a new multispecies case study of conflicts with black caiman, giant otter, boto and tucuxi from the Western Amazon. Documented conflicts occur with 30 crocodilian, cetacean and otter species. 28.6% of the species reviewed in this study had conflicts frequently documented in the literature, with the saltwater crocodile the most studied species. We found a relationship between IUCN Red List status and conflict severity with severity increasing as red list threat status decreased. The results did not find a relationship between body mass and conflict severity. In the Amazonian case study we found that the black caiman was ranked as the greatest 'problem' followed by the boto, giant otter and tucuxi. A significant difference was found between the responses of fishers when each of the four species were found entangled in nets. We make a number of recommendations for future research based on the findings of the review and Amazon case study including the need to standardise data collection.

Introduction

Conflict between humans and wildlife poses a major challenge for biological conservation (Dickman, 2010). Human-wildlife conflicts arise as a result of recurring negative interactions between humans and wildlife 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 and brackish ecosystems, between humans and piscivores, is especially important in the tropics and subtropics given the heavy exploitation pressure and continued decline of wildlife populations in such habitats (He *et al.*, 2019).

Freshwater habitats cover approximately 3% of the Earth's land surface area (Pekel, 2016), exposing 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 and brackish environments, including attacks on people and damage to fishing gear, in addition to co-depletion of fish stocks (Rosas-Ribeiro, Rosas & Zuanon, 2012; Sideleau & Britton, 2013). The species involved in conflicts are usually large-bodied, slow to reproduce, and their persistence can be directly or indirectly affected by the conflict (Alves, Zappes & Andriolo., 2012; Huang *et al.*, 2012; Groenendijk *et al.*, 2014). As species body mass increases it could be expected that conflict severity would also increase due to the greater threat posed to human life, increased potential damage to fishing equipment and risk of the species being exploited itself. Conflicts are expected to increase in the future due to the closing proximity between humans and wildlife driven by a rise in the human population and the recovery of rare conflict generating species (Inskip and Zimmermann, 2009; Groenendijk *et al*., 2014). It could be expected that as IUCN Red List threatened status decreases, as a species become more common, that conflict severity due to increased interactions with humans, would increase. Similarly, distance to the nearest urban area or access to seasonally flooded water could predict conflict severity due to the increased chance of interactions between humans and wildlife (Rosas-Ribeiro, Rosas & Zuanon, 2012). 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 and show negative impacts on both the conservation of large marine predators and the socio-economic viability of fishing activities (Tixier *et al.*, 2021). However, despite the importance of inland fisheries, a review has not yet been undertaken of the conflicts reported in freshwater and inland brackish systems such as estuaries and lagoons. Here, we address this research gap by reviewing conflicts between humans and three groups of piscivores found in the tropics and subtropics; crocodilians, cetaceans and otters. Our research focused on these groups which are large bodied and known to have the potential to generate conflict with humans. Specific research questions of the literature review include (1) what types of human-wildlife conflicts occur with crocodilians, cetaceans and otters (2) how many and which species of crocodilians, cetaceans and otters are involved in human-wildlife conflicts (3) what is the frequency of conflict documentation in the primary literature for each species (4) does increasing species body mass predict human-wildlife conflict severity (5) does decreasing threat status of the species on the IUCN Red List predict higher levels of human-wildlife conflict severity.

In addition, we also conduct an assessment of conflicts between local communities and four aquatic vertebrates in western Brazilian Amazonia to elucidate the nature of conflicts that occur. This case study was conducted to provide additional evidence to the review with a crocodilian, two cetaceans and an otter. We specifically tested (1) whether the black caiman, giant otter, boto and tucuxi are involved in human wildlife conflicts (2) what types of conflicts occur (3) does proximity to the nearest town, Carauari, predict human-wildlife conflict severity (4) does percentage of seasonally flooded forest around communities predict human-wildlife conflict severity.

Materials & Methods

Literature review

We conducted a literature review of human-wildlife conflicts, restricted to tropical and subtropical freshwater crocodilians, cetaceans and otters. The geographic region, between the Tropic of Cancer and Tropic of Capricorn, was selected to ensure that data gathered from the literature review and case study were within the same latitudinal range. Piscivores other than crocodilians, cetaceans and otters were not included in the study to allow comparison between the local case study and the wider literature review. This was to ensure the review could accurately reflect and compliment the four study species from the local case study which were a crocodilian, two cetaceans and an otter. Studies conducted outside the tropics and subtropics were excluded for species with a range that includes the temperate zone. Similarly, studies from freshwater and brackish habitats were included but information from the marine zone were excluded. Studies that focused on interactions with fisheries were restricted to any form of wild fishery and excluded human-made fisheries such as aquaculture. Attacks on humans were restricted to wild animals and attacks on livestock and pets were excluded.

Primary literature sources were collated from Google Scholar and Scopus. A general search using the following keywords, conflicts, crocodilians, cetaceans and otters was conducted before 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. The string search was conducted in the following format (("common name" OR "synonym" OR "scientific name") AND (attack* OR conflict OR depred* OR entangle* OR perce* OR damage)). Additional articles were located through searching reference lists and subsequent citations. We recognise that ISI Web of Science was not used in this search and that this may have precluded some studies. All keyword searches were conducted in English, which may have excluded some studies. For each species, Red List Status was assigned using the IUCN Red List (IUCN, 2020). Body mass in kilograms was also attributed using the following categories ≤ 10 kg, 11-49 kg, ≥ 50 kg adopted from Inskip & Zimmermann (2009) (Macdonald, 2009; Hunter, 2011; Lakin *et al*., 2020). A category was designated for each species describing the severity of conflict based on criteria adapted from Inskip and Zimmermann (2009) (Table 1). We also assigned the frequency of documented conflict based on the frequency of primary literature sources referring to conflict with the species, 5 or more being frequently documented, 2-4 being infrequently documented and 1 or less being rarely documented. We recognise this is a limitation of this method as it does not account for quality or impact of the study.

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 fisher interviews

We employed a semi-structured questionnaire design to investigate perceptions of human-wildlife conflict involving four species 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 minutes 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, and if co-existence with the species in the future depends on whether the population continues to increase in size. Interviewees were asked what their most likely response to finding one of the four species entangled in their fishing nets would be, such as killing or releasing the individual, if the species could escape of its own accord or if they were likely to die before being found. 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).

Data analysis

For the literature review, 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'. A Mann-Whitney U test was used to determine the order of which species generate the highest level of conflict. 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 (ESRI, 2014). 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 (IBM SPSS, 2014; R, 2020).

Results

Literature review

We reviewed a total of 143 primary literature sources reporting conflicts with 30 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 had seven or fewer studies. Studies were published between 1962 and 2020, and the number of sources published per year increased over time, including years with no studies reported (Spearman's: r_s=0.882, p<0.001, n=143; Fig. 3). Attacks accounted for 30.8% of studies, economic and livelihood reasons such as net damage or competition for fish accounted for 28.7% of studies, entanglement for 19.6%, management for 10.5%, perceptions for 9.8% and positive interactions for 0.7%. A total of 19.6% 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 10.5% of all studies covering five nations, notably Australia which accounted for 60.0% of management studies. Regarding conflict documentation, 28.6% of species were frequently documented, 42.9% infrequently documented and 28.6% rarely documented (Table 2). The saltwater crocodile (*Crocodylus porosus*) was the subject of the highest number of publications at 33.

The severity of conflict did not differ significantly between body mass categories (Fisher's: $p = 0.3047$). The severity of conflict did differ significantly between IUCN Red List categories, with species classified in less threatened categories displaying higher levels of conflict (Fisher's: $p < 0.01$). The literature highlighted 44 studies concerning 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: $\chi^2 = 204.692$, $p < 0.001$, n=49). Black caiman was consistently regarded as the greatest source of conflicts (mean rank = 1.37), followed by the boto (2.06), giant otter (2.519) and tucuxi (n=49). The black caiman was ranked significantly higher as a 'problem species' than the boto (Mann-Whitney: $U = 573.5$, $Z = -4.841$, $p < 0.001$, n=49), and the boto was ranked significantly higher than the giant otter ($U = 714.0$, $Z = -3.195$, $p < 0.001$, n=49). 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. 4). In the study areas, at least nine cases of lethal attacks by black caiman 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 pers. comm, 2021).

Fishers' responses showed a significant difference between all species regarding the outcomes whenever found entangled in fishing nets ($\chi^2 = 152.123$, $p < 0.001$, n=49). Black caimans were reported to be killed by 93.0% of fishers (Fig. 5). 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. 5). In response to the black caiman 16.7% of interviewees reported they changed fishing locations due to conflict compared to 33.3% for the giant otter, 12.5% for the boto and no interviewees for the tucuxi. Most interviewees reported that they could continue coexisting with these four species if populations were to increase in the future, ranging from 60.4% of interviewees considering coexistence with the black caiman is possible to 75.0% for the tucuxi (Fig. S1). 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 S1). The exception is the damage caused to gillnets by giant otters, which increased with fluvial distance from Carauari ($B=0.007$, $p=0.009$, $n=49$).

Discussion

Amazonian Case Study

We found that interviewee responses displayed significant differences between the perceptions of black caiman, giant otter, boto and tucuxi as problem species. Black caiman was ranked as the highest problem followed by the boto, giant otter and tucuxi. This reflects the conflict severity findings in our literature review, although the latter failed to detect the difference in conflict severity between the boto and the giant otter. This highlights the value of case studies for identifying differences in conflict severity at a small scale, that global analysis will fail to detect, and to prioritise species for conflict resolution.

Fishers' responses showed a significant difference between all species regarding the normal outcome when individuals were encountered entangled in fishing nets, with black caiman killed, botos and tucuxis released, and the giant otter dying before being discovered. Certain species are better able to escape entanglement in nets. For instance, in our Juruá study 40.0% of interviewees stating that giant otters could escape (Fig. 5). This is higher than for the black caiman, boto or tucuxi, reflecting their ability to tear through nets with their teeth and dexterous paws. For the boto our findings differ from other areas, such as the Central Amazon where the species is intentionally killed as bait for piracatinga catfish (*Calophysus macropterus*) fisheries (Loch, Marmontel & Simoes-Lopes, 2009; Alves*,* Zappes & Andriolo., 2012). To improve the standardisation of data collection for future case studies we would recommend asking interviewees to state the percentage of times each possible response to entanglement was undertaken alongside gathering data on entanglement rate per km of river, although the latter would require long term funding to be effective. This concept can also be expanded to include other areas of importance to conflicts such as the number of nets or financial cost of nets damaged per year for both subsistence and commercial fisheries, and rates of attack on humans (Peres and Carkeek, 1993; Aust *et al*., 2009; Sideleau & Britton, 2013). Such estimations would facilitate comparison between different areas to better prioritise conflict resolution efforts.

Most interviewees reported that they could continue coexisting with these four species if populations were to increase in the future. The percentage of interviewees agreeing with this statement reflected the problem ranking status, being lowest for the black caiman. In areas where conflict is higher we recommend interviewers include questions identifying reasons which may prevent co-existence and consulting local communities on suggested conflict management solutions, which can be a successful conservation approach (Campos-Silva & Peres, 2016; Campos-Silva *et al*., 2018).

We found no relationship between interviewee responses and percentage of *várzea* floodplain forest found within a 5-km buffer area around each community. We expected this to be a factor that influences the potential for conflict severity as access to flooded forest surrounding the community could increase the proximity and potential for interactions between the species and humans. It could be that rather than percentage of flooded forest being the driving influence, that conflicts are higher in either the dry or wet season, when water levels rise allowing species to access flooded forest (Junk *et al*., 2011). There is some evidence that conflict with giant otters is highest during the wet season when fish disperse into the flooded forest and they become more generalist, targeting vulnerable species. This happens to coincide with when fishermen's income decreases (Junk, 1984; Cabral *et al*., 2010; Rosas-Ribeiro, Rosas & Zuanon, 2012).

Coverage of Conflicts

We found conflicts occur with 30 crocodilians, cetaceans and otters and has been documented in the primary literature across 33 countries in the tropics and subtropics. Studies were undertaken over a relatively broad timespan between 1962 and 2020, with most studies focused on the topic of attacks. This is not particularly surprising as threat to human life is a considerable indicator of human-wildlife conflict. Regarding conflict documentation, 28.6% of species were frequently documented, 42.9% infrequently documented and 28.6% rarely documented (Table 2). For three of the four species in our Amazonian case study, we found conflict was frequently documented in the literature. This highlights that conflicts occurring with the majority of crocodilians, cetaceans and otters have been infrequently documented in the literature and there is a need for wider systematic reporting, particularly for species experiencing high levels of conflict. Frequency is an approximate indicator, and we acknowledge that this does not take into account quality or impact of study. For instance, a species may have only one primary literature source but this source can cover conflict and mitigation in detail. We did not include the secondary literature but this can contain useful information as demonstrated with felids (Inskip and Zimmermann, 2009). Better documentation and a method to objectively compare studies, based on quality or impacts of the research would be useful for future review processes to identify 'real' gaps in species studied. Our result does however highlight that for many species further documentation of conflicts would be useful both to identify causes of potential conflict and management solutions. The latter is of particular interest given that we found on 10.5% of studies examined management solutions for species, largely restricted to the saltwater crocodile in Australia (Fukuda *et al*., 2019; Fukuda *et al*., 2020).

Body Mass and Conflict Severity

Our review found no relationship between body mass and conflict severity. This agrees with findings in our Amazonian case study where the order of ranked 'problem species' displayed no clear pattern with body mass. This finding differs from that of Inskip and Zimmermann (2009) who examined conflict severity with felids and found a relationship with body mass, highlighting the need for greater conservation attention of larger species.

For crocodilians we used average female body mass from Lakin *et al*. (2020), rather than maximum reported body mass, information which is not available in one literature source. Our results are contrary to the literature that larger bodied species, such as male crocodilians, are engaged in more severe conflict, probably because they represent a greater threat to human life (Caldicott *et al*., 2015; Campbell *et al*., 2013; Fukuda *et al*., 2015). For instance of the 26 recognised crocodilian species, 15 have been documented to attack humans, 7 of which were responsible for lethal attacks (Sideleau & Britton, 2013). In comparison, otters rarely attack humans, with 95.2% of documented cases linked to the North American river otter (*Lontra canadensis*) and we could find no cases of cetacean attacks (Belanger *et al*., 2011). This last point is important as cetaceans have relatively large body mass but a lower level of conflict severity than crocodilians. This indicates that an important resource for future analysis would be maximum male and female body mass or length of each species as a predictor of conflict severity (Pooley *et al*., 2020).

Calculating attack rates in relation to body mass would be a useful predictor of conflict severity, particularly for crocodilians with the availability of datasets such as CrocBITE (2021). Challenges to be addressed in such a study would include the likely bias in reporting of attacks, between fatal and non-fatal attacks, and countries or regions where the attacks occurred (Scott & Scott, 1994; McGregor, 2005; Sideleau & Britton, 2013; Brackhane *et al*., 2019).

IUCN Red List Status and Conflict Severity

We found species in lower threat categories on the IUCN Red List displayed higher levels of conflict with humans. This suggests that as a species increases in frequency, using the Red List as an indicator for population status, greater levels of conflict are likely to occur. The approach adopted in this study is suitable for investigating broad scale patterns between species at a large-scale but will not identify regional or local differences in conflict severity at the level that may influence species populations, for example the retaliatory killing of 'problem individuals'. This was evident from our Amazon case study where the conflict experienced differed significantly between species but three of the four species were listed in the same threat category of endangered. Similar findings are displayed in the wider literature where the local economic and political situation can influence conflict severity, for instance the higher severity of conflict with saltwater crocodile in Timor-Leste than Australia, despite the species being listed with the same IUCN category (Fukuda, Manolis & Appel, 2014; Brackhane *et al*. 2018; Fukuda *et al*., 2020).

Our findings have important management considerations for species found in lower threat categories, or those that are recovering in population size and increasingly experiencing conflict. Management strategies may be required as the species recovers in population size to prevent humans killing the recovering species or vice versa to reduce attacks on human populations (Jayson, Sivaperuman and Padmanabhan, 2006; Brackhane *et al*., 2018). Human exploitation caused the historic decline of many crocodilians, cetaceans and otters (Smith, 1981; Mintzer *et al*., 2013). 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, crocodilians, cetaceans and otters has in some locations increased negative interactions. This may result in attacks on people, economic losses or coincidental declines in fish stocks, with these species potentially blamed or persecuted even if overfishing is the driving factor (Gopi & Pandav, 2009; Recharte, Bowler & Bodmer, 2009; Fukuda, Manolis & Appel, 2014; Lima, Marmontel & Bernard, 2014a).

Coexistence with recovering species can depend on perceived or actual population trends, and the conservation strategies used to manage conflict (Fukuda *et al*., 2019; Patro & Padhi *et al*., 2019; Fukuda *et al*., 2020; Rose, Fukuda & Campbell., 2020). 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 in our study area reported that coexistence with these species depends on their future population trends (Lima, Marmontel & Bernard, 2014a; Pimenta *et al*., 2018; Marioni *et al*., 2021). Currently such population trend data are limited in Amazonia, as with many other regions globally (Brum *et al*, 2021).

We advise caution in the interpretation of some aspects our result. Firstly, there are a number of species listed as critically endangered or endangered that are exposed to moderate levels of conflict. Secondly, it could be argued that even minimal conflict could have a disproportionately higher effect on more threatened species due to their inherent rarity. Thirdly, rare species which occupy limited ranges or occur in particular countries, may suffer a bias in reduced reporting of conflicts (Sideleau & Britton, 2013). In this study for instance, we found that four critically endangered or endangered species had no documentation of conflicts. Disentangling whether this reflects a lack of evidence or absence of conflict would require more investigation.

Net Damage and Fish Depredation

Crocodilians, cetaceans and otters depredate fish, damaging nets in the process and causing competition with commercial and subsistence fisheries by catching commercially valuable fish and displacing fish. Economic losses are often cited in the literature but studies including quantifiable, standardised data and solutions to resolve these factors are limited (Aust *et al*., 2009. Currently data concerning the coverage of depredation is better compiled for marine ecosystems alongside methods for reducing depredation (Tixier *et al*., 2021). Similarly, in terrestrial ecosystems methods for reducing felid predation on livestock are better documented, although rigorous scientific evaluation remains poor (Inskip & Zimmermann, 2009).

Depredation of fish stocks and net damage 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). Our case study found the black caiman, giant otter and boto all damage fishing equipment, although we did not document the frequency or economic severity of such damage. 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 cause repeated damage to nets (Alary, Moutou & Jacques, 2002; Hussain, Gupta & Da Silva, 2011; Fonseca & Marmontel, 2011). Similarly, for cetaceans there are consistent reports of the boto 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. 4). This contrasts sharply with the sympatric tucuxi, where only 4.1% of interviewees reported damaged nets (Fig. 4).

Otters 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, Ferriera & Zuanon., 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. 4). Perceived competition can lead to retaliatory killing of 'problem individuals' which has detrimental impacts on the species by reducing 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 targeted by dolphins (Kelkar *et al*., 2010).

Entanglement

In this review we found 19.9% of studies focused on entanglement as a source of conflict, where there was a particular focus on cetaceans. Entanglement in fishing equipment threatens crocodilians, cetaceans and otters with impacts ranging from injury to death (Platt & Thorbjarnarson, 2000; Choudhary *et al*., 2006; Alves, Zappes & Andriolo., 2012). All four species in our Amazonian case study were reported to become entangled in nets. Some net types, such as seine nets or nets with polyamide threads, may increase risk of fatality from entanglement, as found with otters and cetaceans (Leatherwood & Reeves, 1994; da Silva & Best, 1996; Lima, Marmontel & Bernard, 2014b). Further research regarding the impacts of different types of fishing equipment and practises on crocodilians, cetaceans and otters is required, building upon documented examples for marine predators (Tixier *et al*, 2021).

Bycatch through entanglement has the potential to be a major factor influencing population trends of species as found in the marine realm (Mangel *et al*., 2013; Anderson *et al*., 2020; Tixier *et al*., 2021). In extreme circumstances entanglement can contribute to 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 IUCN Red List (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). Scientifically rigorous studies are required concerning methods to prevent or reduce risk of entanglement occurring. For instance, many techniques have been tested to prevent entanglement in marine ecosystems, with some methods such as acoustic deterrent pingers now being tested for freshwater cetaceans (Waples *et al*., 2013; Prajith, Das & Edwin, 2014; Snape *et al*., 2018; Tixier *et al*., 2021; Zanon, 2021).

Human responses to entanglement vary from release to retaliatory killing and are often influenced by local perceptions and economics (this study; Sinha, 2002; Alves*,* Zappes & Andriolo., 2012; Campbell *et al*., 2020). In our case study we found that the response between the four studies species varied greatly with black caiman often killed as a food source. The chance of a species being killed rather than released likely reflects the level of local conflict severity which can be influenced by economic and political situations. For instance, both the boto and tucuxi were always reported to be released in our Juruá waterscape, where piracatinga fisheries are not of commercial importance. In contrast, in the Central Amazon negative perceptions of river dolphins from economic losses results in intentional retaliatory killing to use the species 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).

Conclusions

This study is the first review of conflicts with crocodilians, cetaceans and otters in the tropics and subtropics. Conflict was found to occur with 30 species with conflict including attacks on people, depredation of fisheries or livestock, damage to fishing equipment and entanglement in nets. We found as IUCN Red List status threats status decreased conflict severity increased, indicating a need for conflict management strategies as species recover in population size. We make three recommendations for future research. Firstly, there remains considerable gaps in our knowledge for many species. Determining if conflict occurs, the severity of this conflict and what economic or societal factors influence the conflict is a priority, with Table 1 an indicator of which species have been infrequently or rarely documented so far. Species experiencing the greatest level of conflict should be prioritised. Our second recommendation, based upon findings and limitations from our Amazonian case study, is the need to report conflicts in local case studies with commercial and subsistence fishers 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, or frequency of entanglement over a set time period, in questionnaires would improve the ability to understand the severity of conflicts (Campbell *et al*., 2020). Our third recommendation is that for all conflict generating species, there is a need for future studies to focus on the resolution and management of conflicts in a scientifically robust manner.

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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).

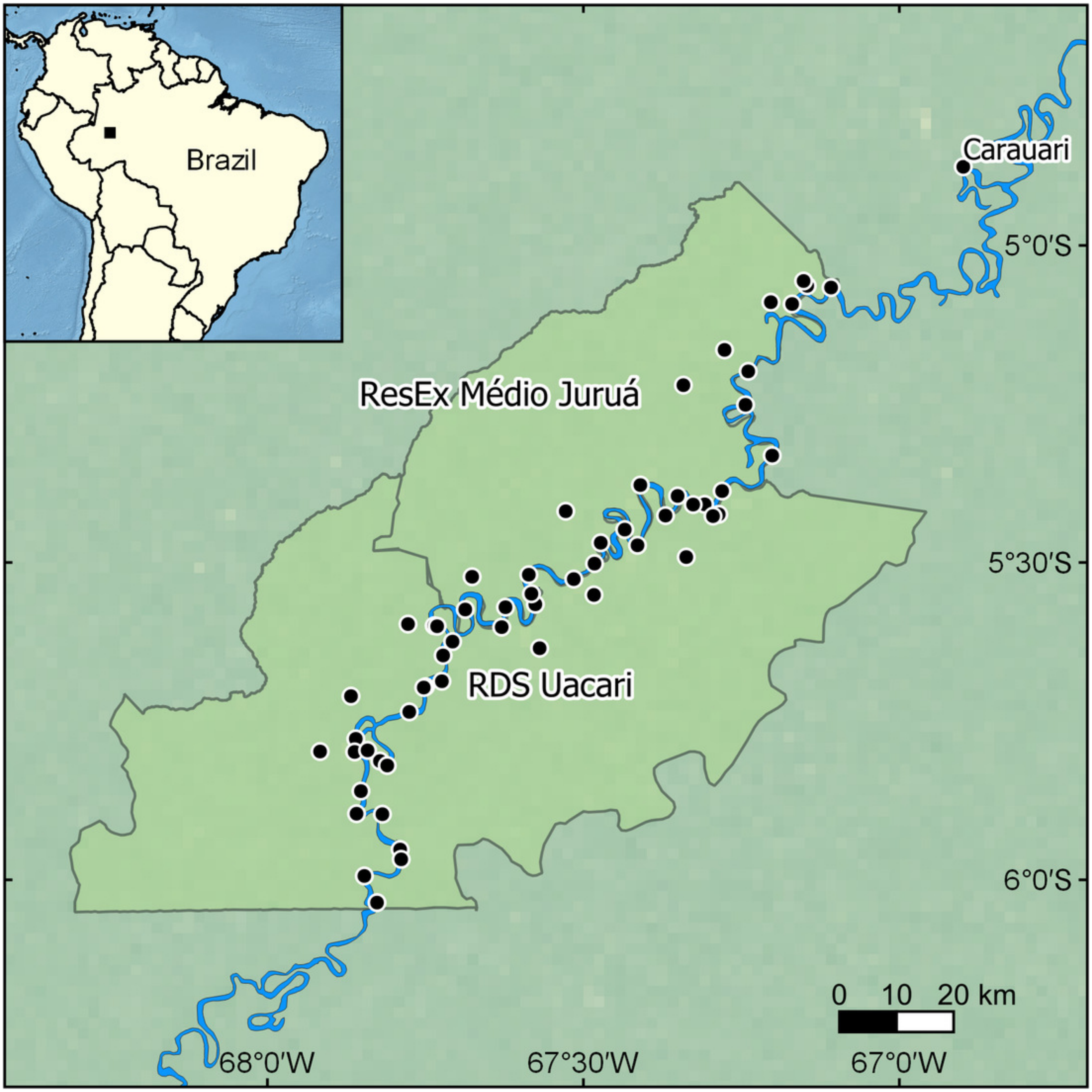
Brazil
Carauari
ResEx Médio Juruá
RDS Uacari
5°0'S
5°30'S
6°0'S
68°0'W
67°30'W
67°0'W
0 10 20 km

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 crocodilians, cetaceans and otters over time (1962-2020).

Prior to 2000 data are displayed in five year categories. From 2000 onwards each year is represented by one bar.

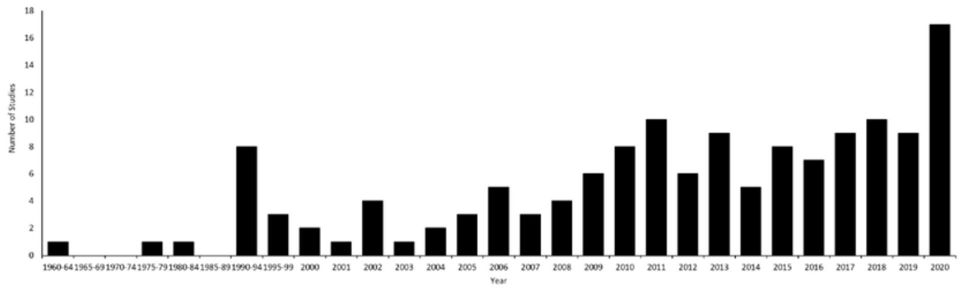
Number of Studies
0
2
4
6
8
10
12
14
16
18
1960-64
1965-69
1970-74
1975-79
1980-84
1985-89
1990-94
1995-99
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Year

Figure 4

Percent of interviewees (n=49) who indicated that each of four species of causes problems in general, damage fishing equipment, frightens away fish, or becomes entangled in nets

The species are black caiman (C, black bars), giant otter (O, dark grey bars), boto (B, light grey bars) and tucuxi (T, white bars)

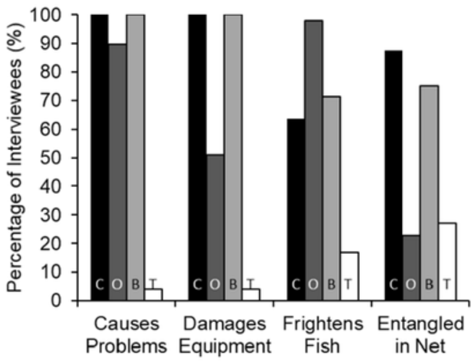
Percentage of Interviewees (%)
100
90
80
70
60
50
40
30
20
10
0
C O B T
Causes Problems
Damages Equipment
Frightens Fish
Entangled in Net

Figure 5

Percent of interviewees (n=49) who indicated the potential outcomes of entanglement in fishing nets by four species of piscivorous mammals and reptiles

Outcomes are being killed by fishers (black), dying without fisher intervention (dark grey), being released by fishers (light grey) or escaping without fisher intervention (white)

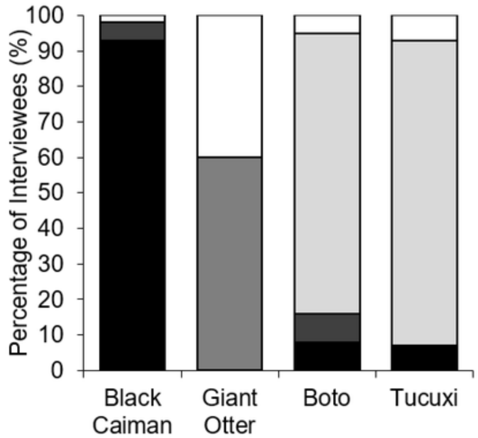
Percentage of Interviewees (%)
100
90
80
70
60
50
40
30
20
10
0
Black Caiman
Giant Otter
Boto
Tucuxi

Table 1(on next page)

Criteria for categories used to determine the frequency of conflict documentation in the primary literature and severity of conflicts found in the literature review.

Table 1. Criteria for categories (adapted from Inskip and Zimmermann, 2009) used to determine the frequency of studies reporting conflict and severity of conflict found in the literature review.

Category	Definition
Frequency of Studies	
Conflict Frequently Documented (CFD)	Conflict with piscivores documented in 5 or more primary literature sources.
Conflict Infrequently Documented (CID)	Evidence in 2-4 primary literature sources.
Conflict Rarely Documented Required (CRR)	Evidence in 1 literature source.
Severity of Conflict	
Severe	Very high frequency of (or perceived) fish depredation and/or attacks on people (>20 reported fatalities or >50 non-fatal attacks as described in Sideleau and Britton, (2013)) and/or very frequent retaliatory killing and/or very frequent entanglement in nets
High	High frequency of (or perceived) fish depredation and/or low frequency of attacks on people (1-20 fatalities or 10-50 non-fatal attacks as described in Sideleau and Britton, (2013)) and/or retaliatory killing and/or frequent entanglement in nets
Moderate	Moderate fish depredation and/or < 10 non-fatal attacks on people as described in Sideleau and Britton, (2013) and/or occasional retaliatory killing and/or occasional entanglement in nets

Low	Infrequent fish depredation and/or no attacks on people and/or very occasional retaliatory killing and/or very occasional entanglement in nets
Data Deficient	No evidence of conflict available

Table 2(on next page)

Species of crocodilian, cetacean and otter found in the tropics and subtropics known or suspected to have conflict with humans

Columns show frequency of conflcit doumentation in the primary literature, severity of the human-wildlife conflict, body mass and IUCN Red List category.

Table 2. List of crocodilian, cetacean and otter species from tropical and subtropical regions. For each species frequency of primary literature studies mentioning conflict, severity of the human-wildlife conflict, body mass and IUCN Red List category are listed.

Species	Primary Literature Coverage	Severity of Conflict	Body Mass Category (kg)	IUCN RED List Status[6]
Crocodilians				
African Dwarf Crocodile (*Osteolaemus tetraspis*)	CID	Data Deficient	10-49[3]	VU
American Alligator (*Alligator mississippiensis*)	CFD	High	≥50[3]	LC
American Crocodile (*Crocodylus acutus*)	CFD	Severe	≥50[3]	VU
Australian FCRDhwater Crocodile (*Crocodylus johnstoni*)	CID	Moderate	10-49[3]	LC
Black Caiman (*Melanosuchus niger*)	CID	High	≥50[3]	LC
Broud-snouted Caiman (*Caiman latirostris*)	CID	Moderate	10-49[3]	LC
Central African Slender-snouted Crocodile (*Mecistops leptorhynchus*)	CRD	Data Deficient	Not available	Not assessed
Chinese Alligator (*Alligator sinensis*)	CRD	Data Deficient	10-49[3]	CR
Cuban Crocodile (*Crocodylus rhombifer*)	CRD	Data Deficient	≥50[3]	CR
Dwarf Caiman (*Paleosuchus palpebrosus*)	CRD	Data Deficient	≤10[3]	LC
False Gharial (*Tomistoma*	CRD	High	≥50[3]	VU

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

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

Tucuxi (*Sotalia fluviatilis*)	CFD	Low	10-49[5]	EN

[1] CFD = Conflict Frequently Documented; CID = Conflict Infrequently Documented; CRD = Conflict Rarely Documented (Table S1)

[2] Conflict categories (Table S1)

[3] Lakin *et al*., 2020

[4] Hunter (2011)

[5] Macdonald (2009)

[6] LC= Least Concern, NT= Near Threatened, VU= Vulnerable, EN= Endangered, CR= Critically Endangered