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Climate change influences the risk of physically harmful human-wildlife interactions

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ABSTRACT

Interactions with wildlife can pose substantial physical risk to humans, as well as damage efforts to protect the species involved. News reports of increasing dangerous interactions with animals indicate climate change may be acting as a risk magnifier for these confrontations, yet its impacts on human-wildlife interactions remain uncertain in the scientific discourse. We analysed 331 media reports on climate change driven human wildlife conflicts involving physically dangerous species and verified the effects found in the media with evidence from scientific literature. Our analysis showed that climate change can increase wildlife-induced physical harm to people. This result was consistent for venomous species, terrestrial-and aquatic carnivorous species and large-bodied terrestrial animals in 44 countries across the globe. We identified four climate driven trends that impact the risk of human casualties: i) increased resource competition between humans and wildlife due to drought; ii) range expansion of dangerous animals due to higher average temperatures; iii) temporary displacement of wildlife due to extreme weather events; iv) and changes in temporal behaviour patterns of wildlife due to higher average temperatures. The identification of overarching trends across different regions and species show the need to bridge the gap between wildlife research and the study of climate-related risks. The existence of, or potential for, wildlife-induced physical harm to people should be taken into account as a component of climate change driven risk. At the same time, we stress the importance of including current and future impacts of climate change into long-term wildlife management- and conservation schemes.

1. Introduction

Climate change acts as a risk magnifier aggravating ecosystem degradation, biodiversity loss, social conflict, food insecurity and many other global, regional and local issues (Huntjens and Nachbar, 2015; United Nations, 2021). Conflicts between humans and wildlife are no exception (Abrahms et al., 2023). Depending on the extent of the human-wildlife interface and the frequency and nature of encounters, direct physical threat from wildlife can pose a significant risk to human health (Gulati et al., 2021; Støen et al., 2018; Treves and Naughton-Treves, 1999). Indeed, the most commonly reported climate-driven human-wildlife conflicts are human casualties, ranging from physical injury to death (Abrahms et al., 2023). Despite its evident importance, a targeted analysis of potential increase in wildlife-induced physical harm to people (subsequently referred to as wildlife-induced harm: WIH) is still lacking, and physically hazardous wildlife are only rarely considered in the study of climate risk at present. This paper seeks to address this knowledge gap.

While Pecl et al.'s (2017) analysis of climate-driven biodiversity redistribution offers valuable insights on the resulting effects for human well-being, the authors do not include physical altercations between humans and wildlife, focusing instead on climate change's effect on economic development and the provision of ecosystem services. Similarly, Cassidy's (2012) analysis of climate change and human-animal relations focuses on animal-centred livelihoods and cultural and spiritual relationships to animals rather than direct confrontations. A number of papers specifically focusing on the effects that climate change has on conflict with a species or animal group have been published in the last decade (e.g. Carter et al., 2018; Haque et al., 2015; Johnson et al., 2018; Moo-Llanes, 2021; Phillips et al., 2019; Vargas et al., 2021), with in particular Wilder et al. (2017), Kitratporn and Takeuchi (2022) and Martín et al. (2021) applying a risk lens to climatic impacts on polar bear attacks, human-elephant conflict in Thailand and the global burden of snakebites respectively. Recorded or potential impacts of climate change

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on human-wildlife interactions in general are hinted at in many scientific papers on the subject (e.g. König et al., 2020; Schell et al., 2021; Ward and White, 2010), and links between human-wildlife conflicts and the changing climate have been investigated for different regions and climate-related events (e.g. Bakare et al., 2020; Bhatt et al., 2019; Gupta et al., 2017; Tiller et al., 2021), with Abrahms (2021) bringing together anecdotal examples from across the globe.

While there is no global database of WIH, both concrete and perceived risks posed by wildlife are frequently discussed in the media, providing a window on global changes. Structured analyses of media content have for example revealed patterns in the risk perception of zoonotic diseases (Decker et al., 2010) and the changing tones in public debate after repeated dangerous incidents involving wild animals (Sabatier and Huveneers, 2018). The news cycle has reported a rise in negative interactions between humans and potentially dangerous animals in the past decades (Charles, 2018; Hart, 2019; Kaushik, 2019; N. Thomas, 2018), with some reports explicitly attributing this trend to climate change and its impacts (e.g. Charles, 2018).

In this study, we assessed how climate change impacts the risk of human casualties through encounters with bodily hazardous wildlife. To this aim, we analyse media reports on climate-driven WIH and verify the phenomena they describe using respective scientific evidence. Our specific objectives were (i) to examine how this issue is presented in the media, (ii) analyse whether the alleged cases of climate-driven changes in WIH presented in the media were supported by scientific evidence, and (iii) identify patterns and trends in climate-driven changes to WIH.

2. Methodology

2.1. Wildlife-induced harm and risk definition

The term "wildlife-induced harm" (WIH) will be used to express the physical threat of injury or death through wildlife in this study, and the term "risk" is defined using the risk formula commonly used in the context of climate change: risk = hazard x vulnerability x exposure (IPCC, 2014, p. 3). This risk definition was selected in order to express that climate change can alter the risk from bodily hazardous wildlife by affecting different risk components. Hazard is interpreted here as the potential occurrence of a physical encounter with a potentially dangerous animal that may cause loss of life, injury or other health impacts. Vulnerability is the propensity to be adversely affected by animals in the context of climate change. Vulnerability encompasses sensitivity or susceptibility to encounters with potentially dangerous animals and lack of capacity to cope with and adapt to these encounters. Exposure is the presence of people in situations where an encounter with a potentially dangerous animal may occur.

2.2. Media case search and selection

In order to collect relevant media articles, we created a search string that named animals frequently associated with wildlife risk to humans, and combined with terms related to physical injury and climate change. To select relevant animal groups we first searched through popular science graphs of human mortalities caused by wildlife (Gates, 2014; McCarthy, 2014), which were picked up in the media (e.g. Ramsey Pflanzer, 2016) and may have shaped the public debate on the risk that wildlife pose to humans. Secondly, we excluded disease vectors, parasites, domesticated animals and fellow humans from the list of animals considered threatening, leaving seven relevant groups: snakes, crocodiles, hippopotamuses, elephants, lions, wolves and sharks. Thirdly, as this list is based on opaque calculations using multiple partial datasets and offers no further context for the recorded casualties, we extended this dataset by adding animal groups that share relevant characteristics with those listed above, such as similar predatory potential, physical aggression and venom potency as recorded in scientific literature. While the resulting selection of species is not an exhaustive list of all potentially hazardous wildlife that could be affected by climate change, attention was given to including a diverse range of animals from different classes. As it would be unlikely for media reports to include scientific species names, common names were used for the search string:

"climate change"
AND
"bite" OR "sting*" OR "attack*" OR "conflict*"*
AND
"wildlife" OR "animal" OR "snake*" OR "crocodile*" OR "hippopotamus*" OR "hippo*" OR "elephant*" OR "lion*" OR "wolf" OR "wolves" OR "shark*" OR "jellyfish" OR "spider*" OR "bear*" OR "tiger*" OR "leopard*" OR "mountain lion*" OR "puma*" OR "cougar*" OR "hyena*" OR "bison*" OR "kangaroo*" OR "moose" OR "wild boar*" OR" wild pig*" OR "wild hog*"*

This search string was applied to English-language media articles in the database Nexis Uni. The search was limited to the publication type "Newspapers" and a publication date between the 1st of January 2010 and the 30th of June 2021, and the "group duplicates" function was activated. The last decade was selected as the time frame for this study as we consider a decade to include sufficient repetition of seasons to be able to distinguish between consistent trends and extreme outlier events. It is assumed that climate change effects are increasing in prominence as time progresses, which is why the most recent time frame was selected. Our search string yielded 16,662 results on August 11th 2021.

We screened the search results in a two-step process, beginning with the articles' titles and the text preview provided in the Nexus Uni results list. Articles in which search terms appeared in a context that was not relevant to the research question were immediately excluded, while the full text of the remaining articles were screened according to the following inclusion criteria: the article (i) identified human-wildlife conflict or encounters with (potential) physical impacts on humans, (ii) put these into the context of climate change/global warming, and (iii) specifically focussed on the direct physical threat that wildlife poses to humans, be it in the shape of predatory, defensive or accidental dangerous encounters. Secondary conflict types such as livestock predation and crop raiding were only taken into account in cases where they increase the exposure of humans to potentially dangerous wildlife, for example if farmers are forced to guard their irrigated fields from wildlife as natural food sources dwindle during a drought. Physical impacts on human well-being through the loss of livelihoods to wildlife and the spread of zoonotic disease vectors and zoological pests were not considered. After the screening process, a total of 331 articles matched all selection criteria. More animals were represented in the dataset than initially named in the search string, as all relevant articles that met the selection criteria were coded regardless of the named wild animal.

2.3. Media analysis

All articles were analysed using qualitative content analysis. During coding, each article was assigned a distinct number for later identification and key information was recorded, namely: article title, year and month of publication, name of the news outlet, country of the WIH and the name of the animal involved. As several articles included more than one animal species, the climate-impacted conflict with each animal species was coded as a separate case under the same article number.

A deductive approach was used in the coding of media articles, with the exception of the predetermined spectrum recording the described development of human-wildlife conflict under the conditions of climate change: increase; hypothesized increase; no effect; hypothesized decrease; decrease; effect uncertain/disputed. The "hypothesized" categories contained articles in which climate change was reported as a possible explanation for changes in WIH but not considered a surety. A deductive approach was used to develop the coding scheme for climate change's impact on WIH, creating the coding variables on the basis of the information provided in the articles. We coded for both recorded climate-change drivers, e.g. higher seasonal temperatures, and the areas of influence, e.g. animal behaviour, through which they impacted dangerous human-wildlife conflict. Where appropriate, similar variables were grouped under overarching drivers and areas of influence based on common denominators. We used descriptive statistics to assess the representation of animal groups, geographic regions and coding variables to identify trends and patterns in the media presentation of climate change's effects on WIH.

2.4. Case verification

Previous studies on media coverage of human-wildlife interactions have shown that newspapers not always present it accurately, for example conflating human-wildlife and human-human conflict (Dayer et al., 2019), sensationalising and negatively framing interactions with wildlife (Ardiantiono et al., 2023), or unduly over-emphasizing the damages caused by certain species (Arbieu et al., 2021; Bombieri et al., 2018). We address this issue by further verifying those cases presented in the media that specified both animal and conflict driver with the help of scientific literature collected through targeted searches on Scopus and GoogleScholar, as well as backward tracking from sources named in the articles themselves. Articles that did not specify a climatic driver or only referred to conflict with wildlife in general were excluded from this process. Peer-reviewed scientific literature as well as science-based reports from organisations such as the WWF were accepted as reliable sources for verification. To indicate the strength of the supporting scientific evidence, cases for which substantiating scientific publications could be identified were divided into two levels of confidence, high certainty cases and low certainty cases (see Table 1 for the criteria). We analysed the nature and frequency of driver-effect combinations documented in both categories of scientifically verified cases (e.g. drought causing resource competition between humans and wildlife) in order to identify ongoing trends in WIH under climate change. Identified trends were contextualised using the components of the risk formula: hazard, vulnerability and exposure.

2.5. Data presentation

Two deliberate communication choices were made in this article. Firstly, while the scientific name of the respective animal is identified to the lowest taxonomic level possible as part of the dataset analysis, common names of animals are used in the subsequent presentation and discussion of the results in order to maintain uniformity as they are the lowest common denominator among articles. Secondly, a dual citation system is applied in the discussion to allow the easy distinction between articles included in the coded dataset, which are cited using their dataset number (for full article list see Appendix I) and additional sources, which are cited with author name and year.

3. Results

3.1. Dataset characteristics

The dataset comprises of articles from 174 different news outlets, not distinguishing between different editions of the same outlet (regional/international or electronic/paper editions). The last decade showed a general increase in the number of newspaper articles on human-wildlife encounters related to climate change within the dataset, rising by an average of 24 % per year from 14 publications in 2010 to 47 publications in 2020 (see Appendix IIa). Almost one third (27 %) of articles reported on cases in Europe, followed by Asia (22 %), grouped together with three articles from the Middle East. Oceania, Africa and North America were represented by a similar amount of articles (16 %, 15 % and 15 % respectively), while Central- and South America and the Caribbean made up only around 3 % together. Four percent of coded articles focused specifically on the Arctic, and around 3 % were not region-specific. A list of countries represented in each geographic regions can be found in Appendix IIb.

The majority of articles (64 %) were published by news outlets from the same country as the story they cover. Approximately 14 % of articles covered stories from several countries, including the country in which the respective news outlet is based, and 2 % of articles were published by regional news outlets from regions that included the country being reported on. Only around 21 % of articles were published by news outlets outside of the geographic range of the story being reported on.

3.2. Represented animals

Overall, venomous animals, dominated by jellyfish, appeared most often in the coded articles (48 % of articles; Fig. 1a). Large terrestrial carnivores were the second largest category, included in 28 % of the dataset, while aquatic carnivorous species appeared in 18 % of the dataset, with this category being almost entirely dominated by sharks (Fig. 1a-d). Terrestrial omnivores and herbivores accounted for 14 % of the dataset, dominated by elephants (Fig. 1a-d). Additionally, 6 % of the dataset included general references to wildlife without specifying a particular animal.

3.3. Media analysis results

Our analysis of climatic drivers revealed that around 31 % of the 331 analysed articles stated that climate change-induced higher average temperatures are a driver of change in dangerous human-wildlife conflict, similar to ocean warming (30 %). A further 14 % of articles identified drought as a key driver of conflict, and 8 % each recorded the driving effect of habitat shifts and changing weather patterns. Approximately 4 % named extreme events as a driver, and a further 3 % sea level rise (SLR). One article each described climatic changes to wave height as a driver, as well as unforeseen negative consequences of human efforts for climate change mitigation and adaptation to climate-driven WIH.

Regarding the effects of these climatic drivers, we could extract six main areas of influence in which climate change impacted human-wildlife conflict from the cases described in our dataset (see Table 2). Climate drivers were most often recorded as altering animal behaviour, with changes being recorded in around 44 % of articles, followed by shifts in animals' distribution ranges (31 %) and the size of animal populations (26 %). A further 16 % of articles described resource competition being impacted by climatic drivers, while only 8 % of articles stated that human behaviour was affected. A further 2 % of articles described an effect on animal's physical characteristics (see Table 2).

We found two distinct patterns in the media coverage of WIH under climate change (Fig. 2). First, the vast majority of cases either reported an increase in potentially dangerous encounters between humans and wildlife because of climate change (41 %), or hypothesized that climate change was a likely exacerbating factor (46 %). Only seven cases recorded either a decrease or a hypothesized decrease, all of them

Table 1
Criteria for case verification through scientific evidence.

High confidence cases	Low confidence cases
1. Case directly proven by scientific observation 2. The case is not specifically described in scientific literature, but there is independent scientific evidence that case's driver increases WIH and the driver will increase in the case region as climate change progresses	1. Case hypothesized/likely in the scientific literature but not conclusively proved 2. Circumstantial scientific evidence supporting the case

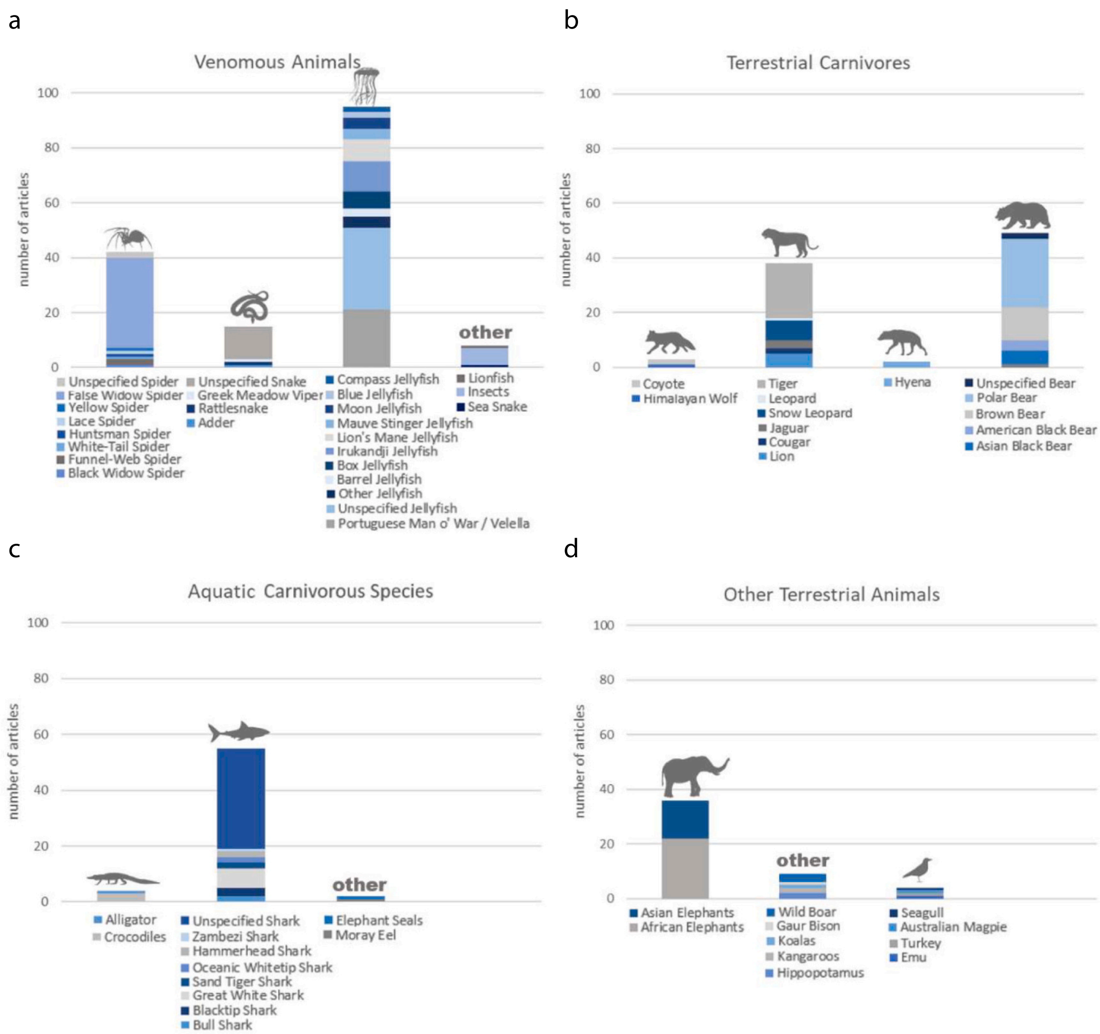

Fig. 1. a-d: Animal groups and -species represented in the dataset, quantified by the number of articles in which they appear. As most articles included several species, many articles are represented in several figures/columns.

covering either sharks or snakes. Not shown in the figure are a further 30 cases which described the potential effects of climate change as uncertain disputed, and a further nine that recorded no change of WIH under climate change. Additionally, four articles did not correspond to this categorization and were excluded from further analysis.

Second, we found a strong difference between animal groups concerning the areas of influence through which climate change can impact WIH. Changes in human- and animal behaviour, as well as resource competition are dominated by terrestrial mammals. Changes in human behaviour were only discussed comparatively rarely in the dataset, with just over half of the cases involving big cats, while altered animal behaviour due to climatic changes was the most diverse category in the dataset, affecting a wide array of animal groups. Resource competition was dominated by elephants and terrestrial carnivores, but both animal behaviour and resource competition also featured high numbers of cases not specifying the animal type involved in the increasing WIH.

In contrast, the areas of influence animal range, animal population and animal's physical characteristics were mainly reported for aquatic animal groups, with the exception of spiders, which figure heavily in these categories. However, this may be a misrepresentation as 80 % of spider cases reported on climate change's impact on the spread of one particular species in the UK (noble false widow spider), a link that was subsequently scientifically discounted (Bauer et al., 2019).

3.4. Verified cases of climate change effects on wildlife induced harm

We were only able to identify cases of WIH increase due to climate change, identifying scientific evidence supporting a total of 35 cases of climate change increasing the risk of physical harm that wildlife poses to humans. These involved 26 specified species as well as 4 cases affecting snakes and jellyfish in general. Cases of all animal groups and most geographic regions were represented in the substantiated results (Table 3).

Higher mean temperatures, the most direct impact of climate change, featured heavily as the direct driver of increased WIH in the cases substantiated with high confidence ($N = 8$). The second most frequently named driver was drought ($N = 7$) and other changes in weather patterns ($N = 5$). Range expansion was reported for five species, all of which were able to move into previously unsuitable territories as climate change altered the habitat conditions at the edges of their original range or, in the case of one invasive species, allowed them to thrive in a new habitat to which they were imported. Altered seasonal behaviour was substantiated for four different species of bear, as warming temperatures delayed or shortened the periods of sufficiently cold temperatures for hibernation or, in the case of polar bears, migration to the arctic sea ice. Extreme weather events, in particular droughts and floods, increased resource competition between humans and animals and temporarily displaced wildlife, pushing them into human-dominated spaces.

Table 2
Description and frequency of occurrence of the climate change-related drivers and the areas of influence in which they take effect on s WIH identified in the media dataset.

Climate-related drivers		N (articles)
Temperature	Changes in the average temperatures of an ecosystem, which an article might express as for example "unusually warm winters". Marine warming is not included in this driver but instead addressed separately as "ocean warming."	102
Weather	Changes in weather patterns, most frequently rainfall patterns but also including for example changes in wind patterns. Droughts were not included in this driver but instead addressed separately as "drought."	27
Drought	Both prolonged droughts named as such in articles and overall drier conditions mentioned were grouped as this driver.	47
Extreme events	Sudden-onset, potentially disastrous environmental events including wildfires, heavy rainfall events and storms were grouped as this driver.	14
Habitat shift	Any geographic shift of habitat types or ecosystems within the species' range, such as for example loss of Arctic sea ice within polar bears' range.	27
Ocean warming	Rising marine temperatures and the corresponding increase in ocean acidification.	100
Sea level rise (SLR)	Both rising sea levels and consequent increased saltwater intrusion into some coastal areas were included in this driver.	11
Wave height	Changes in wave height due to changes in wind patterns and -intensity, shifting ocean currents or other factors (potentially) impacted by climate change.	1
Maladaptation to WIH	Counterproductive human efforts to adapt to increased or increased perceived WIH due to climate change.	1
Climate change mitigation	Human efforts to mitigate climate change, for example afforestation.	1
Areas of influence		
Human behaviour	Temporal, spatial or other changes in human activity that impact human-wildlife interactions, which may be affected by climate change in the shape of e.g. adaptive behaviour, changed activity patterns due to altered weather patterns, etc.	25
Animal behaviour	Temporal, spatial or other changes in animal behaviour that impact the human-wildlife interface, which may be affected by climate change in the shape of e.g. alteration in activity patterns due to changing seasonal temperatures, changing movement patterns to adapt to water shortages due to drought, etc.	145
Resource competition	Competition for natural resources between humans and wildlife that may be aggravated if climate change reduces e.g. water or food availability in an ecosystem. Almost half (49 %) of cases in articles relating to this field of influence also recorded connected changes in animal behaviour, and around 17 % changes in human behaviour.	53
Animal range	Shifts in the geographic range in which an animal occurs, which may be affected by climate change in the shape of altered average temperatures or changing habitat types.	105
Animal population	The number of individuals of a species living in an ecosystem or existing globally. Population size influences human-wildlife conflict as it can impact on the exposure of humans to the animal in question. The size of an animal population is dependent on habitat conditions, which may be impacted by climate change.	86
Animal's physical characteristics	For the sake of this analysis, physical characteristics that contribute to the physical danger an animal can pose to humans are considered, such as the size of individuals. The effects of climate change on habitat conditions may influence this factor.	6

The climatic drivers of WIH increase which could only be substantiated with low confidence are similar to those in the cases that can be considered proven: generally higher temperatures with the additional influences of flooding and droughts. Besides frequently cited climate-effects such as range shifts, increased resource competition and short-term displacement of animals due to extreme weather events, two cases of climate-driven population increase were sufficiently supported by the scientific literature to be considered in this category.

3.5. *Identified trends in climate change impacts on wildlife-induced harm*

Our results show that climate change affects human-wildlife conflict at a global scale, often increasing the risk of bodily harm to humans. From the 35 verified cases, four trends in climate change's influence on the risk of human casualties through encounters with bodily hazardous wildlife were identified (Fig. 3):

1. Increased resource competition between humans and wildlife due to drought ($N = 10$).
2. Temporary displacement of wildlife due to extreme events, i.e. heavy rainfall, flood, storms and droughts ($N = 9$).
3. Range expansion of dangerous animals due to higher average temperatures ($N = 8$).
4. Changes in temporal behaviour patterns of wildlife due to higher average temperatures ($N = 5$).

4. Discussion

By making global trends of climate-related WIH increase visible and showing the risk it poses to humans, this study illustrates the importance of bridging the gap between the fields of wildlife research and human security under climate change. The existence of, or potential for, physically dangerous conflict with wildlife should be taken into account as a component of climate change driven risk. At the same time, wildlife management- and conservation schemes can only be effective long-term if they factor in future impacts of climate change, not only on WIH but also on factors underpinning it such as habitat suitability and range. We will first discuss the portrayal of climate-driven WIH after which we will examine the role of WIH as a climate change driven risk to humans, as well as the implications for wildlife conservation.

4.1. *Climate-driven wildlife induced harm in the media*

While there are large scientific knowledge gaps on climate change's effects on human-wildlife interactions (Abrahms, 2021; Abrahms et al., 2023), the analysed dataset shows that the phenomenon is gaining increasing attention in the media. Direct contradictions between media reports and scientific findings were rare, and several of the cases we could not conclusively verify were nevertheless very credible. In fact, roughly half of the articles reported on scientific findings directly or included quotes from experts to support their claims. In the case of the false noble widow spider in the UK, later media articles even stressed that the previous misconception of the spider's spread being linked to climate change had been disproven by scientists (article 327; 326; 324).

News stories of increased WIH due to climate change dominated our dataset, compared to cases of risk reduction or stagnation. We consider it likely that this is at least in part due to considerations of newsworthiness, as multiple factors influence whether news outlets choose to cover a story (Harcup and O'Neill, 2017). Media may have favoured stories where wildlife risk increased, while leaving cases of decreasing risk due to climate change undiscovered. For example, a study on climate-induced changes in venomous snakes' ranges in Argentina found that while snakes were expanding their ranges into territories where they were previously not present, other parts of their range were becoming

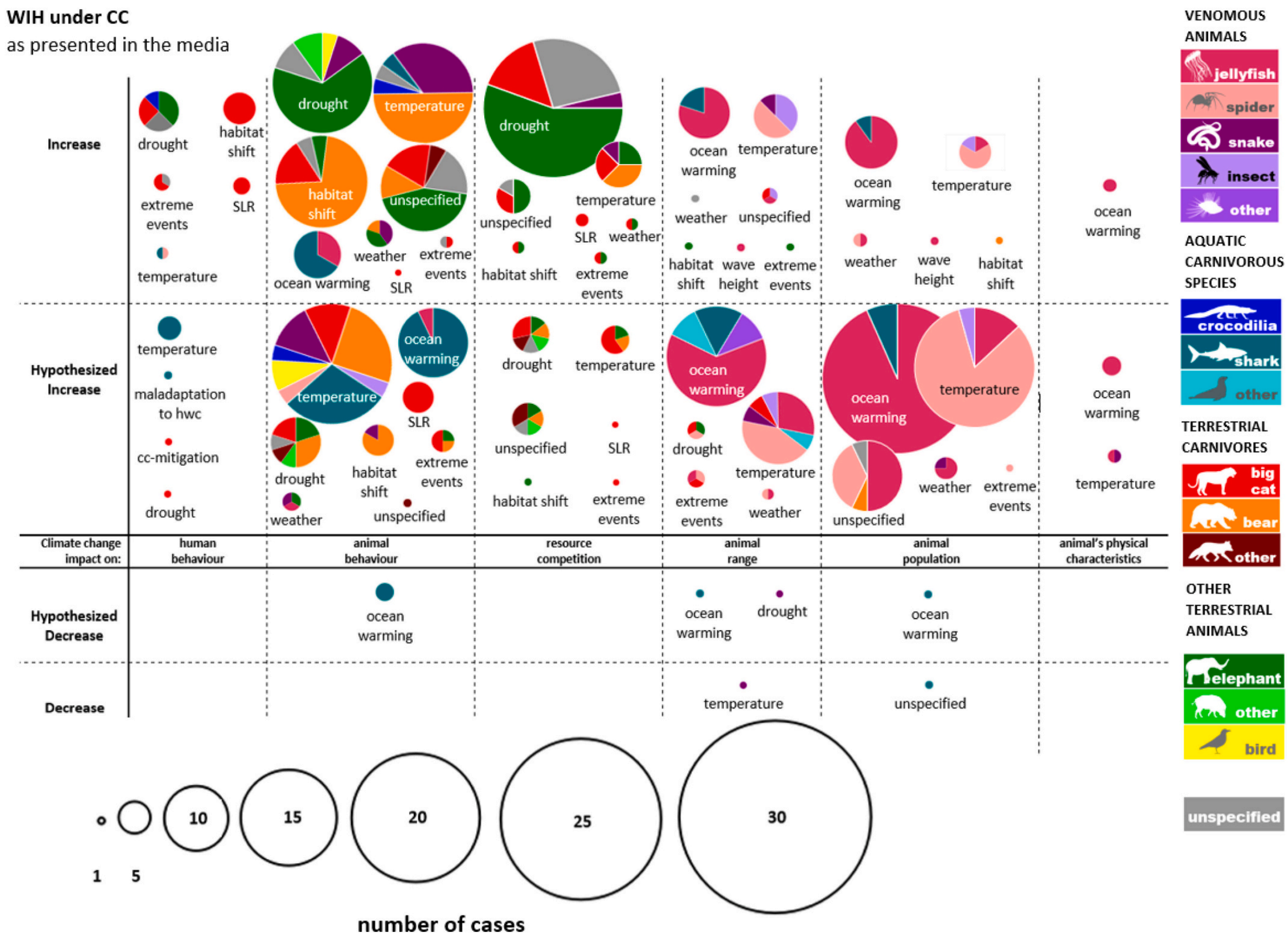

Fig. 2. The influence of climate change on WIH as presented in the media dataset. Articles were coded by area of influence, climate-related driver and animal group, and may consequently appear in more than one pie chart if several animal groups or -species were described in one article. The size of the pie charts indicates the number of cases; the animal group is coded by colour. The position of each pie chart in the graph shows what effect on WIH was attributed to climate change in the case. Cases in which no change due to climate change was discovered or effects were disputed are not included in this graph.

less suitable habitat, shifting and potentially even reducing overall snake bite risk in the region (Nori et al., 2014). Nevertheless, news coverage shows that climate change can cause the risk of WIH to rise considerably at certain locations.

We also observed a bias in the focus on wildlife's role in the increase of WIH risk. In their framework of climate change's impact on human-wildlife interactions, Abrahms et al. (2023) define two pathways in which conflict can be exacerbated: change affecting wildlife and change affecting humans. While it is clear from both the data collected by Abrahms et al. (2023) and from scientific evidence consulted in this study that these pathways are of equal consequence for interaction outcomes, examples from the wildlife pathway dominated our results. This indicates a bias in media framing that places stronger emphasis on wildlife's role in negative interactions than on human contributions (Stafford et al., 2018; Ardiantiono et al., 2023), which may skew public perception and lead to more negative attitudes towards wildlife.

4.2. *Wildlife induced harm as a climate change driven risk*

Our case verification confirmed an overarching climate change driven increase in the risk posed to humans by wildlife at a global scale. We identified four trends in climate change driven WIH increase across geographic regions and animal groups: (i) increased resource competition between humans and wildlife due to drought; (ii) temporary displacement of wildlife due to extreme events; (iii) range expansion of dangerous animals due to higher average temperatures; and (iv) changes in temporal behaviour patterns of wildlife due to higher average temperatures. These identified trends confirm the findings by Abrahms et al. (2023), which similarly found that climate drivers and resulting ecological change can negatively impact human-wildlife interactions by causing spatial-, temporal-, and behavioural change in wildlife and/or humans, as well as demographic change in wildlife and human governance change.

Using the IPCC's definition of risk as hazard x vulnerability x exposure, it is evident that all elements of the physical risk posed to humans by wildlife can be impacted by climate change. Three of the identified trends affected human exposure to physically dangerous wildlife: increased resource competition and temporary displacement during extreme weather events cause spatial change that brings animals and humans into closer contact, increasing the risk of dangerous encounters. Temporal change through the disruption of seasonal weather patterns also contributes to an increase in encounters, for example when disrupted hibernating animals become active at times of the year in which the availability of natural food sources is low, encouraging them to encroach on human areas in search of food. Both the disruption of seasonal animal behaviour and species' range expansion also affect human vulnerability to dangerous incidents involving wildlife, as they may encounter dangerous animals with which they have no prior

Table 3
Verified cases of increased WIH due to climate change, along with substantiating sources and confidence levels. The cases are grouped by animal group.

Animal	Climate-related driver	Climate change effects on WIH	Affected region	Scientific sources	Confidence level
Velella (*Vellela velella*)	Higher winter temperatures	Higher frequency of velella near the coastline & velella strandings	Pacific Northwest Coast, USA	Jones et al., 2021	Low
Venomous jellyfish (general)	Ocean warming	Increased jellyfish blooms	Global	Needleman et al., 2018; Purcell, 2011	Low
Western black widow (*Latrodectus hesperus*), Northern black widow (*Latrodectus variolus*)	Higher average temperatures	Higher reproduction, population growth	Canada	Carere et al., 2018	Low
Venomous snakes (general)	Increased heavy rainfall events and flooding	Snakes are forced into the open and into closer contact with humans	South Asia, South America, southern US	Ochoa et al., 2020	High
	Higher average temperatures	Uphill shift of treeline and habitat lines	Himalayas	Acharya and Chettri, 2012	Low
Seasonally dormant snakes (general)	Higher seasonal temperatures	Shorter or no hibernation	Global	Capula et al., 2016; Markle et al., 2020; Rugiero et al., 2013	Low
Asian giant hornets (*Vespa mandarinia*)	Higher average temperatures	Expansion of the (invasive) population	USA	Moo-Llanes, 2021	High
Oak processionary caterpillar/moth (*Thaumetopoea processionea*)	Higher average temperatures	Range expansion	Western/Southern Europe	Godefroid et al., 2020; Van Oudenhoven et al., 2008	High
Common lionfish (*Pterois miles*)	Warmer ocean surface temperatures	Extension of distribution range	Mediterranean Sea	Dimitriadis et al., 2020	Low
Saltwater crocodile (*Crocodylus porosus*)	Higher average temperatures (inland water bodies)	Range extension to North and South (into more populated areas)	Sub-tropical parts of Australia	Fukuda et al., 2008	Low
Nile crocodile (*Crocodylus niloticus*)	Flooding and droughts	Increased human-crocodile interaction due to changes in spatial activity of crocodiles	Zimbabwe and neighbouring countries	Pooley et al., 2020	Low
Bull shark (*Carcharhinus leucas*)	Ocean warming	Poleward range expansion	Coastlines worldwide	Bangley et al., 2018; Niella et al., 2020; Rider et al., 2021	High
Great white shark (*Carcharodon carcharias*)	Ocean warming	Northern range extension	Northwestern Atlantic	Bastien et al., 2020	Low
Tiger (*Panthera tigris*)	SLR & extreme weather events	Humans forced to enter deeper into forests for livelihoods	Sundarbans mangrove forest	Das, 2018; Dasgupta et al., 2017; Ghosh and Roy, 2022	High
	SLR & extreme weather events	Reduction of tiger habitat forces them into closer contact with humans.	Sundarbans mangrove forest	Aziz et al., 2013; Haque et al., 2015	High
	Environmental stress (droughts, flooding)	Loss of prey; short-term displacement leading to tigers intruding into human-dominated areas	Across tigers' range	Haque et al., 2015; Inskip and Zimmermann, 2009	High
	Human climate change mitigation efforts	Hydropower developments changing ecosystem	Arc Terai, Nepal	Griffioen et al., 2020	Low
	Higher average temperatures	Shift in tiger movement, often utilising agricultural land	Vidarbha, India	Habib et al., 2021	Low
Leopard (*Panthera pardus*)	Environmental stress (droughts, flood)	Loss of prey; short-term displacement leading to leopards intruding into human-dominated areas	Leopard's range	Inskip and Zimmermann, 2009	Low
Lion (*Panthera leo*)	Drought	Livestock herders encroaching on protected areas	African grasslands	Hazzah et al., 2013; Packer et al., 2019	Low
Jaguar (*Panthera onca*)	Drought	Loss of natural prey brings jaguars into closer human contact in search of livestock/ anthropogenic food sources and may even trigger predatory attacks	South America	Hoogesteijn and Hoogesteijn, 2008; Neto et al., 2011	Low
Brown bear (*Ursus arctos*)	Higher seasonal temperatures	Shortened hibernation period	Across species'range	Evans et al., 2016	High
American black bear (*Ursus americanus*)	Higher seasonal temperatures	Shortened hibernation period	Across species'range	Johnson et al., 2018	High
	More intense and prolonged droughts	Increased bear encounters as bears seek out anthropogenic food sources in response to drought-induced shortages in natural food	Western USA	Baruch-Mordo et al., 2008; Klip, 2018	Low
Asiatic/Himalayan black bear (*Ursus thibetanus*)	Higher seasonal temperatures	Shortened hibernation period	Across species'range	Zahoor et al., 2021	High
Polar bear (*Ursus maritimus*)	Loss of Arctic sea ice	Change in seasonal migration, polar bears spend more time on land	Arctic	Davis and Pagano, 2021; Gormezano and Rockwell, 2013a, 2013b	High
Coyote (*Canis latrans*)	Increasing drought	Coyotes attracted to urban and suburban areas by anthropogenic food and water sources	North America	Elliot et al., 2016; Fox, 2006	High

(*continued on next page*)

Table 3 (*continued*)

Animal	Climate-related driver	Climate change effects on WIH	Affected region	Scientific sources	Confidence level
Hyena (*Hyanidae*)	Drought	Increased attacks on livestock and even humans as natural food sources dwindle	Botswana, Zimbabwe	William et al., 2017	Low
African elephant (*Loxodonta africana*)	Drought	Livestock herders encroaching on protected areas	African grasslands	Goldman and Riosmena, 2013; Hazzah et al., 2013; Shaffer et al., 2019	High
		Elephants encroach on human areas in search of food and water	Southern Africa	Mariki et al., 2015; Shaffer and Naiene, 2011	High
Asian elephant (*Elephas maximus*)	Changes to monsoon	Range extension into higher altitudes in the Himalayas	South-East Asia	Kanagaraj et al., 2019	High
	Drought	Increased encroachment of elephants into human habitats in search of food and water	South-East Asia	Campos-arceiz et al., 2009; Sukumar, 2006	High
Wild boar (*Sus scrofa*)	Higher average temperatures	Wild boar's range in Asia expands north and north-eastward	North-East Asia	Markov et al., 2019	High
Kangaroos (*Macropodidae*)	Drought	Kangaroos seek out greener vegetation along roads, increasing the risk of vehicle collisions	Australia	Dean et al., 2019; Lee et al., 2004	High
Hippopotamus (*Hippopotamus amphibious*)	Drought	Increased competition for water with humans	Hippopotamuses' African range	Kendall, 2011; Stears et al., 2019	Low
	Flood	Hippos can move further into human spaces	Hippopotamuses' African range	Ladan et al., 2014; Stears et al., 2019	Low
Emu (*Dromaius novaehollandiae*)	Drought	Emus seek out greener vegetation along roads, increasing the risk of vehicle collisions	Australia	Dean et al., 2019; Ellis et al., 2016	High

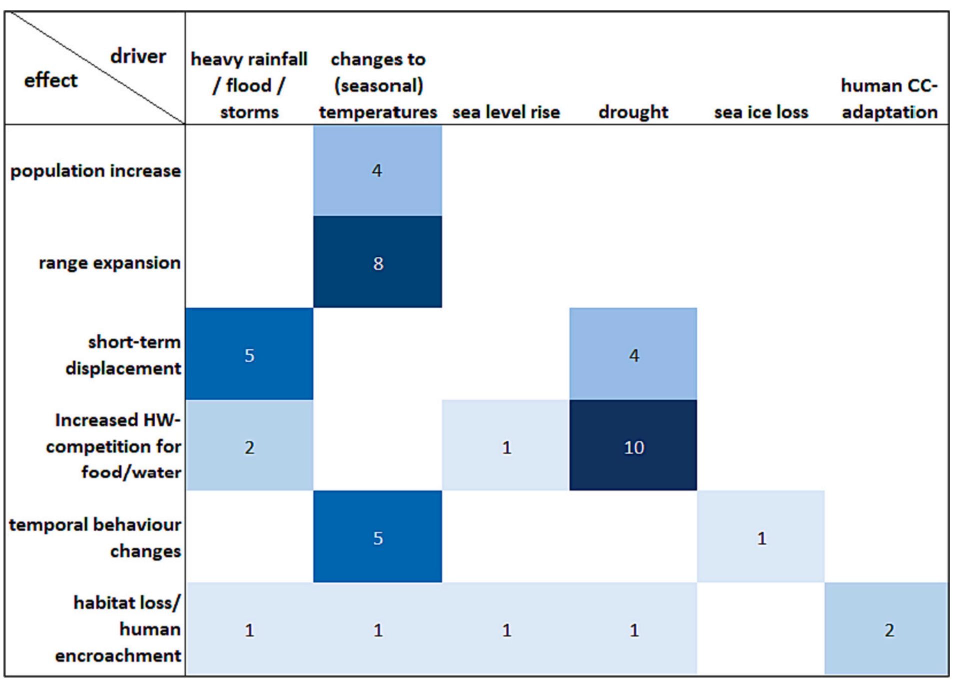

Fig. 3. Frequency of climate-related drivers and -effects in verified cases. Cases can be counted several times if they fall into more than one category.

experience or which they are not expecting to be active in this season. Human behaviour has a significant impact on the risk of dangerous outcomes in wildlife encounters (Penteriani et al., 2016), and humans who are unprepared for such confrontations may take fewer precautions to avoid and show less competence in responding to dangerous incidents. Temporary displacement of wildlife during storms, floods and wildfires may have a similar effect, as animals may be displaced to locations where their presence is not expected by humans. In the case of range expansion, dangerous animals also present a novel hazard in the regions they newly colonise, and it may even be argued that changes in the spatial and temporal behaviour patterns of wildlife presents a modification of the hazard they pose, e.g. in nature, scope or intensity.

The trends on resource competition and temporary displacement of wildlife support the findings of Abrahms (2021), who asserts that "acute climate events can cause rapid changes in resource availability (…), leading to increased co-occurrence and competition" (p.484) of humans and wildlife. Drought-driven increases in confrontations with wildlife are not a new phenomenon, with, for example, dangerous incidents involving lions in Gir, India, rising from an average of 7.3 per year to 40 per year following a severe drought in 1987–1988 (Saberwal et al., 1994). An increase of drought-driven WIH worldwide is therefore not surprising, considering the expected increase in drought frequency and intensity due to climate change (Cook et al., 2018). Our case examples illustrate that increased co-occurrence of humans and dangerous wildlife can also be caused by other extreme events such as flooding (e.g. Ladan et al., 2014) and storms (e.g. Dasgupta et al., 2020), which are increasing in overall frequency and intensity across regions (IPCC, 2022).

In contrast, the trends on range expansion and temporal behaviour patterns are driven by slow-onset changes in local climates, specifically the gradual increase of average temperatures. This process is leading to a geographical shift in habitat types and consequently a geographical redistribution of global biodiversity (Pecl et al., 2017), including species that can pose a risk to humans. Alongside the long-term phenomenon of climate change driven range retraction and -expansion, animals are also acutely impacted by the ongoing changes in the local climates they inhabit. Global-scale studies on climate change impacts on biodiversity indicate a change in the timing of seasonal activities of animals due to altered timing of climatic events (Garcia et al., 2014; Parmesan and Yohe, 2003).

Notably, the identified trends are based mainly on findings of changes for wildlife, while human responses to climate change were largely neglected in the analysed cases. Human responses to climate change can however strongly increase their exposure to dangerous wildlife. For example, as climate change driven sea level rise and ecosystem degradation progress, residents of the Indian and Bangladeshi Sundarbans increasingly venture into the forest to supplement their threatened livelihoods, putting themselves at higher risk of confrontations with tigers (Ghosh and Roy, 2022). A better understanding of climate-induced changes in both human and animal behaviour and their potentially dangerous interactions is therefore an important future research direction.

We showed that climate change-induced changes to WIH affect all elements of risk posed by physically dangerous wildlife, altering animal characteristics (hazard), geographically and temporally shifting WIH in a way that can increase human unpreparedness (vulnerability) and bringing humans and wildlife into closer contact (exposure). As wildlife hazards are still largely neglected in disaster risk reduction (Gaillard et al., 2019), increased risk of harm through dangerous wildlife is rarely incorporated into climate risk analyses. Even when wildlife is acknowledged as a risk factor, WIH's susceptibility to climate change is often overlooked. For example, a climate vulnerability assessment from Nepal categorized wildlife attacks as a "non-climatic hazard" (Maharjan et al., 2017, p. 10). This is problematic because of its overlap with other climatic pressures, in particular on rural communities relying on small-scale agriculture and economic activities in nature. For example, analyses of dangerous confrontations with tigers in the Sundarbans found that fishermen, crab collectors, honey collectors and woodcutters are at the highest risk (Inskip et al., 2013; Das, 2018). Similarly, studies on crop raiding have found that small-scale and subsistence agricultural villages most frequently interact negatively with elephants (Dublin and Hoare, 2004; Wilson et al., 2015), though crop raiding patterns do not automatically translate to those of human injury through elephants (Sitati et al., 2003). In this way, climate-driven increases in WIH often affect those strongest who are already burdened most by other climate change impacts. Developing states experience both particularly high levels of human-wildlife conflict (Seoraj-Pillai and Pillay, 2017; WHO, 2021) and of climate vulnerability (IPCC, 2022). Yet, this pattern is not limited to small-holder farmers but also includes, for example, indigenous communities being at the frontlines of rising conflicts with polar bears in the Arctic (e.g. article 191; 208). For these regions in particular, increasing physical risk posed to humans by wildlife can pose a serious and insufficiently considered climate change driven risk.

4.3. Implications for wildlife conservation

Aside from range expansion, the risk-increasing trends identified in this paper are largely due to climate-driven stressors disrupting these species' ecology. The increased negative interactions between humans and wildlife thus not only poses a risk to human health, but also bring further negative consequences for the animals involved. Preventative and retaliatory killings, especially of carnivores, are a common result of human-wildlife conflict across the globe (Chinchilla et al., 2022), with UNEP describing human-wildlife conflict as "one of the greatest threats to wildlife species" (UNEP, 2021a). This dynamic cements the position of climate-driven increases in WIH at the intersection between the climate- and the biodiversity crisis, and illustrates the importance of considering climate change scenarios in future efforts to reduce WIH and protect both human and wildlife. In an interview on tigers in the Sundarbans in article 117, an expert vividly describes this issue, stating that "(...) the big cats will also be forced to move north, and when this happens, people will kill them. It's an ecological cul-de-sac.". This assertion that tigers must eventually abandon their entire habitat in the Sundarbans is corroborated by Mukul et al.'s (2019) prediction that "by 2070, there will be no suitable tiger habitats remaining in the Bangladesh Sundarbans".

Although there is general agreement on the pressing need to safeguard wildlife in the ongoing biodiversity crisis, scientific research into adapting wildlife conservation to climate change is still lagging, especially so for reducing human-wildlife conflict (LEDee et al., 2021). The results of our study clearly indicate that patterns of negative interactions with wildlife are already changing with the warming climate, implying that data from previous decades may no longer be a reliable basis for wildlife management. Research into the effects of climate change on human-wildlife interactions is therefore necessary. The four overarching trends of climate change driven increase in WIH identified in this study already indicate potential areas of conflict for further investigation. However, climate change effects may be locally distinct, making research into ongoing developments and potential future changes for respective target regions and -species vital for the development of conservation schemes that can safeguard both wildlife and the humans that live alongside them.

4.4. Conclusions and outlook

It is evident that climate change can considerably increase the physical risk that wildlife pose to humans. While the form and extent of this effect is subject to case-specific factors, the overarching trends that we identify as affecting a variety of different animals and geographic regions indicate a global pattern of climate-driven increase in wildlife-induced physical harm to people. Considering these trends, we cannot expect local and regional WIH and wildlife risk to remain the same in the future. More research into climate change's impact on WIH at local, regional and global levels is therefore necessary to fully understand the dynamics of this phenomenon. As climate change increases dangerous interactions between humans and wildlife, both sides stand to lose. In order to develop and implement strategies which can enable humans and wildlife to share rapidly changing landscapes, it is vital to understand and take into account the effect of climate change on WIH.

CRediT authorship contribution statement

Amy Newsom: Conceptualization, Methodology, Investigation, Writing – original draft, Visualization, Formal analysis. **Zita Sebesvari:** Conceptualization, Writing – review & editing, Supervision. **Ine Dorresteijn:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Ine Dorresteijn reports financial support was provided by Dutch Research Council (NWO).

Data availability

The full datasheet containing all information coded from media articles in the analysis is made available as Appendix III.

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Appendix A. Image sources

For Fig. 1a-d, the following open-access creative commons image were used in abridged form:

- Elephant icon: https://pixabay.com/de/illustrations/elefant-symbol-elefanten-symbol-5569069/
- Bird icon: https://thenounproject.com/term/bird/17463/
- Alligator icon: https://pixabay.com/de/illustrations/alligator-gefährlich-reptil-5912493/
- Shark icon: https://pixabay.com/de/vectors/hai-rachen-silhouette-fische-4455974/
- Bear & coyote: https://openclipart.org/detail/228073/woodland-animals-silhouette
- Big cat: https://pixabay.com/de/vectors/tiger-raubtier-katze-großkatze-1394584/
- Hyena: https://pngimg.com/image/31460
- Spider: https://pixabay.com/de/illustrations/spinne-spinnen-spinnentier-3369690/
- Snake: https://commons.wikimedia.org/wiki/File:Coronella_austriaca_female_transparent.png
- Jellyfish: https://www.maxpixel.net/Underwater-Orange-Ocean-Sting-Sea-Jellyfish-4283453

Appendices I-III. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2023.110255.

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