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1 ABSTRACT

Human-wildlife conflict is a broad term that encompasses all negative interactions between humans and wildlife. The root of most conflict is the shared need for vital resources such as food, water and space. In the recent decades, climate change has forced people and wildlife to share increasingly crowded spaces and rapidly depleting resources. As a result, wildlife is depending more on agricultural and urbanised areas to survive. This can place communities' livelihoods and security at risk and, as such, incidences of retaliatory killings have become more frequent in many locations. To minimize the risk to both wildlife and people, management strategies need to be established that enable communities to co-exist with wildlife.

Although human-wildlife conflict is a well-researched area of conservation biology, the impact of climate change on conflict has, to a large extent, been ignored. This is particularly true when compared to other driving factors, such as urbanisation. This results in a sizable challenge when looking at the construction of effective management strategies, as the changing climate will inevitably affect global conflict in a myriad of complex ways. This study analysed current literature to identify areas where climate change will impact the driving factors of human-wildlife conflict and then highlighted global hotspots where climate change will more than likely lead to increased conflict in the future. The regions identified as future conflict hotspots were heavily correlated with lower-income regions, and where many resident communities already have very limited access to resources and damage compensation. Effective management strategies are especially vital to these communities so that they will be able to deal with elevated levels of conflict in the future.

2 INTRODUCTION

Human-wildlife conflict (hereafter HWC) - defined as negative interactions that arise as people and animals come into close proximity - is a global threat to the welfare of both humans and animals (Nyhus 2016). The predominant cause of conflict is competition for shared, and often limited, resources. As people increasingly encroach into the planet's wild places, the severity and frequency of conflicts is escalating, resulting in it being a predominant concern for wildlife management globally (Anand and Radhakrishna 2017). Conflict can have many forms, with direct and indirect consequences for human health, livelihoods, and security. These consequences can include – but are not limited to – damage of crops, predation of livestock and attacks on humans, which can often lead to retaliatory killings of wildlife (Abrahms 2021). In some cases, retaliation has led to severe population declines. Species such as the critically endangered, endemic Javan leopard are exceptionally susceptible to conflict-driven killings due to their already small population size and fractured habitat (Wibisono *et al.* 2018). Keystone (Merson *et al.* 2019), protected (Gomez *et al.* 2021), and poster species (Ontiri *et al.* 2019) are all at risk from HWC, nearly always because they threaten livestock or food supplies.

An equally important but often less considered aspect of HWC is the transmission of zoonotic diseases, which are a considerable health risk for not only humans, but livestock and wildlife as well (Nyhus 2016). A 2010 report by the World Health Organization (WHO) (WHO 2011) estimated that ~60% of human pathogens are zoonotic in origin. The Coronavirus disease (COVID-19) has been the most significantly destructive zoonotic pandemic in decades, being responsible for the deaths of >6,200,000 people globally between January 2020 and April 2022 (WHO 2022).

Despite HWC being a problem for wildlife management worldwide, countries in developing areas of the world can be disproportionately affected. Studies to date have reflected that low-income and medium-income countries (LICs and MICs) are predominantly affected by conflict resulting in damage to food resources, whereas property damage and human injury were focal issues in high-income countries (HICs) (Peterson *et al.* 2010; Seoraj-Pillai and Pillay 2017). Moreover, whilst HICs typically have the resources to deal with the damage caused by HWC, the economic damage to crops and livestock can drain the financial and human resources of developing countries (Anand and Radhakrishna 2017). This consequently can lead to a reduction in the effectiveness of government and state-run aid, and broaden the economic and societal gap between classes (Anand and Radhakrishna 2017). The rural communities of LICs and MICs are often those with the fewest resources available, and the least means to protect livestock and crops from problematic wildlife (Seoraj-Pillai and Pillay 2017). Without sufficient wildlife management strategies, planning and education, these communities are more likely to respond to the threat of wildlife to their livelihoods and safety through retaliatory hunting of species, often including species that are endangered or vulnerable (Torres *et al.* 2018).

A number of the species identified in HWC research are charismatic megafauna, with mega-herbivores being cited in 83% of food resource damage publications, and mega-carnivores being twice as likely to be cited as a species that poses a threat to human safety than any other species group (Peterson *et al.* 2010). This focus on megafauna in research is reflective of the opinion of many communities, who tend to focus blame on the intermittent but devastating events of large mammal damage rather than the consistent but low-level damage of smaller mammals, insects and birds, despite this often causing more serious damage cumulatively (Anand and Radhakrishna 2017).

Human retaliatory actions can be devastating. Despite 60% of the largest mega-herbivores (≥100kg) being threatened by extinction (Ripple *et al.* 2015), the damage they can cause through consumption and trampling has led them to be persecuted (Nyhus 2016). Hunting and extirpation of carnivores has resulted in severe range reductions for species such as lions (*Panthera leo*), tigers (*Panthera tigris*) and wolves (*Canis lupus*) (van Eeden *et al.* 2018). In some cases of HWC, illegal means of wildlife control such as poisoning have been employed, with indiscriminate effects on wildlife including endangered and vulnerable non-target species (Torres *et al.* 2018). However, care must be taken when being disparaging about these actions, as the threat to people already living subsistence lifestyles is far greater than to those with easy access to resources. Without viable alternatives in place for these communities, people will continue to do what is needed to protect their livelihoods and welfare.

Not only are poorer, rural communities often those most at risk from serious HWC damage, they are also some of the communities most at risk from climate change (Tol 2018). As the climate changes, the factors driving HWC will be affected in a myriad of ways. Impacts may range from decreasing availability of water resources to the movement of species tracking their habitats across changing landscapes. The effects of climate change are already being recorded, with an increase of extreme climate events such as droughts (Trenberth 2011) and marine heatwaves (Samhouri *et al.* 2021). Although there is a general acknowledgement and acceptance that HWC will be affected, very few publications directly explore the link. This gap in the research is even more stark when compared to the amount of research into other driving factors of HWC, such as the increasing human population, urbanisation, habitat degradation and increasing demand for resources (Mukeka *et al.* 2018).

With climate model predictions suggesting global surface temperatures will rise by anything from 1.2°C to 7.2°C by the end of the 21st century (Fan *et al.* 2020), the necessity for understanding the relationship between climatic conditions and conflict is absolutely vital. In this paper, I expect to identify correlations between climate change and driving factors of HWC, and to highlight global hotspots where climate change will more than likely lead to increased conflict in future. I hypothesise that the majority of these hotspots will occur in regions of the world that are lower income, so insight into the complex challenge of HWC under climate change will help inform future management, education, and compensation efforts.

3 Methodology

Relevant literature was collated from systematic searches on the Google Scholar cross-reference database. This database was used as it provides wide-ranging and comprehensive coverage of scholarly articles. To find relevant articles, 11 keywords were used individually and in various combinations (Table 1). Searches were limited to literature published between 2010 and 2022; detailed study was made of the selected articles and literature cited in their bibliographies. Resources selected for use in analysis were peer-reviewed journal articles, reports and reviews that were fully accessible through Cardiff University's Library Open Access license. Some of the keyword combinations used yielded results that predominantly referred to impacts on humans only; these articles were only used in analysis if the term "human-wildlife conflict" could be found within the text. Any study that referred to "small" regions (defined as regions smaller than a country) were not included in the initial analysis but, when appropriate, were cited in the discussion. Articles that referenced specific species were only used in analysis if there were ≥3 studies on the species within the first page of results on Google Scholar. Papers that were specific to plant species were not included, other than publications on how vegetation cover may be affected under the food scarcity section of this study.

Table 1: Table displaying the keywords used for searching the Google Scholar database, and the number of scholarly publications found from those searches that were then used in analysis.

Keywords Used in Search	**No. Publications Obtained**
"Human-wildlife conflict" AND "climate change"	10
"Drought frequency" AND "climate change"	8
"Water scarcity" AND "climate change"	6
"Flood frequency" AND "climate change"	5
"Food scarcity" AND "climate change"	1
"Vegetation scarcity" AND "climate change"	2
"Prey scarcity" AND "climate change"	5
"Shrinking habitats" AND "climate change"	1
"Range contractions" AND "climate change"	8
"Range shifts" AND "climate change"	8

4 RESULTS

In total, 54 results from the literature search were included in the analysis. All publications analyzed were published between 2004 and 2021, with 98.1% (n=53) published between 2010 and 2021. The keyword combinations used to search Google Scholar were split into three wider categories: the impact on water scarcity, the impact on food scarcity and the shrinking of habitats. The results of the keyword combination "Human-wildlife conflict" AND "climate change" were used in analysis across all three categories (Table 2). Keyword searches in the food scarcity section of the paper yielded the fewest results, as the majority of publications found from these searches referred exclusively to the economic impact of climate change on human food resources and crop yields. Though it is acknowledged that this could have impacts on HWC due to strain on resources for communities, the relationship between crop yields and conflict is not considered here. 53.7% (n=29) of all search results were included in the water scarcity analysis, then 50% (n=27) were included in analysis of shrinking habitats and only 33.3% (n=18) were used in analysis of food scarcity.

Table 2: The number of publications analyzed in each section of the study, and the keywords that yielded the results.

Section	Keyword Combinations	Total No. Publications
Water Scarcity	"Human-wildlife conflict" AND "climate change"	29
	"Drought frequency" AND "climate change"	
	"Water scarcity" AND "climate change"	
	"Flood frequency" AND "climate change"	
Food Scarcity	"Human-wildlife conflict" AND "climate change"	18
	"Food scarcity" AND "climate change"	
	"Vegetation scarcity" AND "climate change"	
	"Prey scarcity" AND "climate change"	
Changing Habitats	"Human-wildlife conflict" AND "climate change"	27
	"Shrinking habitats" AND "climate change"	
	"Range contractions" AND "climate change"	
	"Range shifts" AND "climate change"	

Phrase parameters were designed for each section of the study to identify consistent findings and conclusions across current research. The phrase parameters were selected to highlight global hotspots of high risk where climate change will likely lead to a significant increase in HWC. Using selected words and phrases pertaining to these parameters (Table 3), the Word Search function was then used to quantify how many publications in the analysis identified these themes in their studies.

Table 3: The words and phrases chosen to identify consistent findings across current publications. The specific words and phrases were selected to investigate trends within phrase parameters. The phrase parameters were designed to identify global regions at high-risk of climate change leading to significantly increased HWC.

Section	Phrase Parameters	Words/Phrases Searched For
Water Scarcity	Drought hotspots	Drought hotspot
		Drought risk
		High risk of drought
	Flood hotspots	Flood hotspot
		Flood risk

		High risk of flooding
	Poor communities disproportionately affected	Less developed
		Poorer communities
		Disproportionate effect
		Low income
Food Scarcity	Vegetation productivity	Productivity
		Less vegetation
	Prey scarcity	Prey availability
		Competition
	Marine heatwaves	Marine heatwave
		Sea temperature
Changing Habitats	Movement to higher altitude	Altitude
		Elevation
	Movement to higher latitude	Latitude
		Poleward
	Species traits as indicators	Species traits
		Life history traits
	Polar degradation	Polar regions
		Sea ice

Of the 29 publications analyzed under the water scarcity section of this paper, the most frequently occurring trend was the locations of future drought hotspots under climate change, which were identified in 31.0% (n=9) publications, whereas the locations of potential future flood hotspots were identified in 20.7% (n=6) of publications. 13.8% (n=4) of publications drew conclusions that climate-induced, water availability-associated risks disproportionately affected lower income or developing areas of the world when compared to higher income regions (Figure 1).

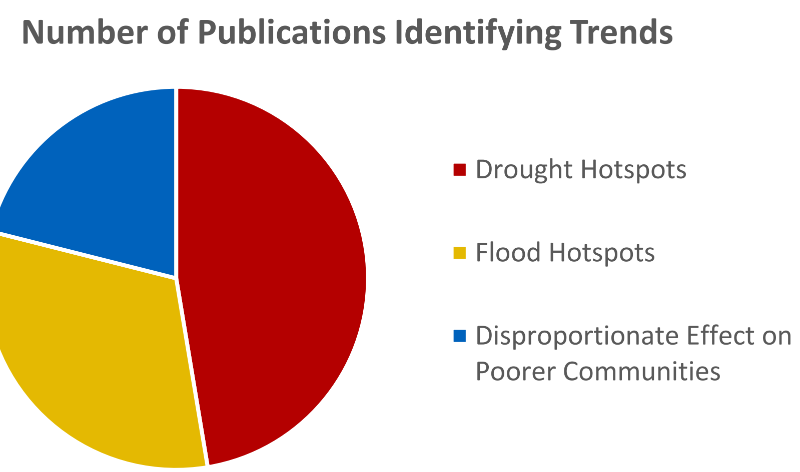

Figure 1: The number of publications in the water scarcity section of the analysis that contained the words and phrases used to identify trends in the research. Trends investigated for water scarcity were the locations of future drought and flood hotspots under climate change and the disproportionate affect climate-induced, water availability-associated risks will have on poor communities.

The most frequent trend across the 18 publications analysed under food scarcity was the impact climate change will have on the availability and ranges of prey species, which was identified in 50% (n=9) of publications. The impact of climate change on marine heatwaves was discussed in 33.3% (n=6) of publications, and vegetation productivity and availability was discussed in 27.8% (n=5) of publications (Figure 2).

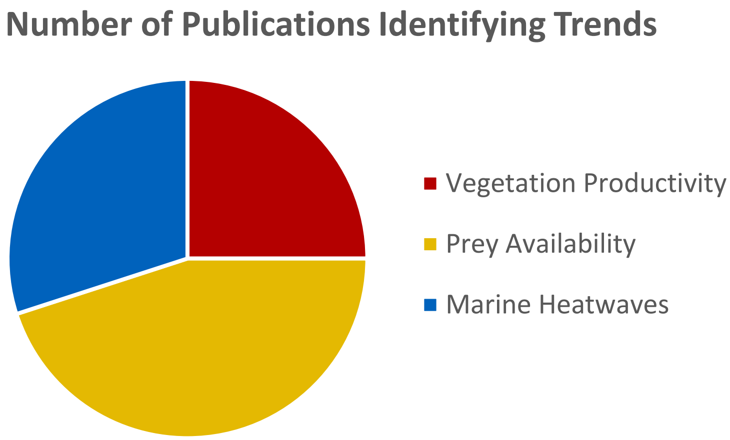

Figure 2: The number of publications in the food scarcity section of the analysis that contained the words and phrases used to identify trends in the research. Trends investigated for food scarcity were the impact of climate change on vegetation productivity, the availability and range of prey species and marine heatwaves.

The discussion of species ranges moving to higher latitudes (poleward), was the most frequently discussed trend within the changing habitats analysis and was a finding in 40.7% (n=11) of the 27 studies in analysis. The movement of species to higher altitudes and the validity of using species' life history traits as indicators of range-tracking ability were both trends mentioned in 30.0% (n=8) of publications (Figure 3), whilst the degradation and fragmentation of polar habitats was a finding in 25.9% (n=7) of studies.

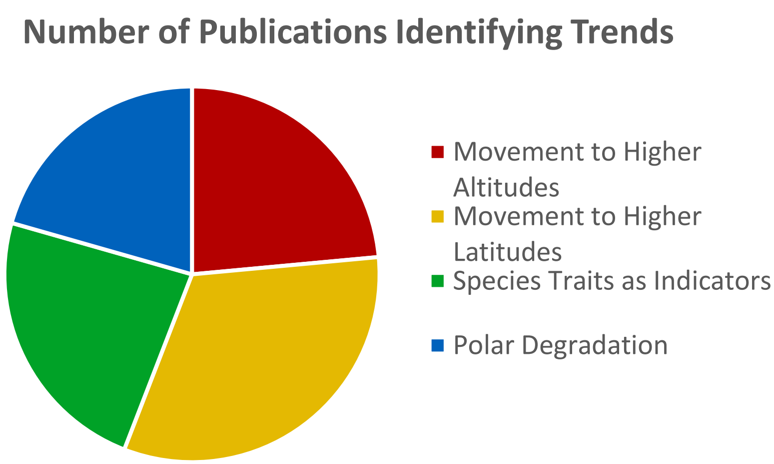

Figure 3: The number of publications in the changing habitats section of the analysis that contained the words and phrases used to identify trends in the research. Trends investigated for shrinking habitats were the movement of species' ranges to higher

latitude and altitudes, how good species' traits are as indicators for their ability to track their range shifts and the decline of polar habitats.

5 Discussions

5.1 Water Scarcity

Understanding how climate change will affect water availability on a global scale is crucial to understanding the relationship between climate and conflict, as droughts and floods can be catastrophically destructive to food resources, destroy viable habitats and cause high peaks in disease transmission (Lau *et al.* 2010; Abrahms 2021). Droughts are predominantly associated with dry spells and high temperatures, whereas floods are typically caused by high levels of precipitation, often caused by extreme weather events such as tropical storms, cyclones and thunderstorms (Schewe *et al.* 2014). The water-holding capacity of the atmosphere increases with temperature, but as global relative humidity is unlikely to change drastically, excess moisture in the atmosphere is likely to fall as increased precipitation levels (Trenberth 2011). The effect on precipitation is, however, determined by the latitude of the region, with tropical and subtropical regions generally experiencing a decrease in precipitation and an increase in droughts (Schewe *et al.* 2014; Winsemius *et al.* 2018), and higher, more temperate latitudes seeing a general increase in precipitation and flooding events (Trenberth 2011).

All nine publications that discussed drought hotspot locations identified sub-Saharan Africa (and in particular the Sahel region) as an area at extremely high risk of increasing drought frequency under multiple climate change models (Trenberth 2011; Müller *et al.* 2014; Schewe *et al.* 2014; Spinoni *et al.* 2014, 2019; Yoo *et al.* 2016; Dai *et al.* 2018; Winsemius *et al.* 2018; Christian *et al.* 2021). Other hotspots included the Mediterranean (Trenberth 2011; Schewe *et al.* 2014; Spinoni *et al.* 2014, 2019; Dai *et al.* 2018; Christian *et al.* 2021), south-eastern Asia (Trenberth 2011; Spinoni *et al.* 2014; Yoo *et al.* 2016; Christian *et al.* 2021) and equatorial South America (Schewe *et al.* 2014; Dai *et al.* 2018; Christian *et al.* 2021). Moreover, these effects are compounded by increased water consumption as a result of continuous human population growth. This alone has led to a global intensification of drought frequency of 27% (Wada *et al.* 2013). In regions such as the Sahel which are already dry, the resultant aridification from climate change will inevitably lead to desertification and land degradation (Mukheibir 2010; Vogt and Barbosa 2018). This will lead to increased food and economic insecurity in rural communities as crop yields decline and livestock predation increase. This was clearly observed during the severe 1986-1988 drought in India. Declines in vegetation led elephants to agricultural land, where they caused huge damage to crops, caused multiple fatalities, and livestock predation by lions rose by more than 600% (Bhatt *et al.* 2007).

Of the six publications identifying potential flood hotspots under climate change, North America (Trenberth 2011; Schewe *et al.* 2014; Dai *et al.* 2018) and Eurasia (Trenberth 2011; Schewe *et al.* 2014; Dai *et al.* 2018) were both identified as hotspots. Many regions of Africa were also considered as at risk of increased flooding, but the regions were not consistent across studies, ranging from eastern African countries such as Ethiopia and Kenya (Schewe *et al.* 2014; Winsemius *et al.* 2018), to tropical regions such as the Congo basin (Dai *et al.* 2018) and to Northern countries such as Egypt (Winsemius *et al.* 2018). The reason for this inconsistency may be that one of the greatest driving factors for flood risk is land use rather than region (O'Donnell and Thorne 2020). Increased flood risk to urban areas was identified as a major potential challenge in 50% of the flood hotspot publications (Müller *et al.* 2014; Winsemius *et al.* 2018; Yang *et al.* 2021). Increasing precipitation levels associated with climate change combined with increasing urbanization, highlights the potential for the urban flood threat to become one of the greatest challenges facing management strategists today (O'Donnell and Thorne 2020).

Urban floods are particularly dangerous because they are often hotspots for outbreaks of disease, including zoonotic pathogens. One of the most prevalent water-borne zoonotic diseases is Leptospirosis, a blood infection that is typically spread by contact with animal urine (Lau *et al.* 2010). The risk of Leptospirosis outbreaks increase drastically after flooding, as contaminated water can expose huge numbers of people to the infection (Schneider *et al.* 2017). This is the case in countries at all levels of wealth, and massive peaks in Leptospirosis have been reported after flooding in the Philippines (Matsushita *et al.* 2018), Australia (Smith *et al.* 2013), Bangladesh (Morshed *et al.* 1994), Pakistan (Ijaz *et al.* 2018), France (Socolovschi *et al.* 2011) and others. Despite Leptospirosis affecting communities worldwide, the highest mortality rates occur in poor, tropical regions where poor sanitation, housing and healthcare create the conditions for epidemics to flourish (Costa *et al.* 2015).

Those most likely to live in flood- and drought-prone areas are poor people, and households affected by floods and droughts are the most likely to fall below the poverty line (Winsemius *et al.* 2018). Of the four articles explored in analysis that discussed the unequal distribution of risk between economic groups, all four identified that in order to cope with future drought and flood events, LICs and MICs will require significant support to replace properties and resources (Mukheibir 2010; Müller *et al.* 2014; DeNicola *et al.* 2015; Winsemius *et al.* 2018). Understanding which regions are at the highest risk of climate-induced conflict will enable pre-emptive management strategies to be put into place before they are needed and mitigate losses to already vulnerable communities.

An example of a community that could face substantial increases in HWC because of climate-induced changes in water availability would be the agropastoral groups in Kenya. The predominant cause of conflict in these communities is crop damage and human attacks by the African elephant (*Loxodonta africana*) (Mukeka *et al.* 2018). The majority of crop damage currently occurs during the dry season, when water sources are drastically reduced and elephants are forced outside the boundary of their protected areas to find water, often leading them to areas of agriculture and pastural livestock (Mukeka *et al.* 2019). As this analysis has identified Kenya as being at high risk of being both a potential drought (Trenberth 2011) and flood (Winsemius *et al.* 2018) hotspot, conflict could be affected throughout the year. If the droughts become more severe and frequent in the dry season, human-elephant conflict over water resources will be intensified, and loss of crops will be even more devastating to local communities due to reduced crop yields. If flooding becomes a problem during wet season, this will severely impact food resources for elephants, humans and livestock, so competition between humans and wildlife will be high (Mukeka *et al.* 2018). Not only that, but as human populations residing in elephant ranges have been found to be some of the poorest and most vulnerable communities globally (Nyumba *et al.* 2020), outbreaks of water-borne zoonotic pathogens are not only very likely to occur – but are likely to have high mortality rates and be devastating for those populations (Costa *et al.* 2015). Informed management plans for these regions will be vital to ensure they are able to cope with the pressures of climate change and increased HWC in the future.

5.2 Food Scarcity

Changes in precipitation and water availability have huge ramifications for vegetation growth and productivity. Increasing drought event frequency caused by climate change will lead to major reductions in global primary production, which, in turn, will positively feed into increasing global temperatures through a feedback loop as less carbon is sequestered by vegetation (Xu *et al.* 2019). Increased global temperatures also impact the function of the Rubisco enzyme, lowering the efficiency of photosynthesis by changing the enzyme's shape and preventing it from fixing carbon dioxide (CO_2) (Bytnerowicz *et al.* 2022). In drier regions, plants can become "stressed", which also limits the amount of CO_2 they are able to absorb for photosynthesis (Whitmore and Whalley 2009). Despite these factors affecting vegetation productivity negatively, the changing climate may have unforeseen benefits for plants as well. As CO_2 increases in the atmosphere from anthropogenic sources, this may actually benefit plants through an effect known as "carbon fertilization" (Drake *et al.* 2017). This can actually lead to increased growth rates (de Graaff *et al.* 2006), but the overall sensitivity of plant species to climate change will ultimately be determined by the plants' phenology, and this can vary dramatically between biomes (Richardson *et al.* 2013).

Of the five studies exploring the impact of climate change on vegetation, three discussed the observation that changing temperatures would lead to changing vegetation communities. Generally, all vegetation boundaries are shifting to higher elevations where temperatures are cooler (Xu *et al.* 2019; Trouwborst and Blackmore 2020; Abrahms 2021). This also means that vegetation that is adapted to colder environments is in decline as temperatures rise (Xu *et al.* 2019), forcing wildlife that relied on these plants to move to lower altitudes where they risk coming into contact – and conflict – with people. This can be seen with blue sheep (*Pseduois nayaur*) in the Trans-Himalayan region of Nepal (Aryal *et al.* 2014). As the vegetation blue sheep have historically foraged upon has declined in the past few decades, they have steadily moved to lower elevations and as such have come into conflict with the local agropastoral communities, where they consume crops and negatively impact the livelihoods of the community (Aryal *et al.* 2014).

Unfortunately, this has also led their iconic predator – the snow leopard (*Panthera uncia*) – also moving to lower elevations (Aryal *et al.* 2016). They pose threats to both the communities inhabitants as well as their livelihoods, as they predate on livestock (Aryal *et al.* 2014). Retaliatory killing of the snow leopard over livestock predation is a major issue in the area, and is directly responsible for 55% of the anthropogenic-caused snow leopard deaths in the region (Hillard 2005; Nowell *et al.* 2016; Khanal *et al.* 2020).

The impact of climate change on prey availability - and the consequences this may have on HWC globally – is well discussed within the literature, appearing in 77.8% of the articles analyzed under the "prey scarcity" phrase parameter of this study (Nyhus and Tilson 2004; Valeix *et al.* 2012; Smith *et al.* 2017; Torres *et al.* 2018; Trouwborst and Blackmore 2020; Abrahms 2021; Sharma *et al.* 2021). When prey populations are affected by climate change, whether this be from extreme weather or climate-induced range shifts and disease outbreaks, conflict with people becomes more likely. This is particularly true of large carnivores such as tigers (Nyhus and Tilson 2004), wolves (Trouwborst and Blackmore 2020) and bears (Smith and Herrero 2018), who often turn to livestock and domesticated animals as an alternative prey source, leading to retaliatory killings and bad relationships between wildlife and people.

Another hotspot for climate-induced shifts in prey availability is in the marine environment. Marine heatwaves are periods of anomalously high sea temperatures lasting longer than 5 days that are confined to specific regions (Hobday *et al.* 2016). These temperature changes can cause species' distributions to shift, which can have knock-on consequences for entire marine food chains (Smale *et al.* 2019). This, in turn, can consequentially affect HWC by limiting prey available to marine predators and seabirds and forcing them to look elsewhere for food, often at marine fisheries or around fishing boats where they can become entangled in nets (Samhouri *et al.* 2021). Of the publications (n=6) included in the marine heatwaves analysis, four discussed the impact of marine heatwaves on marine predators (Crawford *et al.* 2015; Nyhus 2016; Abrahms 2021; Samhouri *et al.* 2021). The changes in ranges of predators follow shifts in the distribution of their prey species, which has followed a trend of species shifting poleward rapidly (Jacox *et al.* 2020).

The potential consequences of marine heatwaves were clearly demonstrated after the 2014-2016 northeast Pacific heatwave, which caused a shift in the distributions of krill and anchovy (Santora *et al.* 2020). As such, foraging whales such as the blue (*Balaenoptera musculus*) and humpback (*Megaptera novaeangliae*) whales experienced an onshore drift of their feeding grounds, leading to unprecedented levels of entanglement in fishing nets (Samhouri *et al.* 2021). Not only did this lead to high levels of whale mortality, it cost the US government $97.5 million in funding relief (Smith *et al.* 2021). Human lives are also threatened by marine predator range shifts, as was seen off the coast of South Africa in 1998 when warm water temperatures displaced great white sharks to areas of high human use, and unprovoked shark attacks quadrupled in that year (Chapman and McPhee 2016). As marine heatwaves continue to occur because of climate change, being able to predict how species may react will allow us to minimize losses to animal life, human life, and our economies.

5.3 Changing Habitats

Climate change is altering landscapes and habitats in a myriad of ways. As the climate affects the temperature, humidity, and community composition of habitats, species are having to track their ecological niches as their previous ranges become unsuitable. The ability of a species to track its niche is determined by its tolerance to changing environmental conditions, and the connectivity between its old and new ranges (Årevall *et al.* 2018). Key trends being observed Not as the climate changes are the shift of species' ranges to higher altitudes and latitudes, and the shrinking and fragmentation of polar habitats (Thomas 2010). Estimates have suggested that without mitigation strategies in place, 57±6% of plants and 34±7% of animals could lose 50% of their present ranges by 2080 (Warren *et al.* 2013). This sharp decline in available habitat will force many species to search for alternative food resources to exploit.

The movement of species to higher latitudes and altitudes is driven by its thermotolerance– ground at higher latitudes and altitudes is cooler, so the ranges of plants and animals shift to stay within the thermal boundaries at which they thrive (Parmesan and Yohe 2003). However, the rate at which these range shifts is happening is far faster than predicted (Chen *et al.* 2011), an occurrence that was identified in 72.7% (n=8) of the studies analyzed under the movement to higher latitudes phrase parameter, and 75.0% (n=6) of the studies analyzed under the movement to higher altitudes phrase parameter. Historically, species moving to higher altitudes is not unusual, however its current rate is unprecedented. This has been observed clearly in the American pika (*Ochotona princeps*), whose range shifted ~43 feet per decade for the majority of the 20th Century, but is now moving to higher elevations at a rate of 475 feet per decade (Beever *et al.* 2011).

These shifts in range elevation and latitude can lead to increased conflict, especially if it brings large carnivores into close proximity to people. The Eurasian lynx (*Lynx lynx*) favours cooler habitats, and has been steadily moving to higher latitudes and altitudes as much of their current range becomes more and more unsuitable for them (Mahdavi *et al.* 2020). This is problematic for local farms, as Eurasian lynx are known to predate on livestock in the French Jura Mountains (Stahl *et al.* 2001). Management of predator-livestock conflict in this area typically involves selective removal of individuals, but this has not always proved effective in reducing predation in the region (Stahl *et al.* 2001). The ineffectiveness of the current management of this issue has consequences for both the local farmers - who lose their livestock and livelihood – and for the lynx, as lethal control is often used which leads to population declines.

Climate change affects the polar regions more than anywhere else on the planet, with ocean and air temperatures increasing more than twice as fact here than anywhere else (Box *et al.* 2019; Clem *et al.* 2020). One of the greatest challenges faced in these regions is the decline in sea ice cover, which is vital habitat for both Arctic and Antarctic species (Garcia *et al.* 2014). Of the seven studies in the polar degradation analysis, the majority focused on the impact of climate change on polar bears (*Ursus maritimus*) (Nyhus 2016; Wilson *et al.* 2017; Wolf and Ripple 2017; Trouwborst and Blackmore 2020; Abrahms 2021). A combination of retreating sea ice and increasing human activity has led an ever increasing number of polar bears to move into towns looking for alternative food resources (Trouwborst and Blackmore 2020). The increased likelihood of conflict occurrence raises concerns over human safety, defensive or retaliatory bear killings, and disruption to general activities in these Arctic towns (Wilson *et al.* 2017). Human-bear attacks are very rare events, and most conflict mortalities are polar bear deaths from defensive measures (Smith and Herrero 2018). If, however, the number of bears coming into close proximity with people continues to increase, attacks may become more common. This is a major human safety issue, as when human-bear attacks do occur they can cause high levels of mortality. A 2017 study by Wilder *et al.* found that despite only 73 polar bear attacks being recorded between 1870-2014, these attacks resulted in 20 human fatalities and 63 injuries. If attacks increase, this could put huge pressure on the healthcare facilities of what are often small and rural towns.

The Antarctic region has also seen a steady decline of sea ice over the last few decades. This has had a notable effect on is the keystone species Antarctic krill (*Euphausia superba*), whose life cycles are intrinsically linked to the sea ice (Flores *et al.* 2012). Antarctic krill are a vital part of the Southern Ocean ecosystem as they are important prey for many large predators (Bargu *et al.* 2002), and are fished extensively for use in medicine and aquaculture (Nicol *et al.* 2012). Estimates suggest that Antarctic sea ice extent could decline by between 30-35% in the next few decades, which could lead to major disruption in the krill availability to predators and to fisheries (Piñones and Fedorov 2016). If krill populations decline, predators and fisheries will be competing for the same resources, which could lead predators to move closer to fishing grounds where they risk being caught as bycatch (Warwick-Evans *et al.* 2018). Though limiting the activity of krill fisheries may appear a suitable management strategy in this situation, the krill oil industry is expected to be worth $1.8 billion by 2031, so the economic loss of curtailing the fisheries would be significant (PMRREP6721 2021).

When predicting species' future ranges, certain life-history traits have generally been considered good indicators of how well a species will be able to track their habitat. More generalist species should be able to find alternative resources in new areas, and species with high reproductive potential should be able to establish populations more easily (Årevall *et al.* 2018). The validity of using species traits as indicators of how taxa will fare under climate change was discussed in eight studies in the analysis above, although they provided different findings. Although it was generally acknowledged that species traits such as physiological tolerances did have predictive power as to how species respond to changing conditions and their capacity for range expansion (MacLean and Beissinger 2017; Borges *et al.* 2019; Nadeau and Urban 2019), seven of the eight articles found that many other factors influenced range shifts, and that life history traits alone were not a good predictor of future ranges of species. Variation in observed species range shifts was heavily impacted by human population growth (Faurby and Araújo 2018) and landscape configuration (Årevall *et al.* 2018). If range shift predictions are going to be effective in informing future management strategies effectively and be valuable in helping identify future hotspots for conflict, a broader understanding of all of the causal factors in range shifts is needed.

Being able to predict range shifts accurately is especially vital for species such as the bumblebee (*Bombus* spp.) which are important pollinators. Wild bees are in global decline, with huge potential ramifications on human life (Suzuki-Ohno *et al.* 2020). Global pollination services are estimated to be worth between 235-577 billion US dollars annually (IPBES 2016), so predicting how bees will fare under changing climate conditions is of huge economic value, as well as crucial to informing agricultural practices. At the moment, many studies of future bumblebee ranges focus on traits such as body size (Nooten and Rehan 2020) and dispersal rate (Sirois-Delisle and Kerr 2018). A more holistic study that focuses on a wider range of contributing factors will ensure that future bee conservation efforts are as well-informed as possible.

6 Conclusions and Future Directions

This study has highlighted the complexity of the relationship between climate change and HWC. It has also identified a number of potential future hotspots for conflict: (1) poor, dry regions such as the Sahel, where drought events are likely to increase in frequency and severity, and communities are unlikely to be able to handle increasing resource depletion and conflict with wildlife; (2) poor, urban areas which are likely to experience increasing flood events, which will increase risk of zoonotic disease transmission and place extreme pressure on already taxed healthcare systems; (3) within the fishing industry, as marine heatwaves lead to more contact between marine predators and fishing gear, risking increased levels of entanglement; (4) agricultural areas where large herbivores are present, as changes in vegetation communities make crop raiding more likely; (5) pastoral areas where large carnivores are present, as changes in prey availability will make livestock predation more likely; and (6) polar regions, as the sea ice habitat is degraded and wildlife is forced into contact with people in order to survive. As per initial hypothesis, many of the communities at greatest risk for increasing conflict are those already existing in subsistence lifestyles, making effective management strategies a crucial factor in the survival of these communities.

For the future, a concerted, multi-disciplinary effort by to provide a deeper, more holistic understanding of the relationship between conflict and climate change will benefit global management strategies, and hopefully minimise future loss of life from attacks on humans and retaliatory killings of wildlife. Studies into the factors affecting future range shifts of species would benefit from considering aspects of human geography and expansion, geographical features and configuration, as well as ecological and biological factors. Crucially, a quantified value of the global economic loss that could be incurred if sufficient steps aren't taken to curb the impact of climate change on conflict would be invaluable in convincing governments to put strategies in place now. With the intensity of HWC looking set to increase rapidly over the next few decades, gaps in the research surrounding conflict under climate change need to be addressed now, before it's too late.

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