Thermal ecology

https://doi.org/10.1038/s41558-024-01975-7

Sharks at risk from climate-driven coastal upwelling

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As climate change redirects migration patterns of marine species towards the extremes of their geographic range, sharks find themselves stunned by rising cold upwelling currents.

In March 2021, it was reported in news outlets that coastal communities in South Africa experienced an anomalous increase in washed-up marine life as a marine heatwave swept across the southeast coast and triggered the stranding of at least 260 animals across 81 species of fishes and invertebrates[1]. The mass die-off in South Africa coincided with a meander in the Agulhas Current, an offshore deviation that brought drastic alterations in temperature, ocean currents and water chemistry[1]. Initial stages of the marine heatwave were characterized by observations of fishes swimming away from warm water along parts of the coast[1]. Successively, upwelling of cold, deep water occurred, causing a large thermal differential at the coast and many fishes and invertebrates were stunned in the shallows. Writing in *Nature Climate Change*, Lubitz et al.[2] show a link between the altered landscape of ocean circulation and the increase in extreme cold events at the western boundary currents. Using the bull shark (*Carcharhinus leucas*) as a case study, they reveal how altered patterns of ocean currents can lead to fatal conditions for marine species seeking thermal refugia under climate change.

Lubitz et al. employed a multidisciplinary approach, integrating environmental data analysis, modelling and animal tracking to explore the relationship between upwelling dynamics and their impact on marine life in western boundary current regions. Their investigation focused on trends in the intensity and frequency of cold events within upwelling cells of the Agulhas Current and East Australian Current, attributed to climate-induced shifts in pressure and ocean circulation systems. They identified current forcing and intermittent eddies as primary upwelling mechanisms, with trends suggesting increased meandering and eddy kinetic energy, potentially amplifying upwelling during the austral summer. Analysis of satellite sea surface temperature data revealed rising trends in both the number and severity of cold events over the past 30 years, influenced by climate-change-driven shifts in pressure and currents that have intensified upwelling processes. Subsequently, the authors delved into the movement patterns and thermal ecology of one of the larger species that beached on the coast of South Africa, bull sharks, to understand their response to upwelling events.

Bull sharks have a global distribution that spans from tropical to warm-temperate areas. They are also known to undertake large-scale migrations and to be a relatively tolerant species to environmental fluctuations[3]. A 6-month dataset from 40 tagged sharks moving inshore of the Agulhas Current and East Australian Current showed that the sharks behaviourally thermoregulated and avoided colder waters, particularly during upwelling events, with a preference for shallower areas to mitigate exposure to suboptimal temperatures. However, acoustic tagging data revealed that bull sharks commonly function near their maximum thermal thresholds when they come across active upwelling cells at the farthest poleward extent of their distribution[2]. Sharks are known to shuttle between areas to promote efficiency of physiological processes such as swimming and digestion[4–6]. For instance, they are known to feed in warmer water and move to deeper, colder water to prolong digestive processes and enhance nutrient absorption[5,6]. Inshore areas are fundamental feeding grounds and thermal refugia for bull sharks during migrations[3]. It is known that many fish species also seek thermal refugia in shallow coastal areas, supposedly because upwelling cannot easily reach inshore areas. Some benthic philopatric elasmobranchs, that is, species that tend to remain in or return to their birth area, exhibit differences in thermal optima across populations that are either exposed to or not subject to upwelling, such as the little skate (*Leucoraja erinacea*)[7], while others, like the white shark (*Carcharodon carcharias*), migrate seasonally in response to temperature changes and avoid cold upwelling cells[8].

In researching the impact of climate change on marine ectotherms, thermal biologists have predominantly concentrated on examining the consequences of extreme heatwaves, often overlooking the effects of cold snaps on these organisms. This study stands out as one of those rare instances that illustrate the link between climate-driven extreme cold events and increased mortality rates in marine life. In another study, research investigating the deaths of Kemp's ridley turtles from cold snaps in the northwestern Atlantic[9] supports the importance of understanding the consequences of low thermal tolerance on survival. With rising average ocean temperatures, Kemp's ridley turtles are moving their distribution poleward, turning waters in the northwestern Atlantic, particularly Cape Cod Bay, into crucial foraging areas. A recent surge in turtle strandings in Cape Cod Bay was linked to the accelerated warming of the Gulf of Maine accompanied by intense cold upwelling events[9]. Even though bull sharks and marine turtles might not seem to have much in common, they are both pushed to the extremes of their geographic range, where warming waters are met by the cold currents of upwelling zones. This suggests that many different species will be affected by cold upwelling in warming waters under climate change.

Temperature is an ecological resource and marine animals tune their behaviour to exploit thermal variability in their environment[5]. Given the practical limitations of investigating the thermal ecology of all species, efforts should prioritize understanding the characteristics that render certain physiotypes, that is, animals with common physiological and ecological characteristics, more vulnerable to changing thermal conditions[10]. Studies like the one carried out by Lubitz et al. show that perhaps thermal extremes, more than temperature averages, are likely to reduce the survival of organisms. Climate change is projected to increase the severity of such extreme events, and maximum as well as minimum tolerable thermal limits need to be quantified to model possible consequences on marine animals[11,12]. As ocean warming and cold upwelling exacerbate extreme events, marine species need to navigate within increasingly narrow thermal corridors to find conditions conducive to their survival, limited by their upper and lower thermal tolerances[4,13]. As this study shows, the escalation of upwelling, propelled by climate change, may heighten the occurrence of lethal cold events for migratory subtropical species. Such shifts are poised to alter their migratory routes, movement corridors and the viability of their seasonal habitats, thereby reshaping the patterns of species movement and distribution[11].

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Published online: 15 April 2024

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Competing interests

The author declares no competing interests.