

# Upwelling areas do not guarantee refuge for coral reefs in a warming ocean

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Global warming is a severe threat to coral reefs. It has been proposed that upwelling could minimise the thermal stress caused by ocean warming, and therefore upwelling areas may serve as a refuge for corals. Here, using 21 yr of satellite sea surface temperature data, we analysed the degree to which the thermal stress experienced by corals is reduced in 4 seasonal upwelling areas with reef development: Colombia in the southern Caribbean, Panama in the eastern tropical Pacific, Oman in the Arabian Sea and Madagascar in the Indian Ocean. Upwelling areas do not always offer protection from thermal stress. When compared with nearby non-upwelling areas, upwelling can only provide defence against warming events if: (1) the threat and the upwelling coincide, and (2) this overlap produces a meaningful decrease in thermal stress in upwelling areas. These conditions were met in only 2 of the 4 upwelling areas analysed: Colombia and Oman. In Oman, upwelling decreased the magnitude, frequency and duration of thermal disturbances (identified when Coral Bleaching HotSpots, anomalies exceeding the average temperature of the warmest month, are larger than 1°C), while in Colombia upwelling only decreased their frequency. The protective role of upwelling seems to be limited geographically; therefore, further upwelling areas need to be assessed individually in order to evaluate their capacity as a refuge from thermal stress.

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