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How Does Climate Change Influence the Regional Ecological–Social Risks of Harmful Dinoflagellates? A Predictive Study of China's Coastal Waters

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ABSTRACT

Harmful dinoflagellates are widely distributed in coastal waters worldwide, posing multiple ecological and socioeconomic threats. Climate change may alter the biogeography of these species; however, few studies have linked shifts in harmful dinoflagellates' ecological distribution to their socioeconomic impacts. This study developed a framework to assess the spatiotemporal ecological–social risks posed by harmful dinoflagellates, identifying these algae as risk sources and considering mariculture and coastal populations as the primary risk receptors. China is the world's largest mariculture producer, with approximately 600 million residents living in coastal areas. Focusing on 14 key harmful dinoflagellate species in Chinese coastal waters, we evaluated ecological–social risks under present conditions and two projected climate scenarios for 2100. Our findings indicate that climate change may lead to reductions in suitable habitats for harmful dinoflagellates in tropical and subtropical regions, while habitats in higher-latitude areas are likely to remain stable or expand. Risk area expansion is projected for four species and increased average risk intensity for three, with two species experiencing both. Nationally, total risk area is projected to remain stable, while cumulative risk intensity may decline by 16.64%. Regionally, risk intensity is expected to rise in northern provinces (up to 30.46%) and decline across most southern provinces. Importantly, we reveal a potential spatial "decoupling" of risk sources and receptors along the coast of China in the future. This decoupling demonstrates a reduced overlap between harmful dinoflagellate distributions and areas with dense mariculture or populations. Our findings suggest that, contrary to the common assumption that climate change universally exacerbates harmful algal impacts, these effects may vary across regions and species, highlighting the importance of localized adaptation strategies in risk assessment. This study provides a robust tool for understanding harmful dinoflagellate risks under climate change, thereby supporting the sustainable management of coastal ecosystems.