Towards Sustainable Seas: Assessing the Relationship Between Shipping Emissions and Marine Biodiversity Decline Using Climate and Operational Data

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Marine ecosystems are experiencing rapid and accelerating degradation, while the contribution of maritime shipping emissions to ecological stress remains insufficiently quantified at both global and regional levels. This study proposes an integrated analytical framework that combines multi-year ocean climate observations (2015–2023) with operational shipping emissions data from Nigerian waterways to investigate the relationship between anthropogenic maritime activities and marine ecosystem health on a global scale. A multi-method approach incorporating statistical correlation analysis, geospatial visualisation, and machine learning techniques was employed to examine the relationships among sea surface temperature (SST), ocean pH, coral bleaching severity, species abundance, and CO_2 emissions generated by shipping operations. The findings indicate a significant negative correlation between SST and species abundance ($r = -0.666$, $p < 0.001$), and a moderate negative relationship between SST and ocean pH ($r = -0.559$, $p < 0.001$), suggesting the presence of interconnected thermal and chemical stressors within marine ecosystems. Analysis of shipping emissions further identified fuel type and vessel category, particularly heavy fuel oil (HFO)-powered tanker and service vessels, as major contributors to CO_2 emissions. To integrate ecological and operational factors, this study introduces the Emissions-to-Ecology Impact Index (EEII), which identifies marine regions such as the South China Sea and the Caribbean Sea as high-impact zones characterised by elevated coral bleaching frequency, declining pH levels, increased coral bleaching severity, and reduced species diversity. Although machine learning models demonstrated high predictive accuracy for CO_2 emissions ($R^2 > 0.99$), their performance in predicting bleaching severity remained limited, highlighting the complexity of ecological response processes. Overall, the results provide empirical evidence of spatial and statistical associations between shipping emissions and marine ecosystem stress. The proposed EEII framework may support future marine monitoring, maritime sustainability policy development, and broader ecosystem risk assessment initiatives.

Keywords: *Coral bleaching, Environmental indices, Machine learning, Marine policy, Maritime shipping emissions, Ocean acidification*