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Satellite-based assessment of marine phytoplankton productivity responses to climate and anthropogenic pressures in Asia-Pacific waters

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Abstract: Marine ecosystems are experiencing changes in response to the synergistic impacts of climate change and anthropogenic pressures. Phytoplankton serve as the basis of marine ecosystems. They provide the source material for trophic transfer and facilitate carbon export to the ocean interior through the biological carbon pump. The rate of this photosynthetic production is quantified by Net Primary Productivity (NPP), a key metric of ecosystem function and carbon sequestration. Understanding the distribution patterns and the associated driving factors that govern NPP has become increasingly crucial for carbon budget assessments and future climate projections. To quantify NPP, we applied an ensemble of three distinct biogeochemical models—the Vertically Generalized Production Model (VGPM), the Carbon-based Production Model (CbPM), and the Carbon, Absorption, and Fluorescence Euphotic-resolving (CAFE) model—to a 25-year (1998-2022) consolidated ocean colour dataset from the ESA Ocean Colour Climate Change Initiative (OC-CCI). Multi-model inter-comparison and weighted ensemble analysis were used to generate robust NPP estimates from coastal waters to open ocean systems across the Asia-Pacific region. Our analysis revealed a decreasing trend in NPP across the Asia-Pacific region (−3.2% per decade, equivalent to −15.31 mg C m−2 day−1 per decade, $P < 0.01$). Consequently, regional phytoplankton-mediated carbon sequestration rates reduced from 6.87 to 6.32 Pg C yr−1. Generalized linear modelling analysis reveals that climate factors (ENSO-induced climate fluctuations, mixed layer depth, precipitation patterns, and sea surface temperature) regulate phytoplankton biomass distribution (Chl-a), while light availability conditions (photosynthetically active radiation (PAR) and diffuse attenuation coefficient (Kd490)) influence photosynthetic efficiency. Given that river systems are critical conduits transferring anthropogenic influences from terrestrial to marine environments, we further investigated NPP changes in major river-influenced coastal regions. These regions are experiencing diverse anthropogenic pressures. The Huang-Huai-Hai Basin (North China Plain, East Asia) is characterized by intensive urbanization and industrial development, the Mekong River Basin (Southeast Asia) is dominated by agricultural expansion and dam construction, and the Swan River Basin (Oceania) is affected by urban development and mining activities. Comparative analysis of these anthropogenically-modified shelf seas reveals heterogeneous NPP declines across latitudinal gradients: Huang-Huai-Hai Basin at −3.04%, Mekong Basin at −2.97%, and Swan Basin at −2.83% per decade (all $P < 0.01$). This study highlights declines in marine productivity across the Asia-Pacific waters, driven by the combined effects of climate variability and regional anthropogenic pressures. These findings provide a scientific basis for targeted marine ecosystem management and inform regional carbon mitigation strategies.

Keywords: *Net primary productivity, ocean colour models, climate change, anthropogenic impacts, carbon sequestration*

