Natural Biodegradation of Biofilms and Its Management Near Coastal Shipping Ports: Integrating Bioprospecting for Ocean Health

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Abstract- Biofilms are structured microbial communities embedded in extracellular polymeric substances (EPS) that readily colonize submerged surfaces in marine environments. In coastal shipping ports, biofilms contribute significantly to biofouling, corrosion of infrastructure, increased fuel consumption, and the spread of non-indigenous species. Natural biodegradation of biofilms mediated by marine microorganisms offers an environmentally sustainable alternative to chemical antifouling strategies. In parallel, bioprospecting of marine biofilm-associated microorganisms has gained attention for its potential to identify novel enzymes, metabolites, and bioactive compounds relevant to biofilm control and broader ocean health. This article reviews the mechanisms of natural biofilm biodegradation in port environments, the role of microbial communities, and emerging management strategies. It further highlights the importance of marine bioprospecting as a tool for enhancing biodegradation processes while supporting sustainable ocean stewardship.

Keywords: marine biofilms, biodegradation, bioprospecting, coastal ports, ocean health, biofouling

I. INTRODUCTION

Marine biofilms develop rapidly on submerged surfaces through the attachment and growth of bacteria, archaea, algae, and fungi within a self-produced EPS matrix. These biofilms represent the initial stage of biofouling, a process that is particularly problematic in coastal shipping ports due to high vessel traffic, nutrient enrichment, and prolonged immersion of port infrastructure (Schultz et al., 2023). Biofouling increases hydrodynamic drag on ship hulls, accelerates material degradation, and facilitates the transport of non-indigenous species across marine regions (Davidson et al., 2024).

Traditional biofouling control methods rely heavily on toxic antifouling coatings, which pose risks to marine ecosystems. Consequently, there is growing interest in environmentally benign approaches such as natural biodegradation of biofilms and the bioprospecting of marine microorganisms for sustainable solutions (Frontiers in Marine Science, 2025).

II. NATURAL BIODEGRADATION OF MARINE BIOFILMS

Biofilm Structure and Biodegradability

Marine biofilms are dynamic systems characterized by complex microbial interactions and metabolic exchanges. The EPS matrix, composed primarily of polysaccharides, proteins, lipids, and extracellular DNA, provides mechanical stability but also serves as a target for biodegradation (Flemming et al., 2023). Certain marine microorganisms naturally secrete enzymes such as glycosidases, proteases, and esterases that degrade EPS components, leading to biofilm destabilization and turnover.

Microbial Communities and Degradation Pathways

The efficiency of biofilm biodegradation depends on microbial community composition and environmental conditions such as salinity, temperature, and nutrient availability. Studies have demonstrated that marine bacteria belonging to Proteobacteria and Firmicutes play key roles in organic matter degradation and polymer hydrolysis in biofilms (Marín et al., 2023). In addition, halophilic and psychrotolerant microbes common in coastal waters exhibit unique enzymatic adaptations that enhance biodegradation under extreme marine conditions (Rezaei et al., 2025).

III. BIOPROSPECTING OF MARINE BIOFILMS AND OCEAN HEALTH

Concept and Relevance of Bioprospecting

Bioprospecting involves the exploration of biological diversity to identify novel organisms, genes, enzymes, or metabolites with potential applications in biotechnology, medicine, and environmental management. Marine ecosystems are considered particularly valuable for bioprospecting due to their immense biodiversity and evolutionary novelty (Leal et al., 2025).

Marine Biofilms as Reservoirs of Bioactive Compounds

Marine biofilms are rich reservoirs of previously uncharacterized microorganisms with unique metabolic capabilities. Recent bioprospecting studies have identified enzymes capable of degrading synthetic polymers such as polyethylene terephthalate (PET), highlighting their potential role in mitigating marine pollution (Galarza-Verkovitch et al., 2023). Additionally, biofilm-associated bacteria have been shown to produce antimicrobial peptides and secondary metabolites that can inhibit biofilm formation and pathogenic colonization (PubMed, 2024).

Contribution to Ocean Health

Bioprospecting supports ocean health by enabling the development of nature-based solutions for pollution mitigation, biofouling control, and ecosystem restoration. Initiatives such as marine microbial repositories aim to catalog and conserve microbial diversity while promoting responsible utilization of marine genetic resources (NIOT, 2025). These efforts align with global ocean sustainability goals by balancing innovation with conservation.

IV. MANAGEMENT STRATEGIES NEAR COASTAL SHIPPING PORTS

Harnessing Natural Biodegradation

Port authorities can enhance natural biofilm biodegradation by promoting conditions favorable to beneficial microbial communities. Strategies include the use of biodegradable or bio-receptive materials for marine infrastructure, microbial bioaugmentation using locally adapted strains, and routine environmental monitoring of biofilm development (Santana et al., 2025).

Integrated and Sustainable Approaches

Effective biofilm management requires integration of biological, physical, and operational measures. Non-toxic antifouling coatings, combined with enzymatic treatments derived from bioprospected marine microbes, offer promising alternatives to conventional chemical methods. Decision-support frameworks that incorporate ecological risk assessment and operational efficiency can further support sustainable port management (Davidson et al., 2024).

Challenges and Future Directions

Despite its promise, natural biodegradation and bioprospecting face challenges related to environmental variability, scalability, and regulatory frameworks governing access to marine genetic resources. Ethical considerations, including benefit sharing and biodiversity protection, must be addressed to ensure responsible bioprospecting (Springer Nature, 2023). Future research should focus on functional genomics of biofilm microbiomes, field-scale validation of biodegradation strategies, and long-term ecological impact assessments.

V. CONCLUSION

Natural biodegradation of biofilms, supported by strategic bioprospecting of marine microbial resources, represents a sustainable approach to managing biofouling in coastal shipping ports. By leveraging the intrinsic capabilities of marine microorganisms, it is possible to reduce environmental impacts, improve port efficiency, and promote ocean health. Integrating biodegradation, bioprospecting, and ecosystem-based management offers a holistic pathway toward sustainable maritime operations.

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