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Sustainable Ships

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Abstract

Our populated world requires movements of goods. Sustainable global shipping is integral to modern society [1] supporting 80 to 90% of consumption [2]. To reach sustainable goals for shipping one needs to consider and eventually modify how ships function with major attention to economic, societal, and ecological components. This brief opinion piece provides context. A few unsustainable aspects that need to be reimagined are highlighted and one perspective on the challenges presented. The literature provided is for entry and vocabulary to those interested in following up on a topic.

Keywords Ship Pollution; Biofouling; Ship Coatings; Antibiofouling; Sustainable Shipping; Environmental and Human Health

Ships as Polluters

Every man-made object pollutes. About 99% of ships use some grade or mixture of heavy fuel oil, bunker fuel [3] which releases greenhouse gases, hydrocarbon particulates, large amounts of sulfur dioxide and trace elements [3]. Although fuel accounts for only 2-3% of greenhouse gas emissions, other emissions like sulfur dioxide, nitrogen oxide, polyaromatic hydrocarbons, and particulates present major concerns for human and environmental health [4]. Ballast water can deliver pathogens and macro-organisms [5]and some ballast water treatments can increase virility of pathogens [6]. Shipping has introduced 100s of species around the world. The faster that ships make journeys the more likely organisms found in ballast water are likely to survive.

Ships are constructed of materials that corrode and most surfaces are protected by coatings [7]. Protective coatings are systems that protect against corrosion and shield the ship from the direct environment. The system closest to the steel is generally a sacrificial anticorrosive zinc coating. The zinc coating is covered generally by epoxy coatings and the epoxy coating can be covered by urethane or acrylate coatings. For reference, most epoxies are mainly bis-phenol A which is a known endocrine disruptor and carcinogen. Epoxies are everywhere. Ask the question, if you shouldn't drink out of a BPA bottle, why would you cover ships, construct wind turbines, and water pipes and countertops with BPA? Ships are covered with plastics to protect the steel and ships are the second greatest source of microplastics in the ocean [8].

Hull Coating Systems

Hull coating systems begin with anticorrosive coatings next to the steel and culminate with fouling management layers which are exposed to the environment and release toxic compounds [9]. Fouling management is crucial because biofouling is corrosive and impacts ship performance by increasing drag. Drag impacts ship speed and fuel consumption. Fouling management coatings deter growth by killing organisms that colonize the surface. Since propagules are usually small enough to fit in the 500 μm boundary layer over surfaces [10] they usually die before they are noticed.

Ships as Vectors

Ships are habitats [11]. Biofouling is found on even protected ships. When ships move between harbors there is potential for introducing new species. Species introductions due to shipping began before marine science existed. As a consequence, in most temperate and tropical harbors there is a common biofouling community [12]. The geographic origin of many of the organisms in this community is unknown. This community an invasive ecosystem [13].

Environmentally Benign Fouling Management

Biofouling

Biofouling is biomolecules, micro-organisms, and macro-organisms. An excellent perspective of how biofouling works in a harbor is presented by Clare et al [14]. There are levels of complexity and interrelationships to biofouling that have been elucidated by a century of study. Those of us who study the details of biofouling are continually debating roles of concepts like surface energy [15-17], preconditioning [18-23], succession [19,24] cues and pheromones [23-26].

Theory and Practice

Some basic principles apply. All natural solid surfaces are fouled. Virtually all man-made surfaces foul and the jury is still out on the mechanisms that result in spectacular antibiofouling properties of the most modern materials like zwitterion surfaces [27]. A very important concept is that though levels of biofouling are interrelated they are also independent. To know if a level of biofouling is controlled it is best to test at sites where biofouling is understood and then to test in service

Biofouling Management

Camouflaging surfaces and killing propagules are two obvious ways to manage biofouling on surfaces. Research is being conducted on ways to make surfaces resemble water to propagules. If a surface resembles water, molecules and propagules can't recognize or stick to it. Since glues are made of molecules, if molecules can't stick, organisms can't stick. The most promising of these kinds of surfaces are zwitterionic surfaces [27].

Commercial biofouling management coatings are part of a complex coating system which also protects hulls from corrosion and has physical and toxic properties that enable it to function for years [9,28,29]. Commercial coatings have a shelf life in the can and application procedure a delivery network and customer support. The vast majority and all but a tiny percentage of commercial biofouling management coatings kill organisms. This is a mix and kill approach.

In theory, the mix and kill approach could be environmentally benign. The perfect toxin(s) would need to be easy to synthesize, stable before and after coating cure, safe to apply, not interfere with curing, protected in the coating and have a chemical/ biological half-life that was comparable to time it took the toxin to diffuse 500µm through the boundary layer [13,28,29]. An environmentally benign mix and kill approach would fit in the existing business models and infrastructure of most coatings manufactures.

Daunting Hurdles to New Approaches

Just as coating systems are complex, development of new coatings approaches have regulation, infrastructure, and acceptance hurdles [12]. Registration of biologically active molecules may take a decade and cost millions of dollars in the US and several years and hundreds of thousands of euros in Europe [12]. Infrastructure includes production, storage, delivery, application, removal, and disposal [12] as well as advertising and customer support. Acceptance takes 15 to 20 years, about three times as long as the theoretical lifetime of a marginally acceptable coating [13,28,29]. This is not at all surprising if one considers the financial consequences of a mistake. If society had the political will to move toward sustainability through novel approaches, policies would be developed to expedite the process. There is one existing commercial alternative to the mix and kill approach. A single company uses a molecule, ketamine, that when encountered by propagules alters their behaviors [30]. The new product has been on the market for several years. The additive is now found in several coatings.

Mixed Mechanisms

All commercial and future novel fouling management systems have primary mechanisms of action that are or will be advertised (examples; antifouling, foul-release, mixed antifouling, and foul-release). Companies minimize all costs to maximize profits, commercial products are routinely constructed from technical grade chemicals and application is in poorly controlled conditions which impact cure. Chemicals that are trapped in the polymers, contaminants, catalysts, intentionally active ingredients, and products of incomplete reactions leach into the environment when ships are returned to the water and large releases known as burst effects occur for various amounts of time [31,32]. No coating system has been demonstrated to be environmentally benign.

Conclusion

Shipping is globally essential. The actual environmental costs of shipping are unknown. There are opportunities to improve the environmental footprint of shipping. The interrelated components of fuel consumption, corrosion and biofouling are obvious places for improvement. This piece is an attempt to shorten the time that those new to the field can get up to speed in their thinking of novel ways forward.

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