ISSN 0974-3618 (Print)
0974-360X (Online)

www.rjptonline.org

REVIEW ARTICLE

A Review on Invasive Species in Marine Biofouling

Maithili Shevalkar, Akanksha Mishra, S. S. Meenambiga*
Department of Bio-Engineering, School of Engineering, Vels Institute of Science, Technology and Advanced Studies (VISTAS), Chennai-600117, Tamilnadu, India.
*Corresponding Author E-mail: **meenambiga.se@velsuniv.ac.in**

ABSTRACT:
Biofouling has become worldwide threat in the recent years. Scientists' researching on biofouling is on peak aboard. There are organisms which colonize the underwater surfaces of ships such as spores of algae, barnacles, seaweeds, etc. which uses manifold array of biological glues to provide adhesion which is the result of biofouling. Invasive species hold world threat because of ships that introduce them the foreign environment through ballast waters and ship hulls. Sea trade expansion lead broad pathway for invasive species and promoted devastation of other native species. The ships struck with biofouling which travel over long distances, raises the content of CO2 release to 14-31%. This increases the concentration of greenhouse gases which make invasive species deplete and finally vanish away. Invasive plant species are the key initiators of global change. Certain chemicals and protein coatings have come into light to resist the adhesion of various biofouling species. This review focuses on various effects of invasive species in marine biofouling and the eco-friendly ways to eradicate them.

KEYWORDS: Biofouling, Biological glues, invasive species, greenhouse gas, protein coats.

INTRODUCTION:
The present context highlights biofouling and its threat to ecosystem. There are organisms (spores of algae, barnacles, diatoms, etc.) which colonize the underwater surfaces of ships which uses manifold array of biological glues to provide adhesion. [1] These species which undergo the process of biofouling and affects the ecosystem by changing the native ecosystem and inducing variations is known to be as invasive species which includes certain plants, microorganisms and animals. Invasive species were present throughout history, but their gradual increase has led to jeopardy. [2]

Invasive species or non-indigenous species are that organism which are non-native to the environment and have negative effects on the respective regions economy, public health, etc. Consequences have risen as their growth rate has taken a boost and covered ample of the space on earth.[3]

Received on 16.07.2019 Modified on 10.11.2019
Accepted on 26.03.2020
Research J. Pharm. and Tech 2020; 13(9):4517-4521.
DOI: 10.5958/0974-360X.2020.00796.9

Biofouling research includes the contribution from many experts all over the world. It has become a devastating scenario for the workers in marine industry, as the transfer of invasive species into a new environment is initiated by the ships and has led to a new danger for the different oceans and it is damaging the conserved biodiversity of that particular new environment.[4] [5] As the ballast water is helpful for the ships stability and safety for the latest shipping operations but also, it is the ballast water which carries almost 87% of the invasive species.[6] This is a worldwide problem, costing $16.2 Billion to New Zealand along $1Billion to US Navy, whereas $5.5 Billion to Canada for 16species alone per annum.[7]

The accumulation of microbes on the immersed surfaces leads to the spoilage of the metal increasing economic and environmental health hazards. The nations are putting their efforts as this biofouling is leading to the endangering and extinction of many of the native species along the way with introduction of new species dominating the ecosystem by recreating new food chain and the nutrient cycles.[8] The type and growth rate of invasive species in biofouling depends on the environment and the habitat pursuing ability. The

greater the adhesiveness of the microbe the more are the survival chances. The marine environment varies in a vast way when compared to another ecosystem.[9] Morphology of microbes in the marine biofouling is with respect to their thickness, adhesive property, density, structure and weight. Growth of invasive aquatic species mainly targets the ships and underwater structures.[10]

These invasive species can be of two types depending on their body type:

1. Calcareous Organisms (Hard-Shell organisms)
2. Non-Calcareous Organisms (Soft-Shell organisms) [11]

As the ships acts as a major carrier of invasive species in a distinct environment, modes of transport (pipes, canals, etc.) are being affected as they grow rapidly and clog the openings.[12] The species like green algae, Caulerpataxifolia has been acting forward as a major threat. In early 2001 and 2004, a commitment was taken by IMO (INTERNATIONAL MARITIME ORGANISATION) to clear biofouling through invasive aquatic species, but issue of transfer of invasive aquatic species through ships' biofouling was first brought officially to IMO's attention in 2006. According to IMO study CO2 has been released as 769 Million tons in 2014 and by 2050 there will be a risk for its increase by 50-250% which will further lead to increase in greenhouse gas emissions and result in global warming. The UN Convention on the Law of the Sea (UNCLOS) provides a global framework by requiring States for the work together "To prevent intentional or accidental introduction of alien species to particular part of marine environment."[13]

BIOFOULING:

Biofouling or biological fouling is the accumulation of the different microorganisms, plants or animals on the submerged surface. It leads to microbial corrosion, loss of heat and mechanical blockages. It even leads to environmental and product contamination and causes problems to the public health indirectly and sometimes directly. [14]

Factors' influencing the expansion of biofouling depends upon type of material, pH, temperature, geographical area, current season and distance from the shoreline. If the water movement is slow then the larvae or organism will not take much time to get adhere to the wetted surface of the submerged object. [15]

The organisms causing biofouling are mostly called as 'Foulers'. Plant fouling is done by the communities of algae, especially green algae. The smaller organism doing biofouling includes algal spore, diatoms, etc. The algal spores can settle down on wet surface in seconds and colonize in few hours. The process takes place in presence of sunlight. Animal biofouling is caused by protozoans, coelenterates, hydroids, etc. They all get attached to surface by the formation of biofilms. This biofouling causes many problems which will be further discussed. [16]

INVASIVE SPECIES IN BIOFOULING:

Invasive species are those foreign species that are introduced in new environment by human activity. It is observed to be mostly done by the ship which travels in distant waters. These species leave their original distribution range to some other habitat or ecosystem affecting the species living in that environment.[17] These species are named variedly such as 'Introduced Marine Pests' in Australia and New Zealand whereas 'Harmful Aquatic Organisms' by IMO Ballast Water Convention.

The percentage of invasive species includes with Australia - 78%, Hawaii Islands - 74%, North America - 70%, New Zealand - 69%, North Sea - 50% and Japan - 42%. [18].

Whenever some clean material surface is immersed in the water, then a sheath of dissolved organic materials develops on the material surface leading to the adsorption of the colonized bacteria getting adhered and travel [19]

Once these species are established in a particular environment it becomes very tough to get rid from them. They spoil the native ecosystem by domination and alteration of the food chain by which the other organisms are also affected [20]

These invasive species get attached to the parts of ships such as ship propellers, impellers and ballast water tanks. They get attached to different zones present in the impeller and because of this reason the weight and loads on impellors increase leading to decrease in its working efficiency. This also leads to increase in fuel consumption and decrease in the speed of ships. Thereby proving problematic to the marine industry and increase in capital expenditure [21]

ADHESION:

This stage is divided into various processes comprising of the cell transport on the material surface, then attachment to the surface and form irreversible attachment along the colonies. The following are the steps for a microorganism to adhere on a surface and grow into complete colony:

1. Thermodynamics of bacterial adhesion
2. The bacterial surface
3. Bacterial adhesives.

The initial attraction takes place when the bacteria is floating around the metal surface through some weak forces of attraction i.e. Van der Waals forces with a minimum distance of less than 50nm. Later leads to increase in the attraction forces with the surface at some distance of 10-20nm through electric impulse exchange mechanism (electrostatic force). The microbe then builds an attraction towards the material surface nearing the distance by 0.5-0.2nm by hydrophobic attraction mechanism in which low lipid molecules attaches to an immersed or submerged surface. The perfect adherence occurs after the bacteria comes near the surface about less than 0.1nm. The microorganism then grows and expands its colony along with the maturation of species. The colony formation leads to a complex 3-dimensional structure formation covered by a peptidoglycan layer which sticks over the surface as a glue. This adhesive property of a microorganism to attach to a immersed surface through various forces and bio glue property is still for study under various organizations and researches but no positive outcome has yet turned over.[22] [23]

TYPES OF BIOFOULING ORGANISMS:

The biofouling organisms are differentiated into two types based on their body type:

1. **Calcareous or Hard-Shell Organisms:-**

These organisms possess shell as an outer protective covering.

2. **Non-Calcareous or Soft-Shell Organisms:-**

These organisms do not possess any outer protective covering.

BARNACLES (CALCEREOUS ORGANISM):

Barnacles are calcareous organisms belonging to class Cirripedia. They contribute in a large amount of over 12,000 species in the ecosystem. The barnacles may be found at different depth areas of the sea but are mostly found in the hard rock zone and the intertidal zones. These organisms are sessile (non-motile) by nature and prefer to attach to hard substrates. Rock and hard metal are the substrates in common, but they can also attach to various other surfaces as example garbage, ship hulls, other organisms. Barnacles are both found in underwater and on dry land i.e. intertidal zones. The barnacles are the organisms which can withstand al l the varied temperature on living land. Like periwinkles, the barnacles are calcareous shell organisms which they can open when the tides hit them and close to keep them hydrated by sealing the moisture when dry, but when submerged their shells are opened to the optimum. Often misunderstood to belong to mollusks these organisms whereas relate to crabs and lobsters more than the periwinkles hence are crustaceans. The barnacles when in underwater is the time they feed. They open their shells and extend their cirri. Cirri are basically the specialized appendages that are covered with sensory hairs called setae which helps in capturing of food, planktons and other grass carried along the water current. These cirri are the reason for the name of class Cirripedia.

Barnacles are classified into two groups:

1. Acorn Barnacles
2. Goose Barnacles [24]

Of which the acorn barnacle is the most common and abundant species of barnacle found around globe about 1400 species. These organisms are hermaphrodite i.e. they possess both male and female gametes. The barnacle recoils its penis at the time of reproduction which in some species is the length 20times greater than its own size. The penis searches for another barnacle and then fertilization takes place. After fertilization, the eggs are released, and the larvae joins the planktons. Each individual can release up to 10,000 eggs. As the growth is initiated the larvae adheres to a solid surface and remains sessile for the whole of adult stage. An outer sheath develops as larvae gets attached to a substrate thereby protecting it from all the predators and the surrounding environment. Once the sheath develops the larvae will then grow and spend all his life there. These shells also act as a protective covering to the organism as when exposed to an unhealthy or toxic atmosphere it closes to stay safe and healthy. These barnacles make up the oldest surviving and is not much genetically altered yet even after great changes in and around the ecosystem. The barnacles attached to a hard surface is shown in reference [25],[26]

EFFECTS:

The biofouling leads to various crisis to the marine environment, marine industry sustaining the human life and the organisms in and around the habitat. Some of these effects are mild whereas some are hazardous to the ecosystem.[27] Depletion of flora and fauna are the main threat caused by the biofouling lead through the invasive species. As these species corrode and block the passages of the ship propellers, the increase in the consumption of fuel has been increased by 30%. Hereby raising the country's economic cost by 50%. This fuel consumption has also led to more amount of CO_2 and SO_2 emission thereby promoting the toxicity level to a higher gradient and harming the life within.[28][29]

The increasing in drag level also makes it difficult in the emergency situations. The propeller blockage leads to the hydrodynamic performance to slow down thereby decreasing the speed with which the ship should travel. The life of the ship hull decreases thereby increasing the cost consumption by 3%. The replacement of ship parts are made to happen very readily by the increasing in adherence of the invasive species [30] The ballast waters are acting as a major threat as these carry waters in their

tanks from one environment to another which leads to introduction of a specie into distinct ecosystem thereby becoming invasive and damaging the host environment [31]

These invasive species once adapted to an environment makes other native creatures recessive and which leads to their depletion thus extinction. The most of important native species may suffer extinction because of over growth of invasive species into their environment [32]. The study on effects of the biofouling through invasive species has led to a varied threat we even have not known about (green house,etc). The native environment species are thereby listed and given protection whereas the non-native ones are discarded of their ecosystem. Certain measures have been coming into implementation, but the progress is yet to be more in this field [33]

INHIBITION:

As we all know that biofouling is a major backup to the ship industry at present time. Various ways are there for the inhibition and control for the same. Since we know that biofouling is caused by Reverse Osmosis (RO) by producing biofilms. If small scale RO installations are one on the surface. The microorganisms won't be able to adhere. These formations of biofouling resistant membrane called as DOW FILMTECTM BW30XFR is currently used now [34]

Chemicals like hyaluronic acid (HA) and chondroitin sulphate (CS) have many non-fouling properties. They were modified to hydrophobic trifluoroethylamine (TFEA) [35] they are used for coating ship surfaces. By the use of these TFEA the adhesion property of the marine fouling species are decreased and a protein resistant coat is formed over to get rid of the biofilms. Antifouling paints are those special type of paints which advert the growth of marine organisms. In 1970's TBT or Tributyltin was used due to its major antifouling properties, but due to its adverse effects its use is on a ban now in many nations [36]

There are many antifouling paints made now to control biofouling which are metallic in nature. They slowly kill the barnacles and other marine biofouling agents in water. Many more works are to be done in this field to control biofouling and save our ecosystem [37]

AUTHOR VIEWS:

The biofouling has been always a threat and that the researches have been advanced to prevent it from growing into more hazardous problem. As respect with invasive species the IMO has put into consideration certain rules to be followed when travelled through waters. The adhesiveness of microorganism and the preventive measures are like some coatings and metallic paints along, though research is to be done in ample. The types of organisms are examined on the basis of resistant properties they possess; the proceedings are carried out for more detailed information regarding the distinct organisms. There are ought to be several hazards when biofouling is considered and to that the invasive species have also been devised for more danger through the preventions are set for use, though more efforts need to be implied on. As the chemical used for the inhibition have proved more or less to be harmful for the flora and fauna.

CONCLUSION:

Desired results and proper research will tend to lead biofouling to deterioration and enhance the quality of ecosystem. So by use of various chemicals are used to act as an effective and ecofriendly way to prevent biofouling such as hydrophobic Trifluoroethylamine (TFEA), Polydimethylsiloxane (PDMS) and sulfobetaine. Cu-Ni alloy also acts as a great paint coating for the biofouling to be prevented. Other protein coating paints are also been in use for the ships. Awareness should be created to not let biofouling agents spread into a healthy ecosystem. Prevention of biofouling is needed to be done as it increases the life of ships important parts like the impellers, propellers and ship hulls also helps the native species to maintain a healthy ecosystem. Monitoring, early detection and rapid response are key to prevent biofouling.

REFERENCE:

1. Callow ME, Callow JA. Marine biofouling: a sticky problem. Biologist. 2002 Feb;49(1):1-5.
2. https://www.nwf.org/Educational-Resources/Wildlife-Guide/Threats-to-Wildlife/Invasive-Species
3. Manchester SJ, Bullock JM. The impacts of non-native species on UK biodiversity and the effectiveness of control. Journal of Applied Ecology. 2000 Oct 1;37(5):845-64.
4. https://www.nationalgeographic.com/environment/habitats/ocean-threats
5. Global Invasie Species Programme (GISP). 2008. Marine Biofouling: An assessment of risks and mangement Initiatives. Edited by Lynn Jackson on befalf of Global Invasive species Programme and the UNEP Regional Seas Programme. 68pp
6. https://www.maritimenz.govt.nz/commercial/environment/operators/ballast-water.asp
7. Callow ME, Callow JA. Marine biofouling: a sticky problem. Biologist. 2002 Feb;49(1):1-5.
8. Fitridge I, DempsterT, Guenther J, de Nys R. The impact and control of biofouling in marine aquaculture: a review. Biofouling. 2012 Aug 1;28(7):649-69.
9. Funk JL. The physiology of invasive plants in low-resource environments. Conservation physiology. 2013 Jan 1;1(1).
10. Phillips BL, Shine R. The morphology, and hence impact, of an invasive species (the cane toad, Bufomarinus): changes with time since colonisation. InAnimal Conservation forum 2005 Nov (Vol. 8, No. 4, pp. 407-413). Cambridge University Press.
11. Odum EP. Ecology, the link between the natural and the social sciences. Oxford and IBH Publishing; 1963.

12. Scalera, Riccardo &Genovesi, Piero&Essl, Franz &Rabitsch, Wolfgang. (2012). The impacts of invasive alien species in Europe. 10.2800/65864.
13. Castro, Maria Cecilia. (2013). International Maritime Organization (IMO) for the Control and Management of Ship's Biofouling to Minimize the Transfer of Invasive Aquatic Species.
14. Venkatesan R. New approaches to Marine Biofouling Control. Journal on Applied Bioengineering. 2007 Dec;1(1).
15. Delauney, Laurent & Compere, Chantal & Michel, Lehaitre. (2010). Biofouling protection for marine environmental sensors. Ocean Science (1812-0784) (Copernicus GesellschaftMbh), 2010 , Vol. 6 , N. 2 , P. 503-511. 6. 10.5194/os-6-503-2010.
16. Callow ME, Callow JA. Marine biofouling: a sticky problem. Biologist. 2002 Feb;49(1):1-5.
17. Hill J. Invasive Species: How They Affect the Environment. Environmental Science. 2018.
18. Jackson L. Marine biofouling and invasive species: guidelines for prevention and management. United Nations Environment Programme. 2008.
19. Sweat, Lynn H. "Exploring the role of biofilms in the transport and establishment of invasive marine macrofoulers." PhD diss., 2016.
20. Inkley DB. Characteristics of home invasion by the brown marmorated stink bug (Hemiptera: Pentatomidae). Journal of entomological science. 2012 Apr;47(2):125-30.
21. Zheng X, Ding C. Effect of temperature and pressure on stress of impeller in axial-centrifugal combined compressor. Advances in Mechanical Engineering. 2016 Jun;8(6):1687814016653547.
22. Meireles A, Gonçalves AL, Gomes IB, Simões LC, Simões M. Methods to study microbial adhesion on abiotic surfaces. AIMS Bioengineering. 2015 Sep 6;2(4):297-309.
23. Kim DJ, Lee MW, Choi JS, Lee SG, Park JY, Kim SW. Inhibitory activity of hinokitiol against biofilm formation in fluconazole-resistant Candida species. PloS one. 2017 Feb 2;12(2):e0171244.
24. Anderson DT. Barnacles: structure, function, development and evolution. Springer Science & Business Media; 1993 Sep 30.
25. Crisp DJ, Walker G, Young GA, Yule AB. Adhesion and substrate choice in mussels and barnacles. Journal of Colloid and Interface Science. 1985 Mar 1;104(1):40-50.
26. Menge BA, Blanchette C, Raimondi P, Freidenburg T, Gaines S, Lubchenco J, Lohse D, Hudson G, Foley M, Pamplin J. Species interaction strength: testing model predictions along an upwelling gradient. Ecological Monographs. 2004 Feb;74(4):663-84.
27. Flemming, Hans-Curt &Cloete, Thomas. (2010). Environmental impact of controlling biofouling and biocorrosion in cooling water systems. Operational and Environmental Consequences of Large Industrial Cooling Water Systems. 365-380.
28. Dukes JS. Will the Increasing Atmospheric CO2 Concentration Affect the. Invasive species in a changing world. 2000;95.
29. Jackson L. Marine biofouling and invasive species: guidelines for prevention and management. United Nations Environment Programme. 2008.
30. Namboothri N, Ali R, Hiremath A. Biological Invasions of Marine Ecosystems.
31. Oemcke D, Leeuwen JH. Seawater ozonation of Bacillus subtilis spores: implications for the use of ozone in ballast water treatment. Ozone: science & engineering. 2004 Aug 1;26(4):389-401.
32. Gurevitch J, Padilla DK. Are invasive species a major cause of extinctions?. Trends in ecology & evolution. 2004 Sep 1;19(9):470-4.
33. Environmental Consequences of Invasive Species: Greenhouse Gas Emissions of Insecticide Use and the Role of Biological Control in Reducing Emissions, George E. Heimpel ,Yi Yang, Jason D. Hill, David W. Ragsdale, Published: August 20, 2013
34. Majamaa K, Johnson JE, Bertheas U. Three steps to control biofouling in reverse osmosis systems. Desalination and Water Treatment. 2012 Apr 1;42(1-3):107-16.
35. Bauer, Stella &PilarArpa-Sancet, Maria & A Finlay, John & E Callow, Maureen & A Callow, James &Rosenhahn, Axel. (2013). Adhesion of Marine Fouling Organisms on Hydrophilic and Amphiphilic Polysaccharides. Langmuir : the ACS journal of surfaces and colloids. 29. 10.1021/la3038022.
36. Takahashi K. (2009) Release Rate of Biocides from Antifouling Paints. In: Arai T., Harino H., Ohji M., Langston W.J. (eds) Ecotoxicology of Antifouling Biocides. Springer, Tokyo
37. Backhaus T, Arrhenius Å. Marine Paint 2003–2011. Final Report. Mistra. Accessed March. 2012;15:2018.