ECO-FRIENDLY BACTERIAL PRODIGIOSIN-BASED ANTIBIOFOULING COATING FOR MARINE STRUCTURE APPLICATIONS

SITI NABILAH BINTI AMIR

UNIVERSITI TEKNOLOGI MALAYSIA

ECO-FRIENDLY BACTERIAL PRODIGIOSIN-BASED ANTIBIOFOULING COATING FOR MARINE STRUCTURE APPLICATIONS

SITI NABILAH BINTI AMIR

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Science
Universiti Teknologi Malaysia

NOVEMBER 2020

ACKNOWLEDGEMENT

I wish to express my deepest appreciation to my supervisor, Assoc. Prof. Dr Razali Ismail for his support, encouragement and guidance. Without his immense knowledge and motivation, this study might have not reached its goal. My deepest gratitude to my family and close friends for their persistent help, guidance, advices and motivation that kept me going through this rocky road journey happily. I would also like to thank Assoc. Prof. Dr Roswanira Abdul Wahab, Prof. Dr Wan Mohd Norsani Wan Nik and Assoc. Prof. Ts. ChM. Dr Nik Ahmad Nizam Nik Malek for their valuable comments and feedback for the thesis. A special acknowledgement shall be presented for Postgraduate Office Faculty of Science that ease me throughout this journey. Without them, my journey would be many times tougher and harder. The assistance, guidance, support and love provided directly or indirectly by everyone is greatly appreciated. Their assistance has been invaluable to me throughout this journey.

ABSTRACT

Marine biofouling, the unwanted accumulation of living organisms on manmade structures is worsening and creating an adverse economic impact. In this study, a more sustainable antibiofouling paint was formulated by using natural antibiofouling agent. Prodigiosin, a bacterial pigment extracted from Serratia marcescens was used as the antibiofouling agent and pigment. The antibiofouling properties of crude prodigiosin were studied by assessing the antibacterial properties, minimum inhibitory concentration (MIC), minimum bactericidal concentration (MBC) and toxicity assay. The performance of antibiofouling paint at different pigment composition incorporated with crude prodigiosin was studied in laboratory and in natural seawater. Based on the result obtained, the antibacterial test demonstrated the largest inhibition zone against *B. subtilis* (4.0 ± 0.3 cm) at 10000 ppm and the smallest inhibition zone against *E. coli* (2.0 ± 0.4 cm) at 1000 ppm. The MIC values ranged from 390 to 3126 ppm and MBC values ranged from 1562 ppm to 6250 ppm for all bacteria tested. Crude prodigiosin showed a low toxicity value (LC50 = 4270.203 ppm). The comparative study of binder showed that vinyl ester resin performed better in comparison to epoxy resin in all tests, namely antibacterial test (*B. subtilis*: 3.77 ± 0.1 cm, *E. coli*: 3.43 ± 0.1, *P. aeruginosa*: 3.63 ± 0.3, *S. aureus*: 4.00 ± 0.1), surface roughness and adhesion test (Class 5B). Steel plate painted with crude prodigiosin was able to retain its cleanliness at high flowrate areas (significant, $p \leq 0.05$) in natural seawater while a thinner mud settlement was observed at low flowrate areas (not significant, $p \geq 0.05$). Based on the research outcomes, it was observed that with thorough study, prodigiosin has a high potential as an effective environmental friendly antibiofouling agent since it can inhibit the attachment of marine organisms on wetted surfaces.

ABSTRAK

Biokotoran laut, iaitu pengumpulan organisma hidup yang tidak diingini pada struktur buatan manusia kian semakin teruk dan memberi kesan ekonomi yang buruk. Dalam kajian ini, cat antibiokotoran yang lebih mampan telah dirumus dengan menggunakan ejen antibiokotoran semula jadi. Prodigiosin, pigmen bakteria yang diekstrak daripada Serratia marcescens telah digunakan sebagai agen antibiokotoran dan pigmen. Ciri-ciri antibiokotoran prodigiosin mentah telah dikaji dengan menilai sifat antibakteria, kepekatan perencatan minimum (MIC), kepekatan bakteria minimum (MBC) dan pengujian ketoksikan. Prestasi cat antibiokotoran pada komposisi pigmen yang berbeza digabungkan dengan prodigiosin mentah telah dikaji di makmal dan di dalam air laut semula jadi. Berdasarkan keputusan yang diperoleh, ujian antibakteria menunjukkan zon perencatan terbesar terhadap *B. subtilis* (4.0 ± 0.3 cm) pada 10000 ppm dan zon perencatan terkecil terhadap *E. coli* (2.0 ± 0.4 cm) pada 1000 ppm. Nilai MIC adalah antara 390 hingga 3126 ppm dan nilai MBC adalah antara 1562 ppm hingga 6250 ppm bagi semua bakteria yang diuji. Prodigiosin mentah menunjukkan nilai ketoksikan yang rendah (LC50 = 4270.203 ppm). Kajian perbandingan perekat menunjukkan bahawa resin vinil ester menunjukkan prestasi yang lebih baik berbanding dengan resin epoksi dalam semua ujian, iaitu ujian antibakteria (*B. subtilis*: 3.77 ± 0.1 cm, *E. coli*: 3.43 ± 0.1, *P. aeruginosa*: 3.63 ± 0.3, *S. aureus*: 4.00 ± 0.1), kekasaran permukaan dan ujian perekatan (Kelas 5B). Keluli yang dicat dengan prodigiosin mentah dapat mengekalkan kebersihannya di kawasan kadar alir yang tinggi (signifikan, $p \leq 0.05$) di dalam air laut semula jadi sementara mendapan lumpur yang lebih nipis telah diperhatikan di kawasan kadar alir yang rendah (tidak signifikan, $p \geq 0.05$). Berdasarkan hasil penyelidikan, diperhatikan bahawa dengan kajian menyeluruh, prodigiosin mempunyai potensi yang tinggi sebagai ejen antibiokotoran mesra alam yang berkesan kerana ia boleh menghalang organisma laut daripada melekat di atas permukaan yang dibasahi.

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CFU	Colony forming unit
DMSO	Dimethyl sulfoxide
DNA	Deoxyribonucleic acid
ER	Epoxy resin
ERO	Epoxy resin with oil
ERS	Epoxy resin with shellac
HCl	Hydrochloric acid
NA	Nutrient agar
NaOH	Sodium hydroxide
NB	Nutrient broth
VOC	Volatile Organic Compound
MEKP	Methyl ethyl ketone peroxide
µg	Microgram
mg	Miligram
mL	Mililiter
MBC	Minimum bactericidal concentration
MIC	Minimum inhibitory concentration
nm	Nanometer
NA	Nutrient agar
NB	Nutrient broth
UV	Ultraviolet
VE	Vinyl ester resin
VEO	Vinyl ester resin with oil
VES	Vinyl ester resin with shellac

LIST OF SYMBOLS

°C	Temperature relative to 273.15 K
cm	Length
mm	Length
g	Mass
g/L	Mass concentration
rpm	Revolutions per minute
kPa	Pressure
L	Volume
μL	Volume
M	Molarity
mg	Mass
mg/m^3	Concentration
ms^{-1}	Velocity
ppm	Volume (mg/L)

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Marine biofouling, the unwanted accumulation of living organisms on man-made structures is worsening every year (Vinagre *et al*., 2020). They grow on structures including deep sea oil platform, pipelines, fish nets, ships, cables as well as the bridge pillars. They basically grow on anything submerged in the seawater including on the living things such as crab and turtles. Biofouling in marine environment usually occurs in any wetted surface, submerged for a period of time in the seawater. This phenomenon happens in few stages. Marine biofouling started with conditioning followed by adhesion and attachment of microorganisms and consequently the attachment of larger organisms or macroorganisms. Conditioning process produces adhesins which lead to the next stage, adhesion of microorganisms (Li *et al*., 2016). Microorganisms on the other hand produces biofilm which facilitate the attachment of larger organisms on the affected surface. The whole process of formation of biofouling occurs within a week. Bacteria species that usually form biofilm in marine environment are *Pseudomonas aeruginosa*, *Klebsiella pneumonia* and *Eschericia coli* (Magana *et al*., 2018; Jamal *et al*., 2018; Schinke *et al*., 2017).

Marine biofouling is a problematic issue that needs immediate action. This is due to the significant impact of marine biofouling on the daily operation of most sectors associated with marine environment. Some of serious problems include the significant increase in expenses for fuel due to an increase in drag resistance and weight, cleaning the formed biofouling, harmful waste scraped from fouled surfaces into the sea, profit loss for dry docking and reduction in shelf life for the man-made structure (Wang *et al*., 2018; Hakim *et al*., 2019). Biofouling affects the aquaculture environment, shipping and power industries and water purification (Bannister *et al*., 2019; Forrest & Atalah, 2017).

The basic composition of the antibiofouling paint comprises of binder, solvent, antibiofouling agent, additives and pigment (Watermann & Eklund, 2019). Binder acts as the agent that hold all components together on the surface of interest. In order for the paint to be possible to be applied on surface, vehicle is needed. Solvent acts as the vehicle for the paint to be applied on the surface of marine structure which could either be organic solvents or water. In the case of antibiofouling paint, organic solvent is preferred over water as to produce a non-water based paints. Additives are optional as they are added to improve the performance of the paint. Some of the common additives used in antibiofouling paints are the pH regulator and anti-corrosive additives (Fay *et al*., 2019).

The International Maritime Organization (IMO) has strictly outlined the standards that needs to be complied by the antibiofouling paint manufacturers as to defend the fate of mother earth. Thus, to develop next of a more sustainable and environmental friendly paint for marine structure applications is needed. Consequently, biofouling is a significant management issue resulting in increased operational expenses. The commonly available in local market antibiofouling paints are Lalizas (Greece), Jotun (Norway) and Nippon (Japan). Hence, a greener and effective approach is highly on demand as to combat this marine biofouling problem as well as to protect the mother earth especially the fate of marine life (Zhou *et al*., 2009).

Up to this day, there is still no promising solution for this biofouling problem. With regard to environmental concern, biofouling makes the man-made structure to not be able to function in its maximum potential within a very short period of time. In the early development of antibiofouling paint, copper is used to prevent biofouling on ship hulls. Problem arises as the copper incorporated in the antibiofouling paint could only last for a very short period of time due to no control release of the copper causing rapid leaching of the antibiofouling agent (Xie *et al*., 2013). Besides, this method is also observed to significantly increase the accumulation of copper salts in the marine environment. After that, biocides were used as an antibiofouling agent (Zhang *et al*., 2000).

Serratia marcescens (*S. marcesens*), a gram negative rod-shaped bacteria that occurs naturally in water and soil (Akl *et al*., 2020). *S. marcescens* produces the red pigment prodigiosin under desired condition. Prodigiosin ($C_{20}H_{25}N_3O$) is a secondary metabolite with a wide range of medicinal and industrial benefits (Lapenda *et al*., 2020). Prodigiosin has demonstrated its potential in various applications as the food and polyolefines colorant, sunscreen, antimalarial, antibacterial and anticancerous agent (Khanam & Chandra, 2018). The antibiofouling paints made from bacterial pigment will result in a non-hazardous scrap waste since it is originated from the environment.

1.2 Problem Statement

It is apparent that biological materials have a higher tendency to attach and settle on a super-hydrophobic surface, the surface modification method has also been developed just to bring about only a little success in terms of efficiency and service life. Currently, only limited products are available to control biofouling in marine structures (Gooch & Hlady, 2015). Biocides have been proven to be an effective antibiofouling agent for up to 5 years (Joshi *et al*., 2015). Despite its effectiveness, the environmental consequences are concerning too due to its high level of toxicity against marine organisms. A self-polishing paint can last long for up to 4 years but however contained a biologically toxic organotin compound such as tributyltin oxide and remarkably toxic to marine organisms at a very low concentration. However, all these methods have their own limitations (Zhou *et al*., 2009).

Current method used against the biofouling problem is not environmental friendly. The antibiofouling paint currently used usually contains heavy metals, continuously leached out killing microfoulers to prevent the attachment of microfoulers as to protect the surface against the biofouling organisms (Lagerstrom *et al*., 2020). Hence, a safer, environmental-friendly and last long method is in need to combat this problem (Zhang *et al*., 2000).

In facts that the current worn out antibiofouling paints need a mechanical action to be removed so that the new antibiofouling paints can be applied, the scraped waste usually goes in back to the sea (Muller *et al*., 2021). The unutilized biofouling agents that goes to the sea will continue poisoning marine life, which is the non-target organisms (Matin *et al*., 2011). Bacterial pigment is chosen to substitute the currently used antibiofouling agents for several reasons. One of the reason is mainly because of its abundance in the world. Bacteria is easily available all around us, in abundance amount. It is easy to get the bacteria of interest by isolation method. In addition, bacteria have a short life cycle and can be easily grown in a large scale in a short period of time. In compared to the current antibiofouling paints that not only prevent the biofouling problem but also highly toxic to the life in its area, bacterial pigment will act as the biofouling agent by killing target organism, not all organisms living in the area.

1.3 Research Objectives

This study will access a new antibiofouling paint by using prodigiosin as the antibiofouling agent. Currently, the antibiofouling paint used in the marine industry is not environmental friendly. A safe way to solve this problem is by using the natural antibiofouling agent. Therefore, in this study, it is proposed the use prodigiosin due to its high antibacterial properties. Since the biofouling problem started with settlement of bacteria on immersed surface, the antibacterial properties of prodigiosin has the potential to prevent the settlement of bacteria. The objectives of the research are:

(a) To determine the antibiofouling properties of the prodigiosin.

(b) To formulate the antibiofouling paint comprising of various composition of prodigiosin.

(c) To evaluate the performance and physical characteristics of the antibiofouling paint in seawater.

1.4 Scopes of Study

To achieve all objectives stated in 1.3, a few experimental procedures was carried out according to the objectives stated. To fulfil the first objective, the study first began by screening for the antibiofouling properties of a bacterial pigment, the antibacterial test on marine bacteria namely *Bacillus subtilis*, *Eschericia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus* using the disc diffusion method was conducted. The Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) of the pigment produced from bacteria against the marine bacteria was conducted as well. This is to determine the concentration at which the crude prodigiosin is able to inhibit the bacterial growth and hence, preventing primary attachment of bacteria on wetted surface in marine structure. Next, to evaluate the toxicity of pigment extracted from bacteria against marine organism namely *Artemia salina*, the in-vivo toxicity test of pigment against brine shrimp was conducted as to determine the toxicity level of the pigment against marine life and human. This is important as to achieve the Sustainable Development Goals, goal number 9 the life below water (Zhuiykov, 2014).

The second objective is to formulate the antibiofouling paint using the crude prodigiosin extracted from *Serratia marcesens*. A number of different formulations with varying ratio crude prodigiosin was tested and monitored for efficacy to prevent biofouling using adhesion test and shelf life test on acrylic plates for up to 14 days.

The third objective is to evaluate the performance of antibiofouling paint formulation and perform a physical characterization on the antibiofouling paint painted on mild steel plate which represent the ship hull for 8 weeks. To achieve this objective, field immersion test in natural seawater was conducted. The dry mass was determined. The antifouling performance was evaluated by evaluating the colour change, dry mass of coated mild steel plates and observation on surface coated after immersion test was conducted.

1.5 Significance of Study

The development of an efficient and environmental friendly antibiofouling paint is crucial. Hence, by evaluating the antibiofouling properties of potential compounds is a promising action in order to produce efficient antibiofouling paint to replace the existing harmful antibiofouling paint. Most people are still unconcerned on the fate of the environment on the currently used antibiofouling paints (Song *et al*., 2020).

Marine life is extremely suffering due to the existing antibiofouling paint, and human and other living organisms will face the same fate if the problem is continuously left unaddressed. Production cost is one of the major problem in developing a sustainable antibiofouling paints. As for bacterial pigment, because of its abundance in the environment and can be easily grown in a large scale in a short period of time, it is also can be grown in a cheap growth medium from waste industrial materials. Hence, it contributed to a lower production cost and reducing waste from industries to be utilized in a good mean (Farkas *et al*., 2020).

In addition, a greener technology leads to a greener environment by reducing the fuel consumption for operation by eliminating the biofouling problem as less greenhouse gasses will be produced by burning of fossil fuels too. Bacterial based antibiofouling paint is a promising candidate to produce an antibiofouling paint as efficient as the currently available in market, but less toxic (Gallagher *et al*., 2015).

REFERENCES

Abdelmola, F. A., & Carlsson, L. A. (2019). Water uptake in epoxy matrix with voids: Experiments and modeling. *Journal of Composite materials, 53*(8), 1049-1065.

Abdikheibari, S., Parvizi, R., Moayed, M., Zebarjad, S., & Sajjadi, S. (2015). Beeswax- colophony blend: a novel green organic coating for protection of steel drinking water storage tanks. *Metals*, *5*(3), 1645-1664.

Abreo, E., & Altier, N. (2019). Pangenome of *Serratia marcescens* strains from nosocomial and environmental origins reveals different populations and the links between them. *Scientific reports*, *9*(1), 1-8.

Ahmed, N., Murosaki, T., Kakugo, A., Kurokawa, T., Gong, J. P., & Nogata, Y. (2011). Long-term in situ observation of barnacle growth on soft substrates with different elasticity and wettability. *Soft Matter*, *7*(16), 7281-7290.

Ahmed, Z., Cho, J., Lim, B. R., Song, K. G., & Ahn, K. H. (2007). Effects of sludge retention time on membrane fouling and microbial community structure in a membrane bioreactor. *Journal of Membrane Science*, *287*(2), 211-218.

Akafuah, N. K., Poozesh, S., Salaimeh, A., Patrick, G., Lawler, K., & Saito, K. (2016). Evolution of the automotive body coating process - A review. *Coatings*, *6*(2), 24.

Akkahat, P., Kiatkamjornwong, S., Yusa, S. I., Hoven, V. P., & Iwasaki, Y. (2012). Development of a novel antifouling platform for biosensing probe immobilization from methacryloyloxyethyl phosphorylcholine-containing copolymer brushes. *Langmuir*, *28*(13), 5872-5881.

Akl, B. A., Nader, M. M., & El-Saadony, M.T. (2020). Biosynthesis of silver nanoparticles by Serratia marcescens spp sakuensis and its antibacterial application against some pathogenic bacteria. *Journal of Agricultural Chemistry and Biotechnology*, *11*(1), 1-8.

Albasi, C., Hernandez Rojas, M., Schetrite, S., & Van Kaam, R. (2005). Role and variations of supernatant compounds in submerged membrane bioreactor fouling. *Desalination*, *179*, 95-107.

Al-Husaini, I. S., Yusoff, A. R. M., Lau, W. J., Ismail, A. F., Al-Abri, M. Z., Al-Ghafri, B. N., & Wirzal, M. D. H. (2019). Fabrication of polyethersulfone electrospun nanofibrous membranes incorporated with hydrous manganese dioxide for enhanced ultrafiltration of oily solution. *Separation and Purification Technology*, *212*, 205-214.Washington, DC: U.S. Patent and Trademark Office.

Al-Mailem, D., Kansour, M., & Radwan, S. (2015). Bacterial communities associated with biofouling materials used in bench-scale hydrocarbon bioremediation. *Environmental Science and Pollution Research*, *22*(5), 3570-3585.

Amidaiji, K., Yamamoto, T., & Muramatsu, H. (2007). U.S. Patent No. 7,297,745.

An, Y. H., & Friedman, R. J. (1998). Concise review of mechanisms of bacterial adhesion to biomaterial surfaces. *Journal of Biomedical Materials Research*, *43*(3), 338-348.

Antunes, J., Leão, P., & Vasconcelos, V. (2019). Marine biofilms: diversity of communities and of chemical cues. *Environmental Microbiology Reports*, *11*(3), 287-305.

Apte, S., Holland, B. S., Godwin, L. S., & Gardner, J. P. (2000). Jumping ship: a stepping stone event mediating transfer of a non-indigenous species via a potentially unsuitable environment. *Biological Invasions*, *2*(1), 75-79.

Arciola, C. R., Campoccia, D., Gamberini, S., Cervellati, M., Donati, E., & Montanaro, L. (2002). Detection of slime production by means of an optimised Congo red agar plate test based on a colourimetric scale in *Staphylococcus epidermidis* clinical isolates genotyped for ica locus. *Biomaterials*, *23*(21), 4233-4239.

Ariono, D., Wardani, A. K., Aryanti, P. T. P., Hakim, A. N., & Wenten, I. G. (2018). Determination of fouling mechanism inultrafiltration of electroplating wastewater. *Jurnal Teknologi*, *80*(3-2).

Ashley, K., Schlecht, P. C., Song, R., Feng, A., Dewalt, G., & McKnight, M. E. (1996). ASTM Sampling methods and analytical validation for lead in paint, dust, soil, and air. In Sampling Environmental Media. ASTM International.

ASTM, D. (2002). D3359-Standard test method for measuring adhesion by tape test. Tool and Tape.

Asuri, P., Karajanagi, S. S., Kane, R. S., & Dordick, J. S. (2007). Polymer–nanotube–enzyme composites as active antifouling films. *Small*, *3*(1), 50-53.

Azeredo, H. M., Magalhães, U. S., Oliveira, S. A., Ribeiro, H. L., Brito, E. S., & De Moura, M. R. (2012). Tensile and water vapour properties of calcium-crosslinked alginate-cashew tree gum films. *International Journal of Food Science & Technology*, *47*(4), 710-715.

Baker, J. S., & Dudley, L. Y. (1998). Biofouling in membrane systems—a review. *Desalination*, *118*(1-3), 81-89.

Bannister, J., Sievers, M., Bush, F., & Bloecher, N. (2019). Biofouling in marine aquaculture: a review of recent research and developments. *Biofouling*, *35*(6), 631-648.

Bauer, A. W., Kirby, W., Sherris, J., & Turck, M. (1966). An in vitro evaluation of antibacterial potential of *Annona squamosa* against bovine mastitis. *Journal of Clinical Pathology*, *45*, 493-496.

Bayat, M., Mehrnia, M. R., Hosseinzadeh, M., & Sheikh-Sofla, R. (2015). Petrochemical wastewater treatment and reuse by MBR: A pilot study for ethylene oxide/ethylene glycol and olefin units. *Journal of Industrial and Engineering Chemistry*, *25*, 265- 271.

Becerra, M. O., Contreras, L. M., Lo, M. H., Díaz, J. M., & Herrera, G. C. (2020). Lutein as a functional food ingredient: Stability and bioavailability. *Journal of Functional Foods*, *66*, 103771.

Benschop, H. O. G., Guerin, A. J., Brinkmann, A., Dale, M. L., Finnie, A. A., Breugem, W. P., & Reynolds, K. J. (2018). Drag-reducing riblets with fouling-release properties: development and testing. *Biofouling*, *34*(5), 532-544.

Berglund, G., & Eriksson, U. (2012). U.S. Patent No. 6,334,483. Washington, DC: U.S. Patent and Trademark Office.

Berlanga, O., Bobe, R., Becker, M., Murphy, G., Leduc, M., Bon, C., & Watson, S. P. (2000). Expression of the collagen receptor glycoprotein VI during megakaryocyte differentiation. Blood, *The Journal of the American Society of Hematology*, *96*(8), 2740-2745.

Bermejo, D. V., Ibáñez, E., Reglero, G., & Fornari, T. (2016). Effect of cosolvents (ethyl lactate, ethyl acetate and ethanol) on the supercritical CO^2 extraction of caffeine from green tea. *The Journal of Supercritical Fluids*, *107*, 507-512.

Bers, A. V., & Wahl, M. (2004). The influence of natural surface microtopographies on fouling. *Biofouling*, *20*(1), 43-51.

Bixler, G. D., & Bhushan, B. (2012). Biofouling: lessons from nature. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370(1967), 2381-2417.

Bott, T. R. (1995). Fouling of heat exchangers. *Elsevier*.

Braeken, L., Boussu, K., Van der Bruggen, B., & Vandecasteele, C. (2005). Modeling of the adsorption of organic compounds on polymeric nanofiltration membranes in solutions containing two compounds. *ChemPhysChem*, *6*(8), 1606-1612.

Bryan, G. W., Gibbs, P. E., Burt, G. R., & Hummerstone, L. G. (1987). The effects of tributyltin (TBT) accumulation on adult dog-whelks, *Nucella lapillus*: long-term field and laboratory experiments. *Journal of the Marine Biological Association of the United Kingdom*, *67*(3), 525-544.

Burgess, J. G., Boyd, K. G., Armstrong, E., Jiang, Z., Yan, L., Berggren, M., ... & Adams, D. R. (2003). The development of a marine natural product-based antifouling paint. *Biofouling*, *19*(S1), 197-205.

Burns-Essock, T., Gohad, N. V., Orihuela, B., Mount, A. S., Spillmann, C. M., Wahl, K. J., & Rittschof, D. (2017). Barnacle biology before, during and after settlement and metamorphosis: a study of the interface. *Journal of Experimental Biology*, *220*(2), 194-207.

Byllaardt, J. K., Adams, J. K., Monroy, O. C, Bailey, S. A. (2018). Examination of an indicative tool for rapidly estimating viable organism abundance in ballast water. *Journal of Sea Research*, *133*, 39-35.

Callow, J. A., & Callow, M. E. (2011). Trends in the development of environmentally friendly fouling-resistant marine coatings. *Nature Communications*, *2*, 244.

Callow, M. E., & Callow, J. A. (2002). Marin biofouling: a sticky problem. *Biologist*, *49*(1), 1-5.

Callow, M. E., Callow, J. A., Pickett-Heaps, J. D., & Wetherbee, R. (1997). Primary adhesion of *Enteromorpha* (chlorophyte, ulvales) propagules: quantitative settlement studies and video microscopy 1. *Journal of Phycology*, *33*(6), 938-947.

Candries, M., Atlar, M., & Anderson, C. D. (2000). Considering the use of alternative antifoulings: the advantages of foul release systems. *Proceedings ENSUS 2000*, 88-95.

Cang, S., Sanada, M., Johdo, O., Ohta, S., Nagamatsu, Y., & Yoshimoto, A. (2000). High production of prodigiosin by *Serratia marcescens* grown on ethanol. *Biotechnology Letters*, *22*(22), 1761-1765.

Cao, X., Pettitt, M. E., Wode, F., Arpa Sancet, M. P., Fu, J., Ji, J., & Grunze, M. (2010). Interaction of zoospores of the green alga ulva with bioinspired micro-and nanostructured surfaces prepared by polyelectrolyte layer-by-layer self-assembly. *Advanced Functional Materials*, *20*(12), 1984-1993.

Carabelli, A. M. (2019). Exploring bacteria-surface interactions (*Doctoral dissertation, University of Nottingham*).

Carlton, J. (2018). Marine propellers and propulsion. Butterworth-Heinemann.

Carvalho, E. P., & Ravagnani, M. A. (2018). Dynamic analysis of fouling buildup in heat exchangers designed according to TEMA standards. *Industrial & Engineering Chemistry Research*, *57*(10), 3753-3764.

Cavalcanti, R. S. D. F. B., & Rabello, M. S. (2019). The effect of red pigment and photo stabilizers on the photo degradation of polypropylene films. *Materials Research*, *22*(3).
Chambers, L. D., Stokes, K. R., Walsh, F. C., & Wood, R. J. (2006). Modern approaches to marine antifouling coatings. *Surface and Coatings Technology, 201*(6), 3642- 3652.
Characklis, W. G., & Cooksey, K. E. (1983). Biofilms and microbial fouling. In Advances in applied microbiology. *Academic Press*, *29*, 93-138.
Charnley, M., Textor, M., & Acikgoz, C. (2011). Designed polymer structures with antifouling–antimicrobial properties. *Reactive and Functional Polymers*, *71*(3), 329-334.
Chen, D., Weavers, L.K., and Walker, H.W. (2006) Ultrasonic control of ceramic membrane fouling: effect of particle characteristics. *Water Research*, *40,* 840.
Chen, R., Nie, Y., Hu, Y., Miao, R., Utashiro, T., Li, Q., & Li, Y. Y. (2017). Fouling behaviour of soluble microbial products and extracellular polymeric substances in a submerged anaerobic membrane bioreactor treating low-strength wastewater at room temperature. *Journal of Membrane Science*, *531*, 1-9.
Cheng, Y., Feng, G., & Moraru, C. I. (2019). Micro-and nanotopography sensitive bacterial attachment mechanisms: A review. *Frontiers in Microbiology*, *10*, 191.
Choi, U., & Lee, C. R. (2019). Distinct roles of outer membrane porins in antibiotic resistance and membrane integrity in *Escherichia coli*. *Frontiers in Microbiology*, *10*, 953.
Christensen, D. G., Orr, J. S., Rao, C. V., & Wolfe, A. J. (2017). Increasing growth yield and decreasing acetylation in *Escherichia coli* by optimizing the carbon-to-magnesium ratio in peptide-based media. *Applied and Environmental Microbiology*, *83*(6).
Claira, A. A., Chidambaran, K. V., Zainul, A. Z., & Ahmad, W. A. (2014). Brown sugar as a low-cost medium for the production of prodigiosin by lozally isolated *Serratia macescens* UTM 1. *International Biodeterioration & Biodegradation*, *95*, 19-24.
Consoli, P., Romeo, T., Angiolillo, M., Canese, S., Esposito, V., Salvati, E., & Tunesi, L. (2019). Marine litter from fishery activities in the Western Mediterranean sea: The impact of entanglement on marine animal forests. *Environmental Pollution*, *249*, 472-481.
Cooksey, K. E. (1981). Requirement for calcium in adhesion of a fouling diatom to glass. *Appl. Environmental Microbiology, 41*(6), 1378-1382.
Cosh, T., Gill, K., Morrison, A., & MacNair, N. (2009). An investigation of low impact and natural treatment options for mitigating the impact of tunicate infestation on mussel aquaculture farms. *PEI Department of Fisheries, Aquaculture, and Rural Development*.
D. R. (2003). The development of a marine natural product-based antifouling paint. *Biofouling*, *19*(S1), 197-205.
Da Gama, B. A., Pereira, R. C., Soares, A. R., Teixeira, V. L., & Yoneshigue-Valentin, Y. (2003). Is the mussel test a good indicator of antifouling activity? A comparison between laboratory and field assays. *Biofouling*, *19*(S1), 161-169.
Dafforn, K. A., Johnston, E. L., & Glasby, T. M. (2009). Shallow moving structures promote marine invader dominance. *Biofouling*, *25*(3), 277-287.

Dafforn, K. A., Lewis, J. A., & Johnston, E. L. (2011). Antifouling strategies: history and regulation, ecological impacts and mitigation. *Marine Pollution Bulletin*, *62*(3), 453-465.
Danevcic, T., Boric Vezjak, M., Zorec, M., & Stopar, D. (2016). Prodigiosin-A multifaceted *Escherichia coli* antimicrobial agent. *PLoS One*, *11*(9), e0162412.
Danevcic, T., Vezjak, M. B., Tabor, M., Zorec, M., & Stopar, D. (2016). Prodigiosin induces autolysins in actively grown *Bacillus subtilis* cells. *Front Microbiology*, *7*(27).
Darshan, N., & Manonmani, H. K. (2015). Prodigiosin and its potential applications. *Journal Food Science Technology*, *52*(9),5393–5407.
Dasan, K. (2016). History of antifouling coating and future prospects for nanometal/polymer coatings in antifouling technology. *Eco-Friendly Nano-Hybrid Materials for Advanced Engineering Applications*, 381.
de Carvalho, C. C. (2018). Marine biofilms: a successful microbial strategy with economic implications. *Frontiers in Marine Science*, *5*, 126.
de Lafontaine, Y., & Veillette, J. Antifouling Effectiveness and Potential Toxicological Risk of an Elastomer-Based Coating against Zebra Mussels.
Debnath, N., Kumar, A., Thundat, T., & Sadrzadeh, M. (2019). Investigating fouling at the pore-scale using a microfluidic membrane mimic filtration system. *Scientific Reports*, *9*(1), 1-10.
Decho, A. W. (1990). Microbial exopolymer secretions in ocean environments: their role(s) in food webs and marine processes. *Oceanography Marine Biology*, *28*, 9-16.
Demirel, Y. K., Uzun, D., Zhang, Y., Fang, H. C., Day, A. H., & Turan, O. (2017). Effect of barnacle fouling on ship resistance and powering. *Biofouling*, *33*(10), 819-834.
Denyer, S. P. (1995). Mechanisms of action of antibacterial biocides. *International Biodeterioration & Biodegradation*, *36*(3-4), 227-245.
Desai, D. V., Anil, A. C., & Venkat, K. (2006). Reproduction in *Balanus amphitrite* Darwin (Cirripedia: Thoracica): influence of temperature and food concentration. *Marine Biology*, *149*(6), 1431-1441.
Desai, D. V., Krishnamurthy, V., & Anil, A. C. (2018). Biofouling Community Structure in a Tropical Estuary of Goa on the West Coast of India. *ASEAN Journal on Science and Technology for Development*, *35*(1-2), 37-42.
Dick, E. P., Ryabov, G. A., Tugov, A. N., & Soboleva, A. N. (2007). Comparing properties of coal ash and alternative-fuel ash. *Thermal Engineering, 54*(3), 231-235.
Dobretsov, S., Dahms, H. U., & Qian, P. Y. (2006). Inhibition of biofouling by marine microorganisms and their metabolites. *Biofouling, 22*(1), 43-54.
D'souza, F., & Bhosle, N. B. (2003). Analysis of microfouling products formed on metallic surfaces exposed in a marine environment. *Biofouling, 19*(2), 95-107.
Edmondson, C. H., & Ingram, W. M. (2011). Fouling organisms in Hawaii. Bernice P. Bishop Museum.
Egan, B. (1987) Marine microbial adhesion and its consequences. In: Steigh M A (ed) Microbes in the Sea. Ellis Horwood, Chichester, 220-238.
El Aleem, F. A., Al-Sugair, K. A., & Alahmad, M. I. (1998). Biofouling problems in membrane processes for water desalination and reuse in Saudi Arabia. *International Biodeterioration & Biodegradation, 41*(1), 19-23.

El-Naggar, M. H., Elgaml, A., Abdel Bar, F. M., & Badria, F. A. (2019). Antimicrobial and antiquorum-sensing activity of Ricinus communis extracts and ricinine derivatives. *Natural Product Research, 33*(11), 1556-1562.

El-Naggar, M. M. A., El-Masry, M. H., & El-Shenawy, M. A. (2003). Distribution of some dominant bacteria in Alexandira eastern harbour that can be used as marine contaminate indicator. *Bulletin National Institute Oceanography Fish, 29*, 323-336.

Erramilli, S., Neumann, T. V., Chester, D., Dickey, M. D., Brown, A. C., & Genzer, J. (2020). Effect of surface interactions on the settlement of particles on a sinusoidally corrugated substrate. *RSC Advances, 10*(19), 11348-11356.

Eran, F. (2011). Cytotoxic and phytotoxic actions of *Heliotropium strigosum*. *Toxicology and Industrial Health, 31*(5), 429-432.

Evac, E. (2021). Cathelco marine growth prevention systems technology description. Retrieved from https://evac.com/solutions/marine-growth-prevention/technology/

Faraag, A. H., El-Batal, A. I., & El-Hendawy, H. H. (2017). Characterization of prodigiosin produced by *Serratia marcescens* strain isolated from irrigation water in Egypt. *Nature and Science*, 1*5*(5), 55-68.

Farkas, A., Degiuli, N., & Martić, I. (2020). An investigation into the effect of hard fouling on the ship resistance using CFD. *Applied Ocean Research, 100,* 102205.

Fattom, A., & Shilo, M. (1984). Hydrophobicity as an adhesion mechanism of benthic cyanobacteria. *Applied Environmental Microbiology, 47*(1), 135-143.

Fay, F., Gouessan, M., Linossier, I., & Rehel, K. (2019). Additives for efficient biodegradable antifouling paints. *International Journal of Molecular Sciences, 20*(2), 361.

Ferrario, J., Caronni, S., Occhipinti-Ambrogi, A., & Marchini, A. (2017). Role of commercial harbours and recreational marinas in the spread of non-indigenous fouling species. *Biofouling, 33*(8), 651-660.

Ferrario, J., Gestoso, I., Ramalhosa, P., Cacabelos, E., Duarte, B., Cacador, I., & Canning-Clode, J. (2020). Marine fouling communities from artificial and natural habitats: comparison of resistance to chemical and physical disturbances. *Aquatic Invasions*, 15(2), 196-216.

Filip, N., Pustam, A., Ells, V., Grosicki, K. M., Yang, J., Oguejiofor, I., & Wyeth, R. C. (2016). Fouling-release and chemical activity effects of a siloxane-based material on tunicates. *Marine Environmental Research, 116,* 41-50.

Finlay, J. A., Callow, M. E., Ista, L. K., Lopez, G. P., & Callow, J. A. (2002). The influence of surface wettability on the adhesion strength of settled spores of the green alga Enteromorpha and the diatom Amphora. *Integrative and Comparative Biology*, *42*(6), 1116-1122.

Flemming, H. C. (1997). Reverse osmosis membrane biofouling. *Experimental Thermal and Fluid Science, 14*(4), 382-391.

Floerl, O., Sunde, L. M., & Bloecher, N. (2016). Potential environmental risks associated with biofouling management in salmon aquaculture. *Aquaculture Environment Interactions*, *8,* 407-417.

Forrest, B. M., & Atalah, J. (2017). Significant impact from blue mussel *Mytilus galloprovincialis* biofouling on aquaculture production of green-lipped mussels in New Zealand. *Aquaculture Environment Interactions, 9,* 115-126.

Franks, A., Egan, S., Holmström, C., James, S., Lappin-Scott, H., & Kjelleberg, S. (2006). Inhibition of fungal colonization by *Pseudoalteromonas tunicata* provides a competitive advantage during surface colonization. *Applied Environmental Microbiol*ogy, *72*(9), 6079-6087.

Funke, H. H., Argo, A. M., Falconer, J. L., & Noble, R. D. (1997). Separations of cyclic, branched, and linear hydrocarbon mixtures through silicalite membranes. *Industrial & Engineering Chemistry Research*, *36*(1), 137-143.

Fusetani, N. (2004). Biofouling and antifouling. *Natural Product Reports*, 21(1), 94-104.

Galiano, F., Friha, I., Deowan, S. A., Hoinkis, J., Xiaoyun, Y., Johnson, D., ... & Figoli,A. (2018). Novel low-fouling membranes from lab to pilot application in textile wastewater treatment. *Journal of Colloid and Interface Science*, *515*, 208-220.

Gallagher, J., Styles, D., McNabola, A., & Williams, A. P. (2015). Making green technology greener: Achieving a balance between carbon and resource savings through ecodesign in hydropower systems. *Resources, Conservation and Recycling*, *105*, 11-17.

Ganapiriya, V., Maharajan, A., & Kumarasamy, P. (2012). Antifouling effect of bioactive compounds from marine sponge *Acanthella elongata* and different species of bacterial film on larval attachment of *Balanus amphitrite* (cirripedia, crustacea). *Brazilian Archives of Biology and Technology*, *55*(3), 395-402.

Gansel, L. C., Plew, D. R., Endersen, P. C., Misimi, E., Guenther, J., Jense, O. (2015). Drag of clean and fouled net panels – measurements and parameterization of fouling. *Plos One, 0131051*.

Garcıa, R., & Perez, R. (2002). Dynamic atomic force microscopy methods. *Surface Science Reports*, *47*(6-8), 197-301.

Garrido-Baserba, M., Sobhani, R., Asvapathanagul, P., McCarthy, G. W., Olson, B. H., Odize, V., & Bott, C. B. (2017). Modelling the link amongst fine-pore diffuser fouling, oxygen transfer efficiency, and aeration energy intensity. *Water Research*, *111*, 127-139.

Giachetti, C. B., Battini, N., Bortolus, A., Tatián, M., & Schwindt, E. (2019). Macropredators as shapers of invaded fouling communities in a cold temperate port. *Journal of Experimental Marine Biology and Ecology*, *518*, 151177.

Giessibl, F. J. (2003). Advances in atomic force microscopy. *Reviews of ModernPphysics*, *75*(3), 949.

Giri, A. V., Anandkumar, N., Muthukumaran, G., & Pennathur, G. (2004). A novel medium for the enhanced cell growth and production of prodigiosin from *Serratia marcescens* isolated from soil. *BMC Microbiology*, *4*(1), 11.

Golinia, P., Nasrolahi, A., & Barboza, F. R. (2019). Biofouling in the Southern Caspian Sea: recruitment and successional patterns in a low diversity region. *Community Ecology*, *20*(2), 110-120.

Gooch, N. W., & Hlady, V. (2015). Two surface gradients of polyethylene glycol for a reduction in protein adsorption. *Surface Innovations*, *3*(3), 172.

Gopikrishnan, V., Radhakrishnan, M., Pazhanimurugan, R., Shanmugasundaram, T., & Balagurunathan, R. (2015). Natural products: Potential and less explored source for antifouling compounds. *Journal of Chemical and Pharmaceutical Research*, *7*(7), 1144-1153.

Grave C. (1937) Notes on the culture of eight species of ascidians. In: Galtsoff PS, Lutz FE, Welch PS, Needham JG (eds). *Culture methods for invertebrate animals* (pp 560-564). New York: Dover Publications.

Gulani, C., Bhattacharya, S., & Das, A. (2012). Assessment of process parameters influencing the enhanced production of prodigiosin from *Serratia marcescens* and evaluation of its antimicrobial, antioxidant and dyeing potentials. *Malays Journal of Microbiology*, *8*(2), 116-122.

Guo, W., Ngo, H. H., & Li, J. (2012). A mini-review on membrane fouling. *Bioresource Technology*, *122*, 27-34.

Guryanov, I. D., Karamova, N. S., Yusupova, D. V., Gnezdilov, O. I., & Koshkarova, L. J. (2012). Effect of adsorbed fibronectin on the differential adhesion of osteoblast- like cells and *Staphylococcus aureus* with and without fibronectin-binding proteins. *Biofouling*, *28*(9), 1011-1021.

Guryanov, A. (2013). Bacterial pigment prodigiosin and its genotoxic effect. *Russian Journal of Bioorganic Chemistry*, *39*(1), 106-111.

Habimana, O., Semiao, A. J. C., & Casey, E. (2014). The role of cell-surface interactions in bacterial initial adhesion and consequent biofilm formation on nanofiltration/reverse osmosis membranes. *Journal of Membrane Science, 454,* 82-96.

Hakim, M. L., Nugroho, B., Nurrohman, M. N., Suastika, I. K., & Utama, I. K. A. P. (2019). Investigation of fuel consumption on an operating ship due to biofouling growth and quality of anti-fouling coating. In IOP Conference Series: *Earth and Environmental Science* (Vol. 339, No. 1, p. 012037). IOP Publishing.

Harris, L., M. Tyrrell and C. Chester (1998). Changing patterns for two sea stars in the Gulf of Maine, 1976-1996. *Proceedings of the 9th International Echinoderm Conference, Mooi and Telford, Rotterdam,* 243-248.

Hejazi, A., & Falkiner, F. R. (1997). *Serratia marcescens*. *Journal of Medical Microbiology*, *46*(11), 903-912.

Hellio, C., & Yebra, D. (Eds.). (2009). Advances in marine antifouling coatings and technologies. *Elsevier*.

Herzberg, M., & Elimelech, M. (2007). Biofouling of reverse osmosis membranes: role of biofilm-enhanced osmotic pressure. *Journal of Membrane Science*, *295*(1-2), 11-20.

Higaki, Y., Nishida, J., Takenaka, A., Yoshimatsu, R., Kobayashi, M., & Takahara, A. (2015). Versatile inhibition of marine organism settlement by zwitterionic polymer brushes. *Polymer Journal*, *47*(12), 811-818.

Hille, A., He, M., Ochmann, C., Neu, T. R., & Horn, H. (2009). Application of two component biodegradable carriers in a particle-fixed biofilm airlift suspension reactor: development and structure of biofilms. *Bioprocess and Biosystems Engineering*, *32*(1), 31-39.

Holberg, S., Losada, R., Blaikie, F. H., Hansen, H. H., Soreau, S., & Onderwater, R. C. (2020). Hydrophilic silicone coatings as fouling release: Simple synthesis, comparison to commercial, marine coatings and application on fresh water-cooled heat exchangers. *Materials Today Communications*, *22*, 100750.

Holcapkova, P., Hurajova, A., Bazant, P., Pummerova, M., & Sedlarik, V. (2018). Thermal stability of bacteriocin nisin in polylactide-based films. *Polymer Degradation and Stability*, *158*, 31-39.

Holcapkova, P., Hurajova, A., Kucharczyk, P., Bazant, P., Plachy, T., Miskolczi, N., & Sedlarik, V. (2018). Effect of polyethylene glycol plasticizer on long-term antibacterial activity and the release profile of bacteriocin nisin from polyactide bends. *Polymers of Advanced Technologies, 29*(8), 2253-2263.

Huo, S., & Ulven, C. A. (2017). Study on Residual Stresses in Unidirectional Flax Fiber/Vinyl Ester Composites by XRD Technique. *Journal of Renewable Materials*, *5*(1), 106-116.
Ianora, A., Miralto, A., Poulet, S. A., Carotenuto, Y., Buttino, I., Romano, G., & Terrazzano, G. (2004). Aldehyde suppression of copepod recruitment in blooms of a ubiquitous planktonic diatom. *Nature*, *429*(6990), 403.
Ibrahim, D., Nazari, T. F., Kassim, J., & Lim, S. H. (2014). Prodigiosin-an antibacterial red pigment produced by *Serratia marcescens* IBRL USM 84 associated with a marine sponge *Xestospongia testudinaria*. *Journal of Applied Pharmaceutical Science*, *4*, 1-6.
Imchen, T. (2012). Effect of temperature, salinity and biofilm on the zoospores settlement of *Enteromorpha flexuosa* (Wulfen) J. Agardh. *Indian Journal of Geo-Marine Sciences*, *41*(4), 355-358.
Instant Ocean (2020). Composition of sea salt. Retrieved from http://www.instantocean.com/
Jamal, M., Ahmad, W., Andleeb, S., Jalil, F., Imran, M., Nawaz, M. A., & Kamil, M. A. (2018). Bacterial biofilm and associated infections. *Journal of the Chinese Medical Association*, *81*(1), 7-11.
Janion, C. (2008). Inducible SOS response system of DNA repair and mutagenesis in *Escherichia coli*. *International Journal of Biological Sciences*, *4*(6), 338.
Jaramillo Isaza, F., Castano, J. G., & Echeverria Echeverria, F. (2011). Field study of experimental antifouling paint formulations. *Dyna*, *78*(170), 135-143.
Jeong, S., Choi, Y. J., Nguyen, T. V., Vigneswaran, S., & Hwang, T. M. (2012). Submerged membrane hybrid systems as pretreatment in seawater reverse osmosis (SWRO): Optimisation and fouling mechanism determination. *Journal of Membrane Science, 411*, 173-181.
Ji, K., & Kim, Y. T. (2019). Antimicrobial activity of prodigiosin from Serratia sp. PDGS 120915 against intestinal pathogenic bacteria. *Microbiology and Biotechnology Letters*, *47*(3), 459-464.
Jin, F. L., Li, X., & Park, S. J. (2015). Synthesis and application of epoxy resins: A review. *Journal of Industrial and Engineering Chemistry*, *29*, 1-11.
Johnson, T. (2019). Vinyl Ester vs. Polyester Resins. *Thought Co.* Retrieved from https://www.thoughtco.com/vinyl-ester-vs-polyester-resins-820376
Joshi, M., Mukherjee, A., Misra, S. C., & Ramesh, U. S. (2015). Need of natural biocides in antifouling paints for prevention of marine pollution. *International Journal Innovovation Mededical Research Development*, *4*, 43-49.
Kanamoto, T., Asakawa, H., & Iwaki, M. (1990). Surface hydrophobicity, adherence, and aggregation of cell surface protein antigen mutants of *Streptococcus mutans serotype c. Infection and Immunity*, *58(2), 289-296.*
Kandale, A., Meena, A. K., Rao, M. M., Panda, P., Manga, A. K., Reddy, G., & Ramesh, B. (2011). Marine algae: an introduction, food value and medicinal uses. *Journal of Pharmacy Research*, *4*(1), 219-221.
Kazi, S. N. (2012). Fouling and fouling mitigation on heat exchanger surfaces. In Heat exchangers-Basics design Applications. *IntechOpen*. DOI: 10.5772/32990.
Keiding, K., & Rasmussen, M. R. (2013). Osmotic effects in sludge dewatering. *Advances in Environmental Research*, *7*(3), 641-645.
Keller, A. A., Adeleye, A. S., Conway, J. R., Garner, K. L., Zhao, L., Cherr, G. N., & Ji, Z. (2017). Comparative environmental fate and toxicity of copper nanomaterials. *Nano Impact*, *7*, 28-40.

Kent, F. C., Farahbakhsh, K., Mahendran, B., Jaklewicz, M., Liss, S. N., & Zhou, H. (2017). Water reclamation using reverse osmosis: Analysis of fouling propagation given tertiary membrane filtration and MBR pretreatments. *Journal of Membrane Science, 382*(1-2), 328-338.

Khanam, B., & Chandra, R. (2018). Comparative analysis of prodigiosin isolated from endophyte *Serratia marcescens*. *Letters in Applied Microbiology*, *66*(3), 194-201.

Kim, D., Mittal, G., Kim, M., Kim, S., & Rhee, K. Y. (2019). Surface modification of MMT and its effect on fatigue and fracture behavior of basalt/epoxy based composites in a seawater environment. *Applied Surface Science, 473*, 55-58.

Kim, H., Han, S., Lee, C., Lee, K., Park, S., & Kim, Y. (2003). U.S. Patent No. 6,638,968. Washington, DC: U.S. Patent and Trademark Office.

Kishihara, M., Nanishi, K., & Yonehara, Y. (1993). U.S. Patent No. 5,218,059.

Klijnstra, J. W. (2020). Field efficacy test of environmentally friendly antifouling products for pleasure boats in The Netherlands. *Endures.* Retrieved from https://www.varendoejesamen.nl/storage/app/media/Nieuws/field-efficacy-test-of-environmentally-friendly-antifouling-products-for-pleasure-boats-in-the-netherlands-endures-waterrecreatie-nederland-varendoejesamen2.pdf

Koga, T., Okahashi, N., Takahashi, I., Koivuluoto, H., Honkanen, M., & Vuoristo, P. (2010). Cold-sprayed copper and tantalum coatings—Detailed FESEM and TEM analysis. *Surface and Coatings Technology*, *204*(15), 2353-2361.

Kokare, C. R., Chakraborty, S., Khopade, A. N., & Mahadik, K. R. (2009). Biofilm: Importance and applications. *Indian Journal of Biotechnology, 8*(2), 159-168.

Komlenic, R. (2010). Rethinking the causes of membrane biofouling. *Filtration & Separation*, *47*(5), 26-28.

Krishnan, S., Weinman, C. J., & Ober, C. K. (2008). Advances in polymers for anti-biofouling surfaces. *Journal of Materials Chemistry*, *18*(29), 3405-3413.

Kristensen, J. B., Olsen, S. M., Laursen, B. S., Kragh, K. M., Poulsen, C. H., Besenbacher, F., & Meyer, R. L. (2009). Enzymatic generation of hydrogen peroxide shows promising antifouling effect. *Biofouling*, *26*(2), 141-153.

Krivorot, M., Kushmaro, A., Oren, Y., & Gilron, J. (2011). Factors affecting biofilm formation and biofouling in membrane distillation of seawater. *Journal of Membrane Science*, *376*(1-2), 15-24.

Kujundzic, E., Greenberg, A. R., Fong, R., Moore, B., Kujundzic, D., & Hernandez, M. (2010). Biofouling potential of industrial fermentation broth components during microfiltration. *Journal of Membrane Science, 349*(1-2), 44-55.

Lagerstrom, M., Ytreberg, E., Wiklund, A. K. E., & Granhag, L. (2020). Antifouling paints leach copper in excess–study of metal release rates and efficacy along a salinity gradient. *Water Research*, *186*, 116383.

Lagos, M. E., White, C. R., & Marshall, D. J. (2016). Biofilm history and oxygen availability interact to affect habitat selection in a marine invertebrate. *Biofouling*, *32*(6), 645-655.

Lambourne, R. (1999). The painting of ships. In Paint and Surface Coatings. *Science Direct* (pp. 529- 549). Woodhead Publishing.

Lapenda, J. C. L., Alves, V. P., Adam, M. L., Rodrigues, M. D., & Nascimento, S. C. (2020). Cytotoxic effect of prodigiosin, natural red pigment, isolated from *Serratia marcescens* UFPEDA 398. *Indian Journal of Microbiology*, 1-14.

Lapenda, J. C., Silva, P. A., Vicalvi, M. C., Sena, K. X. F. R., & Nascimento, S. C. (2015). Antimicrobial activity of prodigiosin isolated from *Serratia*

marcescens UFPEDA 398. *World Journal of Microbiology and Biotechnology*, *31*(2), 399-406.
Larsson, A. I., Mattsson-Thorngren, L., Granhag, L. M., & Berglin, M. (2010). Fouling- release of barnacles from a boat hull with comparison to laboratory data of attachment strength. *Journal of Experimental Marine Biology and Ecology, 392*(1- 2), 107-114.
Le-Clech, P., Chen, V., & Fane, T. A. (2006). Fouling in membrane bioreactors used in wastewater treatment. *Journal of Membrane Science*, *284*(1-2), 17-53.
Lee, C. W., Kim, I. H., & Jung, H. J. (2018). Fabrication and characterization of natural rubber-based magnetorheoological elastomers at large strain for base isolators. *Shock and Vibration*, *2018*, 1-12.
Lehaitre M, & Compere, C. (2007) Biofouling and underwater measurements. In: Babin M, Roesler CS, Cullen JJ (eds) Real-time coastal observing systems for marine ecosystem dynamics and harmful algal blooms, UNESCO series monographs on oceanographic methodology (pp. 463-494). Paris: UNESCO.
Lejars, M., Margaillan, A., & Bressy, C. (2012). Fouling release coatings: a nontoxic alternative to biocidal antifouling coatings. Chemical reviews, 112(8), 4347-4390.
Li, C., Yang, Y., Ding, S., & Hou, L. A. (2016). Dynamics of biofouling development on the conditioned membrane and its relationship with membrane performance. *Journal of Membrane Science*, *514*, 264-273.
Li, X., Fang, X., Pang, R., Li, J., Sun, X., Shen, J., & Wang, L. (2014). Self-assembly of TiO2 nanoparticles around the pores of PES ultrafiltration membrane for mitigating organic fouling. *Journal of Membrane Science*, *467*, 226-235.
Lind, U., Jarva, M., Alm Rosenblad, M., Pingitore, P., Karlsson, E., Wrange, A. L., & Blomberg, A. (2017). Analysis of aquaporins from the euryhaline barnacle *Balanus improvisus* reveals differential expression in response to changes in salinity. *PloS one*, *12*(7), 181-192.
Liu, P., Pitts, J., Lee, S. H., & Tracy, C. (2007). U.S. Patent Application No. 11/752,897. Liu, W., Deng, C., McLaughlin, C. R., Fagerholm, P., Lagali, N. S., Heyne, B., ... & Shinozaki, N. (2009). Collagen–phosphorylcholine interpenetrating network hydrogels as corneal substitutes. *Biomaterials*, *30*(8), 1551-1559.
Loree, J., & Lappin, S. L. (2019). Bacteriostatic Antibiotics. In: StatPearls. *Treasure Island (FL).* Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK547678/
Maan, A. M., Hofman, A. H., de Vos, W. M., & Kamperman, M. (2020). Recent Developments and Practical Feasibility of Polymer-Based Antifouling Coatings. *Advanced Functional Materials, 30*(32), 2000936.
Madou, M.J. (2002). Fundamentals of Microfabrication: The Science of Miniaturization, Second Edition (2nd ed.). *CRC Press*. Retrieved from https://doi.org/10.1201/9781482274004
Magana, M., Sereti, C., Ioannidis, A., Mitchell, C. A., Ball, A. R., Magiorkinis, E., & Tegos, G. P. (2018). Options and limitations in clinical investigation of bacterial biofilms. *Clinical Microbiology Reviews, 31*(3).
Mangwani, N., Shukla, S. K., Kumari, S., Das, S., & Rao, T. S. (2016). Effect of biofilm parameters and extracellular polymeric substance composition on polycyclic aromatic hydrocarbon degradation. *RSC Advances*, *6*(62), 57540-57551.

Marechal, J. P., & Hellio, C. (2009). Challenges for the development of new non-toxic antifouling solutions. *International Journal of Molecular Sciences*, *10*(11), 4623-4637.

Marks, G. S., & Bogorad, L. (1960). Studies on the biosynthesis of prodigiosin in Serratia marcescens. Proceedings of the National Academy of Sciences of the United States of America, 46(1), 25.

Marsden, A. E., Grudzinski, K., Ondrey, J. M., DeLoney-Marino, C. R., & Visick, K. L. (2017). Impact of salt and nutrient content on biofilm formation by *Vibrio fischeri*. *PLoS One*, *12*(1), 169521.

Martin, H. D. (1995). The function of natural colorants: The biochromes. CHIMIA *International Journal for Chemistry*, *49*(3), 45-68.

Matin, A., Khan, Z., Zaidi, S. M. J., & Boyce, M. C. (2011). Biofouling in reverse osmosis membranes for seawater desalination: phenomena and prevention. *Desalination*, *281*, 1-16.

McDougall, T. J., Jackett, D. R., Wright, D. G., & Feistel, R. (2003). Accurate and computationally efficient algorithms for potential temperature and density of seawater. *Journal of Atmospheric and Oceanic Technology*, *20*(5), 730-741.

Melo, L. F., & Bott, T. R. (1997). Biofouling in water systems. *Experimental Thermal and Fluid Science*, *14*(4), 375-381.

Melo, L., Bott, T. R., & Bernardo, C. A. (Eds.). (2012). Fouling science and technology. *Springer Science & Business Media*, *145*.

Meng, F., Chae, S. R., Drews, A., Kraume, M., Shin, H. S., & Yang, F. (2009). Recent advances in membrane bioreactors (MBRs): membrane fouling and membrane material. *Water Research*, *43*(6), 1489-1512.

Meng, F., Zhang, S., Oh, Y., Zhou, Z., Shin, H. S., & Chae, S. R. (2017). Fouling in membrane bioreactors: an updated review. *Water Research*, *114*, 151-180.

Meschke, H., Walter, S., & Schrempf, H. (2012). Characterization and localization of prodiginines from Streptomyces lividans suppressing *Verticillium dahliae* in the absence or presence of *Arabidopsis thaliana*. *Environmental Microbiology*, *14*(4), 940-952.

Meschke, K., Hofmann, R., Haseneder, R., & Repke, J. U. (2020). Membrane treatment of leached mining waste–A potential process chain for the separation of the strategic elements germanium and rhenium. *Chemical Engineering Journal*, *380*, 122476.

Milne, A. (1977). U.S. Patent No. 4,025,693. Washington, DC: U.S. Patent and Trademark Office.

Milne, A. (1977). U.S. Patent No. 4,025,693. Washington, DC: U.S. Patent and Trademark Office.

Minchin, D., Oehlmann, J., Duggan, C. B., Stroben, E., & Keatinge, M. (1995). Marine TBT antifouling contamination in Ireland, following legislation in 1987. *Marine Pollution Bulletin*, *30*(10), 633-639.

Mineur, F., Johnson, M. P., Maggs, C. A., & Stegenga, H. (2007). Hull fouling on commercial ships as a vector of macroalgal introduction. *Marine Biology*, *151*(4), 1299-1307.

Mischke, C. R., & Budynas, R. G. (1989). Mechanical engineering design. New York, NY: McGraw-Hill.

Mossali, E., Picone, N., Gentilini, L., Rodrìguez, O., Pérez, J. M., & Colledani, M. (2020). Lithium-ion batteries towards circular economy: A literature review of opportunities and issues of recycling treatments. *Journal of Environmental Management*, *264*, 110500.

Muller-Karanassos, C., Arundel, W., Lindeque, P. K., Vance, T., Turner, A., & Cole, M. (2021). Environmental concentrations of antifouling paint particles are toxic to sediment-dwelling invertebrates. *Environmental Pollution*, *268*, 115754.

Murray, C. C., Therriault, T. W., & Martone, P. T. (2012). Adapted for invasion? Comparing attachment, drag and dislodgment of native and nonindigenous hull fouling species. *Biological Invasions*, *14*(8), 1651-1663.

Nakai, Y. (1996). U.S. Patent No. 5,514,731. Washington, DC: U.S. Patent and Trademark Office.

National Geographic Society Newsroom (2021). Harvesting the unlikely fruits of oil and gas. Retrieved from https://blog.nationalgeographic.org/2015/01/14/harvesting-the-unlikely-fruits-of-oil-and-gas/

National Maritime Historical Society (2021). Vessels. Retrieved from https://seahistory.org/sea-history-for-kids/worms-and-barnacles-and-algae-oh-my/

Nikolaidis, A., & Moschakis, T. (2018). On the reversibility of ethanol-induced whey protein denaturation. *Food Hydrocolloids*, *84*, 389-395.

Njin, N. R. (2018). Investigation of marine biofouling and the possible need to develop biofouling control measures in Nigeria. *World Mariti,e University Dissertations.*

Numan, M., Bashir, S., Mumtaz, R., Tayyab, S., Ullah, I., Khan, A. L., & Al-Harrasi, A. (2018). Chemical profile and in-vitro pharmacological activities of yellow pigment extracted from Arthrobacter gandavensis. *Process Biochemistry*, *75*, 74-82.

Olivier, F., Tremblay, R., Bourget, E., & Rittschof, D. (2000). Barnacle settlement: field experiments on the influence of larval supply, tidal level, biofilm quality and age on *Balanus amphitrite* cyprids. *Marine Ecology Progress Series*, *199*, 185-204.

Omae, I. (2003). General aspects of tin-free antifouling paints. *Chemical Reviews*, *103*(9), 3431-3448.

Ostojic, J., Herenda, S., Besic, Z., Galic, B.,Milos, M.(2017). Advantages of an Electrochemical Method Compared to the Spectrophotometric Kinetic Study of Peroxidase Inhibition by Boroxine Derivative. *Molecules Journal of Chemistry,* DOI: 10.3390/molecules 22071120. Retrieve from https ://www.mdpi.com/journal/ molecules

Pearce, F. (2016). The new wild: why invasive species will be nature's salvation. *The Quarterly Review of Biology*. *91*(3), 358-359.

Peled, E., Shekhtman, I., Mukra, T., Goor, M., Belenkaya, I., & Golodnitsky, D. (2017). Improving the durability and minimizing the polysulfide shuttle in the Li/S battery. *Journal of The Electrochemical Society*, *165*(1), A6051.

Pembrey, K.C. Marshall, R.P. Schneider, C. (1999). Cell surface analysis techniques: what do cell preparation protocols do to cell surface properties?. *Applied and Environmental Microbiology*, *65* (7), 2877-2894.

Pfaller, M., Davenport, D., Bale, M., Barrett, M., Koontz, F., & Massanari, R. M. (1988). Development of the quantitative micro-test for slime production by coagulase- negative *Staphylococci*. *European Journal of Clinical Microbiology and Infectious Diseases, 7*(1), 30-33.

Phuttapreecha, R., Kajonwattanakul, S., Songkai, P., & Choamanee, C. (2018). Survey of fouling organisms at Songkhla Port in Thailand. *ASEAN Journal on Science and Technology for Development, 35*(1-2), 147-152.

Pinheiro, M. M., Melo, L. F., Bott, T. R., Pinheiro, J. D., & Leitao, L. (1988). Surface phenomena and hydrodynamic effects on the deposition of *Pseudomonas fluorescens*. *The Canadian Journal of Chemical Engineering*, *66*(1), 63-67.

Poon, K. W., Liu, W., Chan, P. K., Yang, Q., Chan, T. W. D., Mak, T. C., & Ng, D. K. (2001). Tetrapyrrole derivatives substituted with ferrocenylethynyl moieties. Synthesis and electrochemical studies. *The Journal of Organic Chemistry*, *66*(5), 1553-1559.

Redfield, A. C., Hutchins, L. W., Deevy, E. S., Ayers, J. C., Turner, H. J., Laidlaw, F. B., & Todd, D. (1952). Marine fouling and its prevention. *Biofouling, 580*.

Rezaei, M., Komijani, M., & Javadirad, S. M. (2012). Bacteriostatic agents. In *A Search for Antibacterial Agents*. IntechOpen.

Ribera-Siguan MA (2002) Review of nonnative marine plants in the Mediterranean Sea. In: Leppa¨koski E, Gollasch S, Olenin S (eds*) Invasive aquatic species of Europe. Distribution, impacts and management* (pp 291–310). Kluwer Academic Publishers, The Netherlands.

Riley, G. A. (1943). The toxicity of heavy metals to fouling organisms. Paper 12, Sirth Report from *Woods Hole Oceanographic Institution to the Bureau of Ships.*

Ris, H. (1997). High-resolution field-emission scanning electron microscopy of nuclear pore complex. *Scanning*, *19*(5), 368-375.

Rittschof, D., & Costlow, J. D. (1989). Bryozoan and barnacle settlement in relation to initial surface wettability: A comparison of laboratory and field studies. *Scientific Material, 53(*2), 411-416.

Rittschof, D., & Parker, K. K. (2001). Cooperative antifoulant testing: a novel multisector approach. *Recent Advances in Marine Biotechnology*, *6*, 239-252.

Rittschof, D., Clare, A. S., Gerhart, D. J., Mary, S. A., & Bonaventura, J. (1992). Barnacle in vitro assays for biologically active substances: toxicity and settlement inhibition assays using mass cultured *Balanus amphitrite* amphitrite Darwin. *Biofouling*, *6*(2), 115-122.

Rittschof, D., Hooper, I. R., & Costlow, J. D. (1986). Barnacle settlement inhibitors from sea pansies, *Renilla reniformis*. *Bulletin of Marine Science, 39*(2), 376-382.

Rittschoff, D. (2001). Natural product antifoulants and coatings development. *Marine chemical ecology, 1*, 543.

Roobha, J. J., Saravanakumar, M., Aravindhan, K. M., & Devi, P. S. (2011). The effect of light, temperature, pH on stability of anthocyanin pigments in *Musa acuminata* bract. *Research in Plant Biology, 1*(5), 5-12.

Rosen, J. E., & Gu, F. X. (2011). Surface functionalization of silica nanoparticles with cysteine: a low-fouling zwitterionic surface. *Langmuir*, *27*(17), 10507-10513.

Rosenberg, M. (1984). Bacterial adherence to hydrocarbons: a useful technique for studying cell surface hydrophobicity. *FEMS Microbiology Letters*, *22*(3), 289-295.

Rosenberg, M., Gutnick, D., & Rosenberg, E. (1980). Adherence of bacteria to hydrocarbons: a simple method for measuring cell-surface hydrophobicity. *FEMS Microbiology Letters*, *9*(1), 29-33.

Salta, M., Chambers, L., Wharton, J. A., Wood, R. J. K., Briand, J. F., Blache, Y., & Stokes, K. R. (2009). Marine fouling organisms and their use in antifouling bioassays. *In Proceeding EUROCORR.*

Scardino, A. J., Harvey, E., & De Nys, R. (2006). Testing attachment point theory: diatom attachment on microtextured polyimide biomimics. *Biofouling*, *22*(1), 55-60.

Scardino, A., De Nys, R., Ison, O., O'Connor, W., & Steinberg, P. (2003). Microtopography and antifouling properties of the shell surface of the bivalve molluscs Mytilus galloprovincialis and Pinctada imbricata. *Biofouling*, *19*(S1), 221-230.

Schell, D., & Beermann, C. (2014). Fluidized bed microencapsulation of *Lactobacillus reuteri* with sweet whey and shellac for improved acid resistance and in-vitro gastro-intestinal survival. *Food Research International*, *62*, 308-314.

Schinke, C., Martins, T., Queiroz, S. C., Melo, I. S., & Reyes, F. G. (2017). Antibacterial compounds from marine bacteria, 2010–2015. *Journal of Natural Products*, *80*(4), 1215-1228.

Schultz, M. P. (2000). Turbulent boundary layers on surfaces covered with filamentous algae. *Journal Fluids Engineering*, *122*(2), 357-363.

Schultz, M. P. (2007). Effects of coating roughness and biofouling on ship resistance and powering. *Biofouling*, *23*(5), 331-341.

Scott-Lappin, H. M., & Costerton, J. W. (1989). Bacterial biofilms and surface fouling. *The Journal of Bioadhesion and Biofilm Research*, *1*(4), 323-342.

Semiao, A. J. C., Gazzola, G., Habimana, O., Heffernan, R., Murphy, C., & Casey, E. (2012). Understanding the Mechanisms of Biofouling on Nanofiltration Membranes: Effect of the Biofilm Structure on Solute Removal. *Procedia Engineering*, *44*, 1557-1560.

Sharma, A. K., Sirota, E. B., & Raterman, M. F. (2013). U.S. Patent No. 8,354,020.

Shirazy, M. S., & Fayed, A. M. (2015). A Survivor of Methyl Ethyl Ketone Peroxide (MEKP) Toxicity. *Journal Clinical Toxicology*, *5*, 257.

Siguan, M. A. R. (2002). Review of non-native marine plants in the Mediterranean Sea. In *Invasive aquatic species of Europe. Distribution, impacts and management* (pp. 291-310). Springer, Dordrecht.

Smit, A. J. (2004). Medicinal and pharmaceutical uses of seaweed natural products: a review. *Journal of Applied Phycology*, *16*(4), 245-262.

Smith, M. C., Crist, R. M., Clogston, J. D., & McNeil, S. E. (2017). Zeta potential: a case study of cationic, anionic, and neutral liposomes. *Analytical and Bioanalytical Chemistry*, *409*(24), 5779-5787.

Soliev, A. B., Hosokawa, K., & Enomoto, K. (2011). Bioactive pigments from marine bacteria: applications and physiological roles. *Evidence-based Complementary and Alternative Medicine*, *2011*, 1-17.

Song, S., Demirel, Y. K., Muscat-Fenech, C. D. M., Tezdogan, T., & Atlar, M. (2020). Fouling effect on the resistance of different ship types. *Ocean Engineering*, *216*, 107736.

Sousa, J., Westhoff, P., Methling, K., & Lalk, M. (2019). The Absence of Pyruvate Kinase Affects Glucose-Dependent Carbon Catabolite Repression in *Bacillus subtilis*. *Metabolites*, *9*(10), 216.

Spettmann, D., Eppmann, S., Flemming, H. C., & Wingender, J. (2007). Simultaneous visualisation of biofouling, organic and inorganic particle fouling on separation membranes. *Water Science and Technology*, *55*(8-9), 207-210.

Spettmann, D., Eppmann, S., Flemming, H. C., & Wingender, J. (2008). Visualization of membrane cleaning using confocal laser scanning microscopy. *Desalination*, *224*(1-3), 195-200.

Standing, J. D., Hooper, I. R., & Costlow, J. D. (1984). Inhibition and induction of barnacle settlement by natural products present in octocorals. *Journal of Chemical Ecology*, *10*(6), 823-834.

Stasolla, G., Tricarico, E., & Vilizzi, L. (2020). Risk screening of the potential invasiveness of non-native marine crustacean decapods and barnacles in the Mediterranean Sea. *Hydrobiologia*, 1-13.

Statz, A., Finlay, J., Dalsin, J., Callow, M., Callow, J. A., & Messersmith, P. B. (2006). Algal antifouling and fouling-release properties of metal surfaces coated with a polymer inspired by marine mussels. *Biofouling*, *22*(6), 391-399.

Stehouwer, P. P., van Slooten, C., & Peperzak, L. (2013). Microbial dynamics in acetate-enriched ballast water at different temperatures. *Ecotoxicology and Environmental Safety*, *96*, 93-98.

Steinle-Darling, E., Zedda, M., Plumlee, M. H., Ridgway, H. F., & Reinhard, M. (2007). Evaluating the impacts of membrane type, coating, fouling, chemical properties and water chemistry on reverse osmosis rejection of seven nitrosoalklyamines, including NDMA. *Water Research*, *41*(17), 3959-3967.

Stoye, D., Funke, W., Hoppe, L., Hasselkus, J., Curtis, L. G., Hoehne, K., & Schupp, H. (2000). Paints and coatings. Ullmann's Encyclopedia of Industrial Chemistry.

Suderman, N., Isa, M. I. N., & Sarbon, N. M. (2018). The effect of plasticizers on the functional properties of biodegradable gelatin-based film: A review. *Food Bioscience*, *24*, 111-119.

Suryawanshi, R. K., Patil, C. D., Borase, H. P., Narkhede, C. P., Salunke, B. K., & Patil, S. V. (2015). Mosquito larvicidal and pupaecidal potential of prodigiosin from *Serratia marcescens* and understanding its mechanism of action. *Pesticide Biochemistry and Physiology*, *123*, 49-55.

Tavares, L.C., Vessoni, P.T.C. andAmaral, A.T. 1997.Synthesis and biological activity of nifuroxazide and analogs. *Boll Chim Farmaceutico*, *3*, 244-249.

Telegdi, J., Trif, L., & Románszki, L. (2016). Smart anti-biofouling composite coatings for naval applications. *Smart Composite Coatings and Membranes* (pp. 123-155). Woodhead Publishing.

Thabard, M., Gros, O., Hellio, C., & Maréchal, J. P. (2011). *Sargassum polyceratium* (Phaeophyceae, Fucaceae) surface molecule activity towards fouling organisms and embryonic development of benthic species. *Botanica Marina*, *54*(2), 147-157.

Thistle, Q. A. (2020). Microbiology legend. Retrieved from http://www.thistle.co.za/pdf_files/education/microbiology/microbiology_legends/Cycle_28/Cycle%2028%20Organism%203%20-%20Aeromonas%20hydrophila.pdf

Thomas, K. V., McHugh, M., & Waldock, M. (2002). Antifouling paint booster biocides in UK coastal waters: inputs, occurrence and environmental fate. *Science of the Total Environment*, *293*(1-3), 117-127.

Thurman, H. V. (1997). Introductory Oceanography. New Jersey, USA: Prentice Hall College. ISBN 978-0-13-262072-7.

Tillbrook, R. (2015). The Chief Inspector of Education, Children's Services and Skills (No. 2).

Townsin, R. L. (2003). The ship hull fouling penalty. *Biofouling*, *19*(S1), 9-15.

Tsai, S. T., Yen, K. P., & Shih, H. C. (1998). The embrittlement of duplex stainless steel in sulfide-containing 3.5 wt% NaCl solution. *Corrosion Science*, *40*(2-3), 281-295.

Tu, S. C., Ravindran, V., & Pirbazari, M. (2006). Membrane Fouling and Transport Models in Water Treatment Applications. In The 2006 Annual Meeting.

Twist, C. (2005). Visual factfinder: Oceans. In Wikipedia. Retrieved from https://en.wikipedia.org/wiki/Barnacle

Valto, P., Knuutinen, J., & Alén, R. (2012). Overview of analytical procedures for fatty and resin acids in the papermaking process. *Bioresources*, *7*(4), 6041-6076.

Van Colen, C., Lenoir, J., De Backer, A., Vanelslander, B., Vincx, M., Degraer, S., & Ysebaert, T. (2009). Settlement of *Macoma balthica* larvae in response to benthic diatom films. *Marine Biology*, *156*(10), 2161-2171.

Van Dolah, F. M., Finley, E. L., Haynes, B. L., Doucette, G. J., Moeller, P. D., & Ramsdell, J. S. (1994). Development of rapid and sensitive high throughput pharmacologic assays for marine phycotoxins. *Natural Toxins*, *2*(4), 189-196.

Venil, C. K., Zakaria, Z. A., & Ahmad, W. A. (2013). Bacterial pigments and their applications. *Process Biochemistry*, *48*(7), 1065-1079.

Vimalathithan, P.K.,Barile, C., & Vijayakumar, C. T. (2018). Investigation of kinetic triplets for thermal degradationof thermally cured vinyl ester resin systems and lifetime predictions. *Journal of Thermal Analysis and Calorimetry*, *133*(2), 881-891.

Vinagre, P. A., Simas, T., Cruz, E., Pinori, E., & Svenson, J. (2020). Marine biofouling: A European database for the marine renewable energy sector. *Journal of Marine Science and Engineering*, *8*(7), 495.

Visscher, P. M., Wray, N. R., Zhang, Q., Sklar, P., McCarthy, M. I., Brown, M. A., & Yang, J. (2017). 10 years of GWAS discovery: biology, function, and translation. *The American Journal of Human Genetics*, *101*(1), 5-22.

Vladkova, T. G., Hsissou, R., Bekhta, A., El Harfi, A., Abdullin, A. I., Emelyanycheva, E. A., & Saleem, Q. M. (2018). Low adhesive surfases for biofouling control. *Journal of Chemical Technology and Metallurgy*, *53*(3), 408-413.

Voulvoulis, N., Scrimshaw, M. D., & Lester, J. N. (2000). Occurrence of four biocides utilized in antifouling paints, as alternatives to organotin compounds, in waters and sediments of a commercial estuary in the UK. *Marine Pollution Bulletin*, *40*(11), 938-946.

Wahl, M. (1989). Marine epibiosis. I. Fouling and antifouling: some basic aspects. *Marine Ecology Progress Series*, *58*, 175-189.

Walker, S. D., & McEldowney, S. (2013). Molecular docking: a potential tool to aid ecotoxicity testing in environmental risk assessment of pharmaceuticals. *Chemosphere*, *93*(10), 2568-2577.

Wang, J., & Scheibel, T. (2018). Recombinant production of mussel byssus inspired proteins. *Biotechnology Journal*, *13*(12), 1800146.

Wang, X., Andriani, Y., Liu, S., Chen, Z., & Zhang, X. (2018). In-situ cure shrinkage characterization of epoxy molding compounds for fan-out wafer-level packaging. *IEEE 20th Electronics Packaging Technology Conference (EPTC), 2018*, 432-437).

Wang, X., Olsen, S. M., Martinez, E. A., Olsen, K. N., & Kiil, S. (2018). Drag resistance of ship hulls: effects of surface roughness of newly applied fouling control coatings, coating water absorption, and welding seams. *Journal of Coatings Technology and Research*, *15*(4), 657-669.

Wang, Y., Subbiahdoss, G., de Vries, J., Libera, M., Van der Mei, H. C., & Busscher, H. Washington, DC: U.S. Patent and Trademark Office.

Want, A., Crawford, R., Kakkonen, J., Kiddie, G., Miller, S., Harris, R. E., & Porter, J. S. (2017). Biodiversity characterisation and hydrodynamic consequences of marine fouling communities on marine renewable energy infrastructure in the Orkney Islands Archipelago, Scotland, UK. *Biofouling*, *33*(7), 567-579.

Watermann, B., & Eklund, B. (2019). Can the input of biocides and polymeric substances from antifouling paints into the sea be reduced by the use of non-toxic hard coatings. *Marine Pollution Bulletin*, *144*, 146-151.

Watson, D. I., Durr, S., Beaz, D., Bergtun, E., Breur, R., Cebria, J., & Lane, A. (2005). Fouling" remediation through the use of grazers in shellfish aquaculture. Taller, Aquaculture and Fisheries Development Centre, University College Cork, Cork. Irlanda.

Watts, J. L. (1995). U.S. Patent No. 5,397,385. Washington, DC: U.S. Patent and Trademark Office.

Wetherbee, R., Lind, J. L., Burke, J., & Quatrano, R. S. (1998). Minireview—the first kiss: establishment and control of initial adhesion by raphid diatoms. *Journal of Phycology*, *34*(1), 9-15.

Wilde, J. (2020), Colonies of *Penicillium* fungi on an agar plate. Retrieved from https://www.eurekalert.org/multimedia/pub/138523.php

Williamson, D., Lynch-Wood, G., & Ramsay, J. (2006). Drivers of environmental behaviour in manufacturing SMEs and the implications for CSR. *Journal of Business Ethics*, *67*(3), 317-330.

Williamson, M. (2006). Explaining and predicting the success of invading species at different stages of invasion. *Biological Invasions*, *8*(7), 1561-1568.

Wisniewski, N., & Reichert, M. (2000). Methods for reducing biosensor membrane biofouling. *Colloids and Surfaces B: Biointerfaces*, *18*(3-4), 197-219.

Wisniewski, N., Moussy, F., & Reichert, W. M. (2000). Characterization of implantable biosensor membrane biofouling. *Fresenius' Journal of Analytical Chemistry*, *366*(6-7), 611-621.

Woodshole Oceanographic Institution (2020). How a biofilm forms in the sea. Retrieved from https://www.whoi.edu/multimedia/how-a-biofilm-forms-in-the-sea/

Xie, F., Dreisinger, D., & Doyle, F. (2013). A review on recovery of copper and cyanide from waste cyanide solutions. *Mineral Processing and Extractive Metallurgy Review*, *34*(6), 387-411.

Xu, X. Y., Wong, C. Y., Tam, N. F. Y., Liu, H. M., & Cheung, S. G. (2020). Barnacles as potential bioindicator of microplastic pollution in Hong Kong. *Marine Pollution Bulletin*, *154*, 111081.

Xu, Z. M., Yang, S. R., Guo, S. Q., Zhao, H., Qi, B., & Zhang, Z. B. (2005). Costs due to utility boiler fouling in China. Heat Transfer—*Asian Research: Co-sponsored by the Society of Chemical Engineers of Japan and the Heat Transfer Division of ASME*, *34*(2), 53-63.

Yang, Z., Peng, X. F., Chen, M. Y., Lee, D. J., & Lai, J. Y. (2007). Intra-layer flow in fouling layer on membranes. *Journal of Membrane Science*, *287*(2), 280-286.

Yebra, D. M., Kiil, S., & Dam-Johansen, K. (2004). Antifouling technology—past, present and future steps towards efficient and environmentally friendly antifouling coatings. *Progress in Organic Coatings*, *50*(2), 75-104.

Yebra, D. M., Kiil, S., Dam-Johansen, K., & Weinell, C. (2005). Reaction rate estimation of controlled-release antifouling paint binders: Rosin-based systems. *Progress in Organic Coatings*, *53*(4), 256-275.

Yokoo, M., Ogura, J., & Ikeda, H. (1971). U.S. Patent No. 3,615,744. Washington, DC: U.S. Patent and Trademark Office.

Yonehara, Y., & Nanishi, K. (1990). U.S. Patent No. 4,910,252. Washington, DC: U.S. Patent and Trademark Office.

Yonehara, Y., Yamashita, H., Kawamura, C., & Itoh, K. (2001). A new antifouling paint based on a zinc acrylate copolymer. *Progress in Organic Coatings*, *42*(3-4), 150- 158.

Yu, L. M., Liu, H. F., & Tian, B. (2005). Antifouling Technology of Fishing Net and Its Application. *Paint & Coatings Industry*, *7*(10).

Yuhas, Y., Weizman, A., Dinari, G., & Ashkenazi, S. (1995). An animal model for the study of neurotoxicity of bacterial products and application of the model to demonstrate that Shiga toxin and lipopolysaccharide cooperate in inducing neurologic disorders. *Journal of Infectious Diseases*, *171*(5), 1244-1249.

Yusim, A. K., & Utama, I. K. A. P. (2017). An investigation into the drag increase on roughen surface due to marine fouling growth. *IPTEK The Journal for Technology and Science*, *28*(3).

Zaleski, R. T., Qian, H., Zelenka, M. P., George-Ares, A., & Money, C. (2014). European solvent industry group generic exposure scenario risk and exposure tool. *Journal of Exposure Science and Environmental Epidemiology*, *24*(1), 27.

Zattini, G., Mazzocchetti, L., Benelli, T., Maccaferri, E., Brancolini, G., & Giorgini, L. (2020). Mechanical Properties and Fracture Surface Analysis of Vinyl Ester Resins Reinforced with Recycled Carbon Fibres. *In Key Engineering Materials* (827, 110-115). Trans Tech Publications Ltd.

Zhang, P., Fawcett, N. C., Evans, J. A., Hurt, T., Harvey, K. G., & Craven, R. C. (2000). Rapid SLT Gene Detection on Polyethylene–Coacrylic Acid Film without Molecular Labels or Surface-Fouling Agents. *Analytical Biochemistry, 282*(2), 218-226.

Zhang, W., Yang, Z. Y., Cheng, X. W., Tang, R. C., & Qiao, Y. F. (2019). Adsorption, antibacterial and antioxidant properties of tannic acid on silk fiber. *Polymers, 11*(6), 970.

Zhang, S., Zheng, W., & Wang, H. (2020). Physiological response and morphological changes of *Heterosigma akashiwo* to an algicidal compound prodigiosin. *Journal of Hazardous Materials, 385*, 121530.

Zhao, L., Liang, J., Liang, J., Liu, B., Deng, Y., Sun, X., & Yang, F. (2020). Experimental study of transgenerational effects, pH and predation risk on byssus production in a swiftly spreading invasive fouling Asian mussel, *Musculista senhousia* (Benson). *Environmental Pollution*, *260*, 114111.

Zhao, X., Qi, Y., Zhang, Z., Li, K., & Li, Z. (2019). Electrochemical impedance spectroscopy investigation on the corrosive behaviour of waterborne silicate micaceous iron oxide coatings in seawater. *Coatings*, *9*(7), 415.

Zhou, M., Liu, H., Kilduff, J. E., Langer, R., Anderson, D. G., & Belfort, G. (2009). High- throughput membrane surface modification to control NOM fouling. *Environmental Science & Technology, 43*(10), 3865-3871.

Zhou, Y., Yu, S., Gao, C., & Feng, X. (2009). Surface modification of thin film composite polyamide membranes by electrostatic self deposition of polycations for improved fouling resistance. *Separation and Purification Technology*, *66*(2), 287-294.

Zhuiykov, S. (2014). Nanostructured semiconductor oxides for the next generation of electronics and functional devices: properties and applications. Woodhead Publishing.

Zupan, I., & Saric, T. (2014). Growth and condition index–two important factors in mussel farming. *Meso: Prvi hryatski Casopis o Mesu*, *3*, 255-258.

LIST OF PUBLICATIONS

Ismail, R., Amir, S. N. Mini Review on Toxic Substance in Building Paint. Environment, 85, 243-252.