DEVELOPMENT OF A NOVEL FILTER-INCUBATION SYSTEM ENCOMPASSING OIL PALM EMPTY FRUIT BUNCH BIOSORBENT AND ANTARTIC MICROALGAE FOR DIESEL REMOVAL

By

NURUL AINI BINTI PUASA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

November 2023

FBSB 2023 10

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF A NOVEL FILTER-INCUBATION SYSTEM ENCOMPASSING OIL PALM EMPTY FRUIT BUNCH BIOSORBENT AND ANTARTIC MICROALGAE FOR DIESEL REMOVAL

By

NURUL AINI BINTI PUASA

November 2023

Chair : Associate Professor Siti Aqlima Ahmad, PhD
Faculty : Biotechnology and Biomolecular Sciences

Diesel is commonly used as a fuel in Antarctica to enable human activities. However, the increasing demand for diesel raises the risk of oil contamination due to accidental events, which can threaten the Antarctic environment. Through the provisions of the Antarctic Treaty, the environment in Antarctica is protected by the implementation of steps to combat and minimise fuel pollution, as required under the Protocol on Environmental Protection to the Antarctic Treaty. Across the continent of Antarctica, chronically low temperatures can reduce the rate of hydrocarbon attenuation, making pollution management challenging in isolated and extreme regions. The current oil remediation technologies have the potential to generate secondary pollution as they are unable to make use of the biomass. New bioremediation approaches adopted for removal of diesel in Antarctic that are environmentally friendly are required. Therefore, there has been increasing interest in the potential for using agricultural waste as a biosorbent. The empty fruit bunch (EFB) produced from oil palms, a cost-effective material, contains cellulose-related materials that have shown good results in trial pollution treatments. In parallel, studies of the potential for remediation of diesel pollution in the Antarctic using indigenous microalgae remain limited to date, while the optimised conditions required are yet to be determined. This study's central goal was to combine evaluation of the diesel-sorption capabilities of EFB and diesel-degrading capabilities of native Antarctic microalgae in a filter-incubation system designed to remove diesel and contribute to potential bioremediation efforts in Antarctica. In this study, EFB was screened using conventional analysis, one-factor-at-a-time (OFAT) and statistical analysis, response surface methodology (RSM), whereby the effects of EFB on diesel biosorption were characterised. The optimum conditions for EFB diesel biosorption were determined to be 172ºC with 19.4 min heating time, 0.096 g/cm^3 packing density and 10% initial diesel concentration. The predicted model was highly significant ($R^2 = 0.9987$) and four interactions, between temperature and packing density, temperature and diesel concentration, time and packing density, and packing density and diesel concentration, were confirmed to significantly affect the diesel biosorption. Using pre-heat treated EFB, 25.33 mL of oil was successfully absorbed from an initial volume of 40 mL. The EFB sample was subjected to morphological and chemical content analysis relating to diesel biosorption. For bioremediation of diesel hydrocarbons, an Antarctic microalgal (strain WCY_AQ5_2) was screened, identified and characterised using conventional OFAT and statistical RSM analysis. The optimal degradation conditions were 1% diesel concentration, 11.17 mg/L NaCl concentration, pH 6.22, 0.415 g/L $NaNO_3$ and photoperiod of 12:12 h L/D. The predicted model was highly significant (R^2 = 0.9848) and confirmed that the parameters of salinity and pH significantly influenced diesel biodegradation. Diesel biodegradation of 66.08% was achieved within 7 d incubation period. Morphological and molecular examination supported that strain WCY_AQ5_2 represents the species *Chlorella vulgaris*. The effect of heavy metal contamination (Ag, Al, As, Cd, Co, Cr, Cu, Ni, Pb and Zn) on the degradation of diesel was further assessed and analysed by assessing their half-maximal inhibition concentration (IC_{50}). The findings demonstrated that Cr, Cu and Ag inhibited the degradation of diesel by more than 50%, with IC_{50} values of 3.165, 3.371 and 4.205 ppm, respectively. These findings were then integrated into the development of a filter-incubation system that uses EFB as the sorbent with optimum packing density (0.1 g/cm^3) in the filter press machine in combination with the native Antarctic microalgal strain WCY_AQ5_2 in a light incubation tank illuminated with optimum red light that boosted the alga’s ability to degrade diesel to 70.7%. The novelty of this study is the used of the bioremediatory agents, EFB as biosorbent and native Antarctic microalgal as diesel degrader integrated in a novel filter-incubation system for diesel removal. The findings of this study help advance the diesel biosorption and bioremediation techniques currently available in Antarctica.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PEMBANGUNAN SISTEM INKUBASI PENAPIS BAHARU MELIPUTI BIOPENYERAP TANDAN KOSONG MINYAK KELAPA SAWIT DAN MIKROALGA ANTARTIK UNTUK PEMBUANGAN DIESEL

Oleh

NURUL AINI BINTI PUASA

November 2023

Pengerusi : Profesor Madya Siti Aqlima Ahmad, PhD
Fakulti : Bioteknologi dan Sains Biomolekul

Diesel biasanya digunakan sebagai bahan api di Antartika untuk menjalankan aktiviti manusia. Walau bagaimanapun, peningkatan permintaan untuk diesel meningkatkan risiko pencemaran minyak akibat kejadian tidak disengajakan, yang boleh mengancam persekitaran Antartika. Melalui peruntukan Perjanjian Antartika, alam sekitar di Antartika dilindungi oleh pelaksanaan langkah-langkah untuk memerangi dan meminimumkan pencemaran bahan api, seperti yang termaktub di bawah Protokol Perlindungan Alam Sekitar kepada Perjanjian Antartika. Di seluruh benua Antartika, suhu rendah yang kritikal boleh mengurangkan kadar penguraian hidrokarbon dan menyebabkan pengurusan pencemaran mencabar di kawasan terpencil dan ekstrem. Teknologi sedia ada bagi penyingkiran minyak mempunyai potensi untuk menjana pencemaran sekunder kerana tidak dapat menggunakan semula biojisim. Pendekatan bioremediasi baharu yang mesra alam dan dapat diterima pakai diperlukan untuk penyingkiran diesel di Antartika. Justeru, terdapat peningkatan minat terhadap potensi untuk menggunakan sisa pertanian sebagai biopenyerapan. Tandan kosong kelapa sawit (EFB) yang dihasilkan daripada kelapa sawit dapat menjimatkan kos dan mengandungi bahan berkaitan selulosa yang telah menunjukkan hasil yang baik dalam percubaan proses rawatan pencemaran. Secara selari, kajian tentang potensi pemulihan pencemaran diesel di Antartika menggunakan mikroalga asli masih terhad sehingga kini, manakala keadaan optimum yang diperlukan masih belum dapat ditentukan. Matlamat utama kajian ini adalah untuk menggabungkan penilaian keupayaan penyerapan diesel oleh EFB dan keupayaan mengurangkan diesel mikroalga asli Antartika dalam sistem penapis-pengeraman yang direka untuk menyingkirkan diesel dan menyumbang kepada usaha biopemulihan yang berpotensi di Antartika. Dalam kajian ini, EFB telah disaring dengan menggunakan analisis konvensional, satu-faktor-pada-satu-masa (OFAT) dan analisis statistik, kaedah permukaan tindak balas (RSM), di mana kesan EFB ke atas penyerapan diesel telah dicirikan. Keadaan EFB optimum untuk penyerapan diesel ditentukan dengan suhu 172ºC dan 19.4 min masa pemanasan, ketumpatan pembungkusan 0.096 g/cm^3 dan kepekatan awal diesel sebanyak 10%. Model yang diramalkan adalah sangat ketara (R^2 = 0.9987) dan empat parameter, antara suhu dan ketumpatan pembungkusan, suhu dan kepekatan diesel, masa dan ketumpatan pembungkusan, dan ketumpatan pembungkusan dan kepekatan diesel, telah disahkan memberi kesan ketara kepada penyerapan diesel. Dengan menggunakan EFB yang dirawat dengan pembakaran, 25.33 mL minyak berjaya diserap daripada isipadu awal 40 mL. Sampel EFB telah tertakluk kepada analisis kandungan morfologi dan kimia yang berkaitan dengan penyerapan diesel. Untuk bioremediasi hidrokarbon diesel, mikroalga Antartika (strain WCY_AQ5_2) telah disaring, dikenal pasti dan dicirikan menggunakan analisis OFAT dan RSM. Keadaan degradasi optimum ialah dengan 1% kepekatan diesel, 11.17 mg/L kepekatan NaCl, pH 6.22, 0.415 g/L $NaNO_3$ dan tempoh fotokala 12:12 h L/D. Model yang diramalkan adalah sangat ketara (R^2 = 0.9848) dan mengesahkan bahawa parameter kemasinan dan pH mempengaruhi biodegradasi diesel dengan ketara. Biodegradasi diesel sebanyak 66.08% telah dicapai dalam tempoh pengeraman 7 hari. Pemeriksaan morfologi dan molekul menyokong bahawa strain WCY_AQ5_2 mewakili spesies *Chlorella vulgaris*. Kesan pencemaran logam berat (Ag, Al, As, Cd, Co, Cr, Cu, Ni, Pb dan Zn) terhadap degradasi diesel dinilai dan dianalisis dengan menilai kepekatan perencatan separuh maksimum (IC_{50}). Penemuan menunjukkan bahawa Cr, Cu dan Ag menghalang degradasi diesel lebih daripada 50%, dengan nilai IC_{50} sebanyak 3.165, 3.371 dan 4.205 ppm. Penemuan ini kemudiannya disepadukan ke dalam pembangunan sistem pengeraman penapis yang menggunakan EFB sebagai penyerap dengan ketumpatan pembungkusan optimum (0.1 g/cm^3) dalam mesin penekan penapis bersama kombinasi dengan strain mikroalga Antartika asli WCY_AQ5_2 di dalam tangki pengeraman cahaya yang diterangi dengan lampu merah optimum yang meningkatkan keupayaan alga untuk mengurangkan diesel sebanyak 70.7%. Kebaharuan kajian ini adalah dengan penggunaan agen bioremediasi, EFB sebagai biopenyerap dan mikroalgal Antartika asli sebagai agen penguraian diesel yang disepadukan dalam sistem penapis-pengeraman untuk penyingkiran diesel. Penemuan kajian ini membantu memajukan teknik penyerapan dan bioremediasi diesel yang kini tersedia di Antartika.

ACKNOWLEDGEMENTS

First and foremost, thanks to the Almighty God, for His showers of blessings throughout my research work to complete the study successfully. I am very much thankful to my mother, Nor Rezan Main, and my father, Puasa Samat, for their endless love, valuable prayers, constant encouragement, biggest support and sacrifices for educating and preparing me for my future. I would not be where I am today without their prayer, care and support. Thank you for everything, my pillar of strength.

I would like to thank my supervisors, Assoc. Prof. Dr. Aqlima Ahmad, Assoc. Prof. Dr. Noor Azmi Shaharuddin, Assoc. Prof. Ts. Dr. Wong Chiew Yen, Assoc. Prof. Dr. Azham Zulkharnain and Prof. Dr. Peter Convey for their guidance, great advice and constant supervision as well as providing necessary information regarding the project throughout my time as a student. Their vast knowledge, extensive expertise, excellent suggestions and willingness in sharing their knowledge helped me in completing my study.

I sincerely appreciate the support and encouragement I have received from my siblings and friends while I pursued my studies. My gratitude to Nidzar, Fairunizam, Izzati, Anis, and Rahimi for their invaluable support, tolerance, and understanding is inexpressible in words. I am forever thankful for their unconditional love and support throughout the entire thesis process and every day. Finally, many thanks and appreciation also go to my labmates, for their kind cooperation and encouragement which help me in completion of this project.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Siti Aqlima binti Ahmad, PhD
Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Chairman)

Noor Azmi bin Shaharuddin, PhD
Associate Professor
Faculty of Biotechnology and Biomolecular Sciences
Universiti Putra Malaysia
(Member)

Wong Chiew Yen, PhD
Associate Professor Ts
School of Health Science
International Medical University
(Member)

Azham Zulkharnain, PhD
Associate Professor
College of Systems Engineering and Science
Shibaura Institute of Technology, Japan
(Member)

Peter Convey, PhD
Professor
British Antarctic Survey
United Kingdom
(Member)

____
ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 18 April 2024

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

β	Beta
%	Percentage
°C	Degree celsius
$<$	Less than
±	Plus–minus sign
≤	Equal or less than
µ	Specific growth rate
µA	Micro-Ampere
µL	Microlitre
µM	Micromolar
18S rRNA	18S ribosomal nucleic acid
3D	Three-dimensional
$(NH_4)_2SO_4$	Ammonium sulphate
$(NH_4)_2CO_3$	Ammonium carbonate
Ag	Silver
Al	Aluminium
ANZ	Antarctic New Zealand
ANOVA	Analysis of variance
As	Arsenic
ATP	Adenosine triphosphate
ATS	Antarctic Treaty System
BAS	British Antarctic Survey
BE	Biodegradation efficiency
BLAST	Basic Local Alignment Search Tool

BLASTN	Basic Local Alignment Search Tool: Nucleotide
BOD	Biological oxygen demand
bp	Base pair
C	Carbon
Car	Carotenoids
C-H	Alkyl group
C-O	Carboxyl group
C-O-C	Ether
C=C	Alkene group
C=O	Carbonyl group
C≡C	Alkynes group
$CaCl_2$	Calcium chloride
CCD	Central composite design
Cd	Cadmium
Chl-*a*	Chlorophyll *a*
Chl-*b*	Chlorophyll *b*
Cl	Chlorine
cm	Centimetre
cm^{-1}	Reciprocal centimetre
cm^3	Cubic centimetre
Co	Cobalt
COD	Chemical oxygen demand
CO_2	Carbon dioxide
$Co(NO_3)_2.6H_20$	Cobalt nitrate
Cr	Chromium
Cu	Copper

$CuSO_4.5H_2O$	Copper(II) sulphate
CYP	Cytochrome P450
d	Day
dH_2O	Distilled water
DNA	Deoxyribonucleic acid
DO	Dissolved oxygen
DoE	Design of experiment
e.g	exempli gratia (for example)
ECA	Emission control area
EFB	Empty fruit bunch
$EDTA.Na_2$	Ethylenediaminetetracetic acid disodium
EPA	Environmental Protection Agency
et al.	and others
F	Fischer value
$FeSO_4$	Ferrous sulphate
FTIR	Fourier transform infrared spectroscopy
g	Gram
gDNA	Genomic deoxyribonucleic acid
h	Hour
HCl	Hydrochloric acid
HFO	Heavy fuel oil
Hg	Mercury
H_3BO_4	Hydrogen perborate
IC_{50}	Half-maximal inhibitory concentration
IFO 180	Intermediate fuel oil
IMO	International Maritime Organisation

Inc.	Incorporated
kb	Kilobase
KCl	Potassium chloride
kg	Kilogram
KH_2PO_4	Potassium dihydrogen phosphate
K_2HPO_4	Dipotassium hydrogen phosphate
kJ	KiloJoule
km	Kilometre
KNO_3	Pottasium nitrate
KOH	Potassium hydroxide
KOPRI	Korea Polar Research Institute
kV	Kilovolt
L	Litre
L/D	Light and dark cycle
m	Metre
M	Molar
MARPOL	International Convention for the Prevention of Pollution from Ships
MFF	Mesocarp fruit fibres
Mg	Magnesium
mg	Milligram
MGO	Marine gas oil
$MgSO_4$	Magnesium sulphate
$MgSO_4.7H_2O$	Magnesium sulphate heptahydrate
min	Minute
MJ	Mega-Joule

mL	Millilitre
mm	Millimetre
mM	Millimolar
Mn	Manganese
$MnCl_2$	Manganese(II) chloride
Mo	Molybdenum
MoO_3	Molybdenum trioxide
N	Nitrogen
Na	Sodium
NaCl	Sodium chloride
$NaNO_3$	Sodium nitrate
NaOH	Sodium hydroxide
NCBI	National Center for Biotechnology Information
NH_4^+	Ammonium
NH_4Cl	Ammonium chloride
NH_4NO_3	Ammonium nitrate
Ni	Nickel
nm	Nanometre
NOx	Nitrogen oxide
NO^{-3}	Nitrate
O	Oxygen
O-H	Hydroxyl
OD_{620}	Optical density at 620 nm
OFAT	One-factor-at-a-time
P	Phosphate
P	Probability value

PacBio	Pacific Biosciences
PAH	Polycyclic aromatic hydrocarbons
Pb	Lead
PBD	Plackett-Burman design
PBS	Phosphate buffered saline
PCR	Polymerase chain reaction
pH	-log H^+ concentration
PKS	Palm kernel shells
pM	picoMolar
POME	Palm oil mill effluent
POPs	Persistent organic pollutants
ppb	Part per billion
ppm	Part per million
ppt	Part per thousand
PVC	Polyvinyl chloride
R^2	Coefficient determination
RNA	Ribonucleic acid
RNAse A	Ribonuclease A
ROS	Reactive oxygen species
rpm	Revolutions per minute
rRNA	Ribosomal ribonucleic acid
RSM	Response surface methodology
SAB	Special Antarctic Blend
Se	Selenium
SC	Sorption capacity
sec	Second

SEM	Scanning electron microscopy
SOx	Sulphur oxide
sp.	Species (singular)
spp.	Species (plural)
TAE	Tris-Acetate-EDTA
Taq	*Thermus aquaticus*
TN93+G	Tamura-Nei with a gamma-distributed model
TPH	Total petroleum hydrocarbon
UV	Ultra-violet
v	Volume
ver.	Version
WAF	Water accommodated fraction
YPASM	Sultan Mizan Antarctic Research Foundation
Zn	Zinc
$ZnSO_4$	Zinc sulphate

CHAPTER 1

INTRODUCTION

Antarctica is the world's most remote continent, located in the southernmost part of the globe. It is a popular target for researchers, explorers and travellers owing to its extreme and exceptional environments. Between 2012–2013 and 2019–2020, the numbers of tourist visitors to Antarctica increased by 52% (Kariminia et al., 2013; IAATO, 2020), before the hiatus created by the global COVID-19 pandemic (Hughes and Convey, 2020), but recovered rapidly to a new record of over 100,000 in the 2022/23 season (Antarctic Treaty Consultative Meeting, 2022). As a result, the demand for diesel in Antarctica has also increased to provide fuel for vehicles and electricity generation in research stations and other activities concentrated (Ruberto et al., 2005: Brown et al., 2023). Large quantities of fuel are transported across the Southern Ocean to facilitate activities in Antarctica (Australian Antarctic Division, 2012), raising the danger of contamination from oil spill incidents (Errington et al., 2018). Accidental oil leaks can be more serious in Antarctica's severe environments, since there can often be no containment of the spilled fuel, making cleaning more challenging. As the rate of natural degradation is reduced under the severe environmental conditions, oil-derived pollutants are challenging to eliminate (Brown et al., 2016; Zakaria et al., 2019a; Abdulrasheed et al., 2020a; Zahri et al., 2020).

Diesel fuel formulations used in Antarctica are adapted to the continent's extreme temperatures. Larger vessels in Antarctica are fueled by Intermediate Grade Fuel Oil (IFO 180) and Marine Gas Oil (MGO) (Wong et al., 2021). Special Antarctic Blend (SAB), a cold-climate diesel formulation with low density and viscosity, is commonly used in Antarctic and sub-Antarctic regions to avoid wax formation (Lim et al., 2017; Bennett, 2014). The composition of hydrocarbons in SAB, MGO and IFO 180 differ, resulting in varying levels of environmental toxicity. Depending on the hydrocarbon composition, diesel can have varied water-accommodated fraction (WAF) characteristics when interacting with water (Brown et al., 2016). The bioavailability of WAF to marine organisms determines how an oil spill will affect them. According to Lim et al. (2021), SAB diesel has the largest magnitude of acute toxicity after brief exposure, although MGO and IFO 180 are typically more hazardous than SAB following extended exposure. These risks have become more prominent in recent years as on average two million litres of SAB and MGO are consumed annually per major facility, sustaining over 100 stations in Antarctica (IAATO, 2020).

Pollution from diesel presents an ongoing threat to the ecosystems of Antarctica. The species involved, level of exposure, as well as types of oil, have distinct impacts on how severe the consequences of any oil spill are. Seabirds from the Haswell archipelago, including Adélie penguins, south polar skuas, brown skuas and Wilson's storm petrels were reported to have oil contamination on their plumage and legs following an oil spill (Golubev, 2021). Birds with light oil contamination need to work harder to fly owing to the plumage's reduced lift and thrust, which makes them more prone to stress injury and limits their ability to search for food, while heavily oiled birds are immobilised because of plumage collapse (King et al., 2021). Due to their higher metabolic rate, oil-coated penguins exhibit a considerable reduction in mass, with serious implications for survival (Culik et al., 1991). Surface-dwelling animals and birds may be killed when exposed to an oil spill. The challenges of pollution in Antarctica is also a global concern since it also holds the largest freshwater reserve in the globe (90%) and plays significant roles in the control of global climate and ocean circulation (Turner et al., 2009; Convey and Peck, 2019; Subramaniam et al., 2020). Hence, human intervention is required in these areas to accelerate the remediation process of polluted sites.

Heavy metals are present naturally in the environment but are also released through human activities. In Antarctica, high levels of heavy metals have been detected in biotic samples from terrestrial and aquatic organisms, as well as in abiotic samples from soil, snow and the atmosphere (Chu et al., 2019a). Parts of the northern Antarctic Peninsula and South Shetland Islands, such as Deception Island, host areas of volcanic activity that can naturally release heavy metals (De Ferro et al., 2014). Anthropogenic sources such as sewage, mining, oil spills, abandoned dump sites and pesticides can also pollute the environment with heavy metals. Evidence of heavy metal contamination has been reported around Russian Antarctic stations due to human activities (Alekseev and Abakumov, 2020). Increased levels of copper (Cu), lead (Pb) and zinc (Zn) have been detected at an abandoned waste dumping site in Antarctica (Snape et al., 2001). Studies have also shown that heavy metals can travel large distances through the atmosphere and arrive in Antarctica (Bargagli, 2008). Heavy metals present in contaminated sites can influence the bioremediation of other contaminants (Tengku-Mazuki et al., 2020; Zakaria et al., 2020; Zahri et al., 2021b). Heavy metal co-contamination is investigated in order to assess the effects of heavy metals on bioremediation processes. This co-contamination could both hinder or accelerate the process rate depending on the resistance of microorganisms to heavy metals at particular concentrations.

Bioremediation is an important tool for environmental clean-up that uses biological mechanisms to reduce pollutant concentrations. In principle, bioremediation can be maximised by precisely controlling abiotic factors such as temperature, pH, medium formulation and substrate concentration (Lee et al., 2018; Sharma, 2021). Biodegradation can be more dependable, cost-saving and environmentally friendly than other currently more widely used chemical or physical approaches (Malla et al., 2018; Yadav et al., 2022). Pollutants can be converted into biodegradable compounds, improving ecosystem long-term viability in the affected areas. Recently, there has been increasing interest in using agricultural biosorbents that are cheap, effective, non-toxic and easily available (Zamparas et al., 2020). The potential use of this biosorbent technology presents an opportunity for increased efficiency of oil removal from water without additional contamination. The use of empty fruit bunch (EFB) agricultural waste as a biosorbent is promising owing to its efficient disposal and cost-effectiveness (Abdullah and Sulaiman, 2013a).

In parallel, microalgae can remove some pollutants by integrating them into their metabolism (Markou and Georgakakis, 2011). For instance, some microalgae have the ability to progressively break off the rings in polycyclic aromatic hydrocarbons (PAHs), leading to conversion to non-toxic products, ultimately carbon dioxide. Given this backgrounds, the development of a combination such as an EFB filter-incubation system approach supplemented with diesel removal by Antarctic microalgae has become more viable (Markou and Georgakakis, 2011; Jahi et al., 2020). This is in accordance with the Antarctic Treaty's requirements, which prohibit the introduction of non-local microorganisms to the continent to ensure the protection of the Antarctic environment (Jesus et al., 2015), meaning that any bioremediation effort in Antarctica must use native microorganisms to reduce the chance of further adverse environmental impacts. The current approaches to address oil pollution in Antarctica use biological resources, such as bacteria. Compared to utilising bacteria, employing microalgae species for diesel degradation is more favourable since microalgae biomass potentially be reused as a filter, biofuel, and feedstock.

The importance of studying hydrocarbon degradation in Antarctic ecosystems has been widely recognised although, as yet, there has been very limited research addressing how local microalgal species respond to the presence of hydrocarbons and heavy metals. Consequently, adopting the microalgal incubation tank approach to support bioremediation may be advantageous since it provides microalgae with a regulated and contained environment to carry out the bioremediation process (Yusoff et al., 2019). A large-scale light-incubation tank may increase the efficiency of bioremediation when combined with the biosorption technology of the filter press machine. This is consistent with earlier research that found that employing physical filtration and bioremediation technologies together increased the effectiveness of cleaning up oil spills in Antarctica (Cappello et al., 2014). Even though synthetic sorbents are currently commonly used, their disposal can be challenging. To develop a synergistic strategy, first, remove diesel from the environment and then undergo biodegradation, the deployment of an eco-friendly biosorbent employing EFB in a filter press machine paired with a light-incubation tank technique is examined in this study. The novelty of this study is the used of the bioremediatory agents, EFB as biosorbent and native Antarctic microalgal as diesel degrader integrated in a novel filter-incubation system for diesel removal. The eventual implementation of a comprehensive strategy to deal with oil spills could be facilitated by the development of such a system. Hence, the findings of this study will advance the currently-available diesel biosorption and bioremediation approaches available in Antarctica.

This study’s primary goal is to evaluate the diesel-sorption capabilities of EFB and the diesel-degrading capabilities of a native Antarctic microalgal in a filter-incubation system intended to enable diesel removal and bioremediation in Antarctica. The study was implemented with four objectives:

1. To screen and characterise the effects of EFB with different pretreatments on diesel biosorption.

2. To screen and identify an effective diesel-degrading native Antarctic microalgal.
3. To investigate the effects of co-contamination with selected heavy metals on microalgal diesel degradation.
4. To assess the most effective EFB biosorbent and microalgal in a newly-designed filter-incubation system for diesel degradation.

REFERENCES

Abbas, S., Yousaf, H., Khan, S., Rehman, M. Z. & Blueschke, D. (2023). Analysis and projection of transport sector demand for energy and carbon emission: An application of the grey model in Pakistan. *Mathematics, 11*, 1443. https://doi.org/10.3390/math11061443

Abdelwahab, O., Nasr, S. M. & Thabet, W. M. (2017). Palm fibers and modified palm fibers adsorbents for different oils. *Alexandria Engineering Journal, 56*, 749–755.

Abdelwahab, O., Thabet, W. M., Nasr, S. M. & Nafea, S. (2021). Oil spill cleanup using chemically modified natural fibers: Trial for practical application. *Egyptian Journal of Aquatic Biology and Fisheries, 25*, 457–464. https://doi.org/10.21608/ejabf.2021.164619

Abdel-Motaal, D. (2016). *Antarctica: The battle for the seventh continent*. Santa Barbara, California: Praeger Press.

Abdel-Shafy, H. I. & Mansour, M. S. (2018). Phytoremediation for the elimination of metals, pesticides, pahs, and other pollutants from wastewater and soil. In Kumar, V., Kumar, M., Prasad, R. (eds). *Phytobiont and Ecosystem Restitution* (pp. 101–136). Springer, Singapore. https://doi.org/10.1007/978-981-13-1187-1_5

Abdullah, N. & Sulaiman, F. (2013a). The oil palm wastes in malaysia. *Biomass Now - Sustainable Growth and Use, 554*. https://doi.org/10.5772/55302

Abdullah, N. & Sulaiman, F. (2013b). The properties of the washed empty fruit bunches of oil palm. *Journal of Physical Science*, *24*, 117–137.

Abdullah, N., Sulaiman, F. & Gerhauser, H. (2011). Characterisation of oil palm empty fruit bunches for fuel application. *Journal of Physical Science, 22*, 1–24.

Abdulrasheed, M., Zulkharnain, A., Zakaria, N. N., Roslee, A. F. A., Abdul Khalil, K., Napis, S., Convey, P., Gomez-Fuentes, C. & Ahmad, S. A. (2020a). Response surface methodology optimization and kinetics of diesel degradation by a cold-adapted Antarctic bacterium, *Arthrobacter* sp. strain AQ5-05. *Sustainability*, *12*, 6966. https://doi.org/10.3390/su12176966

Abdulrasheed, M., Zakaria, N. N., Roslee, A. F. A, Shukor, M. Y., Zulkharnain, A., Napis, S., Convey, P., Alias, S. A., Gonzalez-Rocha, G. & Ahmad, S.A. (2020b). Biodegradation of diesel oil by cold-adapted bacterial strains of *Arthrobacter* spp. from Antarctica. *Antarctic Science, 32*, 1–13.

Abd Wafti, N. S., Lau, H. L. N., Loh, S. K., Aziz, A. A., Rahman, Z. A. & May, C. Y. (2017). Activated carbon from oil palm biomass as potential adsorbent for palm oil mill effluent treatment. *Journal of Oil Palm Research, 29*, 278–290. https://doi.org/10.21894/jopr.2017.2902.12

Abioye, O. P., Aina, P. F., Ijah, J. U. J. & Aransiola, A. S. (2019). Effects of cadmium and lead on the biodegradation of diesel-contaminated soil. *Journal of Taibah University for Science*, *13*, 628–638.

Abutaleb, A., Imran, M., Zouli, N., Khan, A. H., Hussain, S., Ali, M. A., Bakather, O., Gondal, M. A., Khan, N. A., Panchal, H. & Zahmatkesh, S. (2023). FE_3O_4-multiwalled carbon nanotubes-bentonite as adsorbent for removal of methylene blue from aqueous solutions. *Chemosphere, 316*, 137824. https://doi.org/10.1016/j.chemosphere.2023.137824

Acevedo-Barrios, R., Rubiano-Labrador, C., Navarro-Narvaez, D., Escobar-Galarza, J., González, D., Mira, S., Moreno, D., Contreras, A. & Miranda-Castro, W. (2022). Perchlorate-reducing bacteria from Antarctic marine sediments. *Environmental Monitoring and Assessment, 194*. https://doi.org/10.1007/s10661-022-10328-w

Acharya, B. & Dutta, A. (2015). Fuel property enhancement of lignocellulosic and nonlignocellulosic biomass through torrefaction. *Biomass Conversion and Biorefinery, 6*, 139–149. https://doi.org/10.1007/s13399-015-0170-x

Aggarwal, A., Sharma, I., Tripathi, B. N., Munjal, A. K., Baunthiyal, M. & Sharma, V. (2011). Metal toxicity and photosynthesis. In S, Itoh., P, Mohanty., K. N, Guruprasad (Ed.). *Photosynthesis: Overviews on Recent Progress & Future Perspective* (pp. 229–236). New Delhi: IK International Publishing House.

Aggary, S. E., Latinwo, G. K., Dada, E. O. & Owabor, C. N. (2019). Bioremediation of crude oil contaminated soil in the presence of nickel, zinc and cadmium heavy metals using bacterial and fungal consortia-bioaugmentation strategy. *Journal of Environmental Treatment Techniques, 7*, 179–195.

Agwu, O. E., Okon, A. N. & Udoh, F. D. (2015). A comparative study of diesel oil and soybean oil as oil-based drilling mud. *Journal of Petroleum Engineering*, *2015,* 1–10. https://doi.org/10.1155/2015/828451

Ahmad, R., Hamid, R. & Osman, S. A. (2019). Physical and chemical modifications of plant fibres for reinforcement in cementitious composites. *Advances in Civil Engineering*, *518580*, 1–18.

Ahmad, S., Pandey, A., Pathak, V. V., Tyagi, V. V. & Kothari, R. (2020). Phycoremediation: algae as eco-friendly tools for the removal of heavy metals from wastewaters, in: Bioremediation of Industrial Waste for Environmental Safety. Springer, pp. 53–76.

Ahmad, S., Wong, Y. C. & Veloo, K. V. (2018a). Sugarcane bagasse powder as biosorbent for reactive red 120 removals from aqueous solution. *IOP Conference Series: Earth and Environmental Science, 140*, 012027. https://doi.org/10.1088/1755-1315/140/1/012027

Ahmad, I., Sohail, S. M., Khan, H., Khan, R. & Ahmad, W. (2018b).

Characterization of petroleum crude oils by fourier transform infrared (FTIR) and gas chromatography-mass spectrometerys. *Journal of Petroleum Science and Engineering, 2,* 1–7.

Aislabie, J. M., Balks, M. R., Fought, J. M. & Waterhouse, E. J. (2004). Hydrocarbon spills on Antarctic soils: Effects and management. *Environmental Sciences and Technology, 38*, 1265–1274.

Aislabie, J., Fraser, R., Duncan, S. & Farrell, R. L. (2001). Effects of oil spills on microbial heterotrophs in Antarctic soils. *Polar Biology, 24*, 308. https://doi.org/10.1007/s003000000210

Alam, F. A. S. A., Er, A. C. & Begum, H. (2015). Malaysian oil palm industry: Prospect and problem. *Journal of Food, Agriculture and Environment, 13*, 143–148.

Alekseev, I. & Abakumov, E. (2020). Human impacts in antarctica in a changing climate. Polycyclic aromatic hydrocarbons and heavy metals content in soils of vicinities of Russian Antarctic Stations. In Proceedings of the SCAR Open Science Conference 2020, Hobart, Australia, 31 July–11 August 2020. Retrieved from https://az659834.vo.msecnd.net/eventsairseasiaprod/productionleishman-public/d703d685663b44dbb2ade267acac1ecc (accessed on 18 August 2021).

Alexander, F. J., King, C. K., Reichelt-Brushett, A. J. & Harrison, P. L. (2016). Fuel oil and dispersant toxicity to the Antarctic sea urchin (*Sterechinus neumayeri*). *Environmental Toxicolology and Chemistry*, *36*, 1563–1571.

Alharbi, R. M. (2017). Toxicity and bioaccumulation of lead, cadmium and zinc in *Chroococcus minutus* and *Chlorococcum aegyptiacum*. *International Journal of Pharmaceutical Research and Allied Sciences, 6*, 290–300.

Alho, L. O. G., Gebara, R. C., Paina, K. A., Sarmento, H. & Melão, M. (2019). Responses of *Raphidocelis subcapitata* exposed to Cd and Pb: Mechanisms of toxicity assessed by multiple endpoints. *Ecotoxicology and Environmental Safety*, *169*, 950. https://doi.org/10.1016/j.ecoenv.2018.11.087

Almarashi, J. Q. M., El-Zohary, S. E., Ellabban, M. A. & Abomohra, A. E. F. (2020). Enhancement of lipid production and energy recovery from the green microalga *Chlorella vulgaris* by inoculum pretreatment with low-dose cold atmospheric pressure plasma (CAPP). *Energy Conversion and Management, 204*, 112314. https://doi.org/10.1016/j.enconman.2019.112314

Almutairi, A. W., El-Sayed, A. E. K. & Reda, M. M. (2021). Evaluation of high salinity adaptation for lipid bio-accumulation in the green microalga *Chlorella vulgaris*. *Saudi Journal of Biological Sciences, 28*, 3981–3988. https://doi.org/10.1016/j.sjbs.2021.04.007

Alori, E. T., Gabasawa, A. I., Elenwo, C. E. & Agbeyegbe, O. O. (2022). Bioremediation techniques as affected by limiting factors in soil environment. *Frontiers in Soil Science, 2*, 1–13. https://doi.org/10.3389/fsoil.2022.937186

Alsultan, W., Vadamalai, G., Khairulmazmi, A., Saud, H. M., Al-sadi, A., Rashed, O., Jaafar, A. K. M. & Nasehi, A. (2019). Isolation, identification and characterization of endophytic bacteria antagonistic to *Phytophthora palmivora* causing black pod of cocoa in Malaysia. *European Journal of Plant Pathology, 155*, 1077–1091.

Al-Defiery, M. E. J. & Reddy, G. (2014). Influence of metal ions concentration on phenol degradation by *Rhodococcus pyridinivorans* GM3. *Mesopotamia Environmental Journal, 1*, 30–38.

Ameri, M., Baron-Sola, A., Khavari-Nejad, R. A., Soltani, N., Najafi, F., Bagheri, A., Martinez, F. & Hernández, L. E. (2020). Aluminium triggers oxidative stress and antioxidant response in the microalgae *Scenedesmus* sp.. *Journal of Plant Physiology*, *246–247*, 153114.

Amin, N. F., Khalafallah, M. A., Ali, M. A., Abou-Sdera, S. A. & Matter, I. A. (2013). Effect of some nitrogen sources on growth and lipid of microalgae *Chlorella* sp. for biodiesel production. *Journal of Applied Sciences Research, 9*, 4845–4855.

Amjlef, A., Khrach, S., Ait El Fakir, A., Farsad, S., Et-Taleb, S. & El Alem, N. (2021). Adsorptive properties investigation of natural sand as adsorbent for methylene blue removal from contaminated water. *Nanotechnology for Environmental Engineering, 6*. https://doi.org/10.1007/s41204-021-00119-y

Andrade, S., Poblet, A., Scagliola, M., Vodopivez, C., Curtosi, A. & Pucci, A. (2001). Distribution of heavymetals in surface sediments froman Antarctic marine ecosystem. *Environmental Monitoring and Assessment, 66*, 147–158.

Angelova, D., Uzunov, I., Uzunova, S., Gigova, A. & Minchev, L. (2011). Kinetics of oil and oil products adsorption by carbonized rice husks. *Chemical Engineering Journal, 172*, 306–311.

Antarctic Treaty Consultative Meeting (ATCM). (2005). XXVIII/Committee for Environmental Protection (CEP) VIII. Environmental impact assessment information exchange, Stockholm. Retrieved from https://www.ats.aq/devAS/Meetings/Measure/346

Antarctic Treaty Consultative Meeting (ATCM). (2022). *Final report of the forty-fourth Antarctic treaty consultative meeting*, Berlin. Retrieved from https://documents.ats.aq/ATCM44/fr/ATCM44_fr001_e.pdf

Anuzyte, E. & Vaisis, V. (2018). Natural oil sorbents modification methods for hydrophobicity improvement. *Energy Procedia*, *147*, 295–300.

https://doi.org/10.1016/j.egypro.2018.07.095

Arsad, S., Kholifah, S. N., Prabawati, E., Sari, L. A., Kadim, M. K. & Kilawati, Y. (2020). Effect of mercury on growth of several microalgae. *Asian Journal of Water, Environment and Pollution, 17*, 13–17. https://doi.org/10.3233/ajw200029

Arunakumara, K. K. I. U. & Xuecheng, Z. (2008). Heavy metal bioaccumulation and toxicity with special reference to microalgae. *Journal of Ocean University of China, 7*, 60–64.

Asadu, C. O., Anthony, E. C., Elijah, O. C., Ike, I. S., Onoghwarite, O. E. & Okwudili, U. E. (2021). Development of an adsorbent for the remediation of crude oil polluted water using stearic acid grafted coconut husk (*Cocos nucifera*) composite. *Applied Surface Science Advances, 6*, 100179. https://doi.org/10.1016/j.apsadv.2021.100179

Australian Antarctic Division. (2012). *Pollution and waste*. Department of the Environmental and Energy. Retrieved from htpps://www.antarctica.gov.au (accessed on 22 July 2019).

Australian Antarctic Division. (2017). *Who owns Antarctica?* Department of Climate Change, Energy, the Environment and Water. Retrieved from https://www.antarctica.gov.au/about-antarctica/people-in-antarctica/who-owns-antarctica/ (accessed on 16 March 2023).

Ausuri, J., Dell'Anno, F., Vitale, G. A., Palma Esposito, F., Funari, V., Franci, G., Galdiero, M., Della Sala, G., Tedesco, P., Coppola, D. & de Pascale, D. (2022). Bioremediation of multiple heavy metals mediated by Antarctic marine isolated *Dietzia psychralcaliphila* JI1D. *Journal of Marine Science and Engineering*, *10*, 1669. https://doi.org/10.3390/jmse10111669

Azaman, S. N., Nagao, N., Yusoff, F. M., Tan, S.W. & Yeap, S.K. (2017). A comparison of the morphological and biochemical characteristics of *Chlorella sorokiniana* and *Chlorella zofingiensis* cultured under photoautotrophic and mixotrophic conditions. *PeerJ*, *5,* e3473. https://doi.org/10.7717/peerj.3473

Azov, Y. (1982). Effect of pH on inorganic carbon uptake in algal cultures. *Applied and Environmental Microbiology, 43*, 1300–1306. https://doi.org/10.1128/aem.43.6.1300-1306.1982

Baglieri, A., Sidella, S., Barone, V., Fragalà, F., Silkina, A., Nègre, M. & Gennari, M. (2016). Cultivating *Chlorella vulgaris* and *Scenedesmus quadricauda* microalgae to degrade inorganic compounds and pesticides in water. *Environmental Science and Pollution Research, 23*, 18165–18174. https://doi.org/10.1007/s11356-016-6996-3

Bargagli, R. (2008). Environmental contamination in Antarctic ecosystems. *Science of the Total Environment*, *400*, 212–226.

Barral-Fraga, L., Morin, S., Rovira, M. D., Urrea, G., Magellan, K. & Guasch, H. (2015). Short-term arsenic exposure reduces diatom cell size in biofilm communities. *Environmental Science and Pollution Research, 23*, 4257–4270.

Barras, F. & Fontecave, M. (2011). Cobalt stress in *Escherichia coli* and *Salmonella enterica*: Molecular bases for toxicity and resistance. *Metallomics, 3*, 1130–1134.

Bartley, M. L., Boeing, W. J., Dungan, B. N., Holguin, F. O. & Schaub, T. (2013). pH effects on growth and lipid accumulation of the biofuel microalgae *Nannochloropsis salina* and invading organisms. *Journal of Applied Phycology, 26*, 1431–1437. https://doi.org/10.1007/s10811-013-0177-2

Bashir, K. M. I., Lee, H. J., Mansoor, S., Jahn, A. & Cho, M. G. (2021). The effect of chromium on photosynthesis and lipid accumulation in two chlorophyte microalgae. *Energies*, *14*, 2260. https://doi.org/10.3390/en14082260

Bayat, A., Aghamiri, S. F., Moheb, A. & Vakili-Nezhaad, G. R. (2005). Oil spill cleanup from sea water by sorbent materials. *Chemical Engineering and Technology, 28*, 1525–1528.

Begum, M., Sarmah, B., Kandali, G. G., Kalita, S., Ojha, I., Bhagawati, R. & Talukdar, L. (2021). *Persistant organic pollutants in soil and its phytoremediation.* Retrieved from https://doi.org/10.5772/intechopen.99835

Beijerinck, M.W. (1890). Culturversuche mit Zoochlorellen, Lichenengonidien und anderen niederen algen. *Botanische Zeitung*, *47,* 725–739, 741–754, 757–768, 781–785.

Benner, P., Meier, L., Pfeffer, A., Krüger, K., Oropeza Vargas, J. E. & Weuster-Botz, D. (2022). Lab-scale photobioreactor systems: Principles, applications, and scalability. *Bioprocess and Biosystems Engineering, 45*, 791–813. https://doi.org/10.1007/s00449-022-02711-1

Bennett, J. (2014). Advanced fuel additives for modern internal combustion engines. In R, Folkson (Ed.). *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance* (pp. 165–194). Cambridge, UK: Woodhead Publishing.

Bharti, P. K., Sharma, B., Singh, R. K. & Tyagi, A. K. (2016a). Waste generation and management in Antarctica. *Procedia Environmental Sciences*, *35*, 40–50.

Bharti, P. K., Sharma, B., Pal, N., Singh, R. K. & Tyagi, A. K. (2016b). Distribution of major and minor elements in the surface water of southern ocean near East Antarctica. *Journal of the Marine Biological Association of India, 58*. https://doi.org/10.6024/jmbai.2016.58.2.1918-01

Blair, M. F., Kokabian, B. & Gude, V. G. (2014). Light and growth medium effect on *Chlorella vulgaris* biomass production. *Journal of Environmental Chemical Engineering, 2*, 665–674. https://doi.org/10.1016/j.jece.2013.11.005

Blanchette, R. A., Held, B. W., Jurgens, J. A., Aislabie, J., Duncan, S. & Farell, R. L. (2004). Environmental pollutants from the Scott and Shackleton expeditions during the "heroic age" of Antarctic exploration. *Polar Record, 40*, 143–151.

Bolong, N., Saad, I., Makinda, J., Yaser, A. Z., Abdullah, M. H. & Ismail, A. F. (2016). Influence of oil palm empty fruit bunch (OPEFB) agro-waste properties as filtration medium to improve urban stormwater. *Jurnal Teknologi, 78*. https://doi.org/10.11113/jt.v78.5357

Bong, C. W., Obayashi, Y. & Suzuki, S. (2011). Effect of exposure of zinc at low concentration to bacterial production in seawater. *Memoirs of Faculty Agriculture Ehime University, 56*, 42–45.

British Antarctic Survey. (2023). *Antarctic Infrastructure Modernisation Programme*. Natural Environment Research Council. Retrieved from https://www.bas.ac.uk/polar-operations/antarctic-infrastructure-projects/ (accessed on 16 April 2023)

Broady, P. A. (1996). Diversity, distribution and dispersal of Antarctic terrestrial algae. *Biodiversity and Conservation*, *5*, 1307–1335.

Brooks, S. T., Jabour, J., van den Hoff, J. & Bergstrom, D. M. (2019). Our footprint in Antarctica competes with nature for rare ice-free land. *Nature Sustainability, 2*, 185–190. https://doi.org/10.1038/s41893-019-0237-y

Brown, K. E., King, C. K., Kotzakoulakis, K., George, S. C. & Harrison, P. L. (2016). Assessing fuel spill risks in polar waters: Temporal dynamics and behaviour of hydrocarbons from Antarctic diesel, marine gas oil and residual fuel oil. *Marine Pollution Bulletin, 110*, 343–353.

Brown, K. E., Wasley, J. & King, C. K. (2023). Assessing risks from fuel contamination in Antarctica: Dynamics of diesel ageing in soil and toxicity to an endemic nematode. *Ecotoxicology and Environmental Safety*, *249*, 114345. https://doi.org/10.1016/j.ecoenv.2022.114345

Budi, R. M., Rahardja, B. S. & Masithah, E. D. (2020). Potential concentration of heavy metal copper (Cu) and microalgae growth *Spirulina plantesis* in culture media. *IOP Conference Series: Earth and Environmental Science, 441*, 012147. https://doi.org/10.1088/1755-1315/441/1/012147

Bueno, C., Kandratavicius, N., Venturini, N., Figueira, R. C. L., Perez, L., Iglesias, K. & Brugnoli, E. (2018). An evaluation of trace metal concentration in terrestrial and aquatic environments near Artigas Antarctic scientific base (King George Island, Maritime Antarctica). *Water Air Soil Pollution*, *229*, 398. https://doi.org/10.1007/s11270-018-4045-1.

Byeon, E., Kang, H. -M., Yoon, C. & Lee, J. -S. (2021). Toxicity mechanisms of arsenic compounds in aquatic organisms. *Aquatic Toxicology*, *237*, 105901. https://doi.org/10.1016/j.aquatox.2021.105901

Cabrerizo, A., Tejedo, P., Dachs, J. & Benayas, J. (2016). Anthropogenic and biogenic hydrocarbons in soils and vegetation from the South Shetland Islands (Antarctica). *Science of The Total Environment*, *569–570*, 1500–1509. https://doi.org/10.1016/j.scitotenv.2016.06.240

Cameron, H., Mata, M. T. & Riquelme, C. (2018). The effect of heavy metals on the viability of *Tetraselmis marina* AC16-MESO and an evaluation of the potential use of this microalgae in bioremediation. *PeerJ*, 6, e5295. https://doi.org/10.7717/peerj.5295

Cao, S., Dong, T., Xu, G. & Wang, F. (2017). Oil spill cleanup by hydrophobic natural fibers. *Journal of Natural Fibers*, *14*, 727–735.

Cappello, S., Mancini, G., Pistone, A., Rosamarina, M. A. R., Bottino, F., Genovese, L., Iannazzo, D., Luciano, A., Mamo, A., Neri, G., Galvagno, S., Santisi, S., Visco, A. & Yakimov, M. (2014). STRANgE, integrated physical–biological–mechanical system for recovery in of the “oil spill” in Antarctic environment. *Reviews in Environmental Science and Biotechnology*, *3*, 369–337. https://doi.org/10.1007/s11157-014-9346-2

Carfagna, S., Lanza, N., Salbitani, G., Basile, A., Sorbo, S. & Vona, V. (2013). Physiological and morphological responses of lead and cadmium exposed *Chlorella sorokiniana* 211-8K (Chlorophyceae). *Springerplus*, *2,* 147. https://doi.org/10.1186/2193-1801-2-147

Carlsson, A. S., Beilen, J. B., Moller, R. & Clayton, D. (2007). Micro-algae and macro-algae: utility for industrials applications. In D, Bowles (Ed.). *Outputs from the EPOBIO project* (pp 9–33). United Kingdom, UK: CPL Press.

Cavacini, P. (2001). Soil algae from northern Victoria Land (Antarctica). *Polar Bioscience*, *14*, 45–60.

Cavalletti, E., Romano, G., Palma Esposito, F., Barra, L., Chiaiese, P., Balzano, S. & Sardo, A. (2022). Copper effect on microalgae: Toxicity and bioremediation strategies. *Toxics*, *10*, 527. https://doi.org/10.3390/toxics10090527

Celis, J. E., Barra, R., Espejo, W., González-Acuña, D. & Jara, S. (2014). Trace element concentrations in biotic matrices of gentoo penguins (*Pygoscelis papua*) and coastal soils from different locations of the Antarctic Peninsula. *Water Air Soil Pollution*, *226*, 2266. https://doi.org/10.1007/s11270-014-2266-5

Cepák, V., Pribyl, P. & Vítová, M. (2006). The effect of light color on the nucleocytoplasmic and chloroplast cycle of the green chlorococcal alga *Scenedesmus obliquus*. *Folia Microbiologica, 51*, 342–348.

Chaudhary, D. K. & Kim, J. (2019). New insights into bioremediation strategies for oil-contaminated soil in cold environments. *International Biodeterioration and Biodegradation, 142*, 58–72.

Chen, C. Y. & Durbin, E. G. (1994). Effects of pH on the growth and carbon uptake of marine phytoplankton. *Marine Ecology Progress Series*, *111*, 83–94. https://doi.org/10.3354/meps111083

Cheng, J. J., Poduska, B., Morton, R. & Finan, T. (2011). An ABC-type cobalt transport system is essential for growth of *Sinorhizobium meliloti* at trace metal concentrations. *Journal of Bacteriology, 193*, 4405–4416. https://doi.org/10.1128/JB.05045-11

Cheu, S. C., Kong, H., Song, S. T., Saman, N., Johari, K. & Mat, H. (2016). High removal performance of dissolved oil from aqueous solution by sorption using fatty acid esterified pineapple leaves as novel sorbents. *RSC Advances, 6*, 13710–13722.

Chin, S. X., Chia, C. H., Zakaria, S., Fang, Z. & Ahmad, S. (2015). Ball milling pretreatment and diluted acid hydrolysis of oil palm empty fruit bunch (EFB) fibres for the production of levulinic acid. *Journal of the Taiwan Institute of Chemical Engineering*, *52*, 85–92.

Cho, S., Lee, H., Hong, S. & Lee, J. (2020). Study of ecophysiological responses of the Antarctic fruticose lichen *Cladonia borealis* using the PAM fluorescence system under natural and laboratory conditions. *Plants, 9*, 85. https://doi.org/10.3390/plants9010085

Chu, W. L., Dang, N. L., Kok, Y. Y., Ivan, K. S. Y., Phang, S. M. & Convey, P. (2019a). Heavy metal pollution in Antarctica and its potential impacts on algae. *Polar Science, 20*, 75–83. https://doi.org/10.1016/j.polar.2018.10.004

Chu, Z., Yang, Z., Wang, Y., Sun, L., Yang, W., Yang, L. & Gao, Y. (2019b). Assessment of heavy metal contamination from penguins and anthropogenic activities on Fildes Peninsula and Ardley Island, Antarctic. *Science of the Total Environmental*, *646*, 951–957.

Collins, C. D. (2007). Implementing phytoremediation of petroleum hydrocarbons. In: Willey, N. (eds). *Phytoremediation*. Methods in Biotechnology, vol 23. Humana Press. https://doi.org/10.1007/978-1-59745-098-0_8

Convey, P. & Peck, L.S. (2019). Antarctic environmental change and biological responses. *Science Advances*, 5, eaaz0888. https://doi.org/10.1126/sciadv.aaz0888

Cordero, A. P., Vergara, D. E. M. & Mendoza, Y. A. (2023). Evaluation of the potential of *Chlorella vulgaris* for the removal of pollutants from standing water. *Journal of Positive Psychology and Wellbeing, 7*, 626–631.

Coronado-Reyes, J. A., Salazar-Torres, J. A., Juárez-Campos, B. & González-

Hernández, J. C. (2022). *Chlorella vulgaris*, a microalgae important to be used in biotechnology: A review. *Food Science and Technology, 42*, e37320. https://doi.org/10.1590/fst.37320

Council of Managers of National Antarctic Programs (COMNAP). (2016). *Committee for Environmental Protection, Fauna and flora Environmental protection, ATCM XXXIX - CEP XIX, Santiago*. Retrieved from https://www.ats.aq/devAS/Meetings/Measure/640

Crossley, B. M., Bai, J., Glaser, A., Maes, R., Porter, E., Killian, M. L., Clement, T. & Toohey-Kurth, K. (2020). Guidelines for Sanger sequencing and molecular assay monitoring. *Journal of Veterinary Diagnostic Investigation*, *32*, 767–775.

Culik, B. M., Wilson, R. P., Woakes, A. T. & Sanudo, F. W. (1991). Oil pollution of Antarctic penguins: Effects on energy metabolism and physiology. *Marine Pollution Bulletin*, *22*, 388–391.

Čypaitė, A., Žaltauskaitė, J. & Venclovienė, J. (2014). Assessment of chlorophyll-*a*, chlorophyll-*b* and growth rate in freshwater green algae *Pseudokirchneriella subcapitata* exposed to cadmium and copper. *The 9th International Conference "Environmental Engineering" (Section: Environmental protection)*, pp. 1–7. Retrieved from http://leidykla.vgtu.lt/conferences/ENVIRO_2014/Articles/1/009_Cypaite.pdf

Dacey, D. P. & Chain, F. J. (2021). Concatenation of paired-end reads improves taxonomic classification of amplicons for profiling microbial communities. *BMC Bioinformatics, 22*. https://doi.org/10.1186/s12859-021-04410-2

Daher, M., Schaefer, C. E. G. R., Thomazini, A., de Lima Neto, E., Souza, C. D. & do Vale Lopes, D. (2019). Ornithogenic soils on basalts from maritime Antarctica. *Catena*, *173*, 367–374.

Daneshfozoun, S., Abdullah, M. A. & Abdullah, B. (2017). Preparation and characterization of magnetic biosorbent based on oil palm empty fruit bunch fibers, cellulose and *Ceiba pentandra* for heavy metal ions removal. *Industrial Crops and Products*, *105*, 93–103. https://doi.org/10.1016/j.indcrop.2017.05.011

Darham, S., Zahri, K. N., Zulkharnain, A., Sabri, S., Gomez-Fuentes, C., Convey, P., Khalil, K. A. & Ahmad, S. A. (2021). Statistical Optimisation and kinetic studies of molybdenum reduction using a psychrotolerant marine bacteria isolated from Antarctica. *Journal of Marine Science and Engineering, 9*, 648. https://doi.org/10.3390/jmse9060648

Darham, S., Zakaria, N. N., Zulkharnain, A., Sabri, S., Khalil, K. A., Merican, F., Gomez-Fuentes, C., Lim, S. & Ahmad, S. A. (2023). Antarctic heavy metal pollution and remediation efforts: State of the art of research and scientific publications. *Brazilian Journal of Microbiology*, *54,* 2011–2026.

Dave, D. & Ghaly, A. E. (2011). Remediation technologies for marine oil spills: a critical review and comparative analysis. *American Journal of Environmental Sciences*, *7*, 423–440. https://doi.org/10.3844/ajessp.2011.423.440.

Demirel, Y. (2012). Energy: production, conversion, storage, conservation, and coupling. *Green Energy and Technology*. Springer-Verlag London Limited. pp 27–70.

Deprez, P. P., Arens, M. & Locher, H. (1999). Identification and preliminary assessment of contaminated sites at Casey Station, Wilkes Land, Antarctica. *Polar Record, 35*, 299–316. https://doi.org/10.1017/S0032247400015655

Deydier, E., Guilet, R., Sarda, S. & Sharrock, P. (2005). Physical and chemical characterisation of crude meat and bone meal combustion residue: "waste or raw material?". *Journal of Hazardous Materials*, *121*, 141–148. https://doi.org/10.1016/j.jhazmat.2005.02.003

De Castro-Fernández, P., Cardona, L. & Avila, C. (2021). Distribution of trace elements in benthic infralittoral organisms from the western Antarctic Peninsula reveals no latitudinal gradient of pollution. *Scientific Reports, 11*, 16266. https://doi.org/10.1038/s41598-021-95681-5

De Ferro, A. M., Mota, A. M. & Canario, J. (2014). Pathways and speciation of mercury in the environmental compartments of Deception Island, Antarctica. *Chemosphere*, *95*, 227–233.

de Mooij, T., de Vries, G., Latsos, C., Wijffels, R. H. & Janssen, M. (2016). Impact of light color on photobioreactor productivity. *Algal Research*, *15*, 32–42. https://doi.org/10.1016/j.algal.2016.01.015

Dhaka, A. & Chattopadhyay, P. (2021). A review on physical remediation techniques for treatment of marine oil spills. *Journal of Environmental Management, 288*, 112428. https://doi.org/10.1016/j.jenvman.2021.112428

Díaz, M. A., Frómeta, A. E. & Muñoz, C. L. (2022). Improved sorbent for the removal of hydrocarbons spilled in water. *Frontiers in Sustainability, 3*, 962215. https://doi.org/10.3389/frsus.2022.962215

Divya, M., Aanand, S., Srinivasan, A. & Ahilan B. (2015). Bioremediation – an eco-friendly tool for effluent treatment: A review. *International Journal of Applied Research, 1*, 530–537. Retrieved from https://www.allresearchjournal.com/archives/2015/vol1issue12/PartH/1-12-41.pdf

Dong, L. -L., Wang, H. -X., Wang, Y., Hu, X. -Q. & Wen, X. -L. (2022). Effects of CD^{2+} and PB^{2+} on growth and photosynthesis of two freshwater algae species. *Polish Journal of Environmental Studies, 31*, 2059–2068. https://doi.org/10.15244/pjoes/143256

Dong, L. -L., Zhang, G. -Q., Li, W., Ding, T., Wang, H. -X. & Zhang, G. (2020). Effects of Cu^{2+} and Hg^{2+} on growth and photosynthesis of two *Scenedesmus* species. *Polish Journal of Environmental Studies, 29*, 1129–1135. https://doi.org/10.15244/pjoes/105977

Dong, T., Wang, F. & Xu, G. (2014). Theoretical and experimental study on the oil sorption behavior of kapok assemblies. *Industrial Crops and Products*, *61*, 325–330.

Dorst, J., Siciliano, S. D., Winsley, T., Snape, I. & Ferrari, B. C. (2014). Bacterial targets as potential indicators of diesel fuel toxicity in subantarctic soils. *Applied and Environmental Microbiology*, *80*, 4021–4033.

dos Santos, H. F., Cury, J. C., do Carmo, F. L., dos Santos, A. L., Tiedje, J., van Elsas, J. D., Rosado, A. S. & Peixoto, R. S. (2011). Mangrove bacterial diversity and the impact of oil contamination revealed by pyrosequencing: bacterial proxies for oil pollution. *PLoS ONE, 6*, e16943. https://doi.org/10.1371/journal.pone.0016943

Dou, Y., Zuo, G., Chang, X. & Chen, Y. A. (2019). A study of a standalone renewable energy system of the Chinese Zhongshan station in Antarctica. *Applied Sciences*, *9*, 1968. https://doi.org/10.3390/app9101968

Dungani, R., Aditiawati, P., Aprilia, S., Yuniarti, K., Karliati, T., Suwandhi, I. & Sumardi, I. (2018). *Biomaterial from oil palm waste: Properties, characterization and applications.* Retrieved from https://doi.org/10.5772/intechopen.76412

Dwivedi, S. (2012). Bioremediation of heavy metal by algae: Current and future perspective. *Journal of Advanced Laboratory Research in Biology, 3*, 196–199.

Elias, M. A., Hadibarata, T. & Sathishkumar, P. (2021). Modified oil palm industry solid waste as a potential adsorbent for lead removal. *Environmental Chemistry and Ecotoxicology*, *3*, 1–7. https://doi.org/10.1016/j.enceco.2020.10.003

El Gheriany, I. A., Ahmad E. S. F., Abd El, A. R. A. & Hussein, M. (2020). Oil spill sorption capacity of raw and thermally modified orange peel waste. *Alexandria Engineering Journal*, *59*, 925–932.

El-Din, G. A., Amer, A. A., Malsh, G. & Hussein, M. (2017). Study on the use of banana peels for oil spill removal. *Alexandria Engineering Journal, 57*, 2061–2068. https://doi.org/10.1016/j.acj.2017.05.020

El-Sheekh, M. M., Hamouda, R. A. & Nizam, A. A. (2013). Biodegradation of crude oil by *Scenedesmus obliquus* and *Chlorella vulgaris* growing under heterotrophic conditions. *International Biodeterioration and Biodegradation*, *82*, 67–72. https://doi.org/10.1016/j.ibiod.2012.12.015

Erdmann, N. & Hagemann, M. (2001).Salt acclimation of algae and cyanobacteria: A comparison. *Algal Adaptation to Environmental Stresses*, 323–361. https://doi.org/10.1007/978-3-642-59491-5_11

Errington, I., King, C. K., Wilkins, D., Spedding, T. & Hose, G. C. (2018). Ecosystem effects and the management of petroleum-contaminated soils on sub-Antarctic islands. *Chemosphere*, *194*, 200–210.

Espejo, W., Padilha, J. A., Kidd, K. A, Dorneles, P., Malm, O., Chiang, G. & Celis, J. E. (2019). Concentration and trophic transfer of copper, selenium and zinc in marine species of the Chilean Patagonia and the Antarctic Peninsula area. *Biological Trace Element Research*, *197*, 285–293.

Evans, C., Brandsma, J., Pond, D. W., Venables, H. J., Meredith, M. P., Witte, H. J., Stammerjohn, S., Wilson, W. H., Clarke, A. & Brussaard, C. P. (2017). Drivers of interannual variability in virioplankton abundance at the coastal western Antarctic peninsula and the potential effects of climate change. *Environmental Microbiology, 19*, 740–755.

Farrell, J. T., Cernansky, N. P., Dryer, F. L., Law, C. K., Friend, D. G., Hergart, C. A., McDavid, R. M., Patel, A. K., Mueller, C. J. & Pitsch, H. (2007). Development of an experimental database and kinetic models for surrogate diesel fuels. *SAE Technical Paper Series*, *32*. https://doi.org/10.4271/2007-01-0201

Fatemeh, L. & Mohsen, D. (2016). Effects of environmental factors on the growth, optical density and biomass of the green algae *Chlorella vulgaris* in outdoor conditions. *Journal of Applied Sciences and Environmental Management, 20*, 133. https://doi.org/10.4314/jasem.v20i1.16

Fox, R. D. (1996). Physical/chemical treatment of organically contaminated soils and sediments. *Journal of the Air and Waste Management Association*, *46*, 391–413.

Frick, C. M., Farrell, R. E. & Germida, J. J. (1999). *Assessment of phytoremediation as an in-situ technique for cleaning oil-contaminated sites.* Petroleum technology alliance of Canada (PTAC), Calgary, AB, USA. Retrieved from https://pdfs.semanticscholar.org/28e1/c0f93e89b5d8aefe87de9acf0d9999c20b6.pdf?_ga=2.102329097.900078707.15571360941748355359.1521921840(accessed on 10 October 2020).

Fuoco, R., Giannarelli, S., Onor, M., Ghimenti, S., Abete, C., Termine, M. & Francesconi, S. (2012). A snow/firn four-century record of polycyclic aromatic hydrocarbons (PAHs) and polychlorobiphenyls (PCBS) at Talos Dome (Antarctica). *Microchemical Journal*, *105*, 133–141. https://doi.org/10.1016/j.microc.2012.05.018

Gallego, J. L. R., Loredo, J., Llamas, J. F., Vázquez, F. & Sánchez, J. (2001). Bioremediation of diesel-contaminated soils: Evaluation of potential in situ techniques by study of bacterial degradation. *Biodegradation*, *12*, 325–335.

Gambino, E., Chandrasekhar, K. & Nastro, R. A. (2021). SMFC as a tool for the removal of hydrocarbons and metals in the marine environment: a concise research update. *Environmental Science and Pollution Research*, *28*, 30436–30451. https://doi.org/10.1007/s11356-021-13593-3

Gao, S., Wang, D., Huang, Z., Su, C., Chen, M. & Lin, X. (2022). Recyclable NiO/sepiolite as adsorbent to remove organic dye and its regeneration. *Scientific Reports, 12*. https://doi.org/10.1038/s41598-022-06849-6

Garcia-Borboroglu, P., Boersma, D., Reyes, L. M. & Skewgar, E. (2008). Petroleum pollution and penguins: Marine conservation tools to reduce the problem. In T.N, Hofer (Ed.). *Marine Pollution, New Research* (pp. 339–356). New York, NY: Nova Science Publishers Inc.

Gerringa, L. J. A., Alderkamp, A. -C., van Dijken, G., Laan, P., Middag, R. & Arrigo, K. R. (2020). Dissolved trace metals in the Ross Sea. *Frontiers in Marine Science*, *7,* 577098. https://doi.org/10.3389/fmars.2020.577098

Golubev, S. (2021). Seabirds in conditions of local chronic oil pollution, Davis Sea, Antarctica. *Birds*, *2*, 275–284.

Gomes, V., Passos, M., Leme, N. M. P., Santos, T. C. A. & Campos, D. Y. F. (2009). Photo-induced toxicity of anthracene in the Antarctic shallow water amphipod, *Gondogeneia Antarctica*. *Polar Biology*, *32*, 1009. https://doi.org/10.1007/s00300-009-0600-y

Gore, D. B., Revill, A. T. & Guille, D. (1999). Petroleum hydrocarbons ten years after spillage at a helipad in Bunger Hills, East Antarctica. *Antarctic Science*, *11*, 427. https://doi.org/10.1017/S0954102099000541

Gran-Scheuch, A., Fuentes, E., Bravo, D. M., Jiménez, J. C. & Pérez-Donoso, J. M. (2017). Isolation and characterization of phenanthrene degrading bacteria from diesel fuel-contaminated Antarctic soils. *Frontiers in Microbiology*, *8*. https://doi.org/10.3389/fmicb.2017.01634

Gran-Scheuch, A., Ramos-Zuñiga, J., Fuentes. E. & Bravo, D. (2020). Effect of co-contamination by PAHs and heavy metals on bacterial communities of diesel contaminated soils of South Shetland Islands, Antarctica. *Microorganisms, 8*, 1634. https://doi.org/10.3390/microorganisms8111749

Gunawan, T. J., Ikhwan, Y., Restuhadi, F. & Pato, U. (2018). Effect of light intensity and photoperiod on growth of *Chlorella pyrenoidosa* and CO_2 biofixation. *E3S Web of Conferences*, *31*, 03003. https://doi.org/10.1051/e3sconf/20183103003

Habib, S., Ahmad, S. A., Johari, W. L., Shukor, M. Y., Alias, S. A., Khalil, K. A. & Yasid, N. A. (2018). Evaluation of conventional and response surface level optimisation of N-dodecane (N-C12) mineralisation by psychrotolerant strains isolated from pristine soil at Southern Victoria Island, Antarctica. *Microbial Cell Factories, 17*, 44. https://doi.org/10.1186/s12934-018-0889-8

Haehnel, R. B., Melendy, T. D. & Blaisdell, G. L. (2017). Feasibility of using alternate fuels in the U.S. Antarctic Program: initial assessment. *The U.S. Army Engineer Research and Development Center (ERDC): Virginia* (pp. 13–52). Retrieved from https://erdc-library.erdc.dren.mil/jspui/handle/11681/24335

Hallmann, C., Stannek, L., Fritzlar, D., Hause-Reitner, D., Friedl, T. & Hoppert, M. (2013). Molecular diversity of phototrophic bio-films on building stone. *FEMS Microbiology Ecology*, *84*, 355–372. https://doi.org/10.1111/1574-6941.12065

Hamilton, J. (2012). Careers in environmental remediation. *Green Jobs: Environmental Remediation*. Retrieved from https://www.bls.gov/ (accessed on January 2023).

Hamouda, R. A. E. F., Sorour, N. M. & Yeheia, D. S. (2016). Biodegradation of crude oil by *Anabaena oryzae*, *Chlorella kessleri* and its consortium under mixotrophic conditions. *International Biodeterioration and Biodegradation, 112*, 128–134.

Handayani, T., Mulyanto, A., Priyanto, F. E. & Nugroho, R. (2020). Utilization of dairy industry wastewater for nutrition of microalgae *Chlorella vulgaris. Journal of Physics: Conference Series, 1655*, 012123. https://doi.org/10.1088/1742-6596/1655/1/012123

Hanifah, N. A. & Hashim, R. (2012). The Madrid Protocol 1991 and its environmental impacts towards the quality of life. *Procedia - Social and Behavioral Sciences*, *35*, 398–403. https://doi.org/10.1016/j.sbspro.2012.02.104

Hantke, K. (2005). Bacterial zinc uptake and regulators. *Current Opinions in Microbiology, 8*, 196–202. https://doi.org10.1016/j.mib.2005.02.001

Hao, Y., Pan, Y., Du, R., Wang, Y., Chen, Z., Zhang, X. & Wang, X. (2018). The influence of a thermal treatment on the decay resistance of wood via FTIR analysis. *Advances in Materials Science and Engineering*, *2018,* 1–7.

Haron, M. J., Tiansih, M., Ibrahim, N. A., Kassim, A. & Wan Yunus, W. M. Z. (2009). Sorption of cu(II) by polyhydroxamic acid chelating exchanger prepared from polymethyl acrylate grafted oil palm empty fruit bunch (OPEFB). *Bioresources*, *4*, 1305–1318.

Harris, C. M. & Meadows, J. (1992). Environmental management in Antarctica. *Marine Pollution Bulletin, 25*, 239–249.

Harvenda, V., Hamzah, Y., Arfianti, Linda, T. M. & Umar, L. (2019). Influence of artificial light color on cellular respiration of green algae photosynthesis activity. *The 8th National Physics Seminar, 2169*, 030005. Retrieved from https://doi.org/10.1063/1.5132655

Heng, L. Y., Jusoh, K., Ling, C. H. & Idris, M. (2004). Toxicity of single and combinations of lead and cadmium to the cyanobacteria *Anabaena Flos-Aquae*. *Bulletin of Environmental Contamination and Toxicology, 72*, 373–379. https://doi.org/10.1007/s00128-003-8923-9

Hernandez, A., Loera, N., Contreras, M., Fischer, L. & Sánchez, D. (2019). Comparison between *Lactuca sativa L.* and *Lolium Perenne*: Phytoextraction capacity of ni, fe, and co from galvanoplastic industry. In: Wang, T. (ed.). *The Minerals, Metals and Materials Series*, Springer, Cham. https://doi.org/10.1007/978-3-030-06209-5_14

Hisam, N. I. B., Zakaria, M. Z., Azid, A., Abu Bakar, M. F. & Samsudin, M. S. (2022). Phytoremediation process of water spinach (*Ipomoea aquatica*) in absorbing heavy metal concentration in wastewater. *Journal of Agrobiotechnology, 13*, 131–144. https://doi.org/10.37231/jab.2022.13.1s.322

Hoai, N. T., Sang, N. N. & Hoang, T. D. (2016). Oil spill cleanup using stearic-acid-modified natural cotton. *Journal of Materials and Environmental Science, 7*, 2498–2504.

Honda, M. & Suzuki, N. (2020). Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. *International Journal of Environmental Research Public Health*, *17*, 1363. https://doi.org/10.3390/ijerph17041363

Hossain, M. A., Piyatida, P., Teixeira da Silva J. A. & Fujita, M. (2012). Molecular mechanism of heavy metal toxicity and tolerance in plants: Central role of glutathione in detoxification of reactive oxygen species and methylglyoxal and in heavy metal chelation. *Journal of Botany*, *2012,* 1–37. https://doi.org/10.1155/2012/872875.

Ho, S. H., Ye, X., Hasunuma, T., Chang, J. S. & Kondo, A. (2014). Perspectives on engineering strategies for improving biofuel production from microalgae–A critical review. *Biotechnology Advances, 32*, 1448–1459. https://doi.org/10.1016/j.biotechadv.2014.09.002

Huang, X. & Lim, T. T. (2006). Performance and mechanism of a hydrophobic-oleophilic kapok filter for oil/water separation. *Desalination*, *190,* 295–307.

Huang, X., Sheng, X., Guo, Y., Sun, Y., Fatehi, P. & Shi, H. (2022). Rice straw derived adsorbent for fast and efficient phosphate elimination from aqueous solution. *Industrial Crops and Products*, *184*, 115105. https://doi.org/10.1016/j.indcrop.2022.115105

Huang, Z., Chen, B., Zhang, J., Yang, C., Wang, J., Song, F. & Li, S. (2021). Absorption and speciation of arsenic by microalgae under arsenic-copper co-exposure. *Ecotoxicology and Environmental Safety*, *213*, 112024. https://doi.org/10.1016/j.ecoenv.2021.112024

Hughes, K. A. & Convey, P. (2020). Implications of the COVID-19 pandemic for Antarctica. *Antarctic Science*, *32*, 426–439.

Hughes, K. A. & Convey, P. (2010). The protection of Antarctic terrestrial ecosystems from inter- and intra-continental transfer of non-indigenous species by human activities: a review of current systems and practices. *Global Environmental Change, 20*, 96–112. https://doi.org/10.1016/j.gloenvcha.2009.09.005

Hughes, K. A., Pescott, O. L., Peyton, J., Adriaens, T., Cottier-Cook, E. J., Key, G., Rabitsch, W., Tricarico, E., Barnes, D. K., Baxter, N., Belchier, M., Blake, D., Convey, P., Dawson, W., Frohlich, D., Gardiner, L. M., Gonzalez-Moreno, P., James, R., Malumphy, C. & Roy, H. E. (2020). Invasive non-native species likely to threaten biodiversity and ecosystems in the Antarctic Peninsula region. *Global Change Biology, 26*, 2702–2716. https://doi.org/10.1111/gcb.14938

Hughes, K. A. & Pertierra, L. R. (2016). Evaluation of non-native species policy development and implementation within the Antarctic Treaty area. *Biological Conservation*, *200*, 149–159. https://doi.org/10.1016/j.biocon.2016.03.011

Hussain, F., Eom, H., Ali Toor, U., Lee, C. S. & Oh, S. -E. (2021). Rapid assessment of heavy metal-induced toxicity in water using micro-algal bioassay based on photosynthetic oxygen evolution. *Environmental Engineering Research, 26*, 200391. https://doi.org/10.4491/eer.2020.391

Husseien, M., Amer, A. A., El-Maghraby, A. & Hamedallah, N. (2009). A comprehensive characterization of corn stalk and study of carbonized corn stalk in dye and gas oil sorption. *Journal of Analytical and Applied Pyrolysis, 86*, 360–363. https://doi.org/10.1016/j.jaap.2009.08.003

Husseien, M., Amer, A. A., El-Maghraby, A. & Taha, N.A. (2008). Experimental Investigation of thermal modification influence on sorption qualities of barley straw. *Journal of Applied Science Research*, *4,* 652–657.

Ibrahim, S., Baharuddin, S. N. I. B., Ariffin, B., Hanafiah, M. A. K. M. & Kantasamy, N. (2018). Cogon grass for oil sorption: Characterization and sorption studies. *Key Engineering Materials, 775,* 359–364.

Ibrahim, S., Zahri, K. N. M, Convey, P., Khalil, K. A., Gomez-Fuentes, C., Zulkharnain, A., Alias, S. A., Gonzalez-Rocha, G. & Ahmad, S. A. (2020). Optimisation of biodegradation conditions for waste canola oil by cold-adapted *Rhodococcus* sp. AQ5-07 from Antarctica. *Electronic Journal of Biotechnology, 48*, 1–12.

Ibrahim, S., Ha-Ming, A. & Wang, S. (2009). Removal of emulsifed food and mineral oils from wastewater using surfactant modifed barley straw. *Bioresource Technology*, *100*, 5744–5749.

International Association of Antarctica Tour Operators (IAATO). (2020). *IAATO Antarctic Visitor Figures 2019–2020.* Retrieved from https://iaato.org/wp-content/uploads/2020/06/IAATO-on-Antarctic-visitor-figures-2019-20-pdf

Ishchi, T. & Sibi, G. (2019). Azo dye degradation by *Chlorella vulgaris*: Optimization and kinetics. *International Journal of Biological Chemistry, 14*, 1–7. https://doi.org/10.3923/ijbc.2020.1.7

Islam, M. S., Hosen, M. M. & Uddin, M. N. (2018). Phytodesalination of saline water using *Ipomoea aquatica*, *Alternanthera philoxeroides* and *Ludwigia adscendens*. *International Journal of Environmental Science and Technology, 16*, 965–972. https://doi.org/10.1007/s13762-018-1705-z

Ismaiel, M. M. S. & Said, A. A. (2018). Tolerance of *Pseudochlorella pringsheimii* to Cd and Pb stress: Role of antioxidants and biochemical contents in metal detoxification. *Ecotoxicology and Environmental Safety*, *164*, 704. https://doi.org/10.1016/j.ecoenv.2018.08.088

Ismail, Z., Makmor, M., Hashim, R., Shah, R. M., Hanifah, N. A. & Ahmad, S. (2012). The role of Malaysia under the Antarctic Treaty and madrid protocol. *2012 IEEE Colloquium on Humanities, Science and Engineering (CHUSER)*. Retrieved from https://doi.org/10.1109/chuser.2012.6504278

Isroi, C. A., Panji, T., Wibowo, N. A. & Syamsu, K. (2017). Bioplastic production from cellulose of oil palm empty fruit bunch. *IOP Conference Series Earth and Environmental Science*, *65*, 012011. https://doi.org/10.1088/1755-1315/65/1/012011

Jacob-Lopes, E., Scoparo, C. H., Lacerda, L. M. & Franco, T. T. (2009). Effect of light cycles (night/day) on CO_2 fixation and biomass production by microalgae in photobioreactors. *Chemical Engineering and Processing: Process Intensification,* *48*, 306–310. https://doi.org/10.1016/j.cep.2008.04.007

Jahi, N., Othaman, R., Mat Lazim, A. & Ramli, S. (2020). Empty fruit Bunch Cellulose Based Sorbent for oil sorption in palm oil mill effluent. *Sains Malaysiana, 49*, 2323–2333. https://doi.org/10.17576/jsm-2020-4909-29

Januari, A. D. & Agustina, H. (2022). Palm oil empty fruit bunches and the implementation of zero waste and renewable energy technologies. *IOP Conference Series: Earth and Environmental Science*, *1034*, 012004. https://doi.org/10.1088/1755-1315/1034/1/012004

Jan, A. T., Azam, M., Siddiqui, K., Ali, A., Choi, I. & Haq, Q. M. R. (2015). Heavy metals and human health: Mechanistic insight into toxicity and counter defense system of antioxidants. *International Journal of Molecular and Sciences*, *16,* 29592–29630.

Jesus, H. E., Peixoto, R. S. & Rosado, A. S. (2015). Bioremediation in Antarctic soils. *Journal of Petroleum and Environmental Biotechnology*, *6*, 1–11.

Johari, I. S., Yusof, N. A., Haron, M. J. & Mohd Nor, S. M. (2013). Preparation and characterization of polyethyl hydrazide grafted oil palm empty fruit bunch for removal of Ni(II) ion in aqueous environment. *Polymers*, 5, 1056–1067.

Johari, S. A., Sarkheil, M., Tayemeh, M. B. & Veisi, S. (2018). Influence of salinity on the toxicity of silver nanoparticles (AgNPs) and silver nitrate ($AgNO_3$) in halophilic microalgae, *Dunaliella salina*. *Chemosphere, 209*, 156–162.

John, D. M., Brook, A. J. & Whitton, B.A. (2002). *The freshwater algal flora of the British Isles: An identification guide to freshwater and terrestrial algae.* Cambridge University Press.

Joseph, C. G., Daud, W. M. A. W., Shane, Q. K. & Sanmugam, K. (2015). Parametric and adsorption kinetic studies of reactive black 5 removal from textile simulated wastewater using oil palm (*Elais guineensis*) empty fruit bunch. *Journal of Applied Science*, *15,* 1–9.

Jo, S. -W., Do, J. -M., Kang, N. S., Park, J. M., Lee, J. H., Kim, H. S., Hong, J. W. & Yoon, H. -S. (2020). Isolation, identification, and biochemical characteristics of a cold-tolerant chlorella vulgaris KNUA007 isolated from King George Island, Antarctica. *Journal of Marine Science and Engineering*, *8*, 935. https://doi.org/10.3390/jmse8110935

Jung, W. K., Koo, H. C., Kim, K. W., Shin, S., Kim, S. H. & Park, Y. H. (2008). Antibacterial activity and mechanism of action of the silver ion in *Staphylococcus aureus* and *Escherichia coli*. *Applied and Environmental Microbiology, 74*, 2171–2178. https://doi.org/10.1128/AEM.02001-07

Kabyl, A., Yang, M., Shah, D. & Ahmad, A. (2022). Bibliometric analysis of accidental oil spills in ice-infested waters. *International Journal of Environmental Research and Public Health, 19*, 15190. https://doi.org/10.3390/ijerph192215190

Kadiri, M. & Eboigbodin, A. (2012). Phytotoxicity assessment of water soluble fractions of refined petroleum products using microalgae. *Acta Botanica Hungarica, 54*, 301–311. https://doi.org/10.1556/abot.54.2012.3-4.9

Kafil, M., Berninger, F., Koutra, E. & Kornaros, M. (2022). Utilization of the microalga *Scenedesmus quadricauda* for hexavalent chromium bioremediation and biodiesel production. *Bioresource Technology*, *346*, 126665. https://doi.org/10.1016/j.biortech.2021.126665

Kakareka, S., Kukharchyk, T. & Kurman, P. (2019). Major and trace elements content in freshwater lakes of Vecherny Oasis, Enderby Land, East Antarctica. *Environmental Pollution*, *255*, 113126. https://doi.org/10.1016/j.envpol.2019.113126

Kalhor, A. X., Movafeghi, A., Mohammadi-Nassab, A. D., Abedi, E. & Bahrami, A. (2017). Potential of the green alga *Chlorella vulgaris* for biodegradation of crude oil hydrocarbons. *Marine Pollution Bulletin, 123*, 286–290. https://doi.org/10.1016/j.marpolbul.2017.08.045

Kanoun-Boulé, M., Vicentea, J. A. F., Nabaisa, C., Prasad, M. N. V. & Freitas, F. (2009). Ecophysiological tolerance of duckweeds exposed to copper. *Aquatic Toxicology, 91*, 1–9.

Kariminia, S., Ahmad, S. S., Hashim, R. & Ismail, Z. (2013). Environmental consequences of Antarctic tourism from a global perspective. *Procedia Social and Behavioral Sciences*, *105*, 781–791.

Kelly, A., Lannuzel, D., Rodemann, T., Meiners, K. M. & Auman, H. J. (2020). Microplastic contamination in east Antarctic sea ice. *Marine Pollution Bulletin*, *154*, 111130. https://doi.org/10.1016/j.marpolbul.2020.111130

Kennicutt, I. M. (1990). Oil spillage in Antarctica: Initial report of the national science foundation-sponsored quick response team on the grounding of the Bahia Paraiso. *Environmental and Science Technology*, *24*, 620–624.

Kennicutt, M. C., Sweet, S. T., Fraser, W. R., Culver, M. & Stockton, W. L. (1991). The fate of diesel fuel spilled by the Bahia Paraiso in Arthur Harbor, Antarctica. *International Oil Spill Conference Proceedings, 1991*, 493–500.

Kennicutt, M. C. & S. T. Sweet. (1992). Hydrocarbon contamination in the Antarctic Peninsula. III: The Bahia Paraiso-two years after the spill. *Marine Pollution Bulletin*, *25*, 303–306.

Keramea, P., Spanoudaki, K., Zodiatis, G., Gikas, G. & Sylaios, G. (2021). Oil spill modeling: a critical review on current trends, perspectives, and challenges. *Journal of Marine Science and Engineering*, *9*, 181. https://doi.org/10.3390/jmse9020181

Khalid, F. E., Ahmad, S. A., Zakaria, N. N., Shaharuddin, N. A., Sabri, S., Azmi, A. A., Khalil, K. A., Verasoundarapandian, G., Gomez-Fuentes, C. & Zulkharnain, A. (2021). Application of cogon grass (*Imperata cylindrica*) as biosorbent in diesel-filter system for oil spill removal. *Agronomy*, *11*, 2273. https://doi.org/10.3390/agronomy11112273

Khalid, F. E., Zakaria, N. N., Azmi, A. A., Shaharuddin, N. A.,Sabri, S., Khalil, K. A., Gomez-Fuentes, C., Zulkharnain, A., Lim, S. & Ahmad, S.A. (2023). Guinea grass (*Megathyrsus maximus*) fibres as sorbent in diesel bioremediation. *Sustainability*, *15*, 3904. https://doi.org/10.3390/su15053904

Khan, E., Virojnagud, W. & Ratpukdi, T. (2004). Use of biomass sorbents for oil removal from gas station runoff. *Chemosphere*, *57*, 681–689.

Khanna, S. & Gharpure, A.S. (2017). Petroleum carcinogenicity and aerodigestive tract: In context of developing nations. *Cureus*, *9*, e1202. https://doi.org/10.7759/cureus.1202

Kim, S. H., Sunwoo, I. Y., Hong, H. J., Awah, C. C., Jeong, G. T. & Kim, S. K. (2019). Lipid and unsaturated fatty acid productions from three microalgae using nitrate and light-emitting diodes with complementary LED wavelength in a two-phase culture system. *Bioprocess and Biosystems Engineering*, *42*, 1517–1526.

King, M. D., Elliott, J. E. & Williams, T. D. (2021). Effects of petroleum exposure on birds: A Review. *Science of The Total Environment, 755*, 142834. https://doi.org/10.1016/j.scitotenv.2020.142834

Koc, C., Anderson, G. A. & Kommareddy, A. (2012). Use of red and blue light-emitting diodes (LED) and fluorescent lamps to grow microalgae in a photobioreactor. *Israeli Journal of Aquaculture-Bamidgeh*, *65*, 1–10.

Koppel, D. J., Whitelaw, N., Adams, M. S., King, C. K. & Jolley, D. F. (2021). The microalga *Phaeocystis antarctica* is tolerant to salinity and metal mixture toxicity interactions. *Environmental Science: Processes and Impacts, 23*, 1362–1375.

Kozak, M. & Merkisz, J. (2022). Oxygenated diesel fuels and their effect on PM emissions. *Applied Sciences*, *12,* 7709. https://doi.org/10.3390/app12157709

Krausfeldt, L. E., Farmer, A. T., Castro Gonzalez, H. F., Zepernick, B. N., Campagna, S. R. & Wilhelm, S.W. (2019). Urea is both a carbon and nitrogen source for *Microcystis aeruginosa*: Tracking 13C incorporation at bloom pH conditions. *Frontiers in Microbiology*, *10*, 1064. https://doi.org/10.3389/fmicb.2019.01064

Kruczek, Z., Kruczek, Z., Kruczek, M. & Szromek, A. R. (2018). Possibilities of using the tourism area life cycle model to understand and provide sustainable solution for tourism development in the Antarctic region. *Sustainability*, *10*, 89. https://doi.org/10.3390/su10010089

Krzemińska, I., Pawlik-Skowrońska, B., Trzcińska, M. & Tys, J. (2013). Influence of photoperiods on the growth rate and biomass productivity of green microalgae. *Bioprocess and Biosystems Engineering, 37*, 735–741. https://doi.org/10.1007/s00449-013-1044-x

Kubín, S., Borns, E., Doucha, J. & Seiss, U. (1983). Light absorption and production rate of *Chlorella vulgaris* in light of different spectral composition. *Biochemistry and Physiology*, *178,* 193–205.

Kudaybergenov, K. K., Ongarbayev, E. K. & Mansurov, Z.A. (2010). Carbonaceous composites from agricultural wastes for adsorption of hydrocarbon contamination in water. *Eurasian Chemical Journal*, *12*, 151. https://doi.org/10.18321/ectj38

Kudaybergenov, K. K., Ongarbayev, E. K. & Mansurov, Z. A. (2012). Thermally treated rice husks for petroleum adsorption. *International Journal of Biological and Chemical Sciences*, *1*, 3–12.

Kumar, K. S., Dahms, H. U., Lee, J. S., Kim, H. C., Lee, W. C. & Shin, K. H. (2014). Algal photosynthetic responses to toxic metals and herbicides assessed by chlorophyll a fluorescence. *Ecotoxicology and Environmental Safety*, *104*, 51–71.

Kumar, K. S. & Shin, K. -H. (2017). Effect of copper on marine microalga

Tetraselmis suecica and its influence on intra- and extracellular iron and zinc content. *Korean Journal of Environment and Ecology, 50,* 16–28. https://doi.org/10.11614/KSL.2017.50.1.016

Kumar, V., Kumar, M. & Prasad, R. (2019). *Microbial Action on Hydrocarbons*. Berlin: Springer. Retrieved from https://doi.org/10.1007/978-981-13-1840-5

Kunihiro, N., Haruki, M., Takano, K., Morikawa, M. & Kanaya, S. (2005). Isolation and characterization of *Rhodococcus* sp. strains TMP2 and T12 that degrade 2,6,10,14-tetramethylpentadecane (pristane) at moderately low temperatures. *Journal of Biotechnology, 115*, 129–136. https://doi.org/10.1016/j.jbiotec.2004.07.018

Lam, M. K., Yusoff, M. I., Uemura, Y., Lim, J. W., Khoo, C. G., Lee, K. T. & Ong, H. C. (2017). Cultivation of *Chlorella vulgaris* using nutrients source from domestic wastewater for biodiesel production: Growth condition and kinetic studies. *Renewable Energy*, *103,* 197–207. https://doi.org/10.1016/j.renene.2016.11.032

Law, K. N., Daud, W. W. & Ghazali, A. (2007). Morphology and chemical nature of fiber strands of oil palm empty fruit bunch (OPEFB). *Bioresources*, *2*, 351–362.

Law, K. N. & Jiang, X. (2001). Comparative paper making properties of oil-palm empty fruit bunch. *Tappi Journal*, *84*, 1–13.

Leborans, G. F. & Novillo, A. (1996). Toxicity and bioaccumulation of cadmium in *Olishodiscus luteus* (*Raphidophyceae*). *Water Research*, *30*, 57–62.

Lee, G. L. Y., Ahmad, S. A., Yasid, N. A., Zulkharnain, A., Convey, P., Johari, W. L. W., Alias, S. A., Gonzalez-Rocha, G. & Shukor, M. Y. (2018). Biodegradation of phenol by adapted bacteria from Antarctic soils. *Polar Biology, 41*, 553–562.

Lee, J., Hong, S., An, S. -A. & Khim, J. S. (2023). Methodological advances and future directions of microalgal bioassays for evaluation of potential toxicity in environmental samples: A review. *Environment International*, *173*, 107869. https://doi.org/10.1016/j.envint.2023.107869

Lee, J. R., Waterman, M. J., Shaw, J. D., Bergstrom, D. M., Lynch, H. J., Wall, D. H. & Robinson, S. A. (2022a). Islands in the ice: Potential impacts of habitat transformation on Antarctic biodiversity. *Global Change Biology*, *28*, 5865–5880. https://doi.org/10.1111/gcb.16331

Lee, G. L. Y., Zakaria, N. N., Futamata, H., Suzuki, K., Zulkharnain, A., Shaharuddin, N. A., Convey, P., Zahri, K. N. M. & Ahmad, S. A. (2022b). Metabolic pathway of phenol degradation of a cold-adapted Antarctic bacteria, *Arthrobacter* sp.. *Catalysts*, *12*, 1422. https://doi.org/10.3390/catal12111422

Lee, X. J., Lee, L. Y., Hiew, B. Y., Gan, S., Thangalazhy-Gopakumar, S. & Ng, H. K. (2020). Valorisation of oil palm wastes into high yield and energy content biochars via slow pyrolysis: Multivariate process optimisation and combustion kinetic studies. *Materials Science for Energy Technologies*, *3*, 601–610. https://doi.org/10.1016/j.mset.2020.06.006

Lemoine, F., Entfellner, J. B. D., Wilkinson, E., Correia, D., Felipe, M. D., de Oliveira, T. & Gascuel., O. (2018). Renewing Felsentein's phylogenetic bootstrap in the era of big data. *Nature*, *556*, 452–456.

Leshem, Y., Seri, L. & Levine, A. (2007). Induction of phosphatidylinositol 3-kinase-mediated endocytosis by salt stress leads to in-tracellular production of reactive oxygen species and salt tolerance. *The Plant Journal, 51*, 185–197. https://doi.org/10.1111/j.1365-313x.2007.03134.x

Le Faucheur, S., Campbell, P. G. C., Fortin, C. & Slaveykova V. I. (2013). Interactions between mercury and phytoplankton: speciation, bioavailability and internal handling. *Environmental Toxicology and Chemistry, 33*, 1211–1224.

Liebe, B. & Fock, H. P. (1992). Growth and adaptation of the green alga *Chlamydomonas reinhardtii* on diesel exhaust particle extracts. *Journal of General Microbiology, 138*, 973–978. https://doi.org/10.1099/00221287-138-5-973

Liggett, D., McIntosh, A., Thompson, A., Gilbert, N. & Storey, B. (2011). From frozen continent to tourism hotspot? Five decades of Antarctic tourism development and management, and a glimpse into the future. *Tourism Management, 32*, 357–366.

Lim, K. T., Shukor, M. Y. & Wasoh, H. (2014). Physical, chemical, and biological methods for the removal of arsenic compounds. *Biomedical Research International*, *2014*, 1–9.

Lim, Y. K., Kim, J. Y., Kim, J. R. & Ha, J. H. (2017). Study of alternative fuel suitability for special Antarctic blend diesel. *Applied Chemical Engineering*, *28*, 460–466.

Lim, Z. S., Wong, R. R., Wong, C. -Y., Zulkharnain, A., Shaharuddin, N. A. & Ahmad, S. A. (2021). Bibliometric analysis of research on diesel pollution in Antarctica and a review on remediation techniques. *Applied Sciences*, *11*, 1123. https://doi.org/10.3390/app11031123

Lins, U., Barros, C. F., Da Cunha, M. & Miguens, F. C. (2002). Structure, morphology and composition of silicon biocomposites in the palm tree *Syagrus coronata* (Mart) Becc. *Protoplasma*, *220*, 89–96.

Lin, Q. & Lin, J. (2011). Effects of nitrogen source and concentration on biomass and oil production of a *Scenedesmus rubescens* like microalga. *Bioresource Technology*, *102*, 1615–1621.

Li, Y., Wang. B., Wu, N. & Lan, C. Q. (2008). Effects of nitrogen sources on cell growth and lipid production of *Neochloris oleoabundans*. *Applied Microbiology and Biotechnology, 81*, 629–636.

Li, Z., Parris, S. & Saski, C. A. (2020). A simple plant high-molecular-weight DNA extraction method suitable for single-molecule technologies. *Plant Methods, 16*. https://doi.org/10.1186/s13007-020-00579-4

Lu, M. -M., Gao, F., Li, C. & Yang, H. -L. (2021). Response of microalgae *Chlorella vulgaris* to Cr stress and continuous Cr removal in a membrane photobioreactor. *Chemosphere*, *262*, 128422. https://doi.org/10.1016/j.chemosphere.2020.128422

Lu, Y. C., Priyantha, N. & Lim, L. B. L. (2020). *Ipomoea aquatica* roots as environmentally friendly and green adsorbent for efficient removal of auramine O dye. *Surfaces and Interfaces*, *20,* 100543. https://doi.org/10.1016/j.surfin.2020.100543

Lv, B., Liu, Z., Chen, Y., Lan, S., Mao, J., Gu, Z., Wang, A., Yu, F., Zheng, X. & Vasquez, H. E. (2022). Effect of different colored LED lighting on the growth and pigment content of *Isochrysis zhanjiangensis* under laboratory conditions. *Journal of Marine Science and Engineering, 10*, 1752. https://doi.org/10.3390/jmse10111752

Macoustra, G. K., King, C. K., Wasley, J., Robinson, S. A. & Jolley, D. F. (2015). Impact of hydrocarbons from a diesel fuel on the germination and early growth of subantarctic plants. *Environmental Science Process Impacts*, *17,* 1238–1248.

Mahajan, S. & Tuteja, N. (2005). Cold, salinity and drought stresses: An overview. *Archives of Biochemistry and Biophysics, 444*, 139–158. https://doi.org/10.1016/j.abb.2005.10.018

Malla, M. A., Dubey, A., Yadav, S., Kumar, A., Hashem, A. & Abd Allah, E. F. (2018). Understanding and designing the strategies for the microbe-mediated remediation of environmental contaminants using omics approaches. *Frontier in Microbiology*, *9,* 1132. https://doi.org/10.3389/fmicb.2018.01132

Maltsev, Y., Maltseva, K., Kulikovskiy, M. & Maltseva, S. (2021). Influence of light conditions on microalgae growth and content of lipids, carotenoids, and fatty acid composition. *Biology, 10*, 1060. https://doi.org/10.3390/biology10101060

Markou, G. & Georgakakis, D. (2011). Cultivation of filamentous cyanobacteria (blue-green algae) in agro-industrial wastes and wastewaters: A review. *Applied Energy*, *88*, 3389–3401. https://doi.org/10.1016/j.apenergy.2010.12.042

Marnett, L. J. (2000). Oxyradicals and DNA damage. *Carcinogenesis, 21*, 361–370. https://doi.org/10.1093/carcin/21.3.361

Martins, C. C., Bícego, M. C., Taniguchi, S. & Montone, R. C. (2004). Aliphatic and polycyclic aromatic hydrocarbons in surface sediments in Admiralty Bay, King George Island, Antarctica. *Antarctic Science, 16*, 117–122. https://doi.org/10.1017/S0954102004001932

Martínez Álvarez, L. M., Ruberto, L. A. M., Lo Balbo, A. & Mac Cormack, W. P. (2017). Bioremediation of hydrocarbon-contaminated soils in cold regions: Development of a pre-optimized biostimulation biopile-scale field assay in Antarctica. *Science of The Total Environment*, *590–591*, 194–203. https://doi.org/10.1016/j.scitotenv.2017.02.204

Martinez-Varela, A., Casas, G., Berrojalbiz, N., Piña, B., Dachs, J. & Vila-Costa, M. (2022). Polycyclic aromatic hydrocarbon degradation in the sea-surface microlayer at coastal Antarctica. *Frontiers in Microbiology*, *13*, 907265. https://doi.org/10.3389/fmicb.2022.907265

Maynard, A. D. (2007). Nanotechnology: the next big thing, or much ado about nothing?. *The Annals of Occupational Hygiene, 51*, 1–12. https://doi.org/10.1093/annhyg/mel071

Ma, L. -L., Ye, H., Liu, L., Wu, M. -B. & Yao, J. (2023). Polypropylene membranes with high adsorption capacity and anti-adhesion properties achieved by hydrophobic interactions and hydrogen bonded self-assembly for uranium extraction from seawater. *Chemical Engineering Journal*, *451*, 138696. https://doi.org/10.1016/j.cej.2022.138696

Mba, O. I., Dumont, M. & Ngadi, M. (2015). Palm oil: Processing,characterization and utilization in the food industry – A review. *Food Bioscience*, *10*, 26–41.

Mocek-Płóciniak, A., Mencel, J., Zakrzewski, W. & Roszkowski, S. (2023). Phytoremediation as an effective remedy for removing trace elements from ecosystems. *Plants*, *12,* 1653. https://doi.org/10.3390/plants12081653

Mohammad, I. N., Ongkudon, C. M. & Misson, M. (2020). Physicochemical properties and lignin degradation of thermal-pretreated oil palm empty fruit bunch. *Energies*, *13*, 5966. https://doi.org/10.3390/en13225966

Mojiri, A., Ozaki, N., Kazeroon, R. A., Rezania, S., Baharlooeian, M., Vakili, M., Farraji, H., Ohashi, A., Kindaichi, T. & Zhou, J. L. (2022). Contaminant removal from wastewater by microalgal photobioreactors and modeling by artificial neural network. *Water, 14*, 4046. https://doi.org/10.3390/w14244046

Mong, G. R., Liew, C. S., Chong, W. W. F., Idris, R., Ng, J. H. & Chiong, M. C. (2022). Bioenergy generation potential of empty fruit bunch and waste tire through microwave pyrolysis: An energy balance analysis. *Chemical Engineering Transactions*, *97*, 283–288.

Montarroyos, D. C., de Alvarez, C. E. & Bragança, L. (2019). Assessing the environmental impacts of construction in Antarctica. *Environmental Impact Assessment Review*, *79*, 106302.

https://doi.org/10.1016/j.eiar.2019.106302

Morones, J. R., Elechiguerra, J. L., Camacho, A., Holt, K., Kouri, J. B., Ramírez, J. T. & Yacaman, M. J. (2005). The bacterial effect of silver nanoparticles. *Nanotechnology, 16*, 2346–2353. https://doi.org/10.1088/0957-4484/16/10/059

Mosaddegh, M. H., Jafarian, A., Ghasemi, A. & Mosaddegh, A. (2014). Phytoremediation of benzene, toluene, ethylbenzene and xylene contaminated air by *D. Deremensis* and *O. Microdasys* plants. *Journal of Environmental Health Science and Engineering, 12,* 39. https://doi.org/10.1186/2052-336x-12-39

Moscoso, F., Teijiz, I., Deive, F. J. & Sanromán, M. A. (2012). Efficient PAHs biodegradation by a bacterial consortium at flask and bioreactor scale. *Bioresource Technology*, *119*, 270–276. https://doi.org/10.1016/j.biortech.2012.05.095

Motoyama, A. B., Venancio, E. J., Brandão, G. O., Petrofeza-Silva, S., Pereira, I. S., Soares, C. M. & Felipe, M. S. (2000). Molecular identification of *Paracoccidioides brasiliensis* by PCR amplification of ribosomal DNA. *Journal of Clinical Microbiology*, *38*, 3106–3109.

Mueller, N., Westerby, M. & Nieuwenhuijsen, M. (2023). Health impact assessments of shipping and port-sourced air pollution on a global scale: A scoping literature review. *Environmental Research*, *216*, 114460. https://doi.org/10.1016/j.envres.2022.114460

Nafu, Y. R., Foba-Tendo, J., Njeugna, E., Oliver, G. & Omar Cooke, K. (2015). Extraction and characterization of fibres from the stalk and spikelets of empty fruit bunch. *Journal of Applied Chemistry*, *2015,* 750818. https://doi.org/10.1155/2015/750818

Naharudin, A. U., Shaarani, S. H., Rou, L. M., Hamidi, N. H., Ahmad, N. & Rasid, R. (2020). Kapok as an adsorbent for industrial wastewater. *Journal of Chemical Engineering and Industrial Biotechnology, 5*, 48–54. https://doi.org/10.15282/jceib.v5i2.3727

Nakazawa, K., Nagafuchi, O., Tsujimoto, M., Kanefuji, K. & Imura, S. (2021). SCAR Open Science Conference 2020. *Mercury contamination in soil caused by the human activities in Antarctica*. Retrieved from https://az659834.vo.msecnd.net/eventsairseasiaprod/productionleishman public/d703d685663b44dbb2ade267acac1ecc (accessed on 18 August 2021).

Naorbe, M. C. & Serrano, J. A. E. (2018). Effects of heavy metals on cell density, size, specific growth rate and chlorophyll a of *Tetraselmis tetrathele* under controlled laboratory conditions. *AACL Bioflux, 11*, 589–597.

Nasrin, A. B., Vijaya, S., Loh, S. K., Astimar, A. A. & Lim, W. S. (2017). Quality compliance and environmental impact assessments of commercial EFB pellet fuel in Malaysia. *Journal of Oil Palm Research*, *29*, 570–578.

NBCUniversal News Group. (2007). *Sunken Antarctic cruise ship left oil spill*. NBCNews.com. Retrieved from https://www.nbcnews.com/id/wbna22039975

Negroiu, M., Țurcanu, A. A., Matei, E., Râpă, M., Covaliu, C. I., Predescu, A. M., Pantilimon, C. M., Coman, G. & Predescu, C. (2021). Novel adsorbent based on banana peel waste for removal of heavy metal ions from synthetic solutions. *Materials, 14*, 3946. https://doi.org/10.3390/ma14143946

Nguyen, T. T., Nguyen, T. N., Bach, L. G., Nguyen, D. T. & Bui, T. P. (2019). Adsorptive removal of Pb (ii) using exfoliated graphite adsorbent:influence of experimental conditions and magnetic CoFe2O4 decoration. *IIUM Engineering Journal, 20*, 202–215. https://doi.org/10.31436/iiumej.v20i1.965

Nocito, E. S., Sullivan-Stack, J., Pike, E. P., Gjerde, K. M. & Brooks, C. M. (2022). Applying marine protected area frameworks to areas beyond national jurisdiction. *Sustainability*, *14*, 5971. https://doi.org/10.3390/su14105971

Nur Hazirah, R., Nurhaslina, C. R. & Ku Halim, K. H. (2014). Enhancement of biological approach and potential of *Lactobacillus delbrueckii* in decolorization of textile wastewater- A review. *Journal of Environmental Science, Toxicology and Food Technology*, *8*, 6–10.

Nwadiogbu, J. O., Ajiwe, V. I. E. & Okoye, P. A. C. (2016). Removal of crude oil from aqueous medium by sorption on hydrophobic corncobs: equilibrium and kinetic studies. *Journal of Taibah University for Science*, *10,* 56–60.

Obayori, O. S. & Salam, L. B. (2010). Degradation of polycyclic aromatic hydrocarbons: Role of plasmids. *Scientific Research and Essays*, *5,* 4093–4106.

Ojuderie, O. B. & Babalola, O. O. (2017). Microbial and plant-assisted bioremediation of heavy metal polluted environments: A review. *International Journal of Environmental Research Public Health*, *14*, 1504. https://doi.org/10.3390/ijerph14121504.

Onwuka, J. C., Agbaji, E. B., Ajibola, V. O. & Okibe, F. G. (2018). Treatment of crude oil-contaminated water with chemically modified natural fiber. *Applied Water Science*, *8,* 1–10.

Oremland, R. S. & Stolz, J. F. (2003). The ecology of arsenic. *Science, 300*, 939–944. https://doi.org/10.1126/science.1081903

Oren, A. (1999). Bioenergetic aspects of halophilism. *Microbiology and Molecular Biology Reviews, 63*, 334–348. https://doi.org/10.1128/mmbr.63.2.334-348.1999

Oukarroum, A., Bras, S., Rerreault, F. & Popovic, R. (2012). Inhibitory effects of silver nanoparticles in two green algae, *Chlorella vulgaris* and *Dunaliella tertiolecta*. *Ecotoxicology and Environmental Safety*, *78*, 80–85.

Ouyang, D., Lei, X. & Zheng, H. (2023). Recent advances in biomass-based materials for oil spill cleanup. *Nanomaterials, 13*, 620. https://doi.org/10.3390/nano13030620

Ouyang, H. L, Kong, X. Z., He, W., Qin, N., He, Q. S., Wang, Y., Wang, R. & Xu., F. L. (2012). Effects of five heavy metals at sub-lethal concentrations on the growth and photosynthesis of *Chlorella vulgaris*. *Chinese Science Bulletin, 57*, 3363–3370, https://doi.org/10.1007/s11434-012-5366-x

Oyetibo, G. O., Ilori, M. O., Obayori, O. S. & Amund, O. O. (2013). Biodegradation of petroleum hydrocarbons in the presence of nickel and cobalt. *Journal of basic Microbiology, 53*, 917–927. https://doi.org/10.1002/jobm.201200151

Page, G. W., Carter, H. R. & Ford, R. G. (1990). Numbers of seabirds killed or debilitated in the 1986 Apex Houston oil spill in central California. *Avian Biology*, *14*, 164–174.

Palmowski, T. (2020). Development of Antarctic tourism. *GeoJournal of Tourism and Geosites*, *33*, 1520–1526. https://doi.org/10.30892/gtg.334spl11-602

Pancha, I., Chokshi, K., George, B., Ghosh, T., Paliwal, C., Maurya, R. & Mishra, S. (2014). Nitrogen stress triggered biochemical and morphological changes in the microalgae *Scenedesmus* sp. CCNM 1077. *Bioresource Technology*, *156,* 146–154.

Parid, D. M., Abd Rahman, N. A., Baharuddin, A. S., Mohammed, M. A. P., Mat Johari, A. & Abdul Razak, S. Z. (2018). Synthesis and characterization of carboxymethyl cellulose from oil palm empty fruit bunch stalk fibres. *BioResources, 13*, 535–554. https://doi.org/10.15376/biores.13.1.535-554

Parlayıcı, Ş., Avcı, A. & Pehlivan, E. (2019). Electrospinning of polymeric nanofiber (nylon 6,6/graphene oxide) for removal of Cr (VI): Synthesis and adsorption studies. *Journal of Analytical Science and Technology, 10*, 13. https://doi.org/10.1186/s40543-019-0173-5

Patowary, K., Patowary, R., Kalita, M. C. & Deka, S. (2016). Development of an efficient bacterial consortium for the potential remediation of hydrocarbons from contaminated sites. *Frontier Microbiology*, *7,* 1092. https://doi.org/10.3389/fmicb.2016.01092

Piatt, J. F., Lensink, C. J., Butler, W. & Nysewander, D. R. (1990). Immediate impact of the ‘Exxon Valdez’ oil spill on marine birds. *Auk*, *107,* 387–397.

Plens, A. C., Monaro, D. L. G. & Coutinho, A. R. (2015). Adsorption of So_x and NO_x in activated viscose fibers. *Anais Da Academia Brasileira De Ciências, 87*, 1149–1160. https://doi.org/10.1590/0001-3765201520140346

Proelss, A. & Steenkamp, R. C. (2022). Liability annex to the protocol on environmental protection to the Antarctic Treaty. *Corporate Liability for Transboundary Environmental Harm*, 537–557. https://doi.org/10.1007/978-3-031-13264-3_12

Pulles, T., van der Gon, H. D., Appelman, W. & Verheul., M. (2012). Emission factors for heavy metals from diesel and petrol used in european vehicles. *Atmospheric Environment*, *61,* 641–651. https://doi.org/10.1016/j.atmosenv.2012.07.022

Qasim, M., Ansari, T. M. & Hussain, M. (2017). Combustion, performance, and emission evaluation of a diesel engine with biodiesel like fuel blends derived from a mixture of Pakistani waste canola and waste transformer oils. *Energies*, *10*, 1023. https://doi.org/10.3390/en10071023

Qian, H., Sun, Z., Sun, L., Jiang, Y., Wei, Y., Xie, J. & Fu, Z. (2013). Phosphorus availability changes chromium toxicity in the freshwater alga *Chlorella vulgaris*. *Chemosphere, 93*, 885–891.

Qiu, R., Gao, S., Lopez, P. A. & Ogden, K. L. (2017). Effects of pH on cell growth, lipid production and CO_2 addition of microalgae *Chlorella sorokiniana*. *Algal Research*, *28*, 192–199. https://doi.org/10.1016/j.algal.2017.11.004

Raeisossadati, M., Moheimani, N. R. & Parlevliet, D. (2019). Luminescent solar concentrator panels for increasing the efficiency of mass microalgal production. *Renewable and Sustainable Energy Reviews*, *101*, 47–59. https://doi.org/10.1016/j.rser.2018.10.029

Rai, P. K. (2019). Heavy metals/metalloids remediation from wastewater using free floating macrophytes of a natural wetland. *Environmental Technology and Innovation*, *15*, 100393. https://doi.org/10.1016/j.eti.2019.100393

Rai, P. K. & Rai, L.C. (1997). Interactive effect of UV-B and Cu on photosynthesis, uptake and metabolism of nutrients in a green alga *Chlorella vulgaris* under simulated ozone column. *The Journal of General and Applied Microbiology, 43,* 281–288.

Raqiba, H. & Sibi, G. (2019). Light emitting diode (LED) illumination for enhanced growth and cellular composition in three microalgae. *Advances Microbial Research*, *3,* 7. https://doi.org/10.24966/AMR-694X/100007.

Raymond, T., King, C. T., Raymond, B., Stark, J. S. & Snape, I. (2017). Oil pollution in Antarctica. In F, Mervin (Ed.). *Oil spill science and technology* (pp. 759–803). Gulf Professional Publishing.

Rayner, J. L., Snape, I., Walworth, J. L., Harvey, P. M. & Ferguson, S. H. (2007). Petroleum hydrocarbon contamination and remediation by microbioventing at sub-Antarctic Macquarie Island. *Cold Regions Science and Technology, 48*, 139–153. https://doi.org/10.1016/j.coldregions.2006.11.001

Raskin, I., Kumar, P. B. A. N., Dushenkov, S. & Salt, D. (1994). Bioconcentration of heavy metals by plants. *Current Opinion in Biotechnology*, *28*, 115–126.

Rebitanim, N. Z., Ghani. W. A., Mahmoud, D. K., Rebitanim, N. A. & Salleh, M. A. M. (2012). Adsorption capacity of raw empty fruit bunch biomass onto methylene blue dye in aqueous solution. *Journal of Purity, Utility Reaction and Environment, 1*, 45–60.

Rizzo, C., Malavenda, R., Gerçe, B., Papale, M., Syldatk, C., Hausmann, R., Bruni, V., Michaud, L., Lo Giudice, A. & Amalfitano, S. (2019). Effects of a simulated acute oil spillage on bacterial communities from Arctic and Antarctic marine sediments. *Microorganisms*, *7*, 632. https://doi.org/10.3390/microorganisms7120632

Rocha, G. S., Parrish, C. C. & Espindola, E. L. G. (2021). Effects of copper on photosynthetic and physiological parameters of a freshwater microalga (*Chlorophyceae*). *Algal Research Biomass Biofuels Bioproducts, 54*, 102223. https://doi.org/10.1016/j.algal.2021.102223

Rodriguez, N. D. & Katz, B. J. (2021). The effect of oil-based drilling mud (OBM) on the assessment of hydrocarbon charge potential. *Marine and Petroleum Geology*, *133*, 105312. https://doi.org/10.1016/j.marpetgeo.2021.105312

Romaniuk, K., Ciok, A., Decewicz, P., Uhrynowski, W., Budzik, K., Nieckarz, M., Pawlowska, J., Zdanowski, M. K., Bartosik, D. & Dziewit, L. (2018). Insight into heavy metal resistome of soil psychrotolerant bacteria originating from King George Island (Antarctica). *Polar Biology, 41,* 1319–1333.

Romero, M. J. A., Duca, D. & Toscano, G. (2022). Advancements in the conversion of lipid-rich biowastes and lignocellulosic residues into high-quality road and jet biofuels using nanomaterials as catalysts. *Processes, 10,* 187. https://doi.org/10.3390/pr10020187

Ropert-Coudert, Y., Chiaradia, A., Ainley, D., Barbosa, A., Boersma, P. D., Brasso, R., Dewar, M., Ellenberg, U., García-Borboroglu, P., Emmerson, L., Hickcox, R., Jenouvrier, S., Kato, A., McIntosh, R. R., Lewis, P., Ramírez, F., Ruoppolo, V., Ryan, P. G., Seddon, P. J. & Trathan, P. N. (2019). Happy feet in a hostile world? The future of penguins depends on proactive management of current and expected threats. *Frontiers in Marine Science*, *6,* 1–23. https://doi.org/10.3389/fmars.2019.00248

Rosen, B. P. (2002). Biochemistry of arsenic detoxication. *FEBS Letters, 529*, 86–92. https://doi.org/10.1016/S0014-5793(02)03186-1

Roslee, A. F., Gomez-Fuentes, C., Zakaria, N. N., Shaharuddin, N. A., Zulkharnain, A., Abdul Khalil, K., Convey, P. & Ahmad, S. A. (2021). Growth optimisation and kinetic profiling of diesel biodegradation by a cold-adapted microbial consortium isolated from Trinity Peninsula, Antarctica. *Biology, 10*, 493. https://doi.org/10.3390/biology10060493

Rosli, N. S., Harun, S., Jahim, J. M. & Othaman, R. (2017). Chemical and physical characterization of oil palm empty fruit bunch. *Malaysian Journal* *of Analytical Sciences*, *21*, 188–196.

Rosli, S. S., Lim, J. W., Uemura, Y., Lam, M. K., Isa, M. H., Oh, W. D. & Sakidin, H. (2018). pH optimization to promote attached growth of microalgae biomass onto polyurethane foam material. *AIP Conference Proceedings*, *2016*, 020123. https://doi.org/10.1063/1.5055525

Rota, E., Bergami, E., Corsi, I. & Bargagli, R. (2022). Macro- and microplastics in the Antarctic environment: Ongoing assessment and perspectives. *Environments*, *9*, 93. https://doi.org/10.3390/environments9070093

Ruberto, L. A., Vazquez, S., Lobalbo, A. & Cormack, W. M. (2005). Psychrotolerant hydrocarbon-degrading *Rhodococcus* strains isolated from polluted Antarctic soils. *Antarctic Science*, *17,* 47–56.

Ruhela, R., Singh, A. K., Tomar, B. S. & Hubli, R. C. (2014). Separation of palladium from high level liquid waste – a review. *RSC Advances, 4*, 24344. https://doi.org/10.1039/c4ra02024c

Ruoppolo, V., Woehler, E. J., Morgan, K. & Clumpner, C. J. (2012). Wildlife and oil in the Antarctic: A recipe for cold disaster. *Polar Record*, *49,* 97–109.

Ruppert, L., Lin, Z. Q., Dixon, R. P. & Johnson, K. A. (2013). Assessment of solid phase microfiber extraction fibers for the monitoring of volatile organoarsinicals emitted from a plant–soil system. *Journal of Hazardous Materials, 262*, 1230–1236. https://doi.org/10.1016/j.jhazmat.2012.06.046

Russo, C. A. M. & Selvatti, A. P. (2018). Bootstrap and rogue identification tests for phylogenetic analyses. *Molecular Biology and Evolution*, *35,* 2327–2333.

Ryzhik, I. V., Pugovkin, D. V., Salakhov, D. O., Klindukh, M. P. & Voskoboynikov, G. M. (2022). Physiological changes and rate of resistance of *Acrosiphonia arcta* (Dillwyn) gain upon exposure to diesel fuel. *Heliyon, 8*, e10177. https://doi.org/10.1016/j.heliyon.2022.e10177

Sabrina, D. T., Hanafi, M. M., Mahmud, T. M. M. & Azwady, A. A. N. (2009). Vermicomposting of oil palm empty fruit bunch and its potential in supplying of nutrients for crop growth. *Compost Science and Utilization, 17*, 61–67. https://doi.org/10.1080/1065657x.2009.10702401

Sacan, M. T., Oztay, F. & Bolkent, S. (2007). Exposure of *Dunaliella tertiolecta* to lead and aluminum: Toxicity and effects on ultrastructure. *Biological Trace Element Research*, *120,* 264–272.

Said, Z. & Alwi, H. (2014). SEM study of oil adsorption on the surface of *Khaya senegalensis* dried leaves. *APCBEE Procedia*, *9,* 108–112. https://doi.org/10.1016/j.apcbee.2014.01.020

Sati, M.,Verma, M. & Rai, J. P. N. (2016). Phycoremediation of heavy metals by *Chlorella pyrenoidosa* and *Spirogyra communis*. *International Journal of*

Current Microbiology and Applied Sciences, 5, 920–930. https://doi.org/10.20546/ijcmas.2016.510.099

Satoh A., Vudikaria, L. Q., Kurano, N. & Miyachi, S. (2005). Evaluation of the sensitivity of marine microalgal strains to the heavy metals, Cu, As, Sb, Pb and Cd. *Environment International*, *31,* 713–722.

Sattar, S., Hussain, R., Shah, S. M., Bibi, S., Ahmad, S. R., Shahzad, A., Zamir, A., Rauf, Z., Noshad, A. & Ahmad, L. (2022). Composition, impacts, and removal of liquid petroleum waste through bioremediation as an alternative clean-up technology: A review. *Heliyon, 8*, e11101. https://doi.org/10.1016/j.heliyon.2022.e11101

Satthong, S., Saego, K., Kitrungloadjanaporn, P., Nuttavut, N., Amornsamankul, S. & Triampo, W. (2019). Modeling the effects of light sources on the growth of algae. *Advances in Difference Equations, 2019*, 1–6. https://doi.org/10.1186/s13662-019-2112-6

Selvasembian, R., Gwenzi, W., Chaukura, N. & Mthembu, S. (2021). Recent advances in the polyurethane-based adsorbents for the decontamination of hazardous wastewater pollutants. *Journal of Hazardous Materials*, *417*, 125960. https://doi.org/10.1016/j.jhazmat.2021.125960

Semple, K. T., Cain, R. B. & Schmidt, S. (1999). Biodegradation of aromatic compounds by microalgae. *FEMS Microbiology Letters, 170*, 291–300. https://doi.org/10.1111/j.1574-6968.1999.tb13386.x

Shah, R. M., Husin, Z. H., Abdullah, N. C. & Rahman, H. A. (2015). Malaysia strategies in sustaining its Antarctic endeavours. *Procedia- Social and Behavioral Sciences*, *202*, 115–123.

Shaikh, S., Rashid, N., McKay, G. & Mackey, H. R. (2023). Photobioreactor design for polyhydroxyalkanoate production using anoxygenic photoheterotrophs: A review. *Fermentation, 9*, 778. https://doi.org/10.3390/fermentation9080778

Shanmugarajah, B., Chew, I. M., Mubarak, N. M., Choong, T. S. Y., Yoo, C. K. & Tan, K. W. (2019). Valorisation of palm oil agro-waste into cellulose biosorbents for highly effective textile effluent remediation. *Journal of Cleaner Production*, *210*, 697–709.

Sharma, I. (2021). *Bioremediation techniques for polluted environment: Concept, advantages, limitations, and prospects.* Retrieved from https://www.intechopen.com/chapters/70661

Sharmila, D., Suresh, A., Indhumathi, J. & Gowtham, K. (2018). Impact of various color filtered LED lights on microalgae growth, pigments and lipid production. *European Journal of Biotechnology and Bioscience, 6*, 1–7.

Shehata, S. M., Badawy, R. K. & Aboulsoud, Y. I. E. (2019). Phytoremediation of some heavy metals in contaminated soil. *Bulletin of the National*

Research Centre, *43,* 189. https://doi.org/10.1186/s42269-019-0214-7

Shijin, W., Wenli, Q. & Qiaoxia, L. (2023). Key pathways to achieve sustainable development goals in three polar regions. *Sustainability, 15*, 1735. https://doi.org/10.3390/su15021735

Shin, Y., Han, K. S., Arey, B. W. & Bonheyo, G. T. (2020). Cotton fiber-based sorbents for treating crude oil spills. *ACS Omega, 5*, 13894–13901. https://doi.org/10.1021/acsomega.0c01290

Shi, J., Yang, Z., Dai, H., Lu, X., Peng, L., Tan, X., Shi, L. & Fahim, R. (2018). Preparation and application of modified zeolites as adsorbents in wastewater treatment. *Water Science and Technology*, *3,* 621–635. https://doi.org/10.2166/wst.2018.249

Shi, Z., Xu, H., Wang, Z., Du, H. & Fu, X. (2021). Effects of co-exposure to copper and humic acids on microalga *Chlorella vulgaris*: growth inhibition, oxidative stress, and extracellular secretion. *Environmental Pollutants and Bioavailability,* *33*, 415–424, https://doi.org/10.1080/26395940.2021.1995504

Shu, C. H., Tsai, C. C., Liao, W. H., Chen, K. Y. & Huang, H. C. (2012). Effects of light quality on the accumulation of oil in a mixed culture of *Chlorella* sp. and *Saccharomyces cerevisiae*. *Journal of Chemical Technology and Biotechnology*, *87*, 601–607.

Sidik, S. M., Jalil, A. A., Triwahyono, S., Adam, S. H., Satar, M. A. H. & Hameed, B. H. (2012). Modified oil palm leaves adsorbent with enhanced hydrophobicity for crude oil removal. *Chemical Engineering Journal*, *203*, 9–18.

Silva, J. C., Echeveste, P. & Lombardi, A. T. (2018). Higher biomolecules yield in phytoplankton under copper exposure. *Ecotoxicology and Environmental Safety*, *161*, 57–63.

Simon, C. (2020). An evolving view of phylogenetic support. *Systematic Biology, 71*, 1–8.

Singh, A. K. (2022). Oil/water separation using waste-derived functional materials with special wetting behavior. *Resources, 11*, 83. https://doi.org/10.3390/resources11100083

Singh, R., Birru, R. & Sibi, G. (2017). Nutrient removal efficiencies of *chlorella vulgaris* from urban wastewater for reduced eutrophication. *Journal of Environmental Protection,* *08*, 1–11. https://doi.org/10.4236/jep.2017.81001

Singh, S., Eapen, S., Thorat, V., Kaushik, C. P., Raj, K. & D'Souza, S. F. (2008). Phytoremediation of 137cesium and 90strontium from solutions and low-level nuclear waste by *Vetiveria zizanoides*. *Ecotoxicology and Environmental Safety, 69,* 306–311.

Singh, V., Pandey, B. & Suthar, S. (2019). Phytotoxicity and degradation of antibiotic ofloxacin in duckweed (*Spirodela Polyrhiza*) system. *Ecotoxicology and Environmental Safety*, *179*, 88–95. https://doi.org/10.1016/j.ecoenv.2019.04.018

Siti Aisyah, M. S., Uemura, Y. & Yusup, S. (2014). The effect of alkaline addition in hydrothermal pretreatment of empty fruit bunches on enzymatic hydrolysis efficiencies. *Procedia Chemistry*, *9,* 151–157. https://doi.org/10.1016/j.proche.2014.05.018

Smith, D. A. & Simpson, R. D. (1995). Effects of the Nella Dan oil spill on the fauna of *Durvillaea antarctica* holdfasts. *Marine Ecology Progress Series, 121*, 73–89. https://doi.org/10.3354/meps121073

Snape, I., Riddle, M. J., Stark, J. S., Cole, C. M., King, C. K., Duquesne, S. & Gore, D. B. (2001). Management and remediation of contaminated sites at Casey Station, Antarctica. *Polar Record, 1*, 199–214.

Speight, J. G. (2015). Diesel fuel. In *Handbook of petroleum product analysis* (pp. 155–168). Hoboken, NJ, USA: John Wiley & Sons Inc.

Spellman, F. R. (2012). *Forest-based biomass energy: Concepts and applications*. CRC Press.

Sreekumar, P. A., Thomas, S. P., Saiter, J., Joseph, K., Unnikrishnan, G. & Thomas, S. (2009). Effect of fiber surface modification on the mechanical and water absorption characteristics of sisal/polyester composites fabricated by resin transfer molding. *Composites Part A: Applied Science and Manufacturing*, *40*, 1777–1784.

Srinivasan, A. & Viraraghavan, T. (2010). Oil removal from water using biomaterials. *Bioresource Technology*, *101,* 6594–6600.

Srivastava, M., Srivastava, A., Yadav, A. & Rawat, V. (2019). *Source and control of hydrocarbon pollution*. Retrieved from https://www.intechopen.com/chapters/67349

Stark, J. S., Mohammad, M., McMinn, A. & Ingels, J. (2017). The effects of hydrocarbons on meiofauna in marine sediments in Antarctica. *Journal of Experimental Marine Biology and Ecology*, *496,* 56–73. https://doi.org/10.1016/j.jembe.2017.07.009

Stewart, E. J. & Draper, D. (2008). The sinking of the MS explorer: Implications for cruise tourism in Arctic Canada. *Arctic, 61*, 224. https://doi.org/10.14430/arctic68

Subramaniam, K., Ahmad, S. A., Convey, P., Shaharuddin, N. A., Khalil, K. A., Tengku-Mazuki, T. A., Gomez-Fuentes, C. & Zulkharnain, A. (2021). Statistical assessment of phenol biodegradation by a metal-tolerant binary consortium of indigenous Antarctic bacteria. *Diversity, 13,* 643. https://doi.org/10.3390/d13120643

Subramaniam, K., Ahmad, S. A. & Shaharuddin, N. A. (2020). Mini review on phenol biodegradation in Antarctica using native microorganisms. *Asia Pacific Journal of Molecular Biology and Biotechnology*, *28*, 77–89.

Sudhir, P. & Murthy, S. D. S. (2004). Effects of salt stress on basic processes of photosynthesis. *Photosynthetica, 42*, 481–486. https://doi.org/10.1007/s11099-005-0001-6

Sukmawati, A. & Septiani, W. (2022). Potential of biduri fiber (*Calotropis gigantea*) as material for oil spill absorbent. *Journal of Materials Exploration and Findings, 1*, 19–24. https://doi.org/10.7454/jmef.v1i3.1019

Sukumaran, D. (2013). Phytoremediation of heavy metals from industrial effluent using constructed wetland technology. *Applied Ecology and Environmental Sciences*, *1*, 92–97.

Sundaram, T., Rajendran, S., Gnanasekaran, L., Rachmadona, N., Jiang, J. -J., Khoo, K. S. & Show, P. L. (2023). Bioengineering strategies of microalgae biomass for biofuel production: Recent advancement and insight. *Bioengineered, 14*, 1–25. https://doi.org/10.1080/21655979.2023.2252228

Sun, Y., Lu, Z., Xiao, K., Zeng, L., Wang, J. & Gabrielsen, G. W. (2020). Antarctic Adelie penguin feathers as bio-indicators of geographic and temporal variations in heavy metal concentrations in their habitats. *Ecotoxicology and Environmental Safety*, *206,* 111135. https://doi.org/10.1016/j.ecoenv.2020.111135

Suzuki, H., Hulatt, C. J., Wijffels, R. H. & Kiron, V. (2019). Growth and LC-PUFA production of the cold-adapted microalga *Koliella antarctica* in photobioreactors. *Journal of Applied Phycology*, *31*, 981–997.

Szopinska, M., Namiesnik, J. & Polkowska, Z. (2017). How important is research on pollution levels in Antarctica? Historical approach, difficulties and current trends. *Reviews of Environmental Contamination and Toxicology*, *239,* 79–156.

Taufik, S. H., Ahmad, S. A., Zakaria, N. N., Shaharuddin, N. A., Azmi, A. A., Khalid, F. E., Merican, F., Convey, P., Zulkharnain, A. & Abdul Khalil, K. (2021). Rice straw as a natural sorbent in a filter system as an approach to bioremediate diesel pollution. *Water*, *13,* 3317. https://doi.org/10.3390/w13233317

Tavana, M., Pahlavanzadeh, H. & Zarei, M. J. (2020). The novel usage of dead biomass of green algae of *Schizomeris leibleinii* for biosorption of copper(ii) from aqueous solutions: Equilibrium, kinetics and thermodynamics. *Journal of Environmental Chemical Engineering, 8*, 104272. https://doi.org/10.1016/j.jece.2020.104272

Taylor, C., Matzke, M., Kroll, A., Read, D. S., Svendsen. C. & Crossley, A. (2016). Toxic interactions of different silver forms with freshwater green algae and cyanobacteria and their effects on mechanistic endpoints and the production of extracellular polymeric substances. *Environmental Science: Nano*, *3,* 396–408.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. & Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Experientia supplementum, 101*, 133–164. https://doi.org/10.1007/978-3-7643-8340-4_6

Tejada-Tovar, C., Villabona-Ortíz, Á. & Gonzalez-Delgado, Á. D. (2021). Adsorption of azo-anionic dyes in a solution using modified coconut (*Cocos nucifera*) mesocarp: Kinetic and equilibrium study. *Water, 13*, 1382. https://doi.org/10.3390/w13101382

Tekere, M. (2019). *Microbial bioremediation and different bioreactors designs applied.* Retrieved from https://doi.org/10.5772/intechopen.83661

Tengku-Mazuki, T. A., Subramaniam, K., Zakaria, N. N., Convey, P., Khalil, K. A., Lee, G. L. Y., Zulkharnain, A., Shaharuddin, N. A. & Ahmad, S. A. (2020). Optimization of phenol degradation by Antarctic bacterium *Rhodococcus* sp.. *Antarctic Science*, *32,* 486–495.

Thompson, N. E., Emmanuel, G. C., Adagadzu, K. J. & Yusuf, N. B. (2010). Sorption studies of crude oil on acetylated rice husks. *Archives of Applied Science Research*, *2,* 142–151.

Tin, T., Hemmings, A. D. & Roura, R. (2008). Pressures on the wilderness values of the Antarctic continent. *International Journal of Wilderness*, *14,* 7–12.

Tin, T., Fleming, Z. L., Hughes, K. A., Ainley, D. G., Convey, P., Moreno, C. A., Pfeiffer, S., Scott, J. & Snape, I. (2009). Review impacts of local human activities on the Antarctic environment. *Journal of Antarctic Science, 21*, 3–33.

Tin, T. & Summerson, R. (2013). Growing human footprint, diminishing wilderness in Antarctica. *International Journal of Wilderness, 19*, 10–36.

Torres, E. M., Hess, D., McNeil, B. T., Guy, T. & Quinn, J. C. (2017). Impact of inorganic contaminants on microalgae productivity and bioremediation potential. *Ecotoxicology and Environmental Safety*, *139,* 367–376. https://doi.org/10.1016/j.ecoenv.2017.01.034

Trathan, P. N., Fielding, S., Warwick-Evans, V., Freer, J. & Perry, F. (2022). Seabird and seal responses to the physical environment and to spatio-temporal variation in the distribution and abundance of Antarctic krill at South Georgia, with implications for local fisheries management. *ICES Journal of Marine Science, 79*, 2373–2388. https://doi.org/10.1093/icesjms/fsac168

Tuohy, A., Bertler, N., Neff, P., Edwards, R., Emanuelsson, D., Beers, T. & Mayewski, P. (2015). Transport and deposition of heavy metals in the Ross Sea Region, Antarctica. *Journal of Geophysical Research: Atmospheres, 120*, 10996–11011. https://doi.org/10.1002/2015jd023293

Turner, J., Bindschadler, R., Convey, P., di Prisco, G., Fahrbach, E., Gutt, J. Hodgson, D., Mayewski, P. & Summerhayes, C. (eds.). (2009). *Antarctic Climate Change and the Environment*. Scientific Committee on Antarctic Research, Cambridge, xi + 526 pp.

Umor, N. A., Abdullah, S., Mohamad, A., Ismail, S. B., Ismail, S. I. & Misran, A. (2021). Energy potential of oil palm empty fruit bunch (EFB) fiber from subsequent cultivation of *Volvariella volvacea* (bull.) singer. *Sustainability, 13*, 13008. https://doi.org/10.3390/su132313008

Upadhyay, M. K., Yadav, P., Shukla, A. & Srivastava, S. (2018). Utilizing the potential of microorganisms for managing arsenic contamination: A feasible and sustainable approach. *Frontiers in Environmental Science, 6*, 1–11. https://doi.org/10.3389/fenvs.2018.00024

Van Epps, A. (2006). *Phytoremediation of Petroleum Hydrocarbons*. Washington, DC, USA: U.S. Environmental Protection Agency.

Vázquez, S., Monienc, P., Minetti, R. P., Jürgens, J., Curtosi, A., Primitz, J. V., Frickenhaus, S., Abele, D., MacCormack, W. P. & Helmke, E. (2017). Bacterial communities and chemical parameters in soils and coastal sediments in response to diesel spills at Carlini Station, Antarctica. *Science of the Total Environment*, *605–606*, 26–37.

Verasoundarapandian, G., Zakaria, N. N., Shaharuddin, N. A., Khalil, K. A., Puasa, N. A., Azmi, A. A., Gomez-Fuentes, C., Zulkharnain, A., Wong, C. -Y., Rahman, M. F. & Ahmad, S. A. (2021). Coco peat as agricultural waste sorbent for sustainable diesel-filter system. *Plants*, *10*, 2468. https://doi.org/10.3390/plants10112468

Vergara, E. (2007). *Ship's oil spill 'threatens penguins'*. The Sydney Morning Herald. Retrieved from https://www.smh.com.au/world/ships-oil-spill-threatens-penguins-20071201-1e55.html

Vidyadharani, G. & Dhandapani, R. (2013). Fourier transform infrared (FTIR) spectroscopy for the analysis of lipid from *Chlorella vulgaris*. *Elixir Applied Biology*, *61*, 16753–16756.

Vlaev, L., Petkov, P., Dimitrov, A. & Genieva, S. (2011) Cleanup of water polluted with crude oil or diesel fuel using rice husks ash. *Journal of the Taiwan Institute of Chemicals Engineers, 42,* 957–964.

Vicentin, B. M. & da Rocha, R. D. C. (2021). Expanded perlite: Potential for removing antibiotics from water. *Water SA, 47*, 417–422. https://doi.org/10.17159/wsa/2021.v47.i4.3817

Vincent, W. F. & James, M. R. (1996). Biodiversity in extreme aquatic environments: Lakes, ponds and streams of the Ross Sea sector, Antarctica. *Biodiversity and Conservation*, *5,* 1451–1471.

Wahi, R., Chuah, L. A., Choong, T. S. Y., Ngaini, Z. & Nourouzi, M. M. (2013).

Oil removal from aqueous state by natural fibrous sorbent: An overview. *Separation and Purification Technology*, *113*, 51–63.

Waller, C. L., Griffiths, H. J., Waluda, C. M., Thorpe, S. E., Loaiza, I., Moreno, B., Pacherres, C. O. & Hughes, K. A. (2017). Microplastics in the Antarctic marine system: An emerging area of research. *Science of Total Environment*, *598*, 220–227.

Wang, J. T., Zheng, Y. A. & Wang, A. Q. (2012). Effect of kapok fibre treated with various solvents on oil absorbency. *Industrial Crops and Production*, *40,* 178–184.

Wang, L., Camus, A. C., Dong, W., Thornton, C. & Willett, K. L. (2010). Expression of CYP1C1 and CYP1A in *Fundulus heteroclitus* during PAH-induced carcinogenesis. *Aquatic Toxicology*, *99*, 439–447.

Wang, Y., Wang, S., Xu, P., Liu, C., Liu, M., Wang, Y., Wang, C., Zhang, C. & Ge, Y. (2015). Review of arsenic speciation, toxicity and metabolism in microalgae. *Reviews in Environmental Science and Bio/Technology, 14*, 427–451. https://doi.org/10.1007/s11157-015-9371-9

Wani, Z. A., Ahmad, Z., Asgher, M., Bhat, J. A., Sharma, M., Kumar, A., Sharma, V., Kumar, A., Pant, S., Lukatkin, A. S. & Anjum, N. A. (2023). Phytoremediation of potentially toxic elements: Role, status and concerns. *Plants*, *12,* 429. https://doi.org/10.3390/plants12030429

Wilde, K. L., Stauber, J. L., Markich, S. J., Franklin, N. M. & Brown, P. L. (2006). The effect of pH on the uptake and toxicity of copper and zinc in a tropical freshwater alga (*Chlorella* sp.). *Archives of Environmental Contamination and Toxicology*, *51*, 174–185.

Wilhelm, C., Krámer, P. & Wild, A. (1985). Effect of different light qualities on the ultrastructure, thylakoid membrane composition and assimilation metabolism of *Chlorella fusca*. *Physiologia Plantarum*, *64,* 359–364.

Wilkness, P. (1990). Fuel spill clean up in the Antarctic. *Antarctic Journal of the United States*, *25,* 3–8.

Wilson, W., Zhang, Q. & Rickaby, R. E. (2019). Susceptibility of algae to Cr toxicity reveals contrasting metal management strategies. *Limnology and Oceanography, 64*, 2271–2282.

Wong, R. R., Lim, Z. S., Shaharuddin, N. A., Zulkharnain, A., Gomez-Fuentes, C. & Ahmad, S. A. (2021). Diesel in Antarctica and a bibliometric study on its indigenous microorganisms as remediation agent. *International Journal of Environmental Research and Public Health*, *18,* 1512. https://doi.org/10.3390/ijerph18041512

Wong, S. L., Nakamoto, L. & Wainwright, J. F. (1994). Identification of toxic metals in affected algal cells in assays of wastewaters. *Journal of Applied Phycology, 6,* 405–414.

Xiang, L. Y., Mohammed, M. A. P. & Baharuddin, A. S. (2016). Characterisation of microcrystalline cellulose from oil palm fibres for food applications. *Carbohydrate Polymers, 148*, 11–20.

Xiao, X., Bian, J., Li, M. F., Xu, H., Xiao, B. & Sun, R. C. (2014). Enhanced enzymatic hydrolysis of bamboo (*Dendrocalamus gigantus munro*) culm by hydrothermal pretreatment. *Bioresource Technology*, *159*, 41–47.

Xu, Q., Chu, Z., Gao, Y., Mei, Y., Yang, Z., Huang, Y., Yang, L., Xie, Z. & Sun, L. (2020). Levels, sources and influence mechanism of heavy metal contamination in topsoil in Mirror Peninsula, East Antarctica. *Environmental Pollution, 257*, 113552. https://doi.org/10.1016/j.envpol.2019.113552

Xu, Y., Shen, H. & Xu, G. (2019). Evaluation of oil sorption kinetics behavior and wetting characteristic of cattail fiber. *Cellulose*, *27,* 1531–1541.

Yadavalli, R., Rao, S. R. & Rao, C. S. (2012). Lipid accumulation studies in *Chlorella pyrenoidosa* using customized photobioreactor- effect of nitrogen source, light intensity and mode of operation. *International Journal of Engineering Research and Applications, 2*, 2446–2453.

Yadav, A. N., Suyal, D. C., Kour, D., Rajput, V. D., Rastegari, A. A. & Singh, J. (2022). Bioremediation and waste management for environmental sustainability. *Journal of Applied Biology and Biotechnology, 10*, 1–5.

Yang, L., Ziru, W., Yang, L., Li, X., Zhang, Y. & Lu, C. (2017). Coco peat powder as a source of magnetic sorbent for selective oil-water separation. *Industrial Crops Products, 101*, 1–10.

Yang, Y. & Weathers, P. (2015). Red light and carbon dioxide differentially affect growth, lipid production, and quality in the microalga, *Ettlia oleoabundans*. *Applied Microbiology and Biotechnology, 99*, 489–499.

Yang, Y. P., Zhang, H. M., Yuan, H. Y., Duan, G. L., Jin, D. C., Zhao, F. J. & Zhu, Y. G. (2018). Microbe mediated arsenic release from iron minerals and arsenic methylation in rhizosphere controls arsenic fate in soil-rice system after straw incorporation. *Environmental Pollution*, *236,* 598–608. https://doi.org/10.1016/j.envpol.2018.01.099

Yan, C., Zhang, L., Luo, X. & Zheng, Z. (2013a). Effects of various LED light wavelengths and intensities on the performance of purifying synthetic domestic sewage by microalgae at different influent C/N ratios. *Ecological Engineering*, *51*, 24–32.

Yan, J., Fang, C., Wang, F. -M. & Xu, B. (2013b). Compressibility of the kapok fibrous assembly. *Textile Research Journal, 83*, 1020–1029. https://doi.org/10.1177/0040517512460297

Yao, Y., Meng, X. Z., Wu, C. C., Bao, L. J., Wang, F., Wu, F. C. & Zeng, E. Y. (2016). Tracking human footprints in Antarctica through passive sampling of polycyclic aromatic hyrdrocarbons in inland lakes. *Environmental*

Pollution, *213*, 412–419.

Yeo, B. S., Chu, W. L., Wong, C. -Y., Kok, Y. -Y., Phang, S. M., Tan, B. K. & Mustafa, E. M. (2018). Combined effects of glufosinate ammonium and temperature on the growth, photosynthetic pigment content and oxidative stress response of *Chlorella* sp. and *Pseudo-kirchneriella subcapitata*. *Journal of Applied Phycology, 30*, 3043–3055. https://doi.org/10.1007/s10811-018-1613-0

Yi, R., Deng, L., Mu, J., Li, C., Tan, F. & Zhao, X. (2021). The impact of Antarctic ice microalgae polysaccharides on D-galactose-induced oxidative damage in mice. *Frontiers in Nutrition, 8,* 1–16.

Yunos, N. S. H. M., Baharuddin, A. S., Yunos, K. F. M., Hafid, H. S., Busu, Z., Mokhtar, M. N., Sulaiman, A. & Md. Som, A. (2015). The physicochemical characteristics of residual oil and fibers from oil palm empty fruit bunches. *BioResources, 10*, 14–29.

Yusoff, F. M., Nagao, N., Imaizumi, Y. & Toda, T. (2019). Bioreactor for microalgal cultivation systems: Strategy and development. In Rastegari, A., Yadav, A., Gupta, A. (Ed.). *Prospects of Renewable Bioprocessing in Future Energy Systems*. (pp.117–159). Switzerland: Springer, Cham.

Yusoff, S. (2006). Renewable energy from palm oil–innovation on effective utilization of waste. *Journal of Cleaner Production*, *14,* 87–93.

Zahri, K. N. M., Khalil, K. A., Gomez-Fuentes, C., Zulkharnain, A., Sabri, S., Convey, P., Lim, S. & Ahmad, S. A. (2021a). Mathematical modelling of canola oil biodegradation and optimisation of biosurfactant production by an Antarctic bacterial consortium using response surface methodology. *Foods*, *10,* 2801. https://doi.org/10.3390/foods10112801

Zahri, K. N., Gomez-Fuentes, C., Sabri, S., Zulkharnain, A., Khalil, K. A., Lim, S. & Ahmad, S. A. (2021b). Evaluation of heavy metal tolerance level of the Antarctic bacterial community in biodegradation of waste canola oil. *Sustainability, 13*, 10749. https://doi.org/10.3390/su131910749

Zahri, K. N. M., Zulkharnain, A., Gomez-Fuentes, C., Sabri, S. & Ahmad, S. A. (2020). Study of growth kinetics of Antarctic bacterial community for biodegradation of waste canola oil. *Desalination Water Treat*, *213,* 128–138.

Zakaria, N. N., Ahmad, S. A., Lee, G. L. Y., Yasid, N. A., Manogaran, M., Subramaniam, K., Mazuki, T. A. T., Nawawi, N. M. & Shukor, M. Y. (2019a). Biodegradation of phenol by Antarctic bacterium *Rhodococcus baikonurensis* strain AQ5-001 in the presence of heavy metals. *Malaysian Journal of Biochemistry and Molecular Biology*, *21,* 29–36.

Zakaria, N. N., Gomez-Fuentes, C., Abdul Khalil, K., Convey, P., Roslee, A. F. A., Zulkharnain, A., Sabri, S., Shaharuddin, N. A., Cardenas, L. & Ahmad, S. A. (2021). Statistical optimisation of diesel biodegradation at low temperatures by an Antarctic marine bacterial consortium isolated from non-contaminated seawater. *Microorganisms, 9,* 1213. https://doi.org/10.3390/microorganisms9061213

Zakaria, N. N., Man, Z., Zulkharnain, A. & Ahmad, S. A. (2019b). Psychrotolerant biosurfactant-producing bacteria for hydrocarbon degradation: A mini review. *Malaysian Journal of Biochemistry and Molecular Biology*, *22,* 52–59.

Zakaria, N. N., Roslee, A. F. A., Gomez-Fuentes, C., Zulkharnain, A., Abdulrasheed, M., Sabri, S., Ramirez-Moreno, N. & Ahmad, S. A. (2020). Kinetic studies of marine psychrotolerant microorganisms capable of degrading diesel in the presence of heavy metals. *Revista Mexicana de Ingenieria Quimica*, *19,* 1375–1388.

Zakaria, N. N. (2022). *A filter-incubation system approach for diesel removal by Antarctic marine bacteria obtained from non-contaminated seawater.* (Unpublished doctoral dissertation). Universiti Putra Malaysia.

Zamani, S. A., Yunus, R., Samsuri, A. W., Salleh, M. A. & Asady, B. (2017). Removal of zinc from aqueous solution by optimized oil palm empty fruit bunches biochar as low cost adsorbent. *Bioinorganic Chemistry and Applications*, *2017,* 1–9. https://doi.org/10.1155/2017/7914714

Zamparas, M., Tzivras, D., Dracopoulos, V. & Ioannides, T. (2020). Application of sorbents for oil spill cleanup focusing on natural-based modified materials: A review. *Molecules, 25*, 4522. https://doi.org/10.3390/molecules25194522

Zamree, N. D., Puasa, N. A., Lim, Z. S., Wong, C. -Y., Shaharuddin, N. A., Zakaria, N. N., Merican, F., Convey, P., Ahmad, S., Shaari, H., Azmi, A. A., Ahmad, S. A. & Zulkharnain, A. (2023). The utilisation of Antarctic microalgae isolated from Paradise Bay (Antarctic Peninsula) in the bioremediation of diesel. *Plants*, *12*, 2536. https://doi.org/10.3390/plants12132536

Zarrinmehr, M. J., Farhadian, O., Heyrati, F. P., Keramat, J., Koutra, E., Kornaros, M. & Daneshvar, E. (2019). Effect of nitrogen concentration on the growth rate and biochemical composition of the microalga, *Isochrysis galbana*. *Egyptian Journal of Aquatic Research*, *46*, 1687–4285. https://doi.org/10.1016/j.ejar.2019.11.003.

Zelano, I., Malandrino, M., Giacomino, A., Buoso, S., Conca, E., Sivry Y., Benedetti, M. & Abollino, O. (2017). Element variability in lacustrine systems of Terra Nova Bay (Antarctica) and concentration evolution in surface waters. *Chemosphere, 180*, 343–355. https://doi.org/10.1016/j.chemosphere.2017.04.005

Zhang, P., You, Z., Chen, T., Zhao, L., Zhu, J., Shi, W., Meng, Q. & Sun, Y. (2022). Study on the breeding and characterization of high-efficiency oil-degrading bacteria by mutagenesis. *Water*, *14,* 2544.

https://doi.org/10.3390/w14162544

Zhang, Y., Rodionov, D. A., Gelfand, M. S. & Gladyshev, V. N. (2009). Comparative genomic analyses of nickel, cobalt and vitamin B12 utilization. *BMC Genomics*, *10,* 78. https://doi.org/10.1186/1471-2164-10-78

Zhao, Y., Wang, J., Zhang, H., Yan, C. & Zhang, Y. (2013). Effects of various LED light wavelengths and intensities on microalgae-based simultaneous biogas upgrading and digestate nutrient reduction process. *Bioresource Technology*, *136,* 461–468.

Zhou, G. -J., Peng, F. -Q., Zhang, L. J. & Ying, G. G. (2012). Biosorption of zinc and copper from aqueous solutions by two freshwater green microalgae *Chlorella pyrenoidosa* and *Scenedesmus obliquus*. *Environmental Science and Pollution Research, 19*, 2918–2929.

Zhou, M., Ghnaya, T., Dailly, H., Cui, G., Vanpee, B., Han, R. & Lutts, S. (2019). The cytokinin trans-zeatine riboside increased resistance to heavy metals in the halophyte plant species *Kosteletzkya pentacarpos* in the absence but not in the presence of NaCl. *Chemosphere*, *233,* 954–965. https://doi.org/10.1016/j.chemosphere.2019.06.023

Zhu, L., Perwuelz, A., Lewandowski, M. & Campagne, C. (2008). Static and dynamic aspects of liquid capillary flow in thermally bonded polyester nonwoven fabrics. *Journal of Adhesion Science and Technology*, *22,* 745–760.

Zhu, S., Huang, W., Xu, J., Wang, Z., Xu, J. & Yuan, Z. (2014). Metabolic changes of starch and lipid triggered by nitrogen starvation in the microalga *Chlorella zofingiensis*. *Bioresource Technology*, *152,* 292–298. https://doi.org/10.1016/j.biortech.2013.10.092.

Zou, H., Huang, J. C., Zhou, C., He, S. & Zhou, W. (2020). Mutual effects of selenium and chromium on their removal by *Chlorella vulgaris* and associated toxicity. *Science of The Total Environment*, *724,* 138219. https://doi.org/10.1016/j.scitotenv.2020.138219

Zverina, O., Coufalik, P., Bartak, M., Petrov, M. & Komarek, J. (2018). The contents and distributions of cadmium, mercury and lead in *Usnea Antarctica* lichens from Solorina Valley, James Ross Island (Antarctica). *Environmental Monitoring Assessment, 190*, 13. https://doi.org/10.1007/s10661-017-6397-1

.