JURNAL ILMU LINGKUNGAN

ISSN 1829-8907

Vol 21, No 1 (2023): January 2023

Table of Contents

Research Article

Pengaruh Emisi Kendaraan Terhadap Kandungan Logam Timbal (Pb) Tanah dan Bulir Padi pada Lahan Sawah di Kecamatan Tebas Kabupaten Sambas
Rinto Manurung, Shenny Oktoriana, Anita Suharyani
PDF
1-7

| Language: ID | DOI: 10.14710/jil.21.1.1-7

Received: 9 Sep 2021; Revised: 20 Sep 2022; Accepted: 3 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Kontaminan Logam Berat (Pb, Cd, dan Cu) pada Tanah dari Pemupukan Berbasis Jerami Padi
Yulis Hindarwati, Tri Retnaningsih Soeprobowati, Munifatul Izzati, Hadiyanto Hadiyanto
PDF
8-14

| Language: ID | DOI: 10.14710/jil.21.1.8-14

Received: 3 Mar 2022; Revised: 22 Jul 2022; Accepted: 3 Oct 2022; Available online: 3 Jan 2022; Published: 9 Jan 2023.

Identifikasi Senyawa Benzena pada Kabin Mobil
Mumammad Pasha Ariobimo, Adyati Pradini Yudison, Moh. Irsyad
PDF
15-21

| Language: ID | DOI: 10.14710/jil.21.1.15-21

Received: 21 Mar 2022; Revised: 16 Aug 2022; Accepted: 3 Oct 2022; Available online: 3 Jan 2022; Published: 9 Jan 2023.

Pemanfaatan Limbah Lumpur PDAM Gunung Poteng Kota Singkawang Sebagai Bahan Pengganti Tanah Liat Pada Pembuatan Batu Bata
Isna Apriani Budjang, Hendri Sutrisno, Margareta Dini
PDF
22-28

| Language: ID | DOI: 10.14710/jil.21.1.22-28

Received: 12 Apr 2022; Revised: 10 Oct 2022; Accepted: 28 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Penggunaan Karbon Aktif dari Biji Kelor dan Berbagai Biomassa Lainnya dalam Mengatasi Pencemaran Air : Analisis Review
Jacky Anggara Nenohai, Zelen S. Minata, Burhanuddin Ronggopuro, Eli Hendrik Sanjaya, Yudhi Utomo
PDF
29-35

| Language: ID | DOI: 10.14710/jil.21.1.29-35

Received: 10 May 2022; Revised: 6 Aug 2022; Accepted: 3 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Dampak Kegiatan Integrasi Pegaraman Terhadap Kegiatan Pegaraman di Kabupaten Pamekasan

PDF

36-42

Rachmad Dian Kuncoro, Soemarno Soemarno, Andi Kurniawan

| Language: ID | DOI: 10.14710/jil.21.1.36-42

Received: 13 Apr 2022; Revised: 3 Oct 2022; Accepted: 6 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Kerentanan Nafkah Rumahtangga Nelayan dalam Tekanan Variabilitas Iklim: Studi Kasus Desa Dendun, Kabupaten Bintan, Kepulauan Riau

PDF

43-56

Winda Gustika, Arya Hadi Dharmawan, Melani Abdulkadir-sunito Abdulkadir-sunito

| Language: ID | DOI: 10.14710/jil.21.1.43-56

Received: 5 Jun 2022; Revised: 4 Sep 2022; Accepted: 3 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Pemisahan Biosludge pada Proses Integrated Fixed Film Activated Sludge dengan Biofilter sebagai Pengganti Sedimentasi

PDF

57-67

Ridwan Subrata, Sri Sumiyati, Sudarno Utomo

| Language: ID | DOI: 10.14710/jil.21.1.57-67

Received: 10 Jun 2022; Revised: 17 Sep 2022; Accepted: 22 Sep 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Analisis Daur Hidup Produksi Beton Fly Ash sebagai Upaya Mengurangi Dampak Emisi CO2

PDF

68-75

Ahzab Muttaqien, Dwi Nowo Martono, Ninin Gusdini

| Language: INDONESIA | DOI: 10.14710/jil.21.1.68-75

Received: 29 Jun 2022; Revised: 6 Oct 2022; Accepted: 28 Oct 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Karakteristik Sampah Sungai dan Perilaku Masyarakat Pesisir Terhadap Sampah Plastik: Studi Kasus di Sungai Pengarengan, Kabupaten Cirebon

PDF

76-85

Ayu Dwi Astuti, Evi Frimawaty, Dwiyitno Dwiyitno

| Language: ID | DOI: 10.14710/jil.21.1.76-85

Received: 7 Jun 2022; Revised: 8 Dec 2022; Accepted: 20 Dec 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Potensi Kontaminasi Mikroplastik pada Kerang Konsumsi di Pulau Bangka

PDF

86-93

Fika Dewi Pratiwi, Hartoyo Notonegoro, Dwi Rizka Zulkia, Sulastri Arsyad

| Language: IN | DOI: 10.14710/jil.21.1.86-93

Received: 14 Jul 2022; Revised: 21 Oct 2022; Accepted: 12 Dec 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Model Pengelolaan Sampah Organik dengan Biokonversi Larva Black Soldier Fly Berbasis Pemberdayaan Masyarakat.

PDF

94-105

Afifah Zahra, Herdis Herdiansyah, Suyud Warno Utomo

| Language: ID | DOI: 10.14710/jil.21.1.94-105

Received: 31 May 2022; Revised: 21 Dec 2022; Accepted: 22 Dec 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Pengalaman Kultural Mahasiswa Asal Pesisir Sumenep Madura Mengenai Perilaku Membuang Sampah ke Pantai

PDF

106-114

Habibi Habibi

| Language: ID | DOI: 10.14710/jil.21.1.106-114

Received: 15 Feb 2022; Revised: 21 Dec 2022; Accepted: 22 Dec 2022; Available online: 3 Jan 2023; Published: 9 Jan 2023.

Persepsi Masyarakat Terhadap Lingkungan Pemeliharaan Ternak Babi yang Diumbar di Kampung Gaya Baru dan Sekitar Pasar Wosi, Manokwari

PDF

115-124

Freddy Pattiselanno, Budi Santoso, Odiktur Marani

| Language: ID | DOI: 10.14710/jil.21.1.%p

Received: 12 Mar 2022; Revised: 27 Dec 2022; Accepted: 2 Jan 2023; Available online: 7 Jan 2023; Published: 9 Jan 2023.

Social and Environmental Risks Integration into Underwriting of Non-Life Insurance: A Review of Sustainable Finance in Indonesia

Maria Agnes, Raldi Hendro Koestoer, Ahyahudin Sodri

PDF

125-131

| Language: EN | DOI: 10.14710/jil.21.1.125-131

Received: 28 Mar 2022; Revised: 25 Dec 2022; Accepted: 25 Dec 2022; Available online: 7 Jan 2023; Published: 9 Jan 2023.

Pencegahan dan Penanggulangan Kebakaran Lahan Gambut dan Hutan

Yulia Qamariyanti, Rachmadi Usman, Diana Rahmawati

PDF

132-142

| Language: EN | DOI: 10.14710/jil.21.1.132-142

Received: 12 Mar 2022; Revised: 3 Jan 2023; Accepted: 5 Jan 2023; Available online: 25 Jan 2023; Published: 25 Jan 2023.

Jasa Lanskap pada Pekarangan Transmigran Bali di Wilayah Lampung Timur

Muhammad Saddam Ali, Hadi Susilo Arifin, Nurhayati Nurhayati, Made Astawan

PDF

143-149

| Language: ID | DOI: 10.14710/jil.21.1.143-149

Received: 20 Mar 2022; Revised: 4 Jan 2023; Accepted: 7 Jan 2023; Available online: 25 Jan 2023; Published: 25 Jan 2023.

Evaluasi Status Keberlanjutan Budidaya Rumput Laut Di Kecamatan Pasikolaga Kabupaten Muna (Pendekatan Rapfish- Multi Dimensional Scaling)

La Ode Muhammad Iksan Yusuf, Ahyar Ismail, Nuva Nuva

PDF

150-158

| Language: INDONESIA | DOI: 10.14710/jil.21.1.150-158

Received: 6 Apr 2022; Revised: 5 Jan 2023; Accepted: 7 Jan 2023; Available online: 25 Jan 2023; Published: 25 Jan 2023.

Interaction of Organisms in Abandoned Tin Mining Pits: Perspective of Life in Acid Mine Drainage Environment

Andri Kurniawan, Ardiansyah Kurniawan, Robin Robin

PDF

159-171

| Language: EN | DOI: 10.14710/jil.21.1.159-171

Received: 11 Apr 2022; Revised: 5 Jan 2023; Accepted: 7 Jan 2023; Available online: 25 Jan 2023; Published: 25 Jan 2023.

Critical Level of Chromium for Rice in Different Soil Type

Hidayatuz Zu'amah, Sukarjo Sukarjo, Elisabeth Srihayu Harsanti, Siska Apriyani, Baiq Nunung Sulastri

PDF

172-180

| Language: EN | DOI: 10.14710/jil.21.1.172-180

Received: 30 Mar 2022; Revised: 9 Jan 2023; Accepted: 10 Jan 2023; Available online: 27 Jan 2023; Published: 27 Jan 2023.

Struktur Komunitas Ikan di Pantai Pasarbangi, Rembang

Fuad Muhammad, Isti Karim Muhandini, Sapto Purnomo Putro, Thomas Triadi Putranto

PDF

181-186

| Language: IN | DOI: 10.14710/jil.21.1.181-186

Received: 17 Apr 2022; Revised: 10 Jan 2023; Accepted: 12 Jan 2023; Available online: 28 Jan 2023; Published: 28 Jan 2023.

Penentuan Unit Operasi dan Proses Berdasarkan Kualitas Air Baku di Sungai Landak Kecamatan Kuala Behe

Fenny Anita Pasaribu, Isna Apriani, Kiki Prio Utomo

PDF

187-199

| Language: ID | DOI: 10.14710/jil.21.1.187-199

Received: 9 Jun 2022; Revised: 12 Jan 2023; Accepted: 14 Jan 2023; Available online: 28 Jan 2023; Published: 28 Jan 2023.

Strategi Pengelolaan Sampah Berkelanjutan pada Industri Rokok Menggunakan Konsep 5R (Reduce, Reuse, Recycle, Recovery, and Repair)

Yuni Dwi Setyaningsih, Endang Hilmi, Roy Andreas, Edy Suyanto, Abdul Aziz Nasihuddin

PDF

200-209

| Language: ID | DOI: 10.14710/jil.21.1.200-209

Received: 18 Mar 2022; Revised: 16 Jan 2023; Accepted: 21 Jan 2023; Available online: 28 Jan 2023; Published: 28 Jan 2023.

Dynamic Model for Food Security to Realize Food Sovereignty: Case Study in Bantul Regency of Yogyakarta Special Region

Ayub Ayub, Bambang Pramudya Noorachmat, Muhammad Yanuar Jarwadi Purwanto

PDF

210-219

| Language: EN | DOI: 10.14710/jil.21.1.210-219

Received: 27 Mar 2022; Revised: 14 Jan 2023; Accepted: 21 Jan 2023; Available online: 28 Jan 2023; Published: 28 Jan 2023.

Estimasi Karakteristik Sosial-Ekonomi Wilayah dalam Capaian Pembangunan Berkelanjutan untuk 100% Akses Sanitasi di Provinsi Kepulauan Riau

PDF

220-227

Aarce Tehupeiory, Imelda Masni Juniaty Sianipar, Mega Mutiara Sari, Iva Yenis Septiariva, Sapta Suhardono, I Wayan Koko Suryawan

| Language: EN | DOI: 10.14710/jil.21.1.220-227

Received: 25 May 2022; Revised: 15 Jan 2023; Accepted: 21 Jan 2023; Available online: 28 Jan 2023; Published: 28 Jan 2023.

Editor in Chief

- **Dr. Budi Warsito** (ScopusID: 57188561936)
  Departemen Statistika, Fakultas Sains dan Matematika, Universitas Diponegoro, Indonesia

Editorial Board

- **Prof. Jerry Miller**
  Department of Geosciences and Natural Resources, Western Carolina University, United States
- **Prof. Dr. H. Hadiyanto** (ScopusID: 7409585558)
  Center of Biomass and Renewable Energy (CBIORE), Diponegoro University, Indonesia
- **Prof Peter Gell** (ScopusID: 7004028173)
  Environmental and Geoscience, Faculty of Science and Technology, Federation University Asutralia, Australia
- **Dr Lilibeth A Bucol** (ScopusID: 5720424518)
  Biology Department, Negros Oriental State University, Kagawasan Ave., Dumaguete City, Philippines
- **Mochamad Arief Budihardjo** (ScopusID: 56495416600)
  Departemen Teknik Lingkungan, Fakultas Teknik, Universitas Diponegoro, Indonesia
- **Prof. Dr. P Purwanto** (ScopusID: 56096290700)
  Doctoral Program of Environmental Science, School of Postgraduate Studies, Diponegoro University, Indonesia, Indonesia
- **Prof. Tri Retnaningsih Soeprobowati** (ScopusID: 55339731500)
  Department of Biology, Faculty of Sains and Mathematics, Diponegoro University, Indonesia
- **Dr. Widada Sulistya** (ScopusID: 57189756701)
  Deputi Bidang Klimatologi, Jakarta, Indonesia
- **Dr Hartuti Purnaweni** (ScopusID: 57194066861)
  Program Studi Doktor Ilmu Lingkungan, Sekolah Pascasarjana, Universitas Diponegoro, Indonesia
- **Dr S Sunardi** (ScopusID: 7409958211)
  Department of Biology and the Institute of Ecology, Padjadjaran University, Indonesia

©2023 Program Studi Ilmu Lingkungan Sekolah Pascasarjana UNDIP
JURNAL ILMU LINGKUNGAN
Volume 21 Issue 1 (2023) : 159-158 *ISSN 1829-8907*

Interaction of Organisms in Abandoned Tin Mining Pits: Perspective of Life in Acid Mine Drainage Environment

Andri Kurniawan[1*], Ardiansyah Kurniawan[1], Robin[1]

[1]Department of Aquaculture, University of Bangka Belitung; email: andri_pangkal@yahoo.co.id

ABSTRACT

Acid Mine Drainage (AMD) occurred after mining activity exposes metal sulfides to oxidizing conditions that impact acidic conditions with low pH values in the waters and heavy metals contamination. These conditions have also occurred in abandoned tin mining pits, one of places in Bangka Belitung Archipelago Province. This review aimed to elaborate information of micro- and macro-organism' life in acid mine drainage to be associated with the possibility of life in abandoned tin mining pits. Acidophilic and acidotolerant organisms such as bacterial, phyto- and zooplankton, and some macroorganisms including invertebrate or vertebrate like fishes and also water plants were found in these waters. Their presence developed a symbiosis interaction in aquatic environment. Phytoplankton was an autotroph organism, despite being considered an autotroph organism, many phytoplankton require exogenous organic cofactors and nutrients for their life. These cofactors were often served by heterotroph bacterial to sustain the growth of phytoplankton. Instead, bacterial obtained dissolved organic matter derived from phytoplankton to survive in the aquatic environment. Furthermore, phytoplankton was consumed by zooplankton; zooplankton and/or insect on the water surface were consumed by surface feeder or small fish to big fish in the waters. In addition, water plants also support the interaction of organisms in the water by supplying dissolved oxygen, also anorganic and organic material for their life. The symbiosis and quorum sensing played an important role in structuring the aquatic food web and creating a life in the acidic water-polluted heavy metal in biogeochemical cycle. This review only focused on the role of bacterial in biogeochemical cycles in the acid mining environment. Research or review of other biogeochemical mechanisms was needed to reveal the entire biogeochemical cycles in acid mining waters.

Keywords: acidic water, heavy metal, tin mining pit, biogeochemical, quorum sensing

ABSTRAK

Air Asam Tambang (AAT) terjadi setelah kegiatan penambangan yang mengekspose logam sulfida hingga kondisi oksidasi yang berdampak pada kondisi asam dengan nilai pH rendah di perairan dan kontaminasi logam berat. Kondisi ini juga terjadi pada kolong pascatambang timah yang terbengkalai, salah satunya di Provinsi Kepulauan Bangka Belitung. Review ini bertujuan untuk mengelaborasi informasi kehidupan mikro- dan makro-organisme di air asam tambang untuk dikaitkan dengan kemungkinan kehidupan yang terdapat di kolong pascatambang timah yang ditinggalkan tersebut. Organisme asidofilik dan asidotoleran seperti bakteri, fito- dan zooplankton, dan beberapa makroorganisme termasuk invertebrata atau vertebrata seperti ikan dan juga tumbuhan air ditemukan di perairan ini. Keberadaan organisme ini menghadirkan interaksi simbiosis di lingkungan perairan. Fitoplankton adalah organisme autotrof, meskipun dianggap organisme autotrof, banyak fitoplankton membutuhkan kofaktor organik eksogen dan nutrisi untuk hidupnya. Kofaktor ini sering disediakan oleh bakteri heterotrof untuk mempertahankan pertumbuhan fitoplankton. Sebagai gantinya, bakteri memperoleh bahan organik terlarut yang berasal dari fitoplankton untuk bertahan hidup di lingkungan perairan. Selanjutnya, fitoplankton dikonsumsi oleh zooplankton; zooplankton dan/atau serangga di permukaan air dikonsumsi oleh ikan kecil atau ikan pemakan di permukaan hingga ikan besar di perairan. Selain itu, tumbuhan air juga mendukung interaksi organisme di dalam air dengan menyediakan oksigen terlarut serta bahan anorganik dan organik untuk kehidupannya. Simbiosis dan komunikasi interseluler memainkan peran penting dalam strukturisasi jaring makanan di lingkungan akuatik dan menciptakan kehidupan di air asam yang terkontaminasi logam berat dalam siklus biogeokimia. Review ini hanya berfokus pada peranan bakteri di dalam siklus biogeokimia di dalam lingkungan perairan asam tambang. Penelitian atau review tentang mekanisme biogeokimia lainnya diperllukan untuk mengungkap keseluruhan siklus biogeokimia di perairan asam tambang.

Kata kunci: air asam, logam berat, kolong pascatambang timah, biogeokimia, quorum sensing

***Citation**:* Kurniawan, A., Kurniawan, A., Robin. (2023). Interaction of Organisms in Abandoned Tin Mining Pits: Perspective of Life in Acid Mine Drainage Environment. Jurnal Ilmu Lingkungan, 21(1), 159-171, doi:10.14710/jil.21.1.159-171

1. Introduction

Nowadays, acid mine drainage (AMD) problem in abandoned mines have become a global environmental concern (Wang et al., 2021). Acid mine drainage is a waste from industry or activity of mining (Kaur et al., 2018). Abandoned mines and mine wastes are often acidic, sometimes extremely so and they often contain high concentrations of metals and possibly other heavy metals and also metalloids. This condition is also found on abandoned mining pits, include such as in Bangka Island and other producers of tin in the world.

Industrial waste and mining activities such as tin are one of the main sources of metal contamination (Guan et al., 2014; Kurniawan, 2016). Postactivity of tin mining produce metal contaminants such as Pb, Zn, Mn, Fe, Cr, Cu, Ni, and Cd as found in Heipang Nigeria (Daniel et al., 2014); Sn, Pb, Zn, Cr, Cu, and as in Bestari Jaya, Malaysia (Ashraf et al., 2011a; Ashraf et al. 2012a); and Fe, Pb, Cu, and Zn detected at tin mining sites in Bangka Island, Indonesia (Henny, 2011; Rosidah and Henny, 2012).

Other ecological changes can also be seen from the change in the acidity value (pH) of soil and water at the post-tin mining site. Characteristics of relatively acidic to neutral pH values (4.8-7.2) (Ashraf et al., 2013) and can be even lower than pH 4 as well as nutritional deficiencies and low dissolved oxygen values (Kurniawan, 2016). Tin mining activity in soil ecosystems leads to low ion exchange capacity, organic matter, total nitrogen, phosphorus availability, macro nutrients, and clay soil content (Oktavia et al., 2014). Mining activities cause ecological imbalances and damage, including physical, chemical, and biological changes within macro- and microecosystems (Fan et al., 2002; Vyas and Pancholi, 2009; Ashraf et al., 2010; Ahmad, 2013; Singh et al., 2013; Giri et al., 2014; Lad and Samant, 2015).

Therefore, the main objective of this review is to summarize the scientific literature related to AMD water, especially abandoned tin mining pits and its effects on organisms thriving in the heavy metal-contaminated and acidic water, their metabolism in the habitat, and their interactions on biogeochemical mechanism that support their life and succession in the environment. This review focused to role of bacterial in biogeochemical cycle in the acidic water of abandoned tin mining pits.

2. Perspective of Life in Acid Mine Drainage Environment

A. Acid Mine Drainage

Acid mine drainage (AMD) forms when sulfide minerals are exposed to oxidizing condition during metal mining, highway construction, and other large-scale excavations (Skuosen et al., 2000). The formation of AMD is a sequence of complex biogeochemical and mineral dissolution processes (Dold, 2014), characterized by acidic effluents with a high content of sulfide mineral and heavy metal ions in water (Pozo-Antonio et al. 2014). A number of sulfide minerals found in the waters acids are categorized as Potentially Acid Forming (PAF) or materials that can cause the formation of acidic pH conditions in the environment such as pyrite (FeS_2), chalcopyrite ($CuFeS_2$), galena (PbS), sphalerite ((Zn,Fe)S) (Celebi and Oncel, 2016). These minerals undergo oxidation to produce the final product in the form of H^+ ions (Gonzalez-Toril et al., 2006; Mejia et al., 2009; Heidel and Tichomirowa, 2011; Dopson and Johnson, 2012).

Many researches have shown that the exposed pyrite in metal mining is the main cause of acid mine drainage. When pyrite reacts with oxygen and water, the products are Fe ions and sulfuric acid.

The general chemical reaction that describes the oxidation of pyrite and the formation of acid is given by the following equation. There are four generally accepted chemical reactions that represent the weathering chemistry of pyrite that forms AMD. Here is an overview of the overall reactions (Gaikwad and Gupta, 2007; Byrne et al. 2012):

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3\downarrow + 8H_2SO_4 \quad (1)$$

Pyrite + Oxygen + Water → “Yellowboy” + Sulfuric Acid

The first reaction in pyrite weathering involves the oxidation of pyrite by oxygen. Sulfur is oxidized to sulfate and iron is released. This reaction produces two moles of acidity per mole of pyrite oxidized.

$$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+ \quad (2)$$

(*pyrite oxidation process*)

Pyrite + Oxygen + Water → Ferrous Iron + Sulfate + Acidity

The second reaction involves the conversion of ferrous iron to ferric iron. To convert ferrous iron (Fe(II)) to Ferric iron (Fe(III)) need one mol of acidity. Certain bacterial increase the rate of iron (II) oxidation to iron (III). This reaction rate is pH dependent, and the reaction proceeds slowly under acidic conditions (pH 2-3) in the absence of bacterial, and is several orders of magnitude faster at pH values close to 5. This reaction is called "velocity". The "restriction steps" for overall acid production indicate the order.

$$4Fe^{2+} + O_2 + 4H^+ \rightarrow 4Fe^{3+} + 2H_2O \quad (3)$$

(*ferrous iron oxidation process*)

Ferrous Iron + Oxygen + Acidity → Ferric Iron + Water

The third possible reaction is the hydrolysis of iron. Hydrolysis is a reaction that breaks down water molecules. As a by-product, three moles of acidity are produced. Many metals can be hydrolyzed. The formation of ferric hydroxide precipitates (solids) depends on pH. When the pH is above about 3.5, solids are formed, but below pH 3.5, the solids hardly or at all precipitate.

$$4Fe^{3+} + 12H_2O \rightarrow 4Fe(OH)_3\downarrow + 12H^+ \quad (4)$$

(*ferric iron hydrolisis process*)

Ferric Iron + Water → Ferric Hydroxide (yellow boy) + Acidity

The fourth reaction is the oxidation of additional pyrite by ferric iron. Iron (III) is produced in reactions steps 1 and 2. This is a periodic, self-propagating part of the entire reaction that occurs very quickly and continues until either ferric or pyrite is exhausted. Note that in this reaction, iron is an oxidizer, not oxygen.

$$2FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (5)$$

(*ferric iron oxidation process*)

Pyrite + Ferric Iron + Water → Ferrous Iron + Sulfate + Acidity

Equation describes about producing ferric iron as the primary oxidant of pyrite. Under abiotic conditions the rate of oxidation of pyrite by ferric iron is controlled by the rate of oxidation of ferrous iron, which decreases rapidly with decreasing pH. Below about pH 3, the oxidation of pyrite by ferric iron is about ten to a hundred times faster than by oxygen (Dold, 2014).

Oxidation and hydrolysis reactions that occur to elements such as S, Fe, Cu, Zn, Ni, Cr, Pb, into cations such as Cu^{2+}, Zn^{2+}, Ni^{2+}, Cr^{3+}, Pb^{2+}, and other elements in the mining environment cause an increase in the number of H^+ protons that are produced, contribute to an increase in environmental acidity conditions. The more H^+ ions in an environment, the more acidic the pH conditions in the environment (Gaikwad and Gupta, 2007; Hatar et al., 2013). The increase in the value of H^+ also occurs in organic and inorganic materials such as ammonia and carbon dioxide. The acidity caused by the ammonium nitrification process takes place through the reaction of $NH_4^+ + 2O_2 \rightarrow NO_3^- + 2H^+ + H_2O$ and then dissolved nitrate (NO_3^-) (Goulding, 2016). The chemical interaction between carbon dioxide and water produces a weak acid through the reaction of $CO_2 + H_2O \rightarrow H_2CO_3$ and then carbonate ions (HCO_3^-) and protons (H^+) are formed (Stallinga, 2018).

The increase of H^+ ions is responsible for lowering the pH and degrading the quality of the water and disturbing the aquatic organism's life. Increased acidity has a particularly harmful effect on organisms from their early life stages such as fish larvae, impact in their respiration and oxygen consumption, depressing effect on the growth rate and survival rate (Srineetha et al., 2014; Ndubuisi et al., 2015) and also disturb on photosynthesis of water plants (Long et al., 2017). However, some organisms "extremophiles" can thrive under multiple extremes conditions (Merino et al., 2019).

B. Abandoned Tin Mining Pit in Bangka Belitung Archipelago Province

The existence of former mining pit-like a lake, particularly tin mining in Bangka Belitung Archipelago Province, Indonesia (in local language called kolong) presents a significant impact from abandoned mining activities (Kurniawan et al., 2020). Abandoned tin mining pits become a new ecological model for studying of biological life, metabolism, and organisms' interaction in this habitat, especially tin producers in the world such as Indonesia, Malaysia, and others. Some studies result information about this environment such as water quality (Ashraf et al. 2012b; Hashim et al., 2018), heavy metal contamination (Ashraf et al., 2011a; Ashraf et al., 2011b; Ashraf et al. 2012a; Kurniawan, 2020), microorganism and molecular diversity (Sow et al., 2014a, 2014b), and also extremophile fishes (Kurniawan et al., 2020; Kurniawan and Mustikasari, 2021). The morphological view of some abandoned pits in Bangka Island of Indonesia were shown in Figure 1.

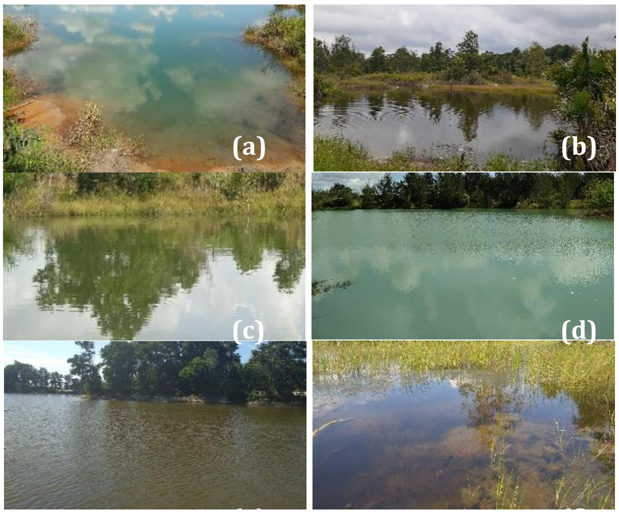

Figure 1 The morphological condition of abandoned tin mining pits in Bangka Island, Indonesia, (a) Station A (age < 5 years); (b) Station B (age 5-15 years); (c) Station C (age 15-25 years); (d) Station D (age 25-50 years); (e) Station E (age 50-100 years); and (f) Station F (age > 100 years) (Mustikasari et al., 2020)

Tin mining activities carried out on land in Bangka Belitung Island have led to the formation of pits by a spray mining method. This process is carried out through the stripping stage in the form of dismantling soil layers to a certain depth, spraying stages to disassemble or dissolve soil or rocks containing tin seeds so that they turn into mud, and washing stages to separate lead seeds from other materials through the deposition process (Harahap, 2016). Tin mining activitiy does not use chemicals, but elements or minerals such as Fe, Sn, Pb, Cu, and so on in nature can undergo oxidation and other chemical reactions that cause changes in water quality and potential heavy metal pollutant residues (Kurniawan et al., 2019; Kurniawan and Mustikasari, 2019). The authors have found in the before research some elements, bacterials, and fishes in abandoned tin mining pits, resumed in Table 1.

Tin mining activity doesn't use chemical materials during the exploration process, but the effect of mining activity is the elements contained in nature can undergo oxidation and chemical reactions. The consequence of pyrite and other sulfide oxidation can cause severe acidification of mine water, accelerate erosion of basins, promote heavy metal migration and threaten local ecosystems such as aquatic life and human health (Li et al., 2018). Authors observe onshore mining activity impact to ecological changes such as deforestation, biodiversity recuding, water flow damages, decrease of environmental stability, also macro- and microorganism structure alteration. Furthermore, for a long chronosequence, it may drive the changes of organisms' metabolism to survive in the environment.

Table 1. Information of abandoned tin mining pit in Bangka Island, Indonesia

Water Quality[a]	Elements[b]	Bacterials (Phylum) [b]	Fishes[a]
pH (3.71-7.09); Tempterature (31.36-31.70 °C); DO (5.20-7.20 ppm); COD (10.17-15.4 ppm); TDS (38.93-98.25 ppm); TSS (3.66-6.0 ppm); Eh (0.01-0.18 V); Conductivity (58.40-143.75 US.cm^{-1}); Total Nitrogen (0.02-0.069 ppm); Total Phosphate (0.013-0.021 ppm)	As; Co; Cr; Cu; Fe; Ga; Hf; Mn; Ni; Pb; Sn; Ta; Te; Th; V; Zn	Proteobacteria; Actinobacteria; Chloroflexi; Firmicutes; Acidobacteria; Planctomycetes; Bacteroidetes; Chlorobi; Cyanobacteria; Gemmatimonadetes; Candidate of Phylum; Parcubacteria; Spirochaetes; Thermi; Nitrospirae; Verrucomicrobia; Armatimonadetes; Chlamydiae; Elusimicrobia; Caldiserica; Chaldithrix; Lentisphaerae; Fibrobacteres	*Channa* sp., *Trichogaster* sp., *Puntius* sp., *Oreochromis* sp., *Gambusia* sp., *Rasbora* sp., *Anabas* sp., *Betta* sp., *Belontia* sp., *Brevibora* sp., *Oryzias* sp., *Aplocheilus* sp.

Sources: [a]Kurniawan et al. (2020), [b]Kurniawan (2020)

C. Organisms in Acid Mine Drainage-Polluted Heavy Metals

Acid mine drainage (AMD) is a highly acidic wastewater rich in heavy metals and metalloids (Plaza-Cazón et al., 2021). In this condition, only selected organisms can survive and life normally. Known as extremophiles, these organisms breed in habitats that are intolerably hostile or even deadly to other terrestrials. One of them thrive in acidic conditions and some can grow in toxic waste, low nutrient content, and also heavy metals pollution. Extremophiles can be broadly divided into two categories; extremophilic organisms that require one or more extreme conditions to grow optimally and extremotolerant organisms which can tolerate extreme values of one or more physicochemical parameters (Rampelotto, 2013). The organisms may be described as acidophilic (optimal growth between pH 1 and pH 5), oligotrophic (growth in nutritionally limited condition), and metallophiles/ metallotolerants (resistant to high concentration of metals). In addition, extremophiles involve thermophiles and hyperthermophiles (optimally thrive at high or very high temperatures), psychrophiles (optimally thrive at low temperatures), alkaliphiles (optimally adapted to alkali pH values), barophiles or piezophilic (optimally thrive at high pressure), halophiles (organisms that require NaCl for growth), endolithic (growth within rock or within pores of mineral grains), and xerophilic (thrive in a dry area) (Rampelotto, 2013; Gupta et al., 2014; Sinha et al., 2014; Zhu et al., 2020).

However, in this review, we only deal with extremophile organisms related with acidic water-polluted heavy metal as well as abandoned tin mining pits conditions, which can categorized as polyextremophiles due to these extremophiles are adapted simultaneously to multiple stresses, as an acidophilic and metallophilic or metallotolerant.

Environmental pH values are an important factor in acidophiles identification so they are grouped into two, namely true or extreme acidophiles and moderate acidophiles. True acidophiles (extreme acidophiles) can live at a pH of 2.7 and even some can live at a pH < 1.0 with an optimum pH of growth of < 3.0. Moderate acidophiles are able to live in the wider pH range, which is 3.0-7.2 with an optimum pH of growth of 3.0-5.0 (Johnson and Hallberg, 2008; Mendez et al., 2008; Oren, 2010). The acidophilic group has a fairly wide growth range, but optimum growth takes place between a pH of 1.0 and a pH of 5.0. This characteristic distinguishes from other groups such as neutrophiles that live tolerant in the pH range of 5.0-9.0 with the optimum pH for growth being 7.0 as well as alkaliphilic tolerant live at pH 6.0-12.0 with optimum pH above 9.0 or often between pH 10.0 and pH 12.0 (Gupta et al., 2014; Horikoshi, 2016).

In addition, in this review we use term acidotolerant to desctribe organisms which can live in acidic condition, while metallotolerant to describe organisms which can survive in environment-contaminated heavy metals, especially in abandoned tin mining pit. We tend to agree with Maltman and Yurkov (2019) that explained organisms that can withstand high concentrations of metals (metalloids) are called metallophile. However, this description can be a bit misleading. The suffix "phile" means that it is highly compatible in the presence of metals (metalloids). This is because even highly resistant microorganisms do not always grow well at such high levels and also it does not require oxyanions to survive. Therefore, term of metallophile/metallophilic is not used in this review and a more appropriate term is metallotolerant.

In this review, authors do references approach to elaborate some acidophilic and metallotolerant organisms found in other mining site or extreme environment to reveal potential of these organisms existing, which might be found in abandoned tin mining pits. In this perspective, we highlight acidophile-metallotolerant as our term to disclose these organisms. Furthermore, it will becomes information as a guide for researching the presence of these organisms in this water. Some researchers has discovered the ability of some organisms to survive in extreme conditions of acidic and heavy metal contamination where some of them are resumed in Table 2.

All of them develop self-abality to survive so they can play an important role in this environment. Metallotolerant microorganism as well as acidophile have been found to be capable of efficiently accumulating heavy by the mechanisms of acidolysis, transport across cell membrane, complexation, ion exchange, precipitation, physical adsorption, accumulation, chelate, redoxolysis, and leaching which are carried out through physical mechanism, chemical modification or by influencing chemical bioavailability (Rao et al., 2002; Siswati et al., 2009; Damodaran et al. 2011; Harms et al., 2011, Javanbakht et al., 2014; Chaturvedi et al., 2015; Dixit et al., 2015; Dusengemungu et al., 2021).

In principle, acidophile, acidotolerant, and metallotolerant which do acidolysis, they can exchange metal oxide and decrease H^+ ion by metal oxide detachment and react oxygen with water, as shown in the reaction $MeO + 2H^+ \rightarrow Me^{2+} + H_2O$. Protons attach and react to the metal and then reduce the strength of chemical bonds so metal ions are removed from the metal surface (Srichandan et al., 2019). Furthermore, Me^{2+} as a metal cation will be processed as well as microbe capability such as accumulate or precipitate the cation ion become solid, as exampled in this reaction $Me^{2+} + HO_2C.CO_2H \rightarrow (Me(O_2C.CO_2)_{(s)} + 6H^+$ and $Me^{2+} + SO4^{2-} \rightarrow MeSO_{4(s)}$ (Dusengemungu et al., 2021). In addition, they can play oxidation and reduction reactions to use the metal as their nutrition or detoxification of the metal to make sure their environment. For example, they are capable of both reactions, that reduction, and oxidation such as reduce Fe^{3+} with H_2 as an electron donor or oxidize Fe^{2+} with NO_3^- as an electron acceptor (Zhang et al., 2009).

Some of aquatic plants do their role as phytoremediator with mechanisms such as phytoextraction, rhizofiltration, phytovolatilization, and phytostabilization during the process of uptaking or accumulating of heavy metals from the environment (Ali et al., 2020). Phytoextraction (phytoaccumulation) refers to the uptake and translocation of metal in the environment by plant roots to above-ground plant parts. The plants can harvest and burn metals for energy, and the pollutants can be recovered/recycled from the ashes as needed by phytoextraction process (Erakhrumen, 2017; Chandra et al., 2018; Sukono et al., 2020). Roots play a very important role for rhizofiltration to absorb or adsorb the pollution, resulting in restricted movement of these contaminants in the environment (Abhilash et al., 2009; Benavides et al. 2018; Sukono et al., 2020). Phytovolatilization is the process in which a plant converts pollutants into a different volatile nature and then transfer them into the atmosphere by the plant' stomata (Ghosh and Singh, 2005; Leguizamo et al. 2017; Sukono et al., 2020). Phytostabilization also known as in place deactivation, using plants to reduce heavy metal bioavailability and to restrict the movement of contaminants in the environment (Abhilash et al., 2009; Benavides et al., 2018; Yan et al., 2020).

While, some fishes improve their external morphology of the chorion (the egg envelope) to enter diapause phase, metabolism buffering of acidity, ion regulation and exchange of mitochondria cell by homeostatic mechanism, and biochemical metabolism by metallothionein (MTs) production (Hirata et al., 2003; Lindeque et al. 2010; Hwang et al., 2011; Daurte et al. 2013; Dominguez-Castanedo et al., 2013; Liu et al., 2014; Kurniawan and Mustikasari, 2021).

D. Life in Acidic-Heavy Metals Water: Perspective of Tin Mining Pit

Interactions of organisms play a critical role in existence and prospects of life in acid-heavy metals waters as formed as acid mine drainage. In addition, we elaborated many papers to construct a life in a perspective of tin mining pit based on life approach in the acid mine drainage. Hui (2012) explained the food chain is an important for ecological concept, especially in a life concept, organisms' interaction, nutritional relationships, and energy flow or transfer, which begins with autotrophs (known as the grazing food chain) and which begins with dead organic matter (known as the harmful food chain). Meanwhile, through this theory, we present a concept of thought about a food chain scheme that might occured in a tin mining pit (Figure 2). The food chain of this habitat offers important informations for studies of the ecological interactions that define energy flows and the relationship of producer and consumer in an ecosystem, directly impact to nutrient cycling and biological life.

An essential part of a food chain is that each organism or their group are of equal importance to the ecosystem and play important role in an environment. We focused to constructed role of some microbes of abandoned tin mining pit, especially phylum of bacterial which affect to its characteristics and ecological exchange in a biogeochemical process (Figure 3).

Bacterial is a group of microorganisms have the highest ability of all life forms to adapt to extreme and stressful environments due to the ability to transfer genetic information as a major factor in adaptation to environment changes. The population genetic diversity also contribut as one of the major factors determining the adaptation ability of a species to environmental variations (Jump et al. 2009). Bacterial, part of microbes can do their activity absolutely in aerobic and anaerobic conditions or facultative between aerob or anaerob conditions depending on the environment they are in.

Furthermore, some of them can do photosynthesis process. The photosynthetic bacterial used sun' light to produce energy in a process similar with plants. Instead of using the chlorophyll, they use bacteriochlorophyll compounds to capture the sun' light and do the photosynthesis (Emmyrafedziawati and Mohd Aziz, 2016).

The aerobic phototrophic bacterial are a recently discovered group capable of producing a photosynthetic apparatus like the purple phototrophic bacterial. These bacterial have bacteriochlorophyll (BChl) *a* incorporated into light harvesting (LH) and reaction center (RC) complexe capable of transforming light into electrochemical energy under aerobic conditions (Rathgeber et al., 2004). To date, thera are six bacterial phyla namely Cyanobacteria, Proteobacteria, Chlorobi, Chloroflexi, Firmicutes, and Acidobacteria that using (bacterio)chlorophyll-based photosynthetic reaction centers (chlorophototrophs) (Zeng et al. 2014). There are four known phylogenetic groups of anoxygenic phototrophs: the green sulfur bacterial, the green non-sulfur bacterial, the heliobacteria, and the purple bacterial which consist of purple sulphur and purple non-sulphur bacterial (Emmyrafedziawati and Mohd Aziz, 2016). These microorganisms use reduced sulfur (S) compounds as electron donors in the process of anoxygenic photosynthesis (Kushkevych et al., 2021).

Kurniawan (2020) has explained the phyla of bacterial found in acid mine drainage, especially abandoned tin mining pits. We assumed that occurred the biogeochemical process in this habitat that involved bacterial so cause characteristic changes in this environment (Figure 3).

The oxidation of sulfide minerals and heavy metals found in abandoned tin mining water make acidic condition in the water. Biologically, Acidophile bacterial such as Actinobacteria, Firmicute, and Chloroflexi oxidized sulfide minerals and heavy metals so accelerate acidic forms in abandoned tin mining pit and increase ion H^+ that cause acid condition in this water. While, the physically and chemically oxidation process also occurs to sulfide minerals and heavy metals (Bao et al., 2022) so cause pit water has acidic characteristic.

Chronosequently, within a certain time, organic matter from bacterial, archaea, microfungi, planktonic organisms were degradated and composed in this water. For quite of while, the organic matters and the degradating or composting product of organic matters were accumulated and caused increasing of c-organic. This organic material and its products were used Bacteroidetes as an energy source for their life and biochemical activity, include to decompost organic matters. Bacteroidetes play important role in decomposition process as a key of carbon cycle in an environment (Herzog et al., 2019).

We analyzed that the presence of organic material implicates to two major mechanisms: (1) carboxylix bond ($COOH^-$) of organic matters bound H^+ ions of sulfide minerals and heavy metals and (2) CO_2 and H_2O as decomposition products can be reacted to produce H_2CO_3, while bicarbonate ion (HCO_3^-) also bound H^+ ions of sulfide minerals and heavy metals. These mechanisms caused H^+ ions in abandoned tin mining water will be decreased and the implication was increasing pH value, changes from acid to be a neutral or base. Vijayakumar et al. (2019) explained that a solution with a high concentration of hydrogen ions have a low pH (acid) and solution with low concentrations of H+ ions have a high pH concentration (neutral to base).

The pH changes contributed to ability of the other bacterials to life in this habitat such as Cyanobacteria, Proteobacteria, and Planctomycetes. The presence of Cyanobacteria as a primary producer contributes to photosynthesis by fixation of inorganic carbon (CO_2) to organic carbon ($(CH_2O)_n$) and releasing oxygen (Prieto-Barajas et al., 2018). Thereby, dissolved oxygen in this habitat will be increase and impact to other organisme, involved bacterial (e.g Proteobacteria and Planctomycetes), plankton, water plants, and fishes.

In addition, degradation organic matter produced ammonia (NH_3) that can be used by group of ammonia oxidizing bacterial (AOB), nitrit oxidizing bacterial (NOB), anaerobic ammoniua oxidation, and complete ammonia oxidation (commamox) to produced nitrogen. Guignard et al., (2017) explained the presence of nitrogen impact to increasing of plant and animal abundances; trophic interactions and population dynamics; and ecosystem dynamics and productivity.

Therefore, the presence of bacterials and they work together, called quorum sensing (Kurniawan and Asriani, 2020) can create a habitable zone for many waters organisms, from micro to macroorganisms and revive the food or web chains in the environment, include abandoned tin mining water.

Table 2. Acidophile-Metallotolerant Organisms in a Extreme Environment

Organism	Individu	Optimum Parameters		References
		pH	Heavy metal	
Bacterial	Phyla of Proteobacteria and Bacteroidetes	3.1	Pb, Cd, As, Ni, Co, Fe, Cr	Oyetibo et al. (2021)
	Phyla of Chloroflexi, Cyanobacteria, Proteobacteria, Firmicutes, Actinobacteria	4.8	Cu, Zn, Co, Ni, Mn, Fe, Cd, 20 Hg	Arif et al. (2021)
	Phyla of Acidobacteria, Actinobacteria, Amatimonadetes, Bacteriodetes, Chlorobi, Chloroflexi, Crenachaeota, Cyanobacteria, Firmicutes, Nitrospirae, Nitrospinae, Parcibacteria, Proteobacteria, Planctomycetes	< 3	Ac, Cu	Zhang et al. (2019)
Fungal	*Penicillium*, *Candida*, *Saccharomycetales*, *Vishniacozyma*, *Trichoderma*, *Didymellaceae*, and *Cladosporium*	5.01	Fe, Cr, Cu, Zn	Kalu et al. (2021)
	Fusarium solani	5,0	Ag	El Sayed and El-Sayed (2020)
Archaea	Phylum Euryarchaeota	2.73-3.4	Fe, As	Bruneel et al. (2008)
	Phylum Euryarchaeota	1.9-2.75	Fe, Ni, Cu, Cr, Mn, Zn, As, Pb	Korzhenkov et al. (2019)
	Phylum Crenarchaeota	3.0	Fe, Mn, Cu	Hao et al. (2010)
Phytoplankton	Genera of Chlorophyta (*Chlamydomonas*, *Scourfieldia cordiformis*); Heterokontophyta (*Ochromonas*, *Chromulina*); Cryptophyta (*Cyathomonas*); Euglenophyta (*Lepocinclis*, *Euglena mutabilis*). Near-spherical non-motile Chlorophyta (*Nanochlorum* sp.); Heterokontophyta (*Eunotia exigua*, *Nitzschia*); Dinophyta (*Gymnodinium*, *Peridinium umbonatum*); and Cryptophyta (*Rhodomonas minuta*)	2.3-2.9	Fe	Lessmann et al. (2000)
	Class of Chlorophyceae (*Mougeotia* sp., *Spirogyra* sp., and *Chlamydomonas* sp.); Ulvophyceae (*Klebsormidium* sp.); Euglenophyceae (*Euglena* sp.); Bacillariophyceae (*Pinnularia* sp., *Eunotia* sp., *Navicula* sp., and *Cyclotella* sp.); Chlorophyceae (*Characium* sp.); Chrysophyceae (*Dinobryon* sp.); Ulothricophyceae (*Oedogonium* sp. and *Ulothrix* sp.) and Trebouxiophyceae (*Chlorella* sp.)	2.1-6.3	As, Cr, Cu, Fe, K, Mg, Mn, Ni, Co, Zn, Cd, Pb	Gomes et al. (2021)
Zooplankton	Rotifer (*Rotaria* sp., *Asplanchna priodonta*, *Aspelta cincinator*, *Brachionus* sp., *Cephalodella* sp., *Colurella colurus*, *Elosa worallii*, *Kellicottia longispina*, *Keratella* sp., *Lecane* sp., *Polyarthra dolichoptera*, *Testudinella patina*, *Trichocerca* sp.)	2.7-4.9	Pb, Cd, Cu, Zn, Cr, Ni, Mn, Fe	Pociecha et al. (2018)
Fish	*Capoeta fusca*	5	Hg	Mansouri and Baramaki (2011)
	Channa striatus		Cu, Zn, Pb	Jalal et al. (2013)
	Cyprinus carpio and *Pelteobagrus fluvidraco*		Cr, Cu, Cd, Pb	Rajeshkumar and Li (2018)
	Oxyeleotris marmorata and *Rasbora lateristriata*	6.56-6.80	Cd, Cu, Fe, Pb, Zn	Syandri et al. (2015)
	Aplocheilus panchax and *Anabas testudineusi*	3.81-7.79	Sn, Hf, Cu, Fe	Mustikasari et al. (2020); Mustikasari and Agustiani (2021)
	Trichogaster pectoralis and *Anabas testudineusi*	6.86	Fe	Herliyanto et al. (2014)
	Gambusia affinis	6.247	Cd, Cr, Cu, Fe, Mn, Pb, Zn	Franssen (2009)
	Esomus malayensis, *Trichogaster pectoralis*, *Oreochromis mossambicus*, *Megalops cyprinoides*	5.69-6.03	Fe, Zn, Mn, Pb, Cr, Cu, Ni, Cd	Widad and Abdullah (2013)
	Hampala microlepidota, *Barbonymus schwanenfeldii*, *Mystacoleucus marginatus*, *Hemibagrus nemurus*, *Cyclocheilicthys apogon*, and *Oreochromis niloticus*	-	Cu, Zn, Pb, Ni, Mn	Baharom and Ishak (2015)
	Puntius schwanenfeldii, *Ompok bimaculatus*, *Cyclocheinichtys apogon*, *Osteochilus hasseltii*, *Notopterus notopterus*, *Chana micropeltes*, *Puntius bulu*, *Labiobarbus festiva*, *Osteochilus melanopleura*, *Hampala macrolepidota*, *Chela oxygastroides*, *Mystus nigriceps*, *Thynnichthys thynnoides*, *Barbichthys laevis*, *Helostoma temmichki*	5.8-6.4	Cu, Pb, Zn, Cd	Ahmad and Shuhaimi-Othman (2010)
Aquatic Plant	*Eleocharis dulcis*, *Cyperus odoratus*, *Hydrilla verticilata*, *Ipomea aquatic*, *Pistia stratatiotes*	4.56-6.09	Fe, Mn	Herniwanti et al. (2013)
	Azolla filiculoides	2	Cr	Babu et al. (2014)

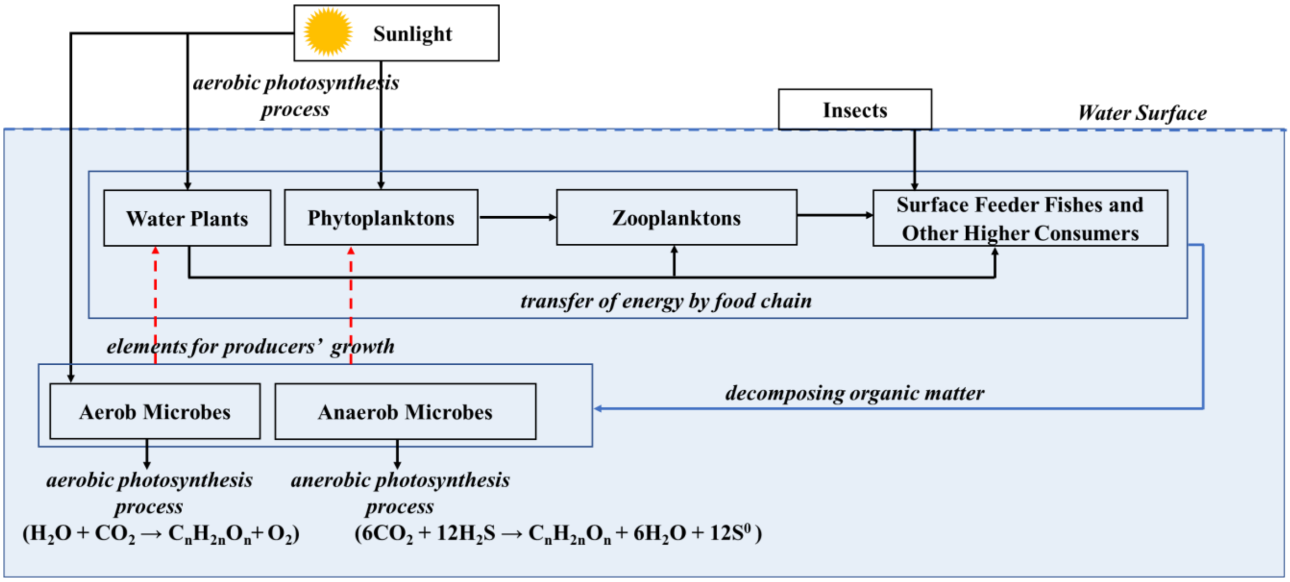

Figure 2 Food chain and energy flow in a pit environment

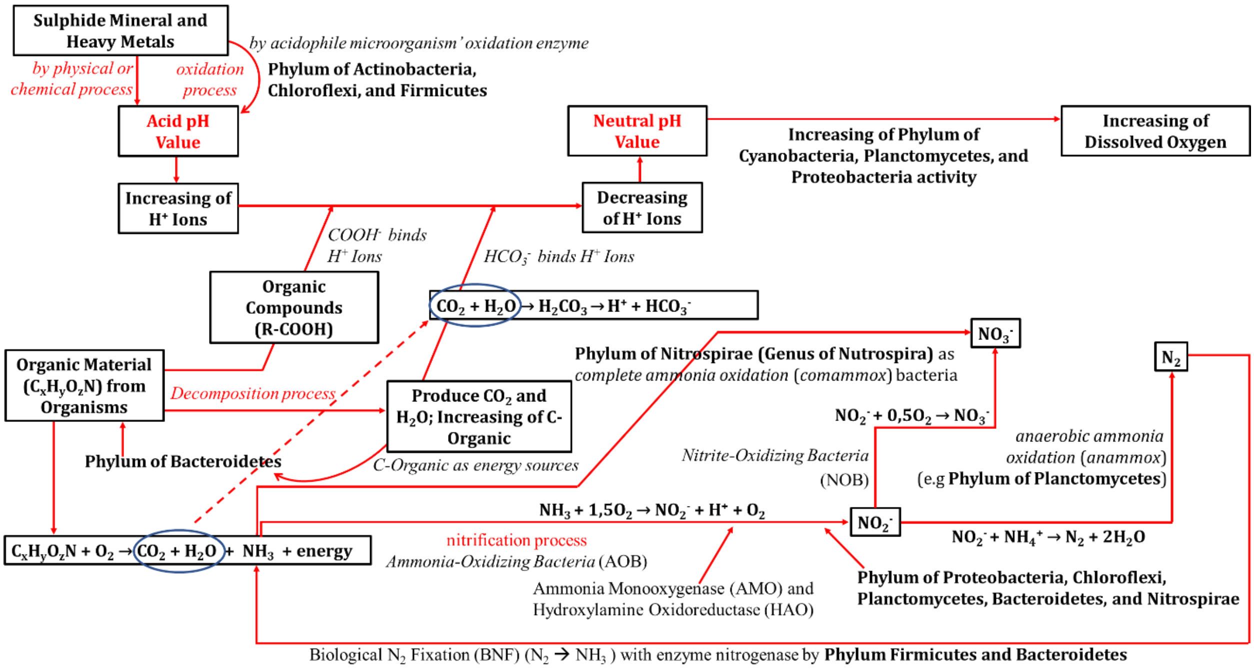

Figure 3 Biogeochemical flow involved some bacterials found in abandoned tin mining pits, which red line indicated biogeochemical process

4. Conclusion

We have disclosed about the interaction of organisms in abandoned tin mining pits by the perspective of life in acid mine drainage environment. We believed some bacterial of abandoned tin mining water as part of acid mine drainage played important role in biogeochemical process to change water quality and create a food or web chains by a creating habitable environment for all organisms, including micro- to macroorganisms. Some groups of bacterial played important role in organic matter cycle and another played in anorganic cycle of biogeochemical mechanisms. This review was only limited to reveal the role of bacterial in abandoned acid mining waters. Further researches were needed to explain about the food chain and energy transfer that occurs in these waters.

Acknowledgment

We would like to thank University of Bangka Belitung for supporting in this research and publication by research grant of Associate Professor acceleration in 2022.

Conflict of Interest

The author declares that there is no conflict of interest in this publication.

References

Abhilash, P., Jamil, S., and Singh, N. 2009. Transgenic plants for enhanced biodegradation and phytoremediation of organic xenobiotics. Biotechnology Advances 27(4): 474-488

Ahmad, A. K., and Shuhaimi-Othman, M. 2010. Heavy metal concentrations in sediments and fishes from Lake Chini, Pahang, Malaysia. Journal of Biological Sciences 10(2), 93-100

Ahmad, F. 2013. Distribusi dan prediksi tingkat pencemaran logam berat (Pb, Cd, Cu, Zn, dan Ni) dalam sedimen di perairan Pulau Bangka menggunakan indeks beban pencemaran dan indeks geoakumulasi. Jurnal Ilmu dan Teknologi Kelautan Tropis 5(1): 170-181

Ali, S., Abbas, Z., Rizwan, M., Zaheer, I. E., Yavaş, İ., Ünay, A., ..., Kalderis, D. 2020. Application of floating aquatic plants in phytoremediation of heavy metals polluted water: a review. Sustainability 12(5): 1927

Arif, S., Nacke, H., Schliekmann, E., Reimer, A., Arp, G., and Hoppert, M. 2021. Composition and niche-specific characteristics of microbial consortia colonizing marsberg copper mine in the Rhenish Massif. Biogeosciences Discussions 2021: 1-31

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2010. Study of water quality and heavy metals in soil & water of ex-mining area Bestari Jaya, Peninsular Malaysia. International Journal of Basic & Applied Sciences IJBAS-IJENS 10(3): 7-12

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2011a. Heavy metals accumulation in plants growing in ex tin mining catchment. International Journal of Environmental Science and Technology 82: 401-416

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2011b. Analysis of physio-chemical parameters and distribution of heavy metals in soil and water of ex-mining area of Bestari Jaya, Peninsular Malaysia. Asian Journal of Chemistry 238: 3493-3499

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2012a. Speciation of heavy metals in the sediments of former tin mining catchment. Iranian Journal of Science and Technology 36(A2): 163-180

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2012b. Morphology, geology and water quality assessment of former tin mining catchment. The Scientific World Journal 2012: 1-15

Ashraf, M. A., Maah, M. J., and Yusoff, I. 2013. Evaluation of natural phytoremediation process occurring at ex-tin mining catchment. Chiang Mai Journal of Science 40(2): 198-213

Babu, D. J., Sumalatha, B., Venkateswarulu, T. C., Das, K. M., dan Kodali, V. P. 2014. Kinetic, equilibrium and thermodynamic studies of biosorption of Chromium (VI) from aqueous solutions using *Azolla Filiculoidus*. Journal of Pure and Applied Microbiology 8(4): 3107–3116

Baharom, Z. S., and Ishak, M. Y. 2015. Determination of heavy metal accumulation in fish species in Galas River, Kelantan and Beranang mining pool, Selangor. Procedia Environmental Sciences 2015(30): 320-325

Bao, Z., Bain, J., Saurette, E., Finfrock, Y. Z., Hu, Y., Ptacek, C. J., and Blowes, D. W. 2022. Mineralogy-dependent sulfide oxidation via polysulfide and thiosulfate pathways during weathering of mixed-sulfide bearing mine waste rock. Geochimica et Cosmochimica Acta 2022(317): 523-537.

Benavides, L. C. L., Pinilla, L. A. C., Serrezuela, R. R., and Serrezuela, W. F. R. 2018. Extraction in laboratory of heavy metals through rhizofiltration using the plant *Zea mays* (maize). International Journal of Applied Environmental Sciences 13(1): 9-26

Bruneel, O., Pascault, N., Egal, M., Bancon-Montigny, C., Goñi-Urriza, M. S., Elbaz-Poulichet, F., ..., and Duran, R. 2008. Archaeal diversity in a Fe–As rich acid mine drainage at Carnoulès (France). Extremophiles 12(4): 563-571

Byrne, P., Wood, P.J., and Reid, I. 2012. The impairment of river systems by metal mine contamination: a review including remediation options. Critical Reviews in Environmental Science and Technology 42(19): 2017-2077

Celebi E .E., and Oncel M. S. 2016. Determination of acid forming potential of massive sulfide minerals and the tailings situated in lead/zinc mining district of Balya (NW Turkey). Journal of African Earth Sciences 2016(124): 487-496

Chandra, R., Kumar, V., Tripathi, S., and Sharma, P. 2018. Heavy metal phytoextraction potential of native weeds and grasses from endocrine-disrupting chemicals rich complex distillery sludge and their histological observations during in-situ phytoremediation. Ecological Engineering 2018(111): 143-156

Chaturvedi, A. D., Pal, D., Penta, S., and Kumar, A. 2015. Ecotoxic heavy metals transformation by bacteria and fungi in aquatic ecosystem. World Journal of Microbiology and Biotechnology 31(10): 1595-1603

Damodaran, D., Suresh, G., and Mohan, R. B. 2011. Bioremediation of soil by removing heavy metals using *Saccharomyces cerevisiae*. 2ndInternational Conference on Environmental Science and Technology. Singapore

Daniel, V. N., Chudusu, E. S., Chup, J. A., and Pius, N. D. 2014. Variations of heavy metals in agricultural soils irrigated with tin water in Heipang District of Barkin Ladi, Plateau State, Nigeria. International Journal of Science and Technology 3(5): 255-263

Duarte, R. M., Ferreira, M. S., Wood, C. M., and Val, A. L. 2013. Effect of low pH exposure on Na^+ regulation in two cichlid fish species of the Amazon. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology 166(3): 441-448

Dixit, R., Wasiullah., Malaviya, D., Pandiyan, K., Singh, U. B., Sahu, A., …, and Paul, D. 2015. Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. Sustainability 7: 2189-2212

Dold, B. 2014. Evolution of acid mine drainage formation in sulphidic mine tailings. Minerals 4(3): 621-641

Dominguez-Castanedo, O., and Mosqueda-Cabrera, M. A., Valdesalici, S. 2013. First observations of annualism in *Millerichthys robustus* (Cyprinodontiformes: Rivulidae). Ichthyological Exploration of Freshwaters 24(1): 15-20

Dopson, M., and Johnson, D. B. 2012. Biodiversity, metabolism and applications of acidophilic sulfur-metabolizing microorganisms. Environmental Microbiology 14(10): 2620-2631

Dusengemungu, L., Kasali, G., Gwanama, C., and Mubemba, B. 2021. Overview of fungal bioleaching of metals. Environmental Advances 2021(5): 100083

El Sayed, M. T., and El-Sayed, A. S. 2020. Tolerance and mycoremediation of silver ions by *Fusarium solani*. Heliyon 6(5): e03866

Emmyrafedziawati, A. K. R., and Mohd Aziz, R. 2016. Photosynthetic bacteria identification and characterization by pufM gene. Technical Report for Crop and Soil Sciences Research Centre, MARDI

Erakhrumen, A. A. 2017. Phytoremediation: An environmentally sound technology for pollution prevention, control and remediation in developing countries. Educational Research and Review 2(7): 151-156

Fan, Y., Lu, Z., Chen, J., Zhou, Z., and Wu, G. 2002. Major ecological and environmental problems and the ecological reconstruction technologies of the coal mining areas in China. Acta Ecologica Sinica 23(10): 2144-2152

Franssen, C. M. 2009. The effects of heavy metal mine drainage on population size structure, reproduction, and condition of western mosquitofish, Gambusia affinis. Archives of Environmental Contamination and Toxicology 57(1): 145-156

Gaikwad, R. W., and Gupta, D. V. 2007. Acid mine drainage (AMD) management. Journal of Industrial Pollution Control 23(2): 283-295

Ghosh, M.,and Singh, S. 2005. A review on phytoremediation of heavy metals and utilization of it's by products. Applied Ecology and Environmental Research 2005(3): 1-18

Giri, K., Mishra, G., Pandey, S., Verma, P.K., Kumar, R., and Bisht, N. S. 2014. Ecological degradation in Northeastern coal fields: Margherita Assam. International Journal of Science, Environment and Technology 3(3): 881-884

Gomes, P., Valente, T., Albuquerque, T., Henriques, R., Flor-Arnau, N., Pamplona, J., Macías, F. 2021. Algae in acid mine drainage and relationships with pollutants in a degraded mining ecosystem. Minerals 11(110): 1-16

Gonzalez-Toril, E., Gomez, F., Malki, M., and Amils, R. 2006. The Isolation and study of acidophilic microorganisms. *In Methods in Microbiology* Vol. 35: 471-510. Academic Press

Goulding, K. W. T. 2016. Soil acidification and the importance of liming agricultural soils with particular reference to the United Kingdom. Soil Use and Management 32(3): 390-399

Guan, Y., Shao, C., and Ju, M. 2014. Heavy metal contamination assessment and partition for industrial and mining gathering areas. International Journal of Environmental Research and Public Health 11(7): 7286-7303

Guignard, M. S., Leitch, A. R., Acquisti, C., Eizaguirre, C., Elser, J. J., Hessen, D. O., ..., and Leitch, I.J. 2017. Impacts of nitrogen and phosphorus: from genomes to natural ecosystems and agriculture. Frontiers in Ecology and Evolution 5(70): 1-9

Gupta, G. N., Srivastava, S., Khare, S. K., and Prakash, V. 2014. Extremophiles: an overview of microorganism from extreme environment. International Journal of Agriculture, Environment and Biotechnology 7(2): 371-380

Hao, C., Wang, L., Gao, Y., Zhang, L., and Dong, H. 2010. Microbial diversity in acid mine drainage of Xiang Mountain sulfide mine, Anhui Province, China. Extremophiles 14(5): 465-474

Harahap, F.R. 2016. Restorasi lahan pasca tambang timah di Pulau Bangka. Society 4(1): 61-69

Harms, H., Schlosser, D., anda Wick, L. Y. 2011. Untapped potential: exploiting fungi in bioremediation of hazardous chemicals. Nature Reviews Microbiology 9(3): 177-192

Hashim, P., Nayan, N., Saleh, Y., Mahat, H., Said, Z.M., and Shiang, W. F. 2018. Water quality assessment of former tin mining lakes for recreational purposes in Ipoh city, Perak, Malaysia. The Indonesian Journal of Geography 50(1): 25-33

Hatar, H., Rahim, S. A., Razi, W. M., and Sahrani, F. K. 2013. Heavy metals content in acid mine drainage at abandoned and active mining area. In AIP Conference Proceedings Vol. 1571, No. 1: 641-646. AIP

Heidel C., and Tichomirowa M. 2011. Galena oxidation investigations on oxygen and sulphur isotopes. Isotopes in Environmental and Health Studies 47(2): 169- 188

Henny, C. 2011. Bioakumulasi beberapa logam pada ikan di kolong bekas tambang timah di Pulau Bangka. Limnotek 18(1): 83-95

Herliyanto, H., Budianta, D., and Hermansyah, H. 2014. Toksisitas logam besi (Fe) pada Ikan air Tawar. Jurnal Penelitian Sains 17(1): 26-28

Herniwanti, Priatmadi, J. B., Yanuwiadi, B., and Soemarno. 2013. Water plants characteristic for phytoremediation of acid mine drainage passive treatment. International Journal of Basic and Applied Sciences 13(6): 14-20

Herzog, C., Hartmann, M., Frey, B., Stierli, B., Rumpel, C., Buchmann, N., and Brunner, I. 2019. Microbial succession on decomposing root litter in a drought-prone Scots pine forest. The ISME Journal 13(9): 2346-2362

Hirata, T., Kaneko, T., Ono, T., Nakazato, T., Furukawa, N., Hasegawa, S., ..., and Hirose, S. 2003. Mechanism of acid adaptation of a fish living in a pH 3.5 lake. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 284(5): R1199-R1212

Horikoshi, K. 2016. Alkaliphiles. In Extremophiles: 53-78. Springer

Hui, D. 2012. Food web: concept and applications. Nature Education Knowledge 3(12): 6

Hwang, P. P., Lee, T.H., and Lin, L. Y. 2011. Ion regulation in fish gills: recent progress in the cellular and molecular mechanisms. American Journal of Physiology, Regulatory, Integrative and Comparative Physiology 301(1): R28-R47

Jalal, K. C. A., John, B. A., Habab, M., Mohd, A. Y., and Kamaruzzaman, B. Y. 2013. Bioaccumulation of selected metals in fresh water Haruan fish (*Channa striatus*) collected from Pahang River Basin, Malaysia. Oriental Journal of Chemistry 29(4): 1553-1558

Javanbakht, V., Alavi, S. A., and Zilouei, H. 2014. Mechanisms of heavy metal removal using microorganisms as biosorbent. Water Science and Technology 69(9): 1775-1787

Johnson, D. B., and Hallberg, K. B. 2008. Carbon, iron and sulfur metabolism in acidophilic micro-organisms. Advances in Microbial Physiology 54: 201-255

Jump, A. S., Marchant, R., Peñuelas, J. 2009. Environmental change and the option value of genetic diversity. Trends in Plant Science 14(1): 51-58

Kalu, C. M., Ogola, H. J. O., Selvarajan, R., Tekere, M., and Ntushelo, K. 2021. Fungal and metabolome diversity of the rhizosphere and endosphere of *Phragmites australis* in an AMD-polluted environment. Heliyon 7(3): e06399

Kaur, G., Couperthwaite, S. J., Hatton-Jones, B. W., and Millar, G. J. 2018. Alternative neutralisation materials for acid mine drainage treatment. Journal of Water Process Engineering 2018(22): 46-58

Korzhenkov, A. A., Toshchakov, S. V., Bargiela, R., Gibbard, H., Ferrer, M., Teplyuk, A. V., ..., and Golyshina, O.V. 2019. Archaea dominate the microbial community in an ecosystem with low-to-moderate temperature and extreme acidity. Microbiome 7(1): 1-14

Kurniawan, A. 2020. The metal oxides of abandoned tin mining pit waters as an indicator for bacterial diversity. Aquaculture, Aquarium, Conservation & Legislation Bioflux 13(5): 2982-2992

Kurniawan, A., dan Asriani, E. 2020. Review: Quorum sensing bakteri dan perananny‍a pada perubahan nilai pH di kolong pascatambang timah dengan umur berbeda. Jurnal Ilmu Lingkungan 18(3): 602-609

Kurniawan, A., dan Mustikasari, D. 2019. Review: Mekanisme akumulasi logam berat di ekosistem pascatambang timah. Jurnal Ilmu Lingkungan 17(3): 408-415

Kurniawan, A., dan Mustikasari, D. 2021. Review tentang kemampuan ikan ekstremofil untuk hidup di perairan asam dan terkontaminasi logam berat pascapenambangan timah. Jurnal Ilmu Lingkungan 19(3): 541-554

Kurniawan, A., Prasetiyono, E., dan Syaputra, D. 2020. Analisis korelasi parameter kualitas perairan kolong pascatambang timah dengan umur berbeda. Samakia: Jurnal Ilmu Perikanan 11(2): 91-100

Kurniawan, A. 2016. Microorganism communities response of ecological changes in post tin mining ponds. Research & Reviews: A Journal of Microbiology and Virology 6(1): 17-26

Kurniawan, A., Oedjijono., Tamad., Sulaeman, U. 2019. The pattern of heavy metals distribution in time chronosequence of ex-tin mining ponds in Bangka Regency, Indonesia. Indonesian Journal of Chemistry 19(1): 254-261

Kushkevych, I., Procházka, J., Gajdács, M., Rittmann, S.K.M., Vítězová, M. 2021. Molecular physiology of anaerobic phototrophic purple and green sulfur bacteria. International Journal of Molecular Sciences 22(12): 6398

Lad, R., and Samant, J. 2015. Impact of bauxite mining on soil: a case study of bauxite mines at Udgiri, Dist-Kolhapur, Maharashtra State, India. International Research Journal of Environment Sciences 4(2): 77-83

Leguizamo, M. A. O., Gómez, W.D.F., and Sarmiento, M. C. G. 2017. Native herbaceous plant species with potential use in phytoremediation of heavy metals, spotlight on wetlands-A review. Chemosphere 2017(168): 1230-1247

Lessmann, D., Fyson, A., and Nixdorf, B. 2000. Phytoplankton of the extremely acidic mining lakes of Lusatia (Germany) with pH ≤ 3. Hydrobiologia 433(1): 123-128

Li, Q., Wu, P., Zha, X., Li, X., Wu, L., Gu, S. 2018. Effects of mining activities on evolution of water chemistry in coal-bearing aquifers in karst region of Midwestern Guizhou, China: evidences from δ13C of dissolved inorganic carbon and δ34S of sulfate. Environmental Science and Pollution Research 25(18): 18038-18048

Lindeque, J. Z., Levanets, O., Louw, R., and Van Der Westhuizen, F. H. 2010. The involvement of metallothioneins in mitochondrial function and disease. Current Protein and Peptide Science 11(4): 292-309

Liu, Y., Wu, H., Kou, L., Liu, X., Zhang, J., Guo, Y., and Ma, E. 2014. Two metallothionein genes in Oxya chinensis: molecular characteristics, expression patterns and roles in heavy metal stress. PloS ONE 9(11): e112759

Long, A., Zhang, J., Yang, L. T., Ye, X., Lai, N. W., Tan, L. L., ..., and Chen, L. S. 2017. Effects of low pH on photosynthesis, related physiological parameters, and nutrient profiles of citrus. Frontiers in Plant Science 8: 185

Maltman, and C., Yurkov, V. 2019. Extreme environments and high-level bacterial tellurite resistance. Microorganisms 7(12): 601

Mansouri, B., and Baramaki, R. 2011. Influence of water hardness and pH on acute toxicity of Hg on fresh water fish *Capoeta fusca*. World Journal of Fish and Marine Sciences 3(2): 132-136

Mejia, E. R., Ospina, J. D., Marquez, M. A., and Morales, A.L. 2009. Oxidation of chalcopyrite ($CuFeS_2$) by *Acidithiobacillus ferrooxidans* and a mixed culture of *Acidithiobacillus ferrooxidans* and *Acidithiobacillus thiooxidans* like bacterium in shake flasks. In Advanced Materials Research 2009(71-73): 385-388. Trans Tech Publications. Switzerland

Mendez, M. O., Neilson, J. W., and Maier, R. M. 2008. Characterization of a bacterial community in an abandoned semiarid lead-zinc mine tailing site. Applied and Environmental Microbiology 74(12): 3899-3907

Merino, N., Aronson, H. S., Bojanova, D. P., Feyhl-Buska, J., Wong, M. L., Zhang, S., and Giovannelli, D. 2019. Living at the extremes: extremophiles and the limits of life in a planetary context. Frontiers in Microbiology 10: 780

Mustikasari, D., and Agustiani, R. D. 2021. DNA barcoding ikan kepala timah dan betok berdasarkan gen coi sebagai ikan pioneer di kolong pascatambang timah, Pulau Bangka. Samakia: Jurnal Ilmu Perikanan 12(1): 86-95

Mustikasari, D., Nuryanto, A., and Suryaningsih, S. 2020. The presence of blue panchax (*Aplocheilus panchax*) in the waters, contaminated by heavy metals, of the abandoned tin mining pits of different age. Aquaculture, Aquarium, Conservation & Legislation 13(5): 2538-2550

Ndubuisi, U. C., Chimezie, A. J., Chinedu, U. C., Chikwem, I. C., and Alexander, U. 2015. Effect of pH on the growth performance and survival rate of Clarias gariepinus fry. International Journal of Research in Biosciences 4(3): 14-20

Oktavia, D., Setiadi, Y., dan Hilwan, I. 2014. Sifat fisika dan kimia tanah di hutan kerangas dan lahan pasca tambang timah Kabupaten Belitung Timur. Jurnal Silvikultur Tropika 5(3): 149-154

Oren A. 2010. Acidophiles. In Encyclopedia of Life Sciences (ELS). John Wiley & Sons, Ltd: Chichester

Oyetibo, G. O., Enahoro, J. A., Ikwubuzo, C. A., and Ukwuoma, C. S. 2021. Microbiome of highly polluted coal mine drainage from Onyeama, Nigeria, and its potential for sequestrating toxic heavy metals. Scientific Reports 11(1): 1-15

Plaza-Cazón, J., Benítez, L., Murray, J., Kirschbaum, P., and Donati, E. 2021. Influence of extremophiles on the generation of acid mine drainage at the abandoned pan de azúcar mine (Argentina). Microorganisms 9(2): 281

Pociecha, A., Bielańska-Grajner, I., Szarek-Gwiazda, E., Wilk-Woźniak, E., Kuciel, H., Walusiak, E. 2018. Rotifer diversity in the acidic pyrite mine pit lakes in the Sudety Mountains (Poland). Mine Water and the Environment 37(3): 518-527

Pozo-Antonio, S., Puente-Luna, I., Lagüela-López, S., and Veiga-Ríos, M. 2014. Techniques to correct and prevent acid mine drainage: A review. Dyna 81(186): 73-80

Prieto-Barajas, C. M., Valencia-Cantero, and E., Santoyo, G. 2018. Microbial mat ecosystems: Structure types, functional diversity, and biotechnological application. Electronic Journal of Biotechnology 2018(31): 48-56

Rajeshkumar, S., and Li, X. 2018. Bioaccumulation of heavy metals in fish species from the Meiliang Bay, Taihu Lake, China. Toxicology Reports 2008(5): 288-295

Rampelotto, P. H. 2013. Extremophiles and extreme environments. Life 3(3): 482-485

Rao, D. V., Shivannavar, C. T., and Gaddad, S. M. 2002. Bioleaching of copper from chalco pyrite ore by fungi. Indian Journal of Experimental Biology 2002(40): 319-324

Rathgeber, C., Beatty, J. T., and Yurkov, V. 2004. Aerobic phototrophic bacteria: new evidence for the diversity, ecological importance and applied potential of this previously overlooked group. Photosynthesis Research 81(2): 113-128

Rosidah, dan Henny C. 2012. Kajian logam Fe, Al, Cu dan Zn pada perairan kolong paska penambangan timah di Pulau Bangka. Prosiding Seminar Nasional Limnologi VI: 611-619

Singh, P. K., Afzal, I., Ravi, S., Dhanesh, S., and Shivi, S. 2013. A study about ecological imbalance in Surguja (India) coalfield area due to mining. International Research Journal of Environment Sciences 2(4): 10-14

Sinha, A., Sinha, R., and Khare, S. K. 2014. Heavy metal bioremediation and nanoparticle synthesis by metallophiles. In *Geomicrobiology and Biogeochemistry* (pp. 101-118). Springer, Berlin, Heidelberg

Siswati, N. D., Indrawati, T., and Rahmah, M. 2009. Biosorpsi logam berat plumbum (Pb) menggunakan biomassa *Phanerochaete chrisosporium*. Jurnal Ilmiah Teknik Lingkungan 1(2): 67-72

Skousen, J. G., Sexstone, A., and Ziemkiewicz, P. F. 2000. Acid mine drainage control and treatment. Reclamation of Drastically Disturbed Lands 2000(41): 131-168

Sow, S. L. S., Khoo, G., Chong, L. K., Smith, T. J., Harrison, P. L., and Ong, H. K. A. 2014a. Molecular diversity of the methanotrophic bacteria communities associated with disused tin-mining ponds in Kampar, Perak, Malaysia. World Journal of Microbiology and Biotechnology 30(10): 2645-2653

Sow, S. L. S., Khoo, G., Chong, L. K., Smith, T. J., Harrison, P. L., and Ong, H. K. A. 2014b. Molecular diversity of the ammonia-oxidizing bacteria community in disused tin-mining ponds located within Kampar, Perak, Malaysia. World Journal of Microbiology and Biotechnology 30(2): 757-766

Srichandan, H., Mohapatra, R. K., Parhi, P. K., and Mishra, S. 2019. Bioleaching approach for extraction of metal values from secondary solid wastes: a critical review. Hydrometallurgy 2019(189): 105122

Srineetha, U., Reddy, M. V., and Bhaskar, M. 2014. Effect of environmental acidic ph on oxygen consumption in different stages of fish, *Cyprinus carpio* (L). IOSR Journal of. Environmental Science, Toxicology and Food Technology 8(8): 17-21

Stallinga P. 2018. Carbon dioxide and ocean acidification. European Scientific Journal 14(18): 1857-7881

Sukono, G. A. B., Hikmawan, F. R., Evitasari, E., dan Satriawan, D. 2020. Mekanisme Fitoremediasi. Jurnal Pengendalian Pencemaran Lingkungan 2(2): 40-47

Syandri, H., Azrita., Junaidi., dan Elfiondri. 2015. Heavy Metals in Maninjau Lake, Indonesia: water column, sediment and biota. International Journal of Fisheries and Aquatic Studies 3(2): 273-278

Vijayakumar, S., Sakthivel, M., Murugesan, S., dan Narmada, K. 2019. Potential of Hydrogen (pH) to monitor the multi temporal: A case study of Nagapattinam District. Journal of Applied Science and Computation 6(1): 1173-1152

Vyas A, dan Pancholi A. 2009. Environmental degradation due to mining in South Rajasthan: a case study of Nimbahera, Chittorgarh (India). Journal of Environmental Research and Development 4(2): 405-412

Wang, Z., Xu, Y., Zhang, Z., dan Zhang, Y. 2021. Acid mine drainage (AMD) in abandoned coal mines of Shanxi, China. Water 13(8): 1-21

Widad, F., dan Abdullah, M. 2013. Preliminary study of heavy metals pollution in freshwater fishes of Sungai Simpang Empat, Penang. Journal of Academia 3(1): 48-65

Yan, A., Wang, Y., Tan, S. N., Mohd Yusof, M. L., Ghosh, S., and Chen, Z. 2020. Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. Frontiers in Plant Science 11: 359

Zeng, Y., Feng, F., Medová, H., Dean, J., and Koblížek, M. 2014. Functional type 2 photosynthetic reaction centers found in the rare bacterial phylum Gemmatimonadetes. Proceedings of the National Academy of Sciences, 111(21): 7795-7800

Zhang, G., Dong, H., Jiang, H., Kukkadapu, R. K., Kim, J., Eberl, D., and Xu, Z. 2009. Biomineralization associated with microbial reduction of Fe^{3+} and oxidation of Fe^{2+} in solid minerals. American Mineralogist 94(7): 1049-1058

Zhang, X., Tang, S., Wang, M., Sun, W., Xie, Y., Peng, H., ..., and Hecker, M. 2019. Acid mine drainage affects the diversity and metal resistance gene profile of sediment bacterial community along a river. Chemosphere 2019(217): 790-799

Zhu, D., Adebisi, W. A., Ahmad, F., Sethupathy, S., Danso, B., and Sun, J. 2020. Recent development of extremophilic bacteria and their application in biorefinery. Frontiers in Bioengineering and Biotechnology 8: 483