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Risk Assessment and Ecotoxicology

Limitations and Recommendations for Ocean Disposal of Mine Waste in the Coral Triangle

BY AMANDA REICHELT-BRUSHETT

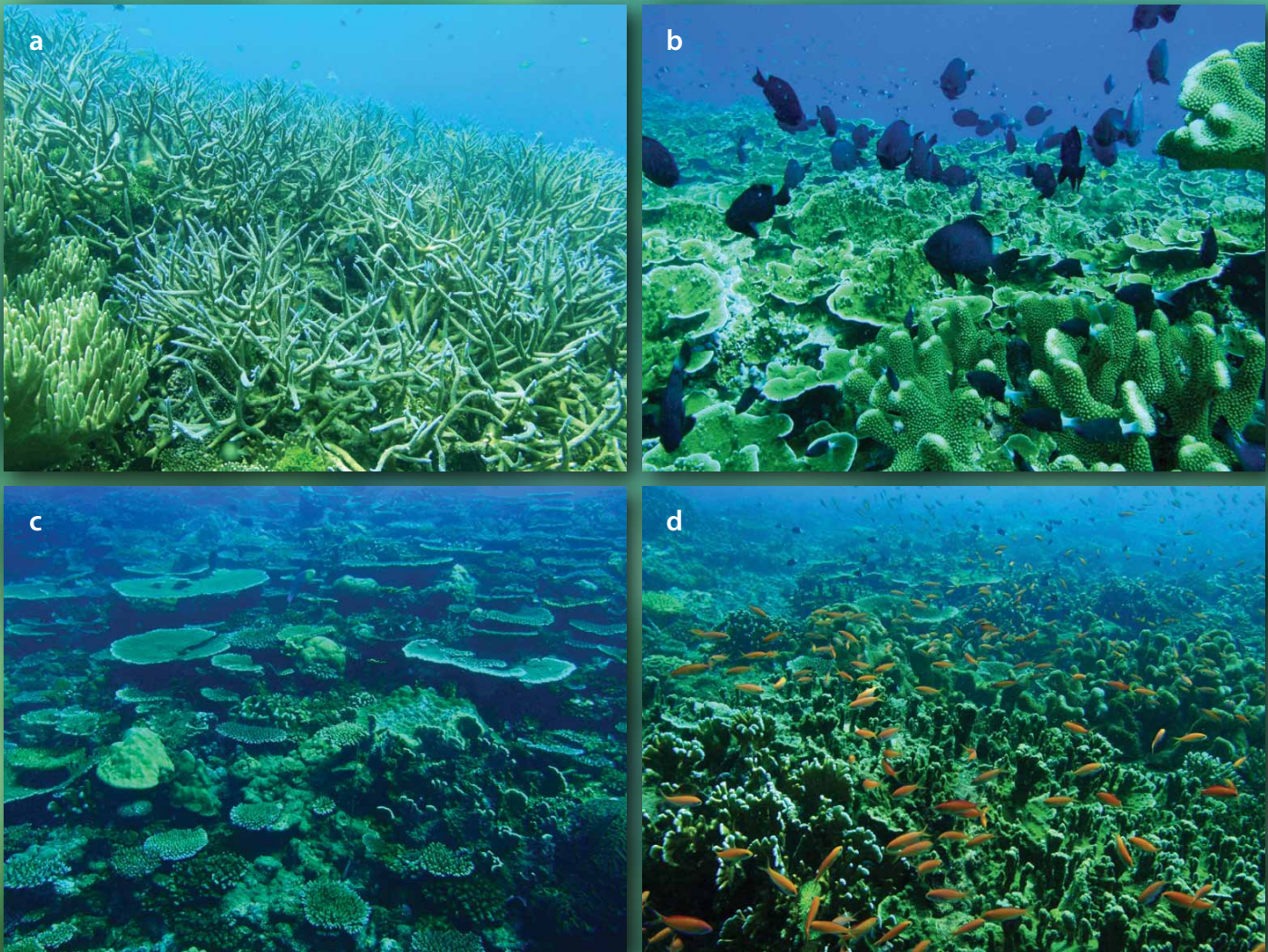


Figure 1. Examples of coral reef communities in Astrolabe Bay, Madang, PNG, near where disposal of Ramu Nickel Project tailings is expected to commence in 2012. (a) Reef slope dominated by a fast-growing *Acropora formosa* community (*Sinularia* sp. soft coral colonies on the left). (b) Massive branching blade-like *Pocillopora eydouxi* in the foreground, complemented by an extensive monospecific stand of *Montipora* sp. in the background. (c) High-diversity reef slope dominated by fast growing *Acropora* sp. plate corals. (d) High-impact reef front characterized by female *Anthias* sp. nestling amongst encrusting *Montipora* sp. and massive *Psammocora* sp. (background). Photos by A. Reichelt-Brushett, taken in 2010

ABSTRACT. Mining is an important contribution to the economy of many developing tropical regions. Many sites of mining interest in the tropics have island geographies and potentially limited land area. While the limited land area may drive consideration of tailings disposal to the ocean, it is important to recognize that local communities depend on the ocean as a major supplier of dietary protein. Impact assessment of tailings disposal to the ocean is usually limited by budgets and time frames that result in a limited capacity to understand longer-term risks to food chains and marine ecosystems, including the interactions between deeper- and shallower-water ecosystems. This article reviews three factors—tailing characterization, ecotoxicology, and bioaccumulation/biomagnification—in relation to the current application of these methods to risk assessment of submarine tailings disposal (STD), and it identifies ways to improve current practices. A decision-tree approach has been developed specific to STD risk assessment for implementation at the pre-proposal stage of a project. This decision tree highlights the urgent need for development and application of suitable and relevant risk assessment tools for tropical marine environments and identifies opportunities for intergovernmental standards for risk assessment of marine disposal of mine tailings within the framework of the Coral Triangle Initiative.

INTRODUCTION

The Coral Triangle region is located on the equator at the confluence of the Western Pacific and Indian Oceans (Veron et al., 2009). The boundaries cover an area that, from a broad scientific consensus, represents the global epicenter of marine life abundance and diversity (Coral Triangle Initiative, 2009). The region contains 53% of the world's coral reefs (e.g., Figure 1), 76% of all known coral species (Veron et al., 2009), 37% of all known coral reef fish species, and the largest area of mangroves in the world, and it is the spawning ground for the world's largest tuna fishery (Coral Triangle Initiative, 2009).

The leaders of Indonesia, the Philippines, Timor Leste, Papua New Guinea, Solomon Islands, and Malaysia signed the Coral Triangle Initiative Leaders' Declaration on Coral Reefs, Fisheries and Food Security on May 15, 2009 (see <http://www.coraltriangleinitiative.org/library/cti-leaders-declaration>). The Declaration

expresses concern over the increasing level of degradation of marine, coastal, and small island ecosystems. It reaffirms the need for cooperative sustainable management and states that these efforts “contribute effectively to strengthening food security, increasing resilience, and adaptation to climate change.” These considerations are important when assessing the impacts of submarine tailings disposal (STD).

SUBMARINE TAILINGS PLACEMENT IN THE CORAL TRIANGLE

There is currently a resource boom worldwide, with an increasing number of international players in the field of resource development. Mineral-rich ores are abundant in countries in the Coral Triangle region, in particular, Indonesia, Papua New Guinea, and the Philippines (e.g., Tse, 2007; Laznicka, 2010). The development of mine sites in these areas is a potential source of income to communities and regions;

however, distribution of income is often fraught with difficulties, and little attention is paid to sustainable management practices.

Figure 2 shows past, current, and potential future STD operations in the Coral Triangle. Three mines currently use STD (Lihir and Simberi Island in Papua New Guinea [PNG] and Batu Hijau in Indonesia), and 14 more operations have recently considered or are currently considering tailings disposal into the ocean (Table 1). The current and proposed use of STD is most prominent in Papua New Guinea. The area around the recently approved STD for the Ramu Nickel Project in northern Papua New Guinea was identified as contributing high levels of biodiversity to the Coral Triangle as a result of present-day ocean currents (Kool et al., 2011). Mines in the Philippines and Indonesia where STD has recently been considered have opted for other tailings management systems.

There are several areas of environmental concern in shallow and deeper waters associated with tailings behavior during STD. These concerns are demonstrated in the conceptual model in Figure 3 and explained below.

- At the site of disposal (the end of a pipeline), which is usually between 50 and 150 m depth, tailings spread over benthic communities. The physical smothering of organisms by tailings and the toxicity of the tailings must both be considered in risk assessment.

Amanda Reichelt-Brushett (*amanda.reichelt-brushett@scu.edu.au*) is Senior Lecturer, School of Environmental Science and Management, Southern Cross University, Lismore, NSW, Australia.

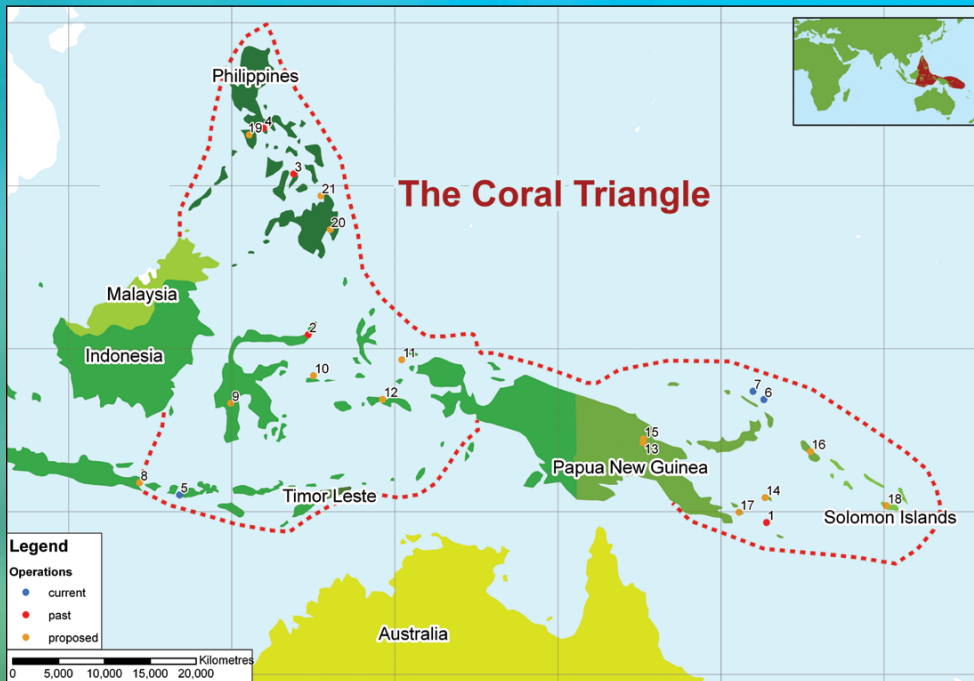


Figure 2. Map showing distribution of past, current, and proposed/under consideration submarine tailings disposal (STD) operations within the Coral Triangle. Numbers are relevant to site information in Table 1. Map adapted from Veron et al. (2009) by Greg Luker, Southern Cross University

Table 1. Details of past, present, and proposed submarine tailings disposal (STD) sites identified in Figure 2.

FIGURE 2 SITE NUMBER	TAILINGS DISPOSAL DETAILS	GENERAL LOCATION	LATITUDE/LONGITUDE
Past Mining Operations			
1 Misima (Au)	Pipe depth: 110 m	Misima Island, Papua New Guinea; Buyat Bay, North Sulawesi, Indonesia	10°40'42"S/152°47'50"E
2 Minahasa Raya (Au)	Pipe depth: 82 m	Buyat Bay, North Sulawesi, Indonesia	0°50'54"N/124°42'08"E
3 Atlas Mine (Cu, Au)	Pipe depth: 10–30 m	Cebu Island, Philippines	10°43'16.52"N/123°48'18.30"E
4 Marcopper (Cu)	Pipe depth: 6 m	Marinduque Island, Philippines	13°31'33.14"S/121°57'57.04"E
Current Mining Operations			
5 Batu Hijau (Cu/Au)	108 m	Sumbawa Island, Indonesia	8°59'00"S/116°48'43"E
6 Lihir (Au)	120 m	Papua New Guinea	03°07'34.02"S/152°38'15.7"E
7 Simberi Island (Au, Ag)	130 m	Papua New Guinea	2°37'29"S/151°58'26"E
STD Option Considered			
8 Banyuwangi (Au)	STD now considered unlikely	Banyuwangi, East Java	8°14'11"S/114°21'30"E
9 Awak Mas (Au)	STD now considered unlikely	Sulawesi, Indonesia	3°21'38"S/119°57'26"E
10 Toka Tindung (Au)	STD now considered unlikely	Sulawesi, Indonesia	1°39'41"S/125°01'25"E
11 Gag Island (Ni)	Mine development uncertain; STD now unlikely	Indonesia	0°41'00"S/130°25'54"E
12 Central Maluku (Au)	STD considered; mine development on hold	Indonesia	3°07'16"S/129°15'47"E
13 Marobe, Yandera (Cu, Mo)	STD recently considered and land-based tailings disposal option announced May 30, 2012	Papua New Guinea	05°46'28.20"S/145°14'1.55"E
14 Woodlark (Au)	STD currently being considered	Papua New Guinea	09°08'40.8"S/152°42'46.85"E
15 Ramu Nickel Project (Ni, Co)	STD approved; not yet commenced	Papua New Guinea	5°33'05.47"S/145°14'57.04"E
16 Bougainville (Cu)	STD considered an option	Bougainville, Papua New Guinea	6°18'52.00"S/155°29'39.51"E
17 Imwauna (Normanby) (Au, Ag)	STD previously considered; currently on-land storage of tailings	Papua New Guinea	10°02'58"S/151°07'20"E
18 Buguto Mine (Ni)	STD may be considered	Solomon Islands	
19 Mindoro Oriental (Ni)	STD now considered unlikely	Philippines	13°06'56.42"N/121°04'54.87"E
20 Kingking, Mindanao (Au, Cu)	STD now considered unlikely	Philippines	07°18'12.50"N/126°02'57.51"E
21 Surigao Project (Ni)	STD currently being considered	Philippines	09°22'35.04"N/125°28'40.24"E

- There is a risk of pipe breakage and tailings leakage into shallow waters, resulting in shallow water impacts.
- The pipeline is preferably near a submarine canyon, and once discharged, tailings are expected to travel downslope to the deep seafloor and settle. Tailings density, local upwelling, currents, and other conditions will influence the likelihood of tailings redistribution and settlement (Figure 3).
- Tailings movement may be subject to plume shearing, where part of the tailings plume is “sheared off” at various depths. Instead of falling to the seafloor, tailings become distributed in the water column and transported with tide and currents, subsequently impinging on a much greater area and increasing the risk of chemicals entering the food chain (Figure 3).
- Upwelling and current patterns may influence where tailings are transported and deposited. The upwelling and currents can be related to ocean systems and cycles that occur over years to decades (e.g., El Niño/La Niña).
- Catastrophic events such as underwater earthquakes or tsunamis may redistribute tailings into nearshore environments.
- Site-specific conditions over time will ultimately control the movement of tailings.

Past operations where STD has been used in the Coral Triangle have reported impacts to marine communities, including biological degradation due to heavy siltation (Carr et al., 2000; Shimmield et al., 2010), metal toxicity and/or metal contamination in sediments (e.g., Carr et al., 2000; Edinger, 2008; Shimmield et al., 2010), metal accumulation in biota

(Brewer et al., 2007; Lasut et al. 2010), and impacts to coastal people such as mercury exposure through food and subsequent accumulation (e.g., Lasut et al., 2010). Some of these impacts, such as widespread metal contamination (e.g., McKinnon, 2002; Edinger, 2008; Shimmield et al., 2010), were not predicted in the risk assessments to the extent they prevailed, or such risk assessments were not required. Recent studies of STD from Lihir Gold (PNG) have also shown that animal diversity and abundance have been greatly affected in areas where tailings have been deposited, and it was reported in 2005 that the tailings spread over a 60 km² area of the seafloor (Shimmield et al., 2010; see also McKinnon, 2002). Shimmield et al. (2010) also found that trace metal concentrations in sediment at the affected sites were far greater than those found in natural sediments, in some cases 50 times higher than background.

TAILINGS DISPOSAL AND DEPOSITIONAL ENVIRONMENTS

Tailings distribution and transport in the water column pose some risks, and they also directly affect benthic communities at the disposal site. Tailings are expected to move from the pipelines several kilometers down canyon areas to the seafloor, affecting not only benthic environments at the end of the pipeline but also deeper sea ecosystems (actual depth depends on location). Deep-sea diversity in the Coral Triangle is among the highest on Earth (e.g., Snelgrove and Smith, 2002), and communities are distinct from shallow-water fauna (Pante et al., 2012). Since 1840, 28 new habitats/ecosystems have been discovered during deep-sea research in

general (Ramirez-Llodra et al., 2010). Furthermore, the heads of canyons are described as productive nursery areas for fish (Yoklavich et al., 2000).

Depths below ~ 50–100 m are often referred to as suitable for STD (e.g., Ellis, 2008), and all mines using STD discharge at < 150 m depth, often much shallower, and often very close to shore. Biodiversity research at around 60–150 m depth shows a rich diversity of fish species, many new to science (Pyle, 2000). Based on these studies, it is conservatively estimated that 2,000 or more coral-reef fish species await discovery at these depths throughout the Indo-Pacific region (Pyle, 2000).

The impacts of chemical contaminants and sedimentation introduced by anthropogenic sources are largely unexplored in waters deeper than the scuba range (~ 50 m; Ahnert and Borowski, 2000; Madin et al., 2004; Ramirez-Llodra et al., 2010). For example, at the bottom of canyons where tailings eventually settle, we have little understanding of how chemoautolithotrophic bacteria (bacteria that depend on chemical reactions instead of photosynthesis to provide energy and essential nutrients), which play the role of primary producers, respond to contaminant loads. The relationships between bacteria and other species in these areas are only beginning to be understood (e.g., Ramirez-Llodra et al., 2010). The potential future value of these unique ecosystems has barely been contemplated (e.g., Fenical, 2006).

WEIGHT-OF-EVIDENCE APPROACH TO ASSESS RISK

There is a notable lack of research on both the short- and long-term impacts of STD. New research is needed in areas related to plume modeling, toxicology,

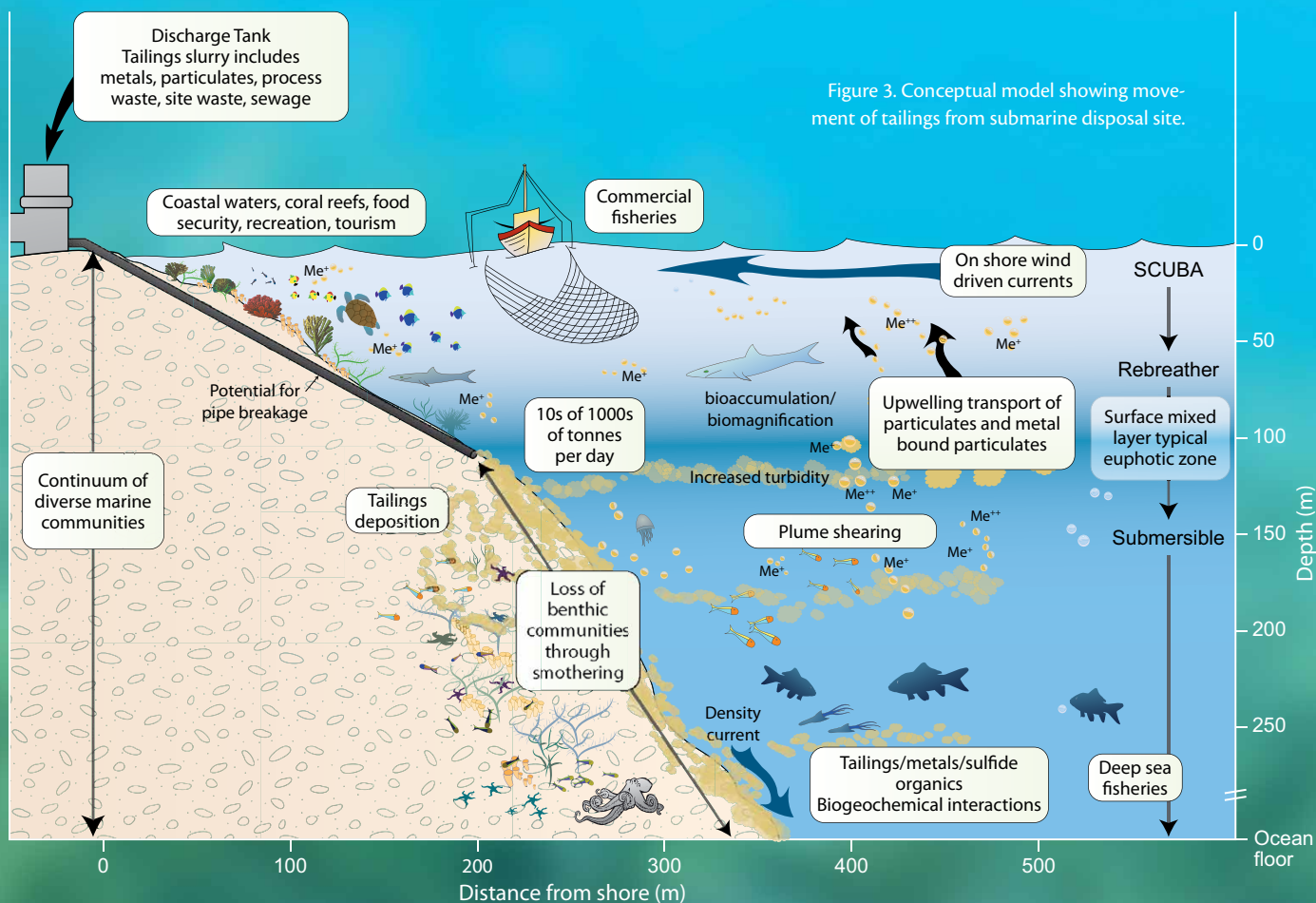
biological impacts, and environmental economics (e.g., Ellis, 2008). Risk assessment in general is a broad, multidimensional framework that covers concerns, consequences, calculations, certainties and uncertainties, comparisons with criteria, control, and communication (Beer and Ziolkowski, 1995). Using a weight-of-evidence approach to determine when contamination (elevation in the concentration of substances compared to natural condition) becomes pollution (elevation in the concentration of substances that results in detrimental effects) (e.g., Chapman, 2007) provides a focus for assessing the potential impacts of STD. This approach uses multiple lines

of evidence, including both chemical and biological measurements with laboratory and field components of study where manipulations are conducted to assist in understanding and predicting future conditions (Chapman, 2007). Three factors in the weight-of-evidence approach to risk assessment are considered below in regard to STD.

Tailings Characterization

The specific mixture of trace metals and other contaminants in tailings depends on ore type and extraction processes. Given the high volumes of tailings that must be managed, the rate of supply of these contaminants also needs to be

understood. Basic chemical and physical studies are required to investigate tailings characteristics, including mineralogy, grain size, density, and the range of contaminants as well as their concentration and their bioavailability (e.g., Koski, 2012). Operationally defined tests such as weak acid leaches and acid-volatile sulfide and simultaneously extracted metals (AVS-SEM) are available to provide a proxy for metal bioavailability (ANZECC and ARMCANZ, 2000). These tests are conducted under standardized laboratory conditions that do not account for the different conditions the tailings will be exposed to at the disposal environment, in plume shearing,



down the canyon areas where tailings are expected to traverse, or on the sea-floor where the tailings are expected to settle. Conditions such as pressure, dissolved oxygen, pH, temperature, organic loads, and microorganism behavior will vary along the depth continuum of the affected area. Studies that take these varying conditions into consideration should be completed (see also Chapman, 2008). Furthermore, these studies should be conducted on the “mixture” or whole effluent being discharged. The effluent may contain not only the tailings but also potentially mine site and mine accommodation sewage and wastewater, and wastewater from mine operations, including cleaning, processing, and on-site laboratory wastes. The addition of organic wastes may result in extreme changes in metal behavior and availability (e.g., Simpson et al., 2005).

Once tailings are disposed of in the ocean, trace metal availability to organisms will depend on the physico-chemical conditions specific to the location, and these conditions will have varied toxicity implications for different metals (e.g., Luoma, 1996; Koski, 2012). On a finer scale, benthic organisms living within or close to sediment may interact with anoxic sediment and be exposed to higher levels of the toxic-free metal ions that have dissociated from complexes in the pore water. Organism interaction with sediment may also change local physico-chemical conditions (e.g., pH change through digestive acids and organic complexation through mucus secretion) and influence the availability and subsequent toxicity of trace metals and their complexes (see also McConchie and Lawrence, 1991; Luoma, 1996; Reichelt-Brushett and McOrist, 2003). Microbial activity in the deep

sea is abundant (Smith and D’Hondt, 2006) and influences metal availability in ways we do not yet fully understand (Apte and Kwong, 2004).

Ecotoxicology

Ecotoxicological studies used to document the effects of pollutants, at known concentrations, on living organisms are part of the “tool kit” for risk assessment (e.g., Chapman and Long, 1983; Chapman 2008). These studies supplement conventional analyses of pollutant concentrations in the environment. Effective environmental management requires having relevant ecotoxicological data specific to the environment of concern (Chapman et al., 2006) that considers not only concentrations of pollutant mixtures but also their rate of supply to the environment. Peters et al. (1997) stressed that managers of tropical marine ecosystems have few tools to aid in decision making and policy implementation, and little has changed since their article’s publication. More recently, in 2008, van Dam and coworkers reviewed tropical marine ecotoxicology in Australia and identified a paucity of fully developed routine and regionally relevant toxicity tests, a deficiency that is also evident in other tropical regions of the world.

Due to the lack of tropical marine ecotoxicology data, it is not possible to compare differences in sensitivities between tropical and temperate marine organisms. However, a study by Kwok et al. (2007) on the sensitivities of freshwater tropical and temperate animals to various chemicals suggests that there are, indeed, differences in species sensitivities to different chemicals, highlighting that temperate species are not suitable proxies for tropical species, at least in freshwater environments. It is also important

to recognize that tropical ecosystems have different taxonomic structures than temperate ecosystems, and in tropical coral reefs, cnidarians and, specifically, hard corals are keystone organisms (key species in ecosystem structure and function). Though cnidarians in general are poorly represented in ecotoxicology, various studies show that, compared to other marine species, they are relatively sensitive to chemicals (Reichelt-Brushett and Harrison, 1999, 2000, 2004, 2005; Negri and Hayward, 2001; Reichelt-Brushett and Michalek-Wagner, 2005; Hughes et al., 2005; Gopalakrishnan et al., 2008; Harford et al., 2011; and Negri et al., 2011). In particular, the studies cited show that coral fertilization and early life stage development are commonly more sensitive to chemicals than other marine species.

Currently, most commercial toxicity tests available are used for assessing contaminants in waters, while sediment/tailings toxicity tests and porewater toxicity tests are generally less common (Adams and Stauber, 2008). This limitation is serious in the case of STD because tailings and porewater toxicity are important concerns when considering the benthic impacts of the discharge material, potential recolonization of tailings by benthic communities, and food chain interactions.

Limitations in the appropriate application of ecotoxicity testing in risk assessment of STD is evident in the Ramu Nickel Project Environmental Plan (NSR, 1999) and in later studies after ore processing conditions changed (e.g., Enesar, 2007). This project will discharge an estimated 14,000 tonnes of tailings per day for more than 20 years in the Basamuk area of PNG, and it is likely to commence in 2012. The ecotoxicity

studies in the environmental plan and follow-up studies mostly used temperate species available from commercial laboratories—not local species. Some basic expectations of broad ecotoxicological applications to risk assessment were lacking. All ecotoxicity testing used filtered water (either 0.22 µm or 0.45 µm) from tailings extracts; some filtered samples were stored for several days and transported before testing commenced, resulting in measured and documented metal loss in the test water, which was probably due to adsorption onto container walls. All tests were ≤ 96 hours exposure duration and in static conditions. While a short-term chronic test was completed, no longer-term tests (weeks to months) were completed to assess the effects of exposure over longer time periods on organisms with longer life cycles. No porewater toxicity tests or sediment/tailings toxicity tests using organisms were conducted. Toxicity Identification Evaluations (TIE) methods were not used but could have provided valuable biological and chemical information to assist with understanding toxicity in different physico-chemical conditions such as described in Ankley et al. (1992) for assessing dredged materials.

Toxicity tests that have been conducted at other sites that use STD are generally not in the public domain. This lack of transparency reduces our capacity to enhance understanding of the risks associated with STD.

Bioaccumulation/ Bioconcentration/ Biomagnification

Studies on the uptake and storage of contaminants, including trace metals, are important for identifying food chain transfer and transfer to offspring

(e.g., Lasut and Yasuda, 2008; Lasut et al., 2010). Enhanced metal loads can affect critical stages of growth and development of offspring and/or the reproductive capacity of adults. Some marine organisms are quite efficient at detoxifying metals using storage mechanisms such as the production of metal-rich granules (e.g., Wang and Rainbow, 2005) and/or metallothioneins (MTNs; e.g., Cajaraville et al., 2000; Lui and Wang, 2011). These storage mechanisms can be used to measure organisms' protective biological responses from enhanced metal loads and the limits of this protective capacity. Metal loads that are stored in such ways may also become available to predators.

Metal accumulation in organisms depends on the amount taken up through various pathways, including from food, water, and sediment, through gills, feeding, and diffusion, and the amount depurated (removed) over time. The uptake rate will vary with key characteristics of the organism such as species, food source, feeding mechanisms, age, sex, reproductive status, and health. Studies designed to measure uptake in organisms must define the rate of supply through various exposure pathways over time. Such studies conducted in situ must account for degree of exposure related to the home range of the organism and the location of this range in the context of the metal source. Although studies are best conducted on sessile or sedentary organisms to ensure some certainty about exposure rate, there is a tendency to investigate metal loads in large edible fish that are "caught" near defined impact sites and at set distances from these impact sites. Studies on metal accumulation in fish are often hampered by the lack of certainty

about their history and exposure rates (e.g., Brewer et al., 2007).

Very little is known about trace metal concentrations in deep-sea organisms that might be found where tailings settle at the bottom of canyons and their responses to changes in environmental conditions (Koschinsky et al., 2003). Due to the types of energy sources used by these organisms, the bioaccumulation pathways may be quite unlike other organisms and may explain the generally high metal burdens found in some deep-sea organisms (Geret et al., 1998). A better understanding of life history, reproductive mechanisms, taxonomic detail, food chains, metal accumulation pathways, toxic responses, and toxicity thresholds in deep-sea communities is required to adequately assess risk in these environments. Bioaccumulation studies of deep-sea organisms will rely on the development of good taxonomic and life-history information of the species being studied.

THE WAY FORWARD FOR STD RISK ASSESSMENT

Understanding the risk to the environment from STD covers a range of discipline-specific areas that must take into consideration not only the impact of tailings at the discharge site but also the risk associated with movement and redistribution of tailings, including down submarine canyons into abyssal areas. The decision-tree approach to toxicity risk assessment in Figure 4 has been developed for use in STD and takes into consideration the limitations that have been identified in this review. The process must also enable communities that are potentially affected by STD to have an opportunity to respond to the risk assessment and raise any additional

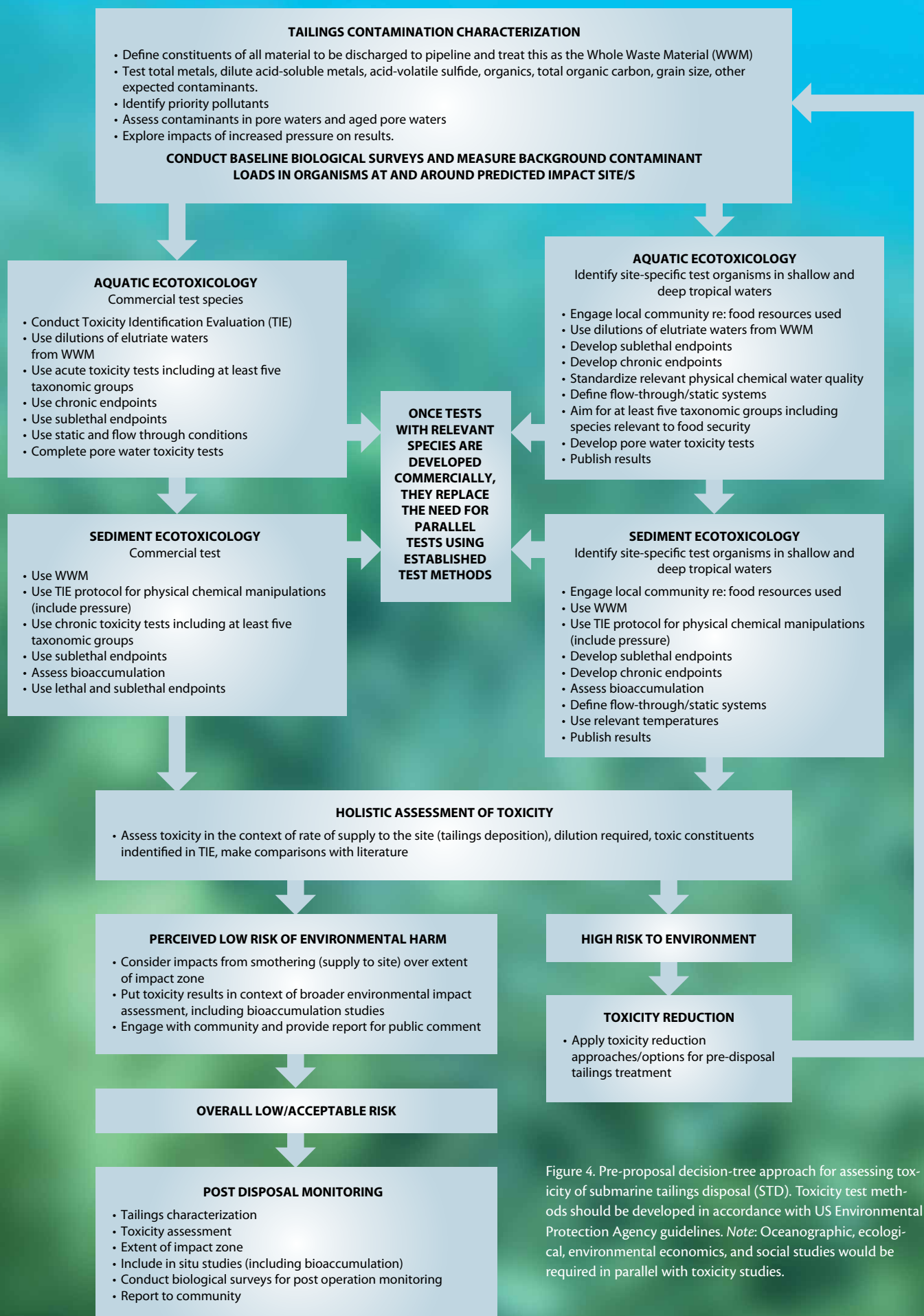


Figure 4. Pre-proposal decision-tree approach for assessing toxicity of submarine tailings disposal (STD). Toxicity test methods should be developed in accordance with US Environmental Protection Agency guidelines. *Note:* Oceanographic, ecological, environmental economics, and social studies would be required in parallel with toxicity studies.

concerns. The development of relevant methods for STD risk assessment must include data that address concerns raised by communities that live near discharge areas and rely on those waters for food security (see Figure 4).

Progress in the development of standard toxicity tests using tropical marine species continues (e.g., Lee et al., 2007; Harford et al., 2011; Howe et al., 2011; Negri et al., 2011). Furthermore, Reichelt-Brushett et al. (2012) are currently investigating a species for use in ecotoxicology with a tropical distribution and a depth range from the shoreline to 1,300–1,400 m. Research activity would be enhanced if there were a much more focused direction from regulators to require mining companies to develop suitable toxicity tests for assessment of tailings (see also McKinnon, 2002).

Tests should be developed using a range of regionally relevant species that collectively are ecologically suitable for assessing sediment, water, and porewater toxicities (Figure 4). This information should be made available to the scientific community through publications in order to enhance a collective increased knowledge that can be applied to future projects. Studies should include chronic exposure durations with sublethal endpoints as well as longer-term exposure times that represent effects on longer-lived species; species selection could include those with a notable depth range. The newly developed and site-specific test methods would then be available for the ongoing monitoring stage of a project if STD were approved (Figure 4). This type of requirement is practiced in other mining operations in developed countries and also in some instances in developing countries (e.g., Ranger uranium

mine projects in Australia; Riethmuller, et al., 2003), including for drilling muds in western Australia (Tsvetnenko et al., 2000) and for alumina refinery waste (Harford et al., 2011; Negri et al., 2011) as well as mine sites in PNG (Ross Smith, Hydrobiology Pty Ltd., *pers. comm.*, June 2010).

As part of broader environmental impact assessment, bioaccumulation studies that include dietary uptake through food, water, and sediment should be assessed in parallel with operationally defined AVS-SEM bioavailability test methods. The focus of these studies should be on sessile or sedentary species that are keystone species of ecosystems and on edible species from sites where local communities source their food.

These recommendations are not a bold new approach to risk assessment; they are standard approaches adapted for STD. To summarize, Table 2 shows opportunities and threats for investigating risk associated with STD. A precautionary principle is best applied in all cases because if significant impacts are determined, there is very little that can be done to remediate the situation. Considering the cost of court cases related to STD (e.g., Ramu Nickel Project) and compensation to communities when impacts are greater than predetermined (e.g., Minahasa Raya), it is in mine developers' best interest to provide a weight-of-evidence approach to ensure more confidence in the understanding of environmental impacts when considering STD.

To provide a streamlined approach to assessing potential impacts from STD, the signatory countries of the Coral Triangle Initiative (CTI) could agree to a set of requirements and an assessment framework (as suggested in Table 2 and

Figure 4) for all environmental impact assessments for STD. With the development of an independent body of supervising scientists funded by industry, informed decisions about acceptable environmental harm could be made. Alternatively, the CTI would be a useful platform for instigating a multicountry ban on the practice of STD that would resolve financially competitive advantages to industries that develop mines and processing facilities in countries that favor STD.

CONCLUSION

Marine pollution is of growing concern to the global community, and at the same time the risk of pollution in the Coral Triangle from STD is unprecedented. Experience shows that submarine tailings disposal can seriously impact the marine environment and the local communities that depend on the ocean for their livelihood and food security (e.g., Carr et al., 2000; Fallon et al., 2002; Brewer et al., 2007; Tse, 2007; Edinger, 2008; Lasut et al., 2010). Impact assessment of STD has been poorly managed, with approvals being given in spite of insufficient detail being provided in environmental assessments. STD is considered a cheap way to dispose of large volumes of waste; however, the definition of “cheap” has not previously included placing a value on the marine environment or local communities. Because STD comes from a pipe, it is not subject to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 (also known as the London Convention; see <http://www.imo.org/about/conventions/listofconventions/pages/convention-on-the-prevention-of-marine-pollution-by-dumping-of-wastes-and-other-matter.aspx>). It is

timely for regulators to use a precautionary approach and demand more rigorous and relevant assessment when they are faced with considering proposals for STD in waters of their jurisdiction. While implementing the decision-tree process proposed for developing countries

presents challenges, it also offers opportunities for drawing on international and independent expertise.

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Table 2. Threats and opportunities for development of risk assessment frameworks for submarine tailings disposal (STD) in the Coral Triangle.

THREATS	OPPORTUNITIES
Limited value placed on disposal environment	<ul style="list-style-type: none"> • Use ecosystem services methods to identify natural capital (e.g., Costanza, 1997) • Use increasing knowledge of biodiversity to recognize value • Coral Triangle Initiative declaration and acknowledgement of value of the deep-sea environment
Default to currently existing standard test methods using unsuitable species	<ul style="list-style-type: none"> • Development of commercial ecotoxicity tests using aquatic and benthic species with broad tropical distribution that may be applied to various sites • Use Toxicity Identification Evaluation (TIE) approaches
Unknown toxicity of metals to organisms in the disposal environment	<ul style="list-style-type: none"> • Develop test endpoints that are reflective of organisms in the deep sea, for example, growth, development, reproduction, behavior, bioluminescence, microbiological communities • Develop tools that enable tests to be conducted under temperatures and pressures of the deep sea and work toward the capacity of using organisms from these environments • Continue to develop opportunities to investigate deep-sea organisms
High cost of assessment and monitoring in deep waters	<ul style="list-style-type: none"> • Gain enhanced understanding of biological, ecological, chemical, and physical aspects of deep-sea environment by conducting baseline surveys and follow-up monitoring • Incorporate assessment and monitoring costs into the real cost estimates of STD • Share results of studies from different STD sites
Limited scope of environmental impact assessments	<ul style="list-style-type: none"> • Set stringent environmental assessment requirements for STD applications and standardize through the Coral Triangle Initiative
Lack of comprehension of ownership, tenure, and jurisdiction of the ocean resources	<ul style="list-style-type: none"> • Implement a legal framework
Lack of industry responsibility for long-term impacts that arise from STD and lack of possible remediation/ management options	<ul style="list-style-type: none"> • Collect environmental levies from companies, including an up-front fee and annual contributions; some of the interest could be used to generate long-term benefits to local communities
Default to STD as a “cheap” disposal option	<ul style="list-style-type: none"> • Set stringent environmental assessment requirements for STD applications and standardize through the Coral Triangle Initiative • Define full cost of STD, including monitoring, assessment, pipe repairs, environmental levies, community engagement, etc. • Real valuing of environmental assets will drive industry to develop solutions and improve technologies for on-land tailings management
Lack of industry leadership and guidance	<ul style="list-style-type: none"> • Identify industry advocates for good environmental, social, economic outcomes in projects
Lack of scientific knowledge in government departments to assess STD applications and review results of monitoring	<ul style="list-style-type: none"> • Develop initiatives that would invest in the education of people in developing countries • Set up an expert panel to advise government
Risk of corruption	<ul style="list-style-type: none"> • Put in place an independent scientific and sociological assessment body
Incomplete community engagement hindered by local education level, language barriers, and other problems	<ul style="list-style-type: none"> • Implement a step-by-step plan for engagement and high-quality research from conception to gain community support
Continued poor environmental outcomes as a result of using STD	<ul style="list-style-type: none"> • Apply alternative disposal method • Ban STD

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