Chapter 23. Offshore Mining Industries

Contributors: Elaine Baker (Lead member and Convenor of Writing Team), Françoise Gaill, Aristomenis P. Karageorgis, Geoffroy Lamarche, Bhavani Narayanaswamy, Joanna Parr, Clodette Raharimananirina, Ricardo Santos, Rahul Sharma, Joshua Tuhumwire (Co-Lead member)

Consultors: James Kelley, Nadine Le Bris, Eddy Rasolomanana, Alex Rogers,
Mark Shrimpton

1. Introduction

Marine mining has occurred for many years, with most commercial ventures focusing on aggregates, diamonds, tin, magnesium, salt, sulphur, gold, and heavy minerals. Activities have generally been confined to the shallow near shore (less than 50 m water depth), but the industry is evolving and mining in deeper water looks set to proceed, with phosphate, massive sulphide deposits, manganese nodules and cobalt-rich crusts regarded as potential future prospects.

Seabed mining is a relatively small industry with only a fraction of the known deposits of marine minerals (Figure 1) currently being exploited. In comparison, terrestrial mining is a major industry in many countries (estimated to be worth in excess of 700 billion United States dollars per year, PWC, 2013). Pressure on land-based resources may spur marine mining, especially deep seabed mining. However, global concerns about the impacts of deep seabed mining have been escalating and may influence the development of the industry (Roche and Bice, 2013).

The exploitation of marine mineral resources is regulated on a number of levels: global, regional and national. At the global level, the most important applicable instrument is the United Nations Convention on the Law of the Sea (UNCLOS). It is complemented by other global and regional instruments. At the national level, legislation governing the main marine extractive industries (i.e. aggregate mining) may be extremely complex and governed in part by national or subnational authorities (Radzevicius et al., 2010). As regards national legislation to regulate deep-sea mining, terrestrial mining legislation often applies to the continental shelf or EEZ, rather than specific deep-sea mining legislation (EU, 2014). However many Pacific Islands States, that are gearing up for deep seabed mining have made significant efforts to adopt concise and comprehensive domestic laws (SPC, 2014).

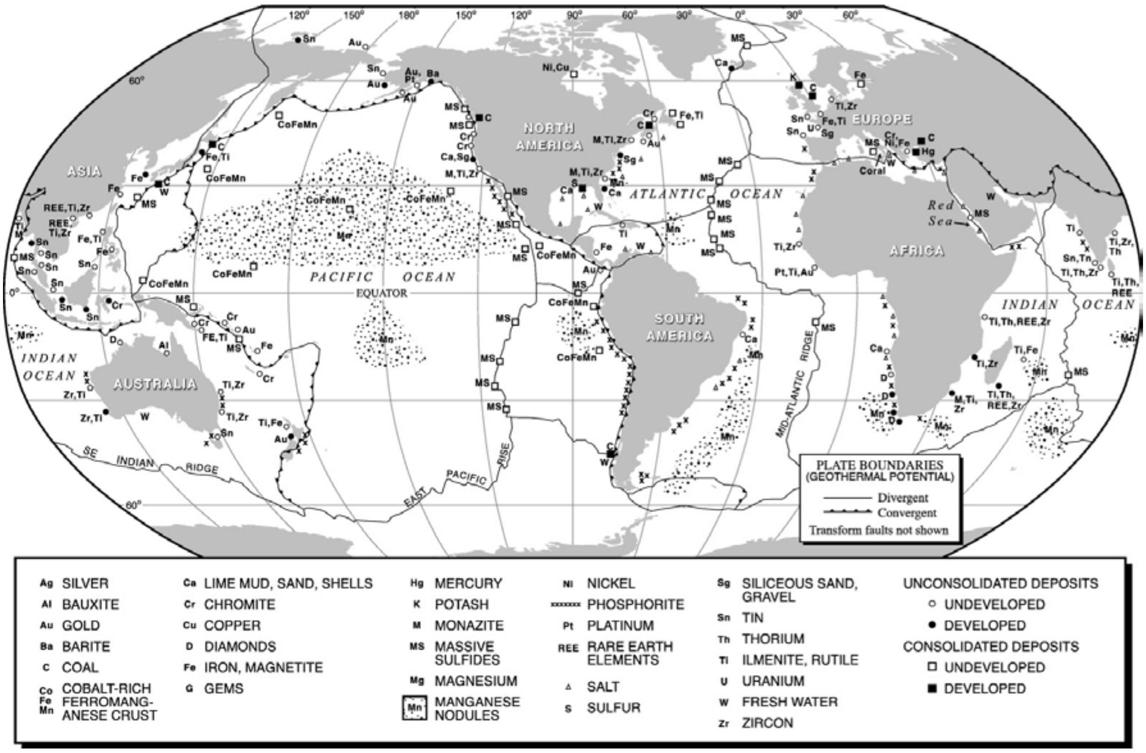

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Figure 1. Global distribution of known marine mineral resources (from Rona, 2008).

2. Scale and significance of seabed mining

2.1 *Sand and gravel extraction*

Aggregates are currently the most mined materials in the marine environment and demand for them is growing (Bide and Mankelow, 2014). Due to the low value of the product, most marine aggregate extractions are carried out at short distances from landing ports close to the consumer base and at water depths of less than 50 m (UNEP, 2014).

In Europe, offshore sand and gravel mining is an established industry in Denmark, France, Germany, the Netherlands and the United Kingdom of Great Britain and Northern Ireland (Earney, 2005). Marine aggregates are also mined in the tidal channels of the Yellow River China, the west coast of the Republic of Korea, tidal channels between the islands south of Singapore and in a range of settings in the waters surrounding Hong Kong, China (James et al 1999). In many of the Pacific Islands States, aggregates for building are in short supply and the mining of terrestrial sources, principally beaches, has been associated with major increases in coastal vulnerability (e.g. impacts of beach mining in Kiribati and the Marshall Islands are well documented (Webb 2005, McKenzie et al 2006). Therefore, marine sources of aggregates are considered as a preferred source. The Secretariat of the Pacific Islands Applied Geoscience Commission (SOPAC), now part of the Secretariat of the Pacific Community, has been involved in assisting Pacific Island States in the planning, development and management of sand and gravel resources, (SOPAC, 2007).

Although globally the majority of the demand for aggregates is met by aggregates extracted from land-based sources, the marine-based industry is expanding (JNCC, 2014). However, no figures are available on the global scale of marine aggregate mining.

2.1.1 Case Study: North-East Atlantic

The Working Group on the Effects of Extraction of Marine Sediments (WGEXT) of the International Council for the Exploration of the Sea (ICES) has provided yearly statistics since 1986 on marine aggregate production (ICES 2007, 2008, 2009, 2010, 2011, 2012, 2013; Sutton and Boyd, 2009; Velegrakis et al., 2010). Since 1995, an average of 56 million m^3 y^{-1} has been extracted from the seabed of the North-East Atlantic (Figure 2). Five countries account for 93 per cent of the total marine aggregate extraction (Denmark, France, Germany, the Netherlands, and the United Kingdom; OSPAR, 2009). The Netherlands is the largest producer (average 27.3 million m^3 y^{-1}). There are thirteen landing ports and 17 specialist wharves in Europe (Belgium, France and the Netherlands; Highley et al., 2007).

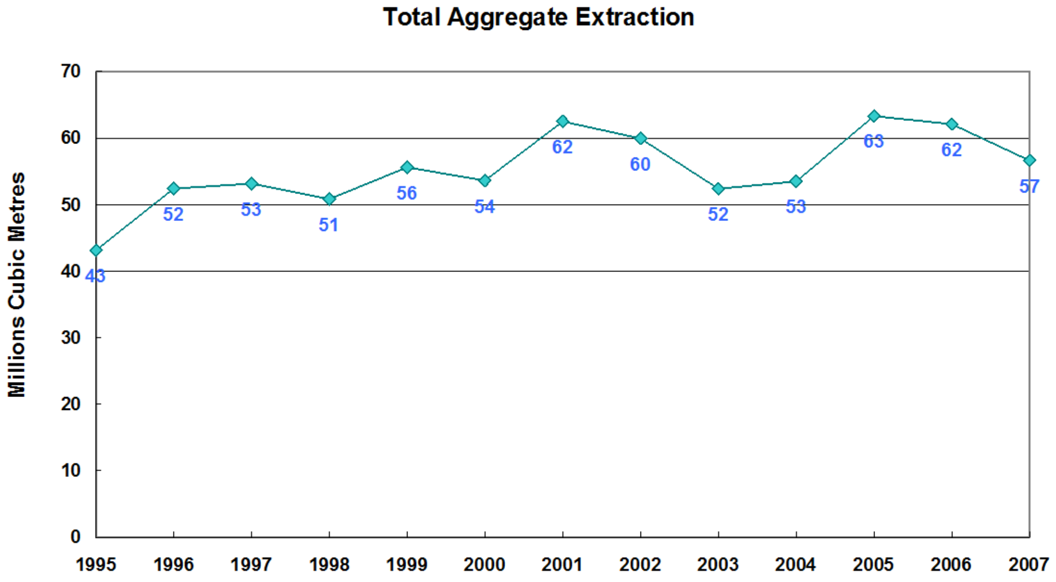

Figure 2. Total marine aggregate extraction in the OSPAR maritime area (in million m^3). Data from: ICES, 2005, 2006, 2007, 2008, 2009 (OSPAR 2009).

The United Kingdom, one of the largest producers of marine aggregates in the region, currently extracts approximately 20 million tons of marine aggregate (sand and gravel) per year from offshore sites (Figure 3). Production meets around 20 per cent of the demand in England and Wales (Crown Estate, 2013). Around 85 per cent of the mined aggregate is used for concrete, with the remainder used for beach nourishment and reclamation. In 2010, the area of seabed dredged was 105.4 km^2, although 90 per cent of dredging effort was confined to just 37.63 km^2. Between 1998 and 2007, aggregate extraction produced a dredge footprint of 620 km^2 (BMAPA, 2014). In 2012, 23 dredging vessels were operating (BMAPA, 2014) and aggregates were landed at 68 wharves in 45 ports in England and Wales. Wharves are mainly located in specific regions where a shortfall in land-derived supplies exists and/or there are economic advantages because of river access and proximity to the market (Highley et al., 2007).

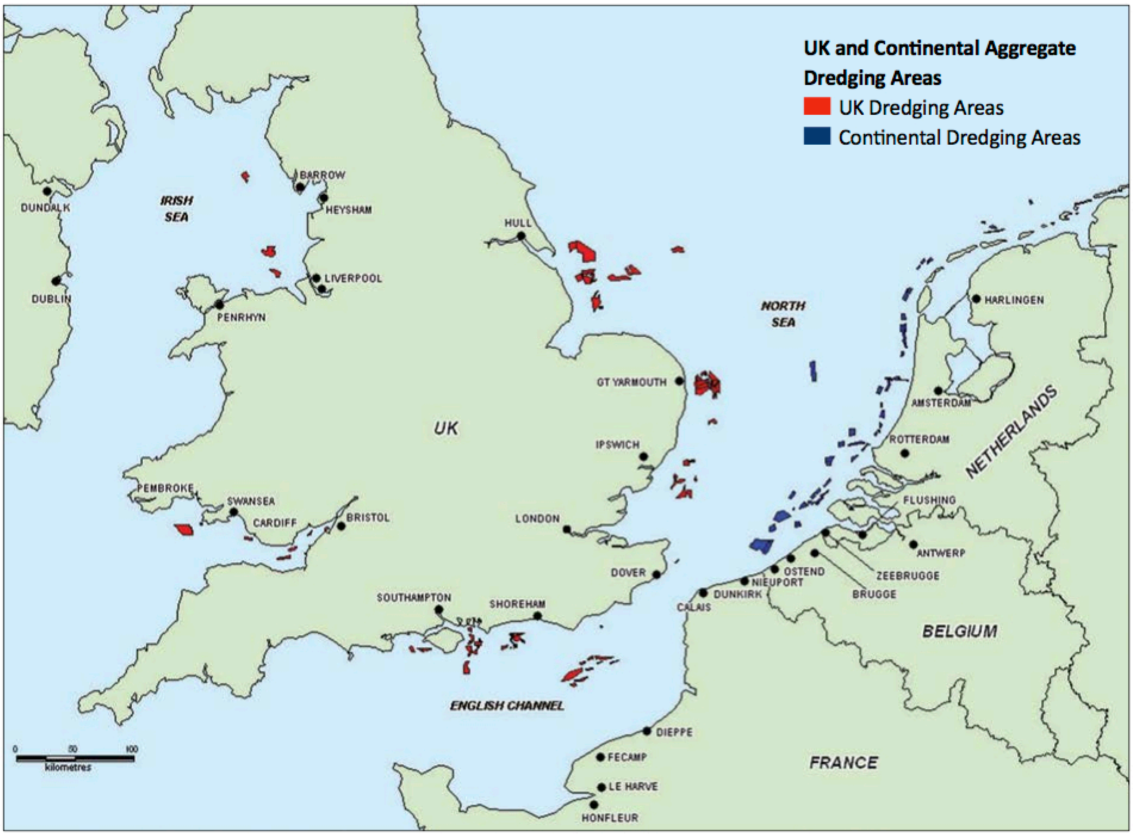

Figure 3. Map of the coastline showing the location of aggregate license areas in the United Kingdom and the adjacent coast of continental Europe (Newell and Woodcock, 2013).

The European Union Marine Strategy Framework Directive (MSFD: 2008/56/EC) requires that its Member States take measures to achieve or maintain Good Environmental Status (GES) by 2020. The Descriptor 6 of the MSFD, referred to as “Sea-floor integrity”, is closely linked to marine aggregate extraction from the seabed – seafloor integrity is defined as a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected (Rice et al., 2010). Descriptor 6 requires immediate actions from Member States to develop suitable pressure indicators (calculated from several parameters such as the species diversity, the number of species and the proportion of different types of species in benthic invertebrate samples) and launch continuous monitoring schemes to contribute to GES achievement.

2.1.2 Case Study: Pacific Islands - Kiribati

The adverse effects of sand mining on the beaches (above the high water mark) of South Tarawa, the main island of Kiribati, were recognized in the 1980s. Removal of the beach sand changes the shape of the beach, increasing erosion and the island's vulnerability to flooding from storm surges and rising sea level. As a consequence of ongoing beach mining, the EU-funded Environmentally Safe Aggregate Project for Tarawa (ESAT) was started in 2008. A purpose-built dredge vessel, the "*MV Tekimarawa*" was commissioned and a State-owned dredging company was developed to provide marine aggregates for urban construction. The mined material is processed by local people at a processing facility, used on the island for building material and also sold to other islands. The resource area in Tarawa Lagoon (Figure 4), which is currently being mined for coarse sand and gravel, is expected to provide aggregates for 50 to 70 years. ESAT also has a license to excavate access channels on the intertidal reef flats in Beito and Bonriki. This provides fine intertidal silt suitable for road base.

The introduction of marine mining in Tarawa Lagoon has not stopped illegal beach mining. Reviews have found that controlling beach mining by communities is difficult, and that trying to regulate this practice in the absence of a suitable alternative source of revenue is next to impossible (Babinard et al., 2014).

The shoreline and beach profile in South Tarawa has been severely altered, with the almost complete removal of the high protective berm. Mining has now moved on to other untouched beaches. It is estimated that natural recovery of damaged areas will take decades (SOPAC, 2013).

Figure 4. Tarawa Atoll. ESAT resource area in yellow (50-70 year supply). The dot is larger than the absolute maximum surface area that could be mined in any given year (SOPAC, 2013, Figure courtesy Dr. Arthur Webb).

2.2 *Placer mining*

Placer deposits include minerals that have been concentrated by physical processes, such as waves, wind and currents. Globally, diamonds dominate this sector, but placer deposits also contain valuable minerals. Harben and Bates (1990) identify the most economically important of these minerals (and their associated elements) as: cassiterite (tin), ilmenite (titanium), rutile (titanium), zircon (zirconium), chromite (chromium), monazite (thorium), magnetite (iron), gold and diamonds. About 75 per cent of the world's tin, 11 per cent of gold, and 13 per cent of platinum are extracted from placers (Daesslé and Fischer, 2013).

Table 1. Principal marine placer mining activities (from Murton, 2000)

Placer Minerals	Mined locations
Rutile and ilmenite	South-east and south-west Australia Eastern South Africa South India Mozambique Senegal Brazil Florida
Titanium-rich magnetite	North Island, New Zealand Java, Indonesia Luzon, Philippines Hokkaido, Japan
Tin	Indonesian Sunda shelf, extending from the islands of Bangka, Belitung, and Kundur Malaysia Thailand
Diamonds	West Coast, South Africa Namibia Northern Australia

Diamond placer deposits exist in two distinct areas: a 700-km stretch along the coastal borders of Namibia and South Africa, and an area off the northern coast of Australia (Rona, 2005). Deposits off the coast of South Africa have not been actively mined since 2010 (De Beers, 2012) and Australian operations have not progressed since discovery. Offshore of Namibia, five vessels operated by NAMDEB (a joint partnership between the Namibian government and De Beers) currently extract approximately 1 million carats/year (De Beers, 2007; 2012). In addition there are diver operated mining activities conducted from smaller vessels. A report from The World Wide Fund for Nature (WWF) South Africa (Currie et al., 2008) identified a number of environmental concerns associated with offshore diamond mining. These included destruction of kelp beds, which provide important habitat for juvenile rock lobsters and the destruction of healthy reefs during the removal of diamondiferous gravels. The authors also suggested that the dumping of tailings back into the ocean or onto the beach (after processing) could also potentially result in the formation of land bridges from some islands to the mainland in the vicinity of islands.

Dredging of tin placers is the largest marine metal mining operation in the world (Scott, 2011). The tin belt, as it is called, stretches from Myanmar, down through Thailand, Malaysia, Singapore and Indonesia. The largest operations are offshore of Indonesia, where submerged and buried fluvial and alluvial fan deposits are mined up to 70 meters below sea level, using large dredgers. P.T. TIMAH, a state-owned enterprise, operates the official tin mine offshore of Bangka and Belitung islands. Their dredges can recover more than 3.5 million cubic meters of material per month (Timah, 2014). Numerous “informal miners” also dredge in the shallow coastal area (see Figure 5). These operations use divers to suck sediment from the seafloor using plastic tubing connected to a diesel pump (which also pumps air to the divers). The Indonesian islands produce 90 per cent of Indonesia's tin, and Indonesia is the world's second-largest exporter of the metal.

Commercial production of tin began in Thailand in the late 1800s. Most of the offshore tin is located off the Malay Peninsula. The major offshore mining operations ceased in 1985 when the tin price collapsed. Prior to that, large-scale operations were located in the Andaman Sea and the Gulf of Siam (now Gulf of Thailand). The Thaisarco tin smelter in Phuket processes tin from inside and outside Thailand. While most of the Thai-sourced tin originates from land-based deposits, a number of privately owned suction boats still work the near shore during the dry season; a typical boat can recover about 15 kg of cassiterite ore per day.

Gold placer deposits along the Gulf of Alaska of the United States of America coast have been worked since 1898. The gold is recovered from sands exposed at low tide, but the gold-bearing sands extend for approximately 5 km offshore to water depths of 20 m (Jewett et al., 1999). The deposit was most recently actively mined from 1987 to 1990, when the lease was terminated. During that period, 3,673 kg of gold were recovered (Garnett, 2000). The Placer Marine Mining Company purchased an offshore lease at Nome from the Alaska Department of Natural Resources in 2011. The AngloGold-De Beers partnership also has an offshore lease and has invested several million US dollars in exploration and baseline studies. They are hoping to have the required permits in place to begin mining by 2017. There are also a number of individual leases, and due to interest from the general public in shallow water gold mining, the Alaska Department of Natural Resources has also established two recreational mining areas offshore of Nome.

Figure 5. Homemade dredges operating offshore Bangka Island Indonesia (Photo Rachel Kent, The Forest Trust).

2.2.1. Case Study: New Zealand

Iron sands constitute a very large potential resource in New Zealand. Iron sands occur extensively in the coastal zone, and exploration off the west coast of the North Island of New Zealand's exclusive economic zone has identified potential resources concentrated on the continental shelf. In 2014, following an exploration phase, Trans-Tasman Resources Limited (TTR) was granted a 20-year mineral mining permit by the New Zealand Ministry of Business, Innovation and Employment for the extraction of iron sand from the South Taranaki Bight (Figure 6). This permit is the first step in a regulatory process that may allow the company to extract iron sand over a 66-km^2 area of seabed located in water depths of between 20-42 m, up to 36 km offshore. It is estimated that 50 million tons per year of sand could be extracted from the seabed (TTR, 2015). It may still take several years before mining commences and, in addition, the company also needs to obtain consent from the New Zealand Petroleum and Minerals branch of the Environmental Protection Authority (EPA) before any mining can begin (NZ Petroleum and Minerals, 2014). At the time of publication of this report, the decision-making Committee appointed by the EPA has refused to grant the mining consent to TTR (NZ EPA, 2015). The reason for this decision is related in part to the uncertainties about the scope and significance of the potential adverse environmental effects.

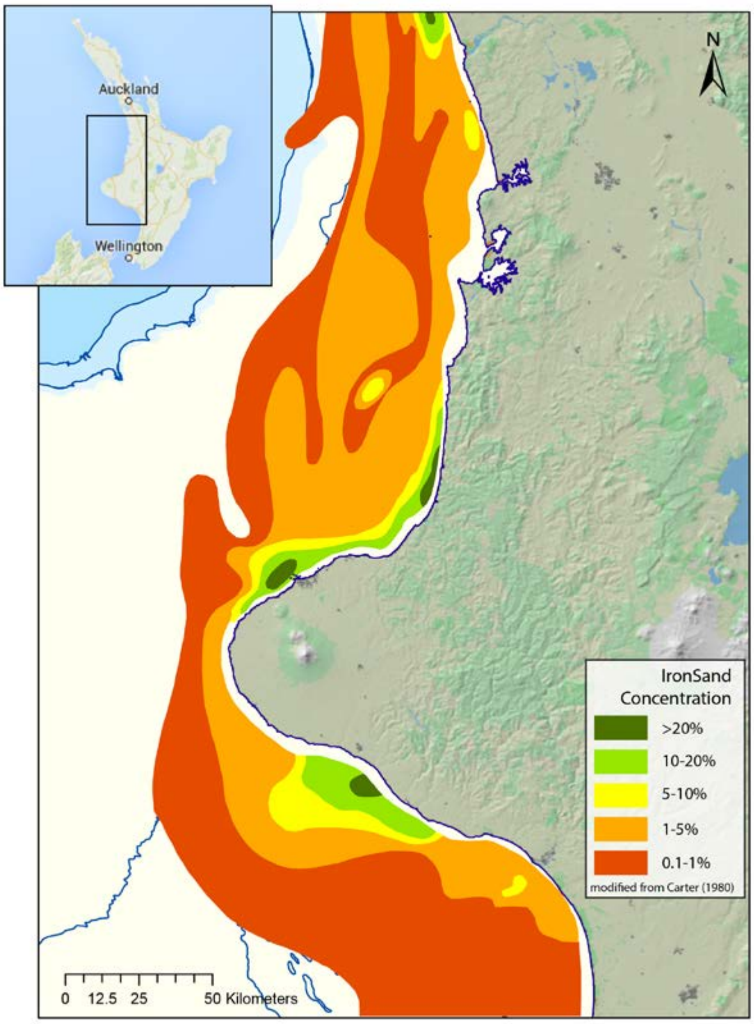

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Figure 6. Surficial concentrations of iron sand along the west coast of the North Island of New Zealand (Taranaki region) (modified from Carter, 1980, Taylor & Francis, Ltd., www.tandfonline.com).

2.3 Sulphur mining

Sulphur is used in manufacturing and agriculture. Most is produced onshore, but native sulphur is associated with offshore salt domes in the Gulf of Mexico. One offshore mine, the Main Pass 299 facility, located in shallow water off central Louisiana, United States, was operational until 2000 (Kyle, 2002). The sulphur was extracted by the Frasch system, which uses the injection of superheated water through boreholes to melt the sulphur, which is then forced to the surface by compressed air (Ober, 1995). The mine facility is one of the largest platform configurations in the Gulf, with 18 platforms. However, it is unlikely that the mine will resume operations in the near future, due to a glut in the supply of sulphur. This over-supply stems from the fact that sulphur is now extracted in environmental control systems and petroleum refining, which account for 55 per cent of the world sulphur production.

3. Significant environmental, economic and/or social aspects in relation to offshore mining industries

3.1 Environmental Impacts

The current shallow-water seabed mining activities all employ dredging systems to excavate material from the seabed. Dredging techniques vary depending on the nature of the material being mined. They include: a plain suction dredge, which vacuums up unconsolidated material; a rotary cutter dredge, which has a cutting tool at the suction inlet to dislodge more consolidated material; and bucket dredges, which drag a bucket along the sea floor. In marine mining, the dredged material is generally placed into an onboard hopper and excess water and tailings are discharged back into the environment.

Environmental impacts include physical alteration of the benthic environment and underwater cultural heritage. Table 2 summaries the environmental impacts associated with aggregate mining, which are potentially applicable to all types of shallow water marine mining. Examples of documented impacts are listed in Table 3. The most immediate impacts relate to sediment removal resulting in loss of benthic communities. The removal of the sediment may also affect (re) colonization and recovery rates of impacted communities (Tillin et al., 2011). Most studies on the impact of dredging on marine benthos show that dredging can result in a 30–70 per cent reduction in species variety, a 40–95 per cent reduction in the number of individuals, and a similar reduction in biomass in dredged areas (Newell et al., 1998).

In addition to removal, sediment disturbance can expose marine organisms to increased turbidity and elevated suspended sediment concentrations. This can reduce light availability, which can impact photosynthetic organisms like phytoplankton. Tides and currents can spread turbidity plumes and sediment beyond the mine area. This can be accompanied by changes in water chemistry and contamination (such as algal spores, and from formerly buried substances).

Changes in hydrodynamic processes and seabed geomorphology can also occur. For example, trailer suction dredging, a common form of aggregate dredging, involves dragging the dredge slowly along the seabed, resulting in furrows that are up to 2-3 m wide and 0.5 m deep. These furrows can persist, depending on the local current regime and mobility of the sediments (Newell and Woodcock, 2013). Static suction dredges are employed at sites where deposits are thick and can result in the formation of large pits. Hitchcock and Bell (2004 and references therein) reported that pits within gravelly substrates may fill very slowly and persist after several years, whereas pits in channels with high current velocities have been observed to fill within one year, and those in intertidal watersheds can take 5–10 years to fill.

The European SANDPIT project (Van Rijn et al 2005) aimed to develop reliable techniques to predict the morphological behaviour of large-scale sand mining pits/areas and to understand associated sediment transport processes (Idier et al., 2010). In the study, a baseline pit, based on an actual Dutch pit, was defined as an inverted truncated pyramid 10 m below the seabed, with dimensions at the seabed of 500m x1300m, an excavated volume of 3.5Mm^3, and located 1.5km from shore at a water depth of 10m (Soulsby et al., 2005). Modelling results using this baseline pit indicate that, for example, there could be a reduction of current speed of up to 10 per cent in the pit; an increase in wave height in the centre of the pit of 1-5 per cent, increasing to 10-15 per cent in the areas surrounding the pit; a reduction of sediment transport in the centre of the pit by 40-90 per cent and an increase of 70-200 per cent outside the pit (Soulsby et al., 2005).

Changes in sediment grain size composition can also occur. For example, diamond mining on the continental shelf of Namibia in 130 m depth was shown to have altered the surficial sediments in a mined area, from previously predominantly homogenous well-sorted sediment, to a more heterogeneous mud, coarse sand and gravel. This is because, as part of the on-board processing, cobbles, pebbles and tailings are discarded over the side (Rogers and Li, 2002). Long-term or permanent changes in grain size characteristics of sediments will affect other factors such as organic content, pore-water chemistry, and microbe abundance and composition (Anderson, 2008).

Less well-documented potential impacts include underwater noise. A review by Thomsen et al. (2009) summarized information on the potential risks from dredging noise. They noted that dredging produces broadband and continuous low frequency sound, that studies indicate that dredging can trigger avoidance reaction in marine mammals, and that marine fish can detect dredging noise over considerable distances. They report that the sparse data available indicates that dredging is not as noisy as seismic surveys, pile driving and sonar; but it is louder than most shipping, operating offshore wind turbines and drilling, and should be considered as a medium impact activity. Marine fauna and birds may collide with or become entangled in operating vessels, but this potential impact is also not well studied. Todd et al (2015) noted that collisions with marine mammals are possible, but unlikely, given the slow speed of dredgers.

Because most marine mining currently occurs close to shore there has been considerable concern regarding the potential impact of mining on archaeological sites. Mining activities, particularly aggregate dredging, has been shown to irreversibly damage underwater cultural heritage, including shipwrecks, airplane crash sites and submerged prehistoric sites (Firth, 2006). Individual States, such as the United States have prepared recommendations and guidelines to avoid dredging impacts on cultural sites (Michel et al., 2004). These include improved location of cultural sites using remote sensing technology, the establishment of buffer zones around known sites, and preparation of plans to preserve resources and subsequent monitoring of dredging activity. Government policies in the United Kingdom on marine mineral extraction from the seabed off the coast of England are set out in Marine Minerals Guidance Note 1 (MMG 1; Wenban-Smith, 2002). The MMG 1 states that all applications for dredging in previously undredged areas require an environmental impact assessment. The Office of the Deputy Prime Minister, which approves applications, can request the applicant to provide information relating to potential impacts to archaeological heritage and landscape and provide information on the measures envisaged to prevent, reduce and where possible offset any significant adverse effects. A review by Firth (2013) of marine archaeology in the

United Kingdom recommends that thorough exploration of cultural sites, to constrain their area, may be more cost effective than blanket buffer zones, which can disrupt dredging activity.

Table 2. Spatial and temporal scale of the main effects arising from aggregate extraction activities and the confidence associated with the evidence (from Tillin et al 2011).

Effects arising from aggregate extraction activities	Spatial Scale of Effect	Temporal Scale of Effect	Confidence in Evidence
Direct Impacts: Removal of aggregates:	Impacts on benthic marine organisms and seabed morphology. Confined to footprint of extraction: the active dredge zone.	Recovery may begin after cessation of activity.	Good evidence for impacts on seabed habitats and biological assemblages (Newell et al 2004).
Direct Impacts: Removal of aggregates:	Impacts on cultural heritage and archaeology	May be permanent and irreversible	Good evidence for impacts (Michel et al., 2004)
Direct Impacts: Formation of sediment plumes	From 300-500m for sand particle deposition to 3km where particles are remobilised by local hydrodynamic conditions	Longevity of sediment plumes, up to 4-5 tidal excursions for fine particles (MALSF 2009)	Confidence in understanding of sediment plume has been assessed as high (MALSF 2009)
Indirect Impacts: Visual Disturbance	May affect seabirds and marine mammals, spatial extent of effect depends on visual acuity of organism and response.	Confined to period of extraction activities	Little evidence, unlikely to be different from other forms of shipping.
Indirect Impacts: Noise Disturbance	Changes in noise levels detectable up to several km. Behavioural responses likely to occur over much more limited distances and little	Confined to period of extraction activities	Evidence of hearing thresholds only available for a few species (Cefas 2009).

	risk of hearing damage.		
Indirect Impacts: Collision Risk	Confined to activity footprint	Confined to period of extraction activities	Little evidence, unlikely to be different from other forms of shipping.
Indirect Impacts: Sediment deposition	From 300-500m for sand particle deposition to 3km where particles are remobilised by local hydrodynamic conditions.	Heaviest particles settle almost immediately, lightest particles will settle within 1 tidal excursion (a tidal cycle of ebb and flood) (Cefas 2009).	High (from modelling studies and direct observations at a number of sites).

The scale of impacts will vary depending on the method and intensity of dredging, level of screening (for example in aggregate mining screening may be employed to alter the sand to gravel ratio, in which case significant quantities of sediment, typically unwanted fine sediment particles, can be returned to the seabed), sediment type and local hydrodynamics (Newell and Woodcock, 2013).

Physical and biological impacts (e.g. smothering leading to death or impaired function) may persist well after the mining finishes. Recovery times are likely to vary greatly and be species dependent (Foden et al., 2009). Cumulative impacts such as climate change and other anthropogenic activities may also affect recovery timing.

Some of the mitigation measures now used with dredging operations include:

- The use of silt curtains to contain dredge plumes;
- The return of overflow waste to the seabed rather than in the water column;
- Locating mining activities away from known migratory pathways and calving or feeding grounds;
- Limiting the number of vessels or operations in given areas;
- Requiring reduced boat speeds in areas likely to support marine mammals;
- Engineering to reduce the noise of the primary recovery and ore-lift operations;
- Limiting unnecessary use of platform and vessel flood lights at night and ensuring that those that are required are directed approximately vertically onto work surfaces to avoid or mitigate seabird strikes;

– Leaving patches within a mining site un-mined to increase the rate of recolonization and recovery of benthic fauna;

– Excluding areas from mining if they support unique populations of marine life;

– Excluding areas of mining if they are potential sites of cultural heritage;

– Depositing tailings within as small an area as possible surrounding the mining block, or onshore; and

– Avoiding the need for re-mining areas by mining target areas to completion during initial mining.

Table 3. Documented environmental impacts of offshore mining

Mining activity	Location	Impact	Reference
Shell and sand extraction	Owen Anchorage, south-west of Fremantle, Western Australia	Dredging in shallow near-shore waters associated with significant conservation values, e.g., seagrass, coral communities; adverse effects on marine habitats due to direct seabed disturbance and indirect effects, such as elevated turbidity levels. Other concerns include changes in near-shore wave and current conditions, which could affect shipping movements and seabed/shoreline stability	Walker et al., 2001
Sand and gravel extraction	European Union	Loss of abundance, species diversity and biomass of the benthic community in the dredged area. Similar effects from turbidity and resuspension of sediment over a wide area. Benthic impact is a key concern where dredging activities may impinge on habitats or species classified as threatened or in decline (such as Maerl or *Sabellaria* reefs).	OSPAR, 2009
Sand and gravel extraction	Dieppe, France	10-year monitoring programme revealed a change in substrate from gravel and coarse sand to fine sand in the dredged area. The maximum impact on benthic macrofauna was a reduction by 80 per cent in species richness and 90 per cent in both abundance and biomass. In the surrounding area, the impact was almost as severe. Following cessation of dredging, species richness was fully restored after 16 months, but densities and biomass were still 40 per cent and	Desprez, 2000

		25 per cent, respectively, lower than in reference stations after 28 months. The community structure differed from the initial one, corresponding to the new type of sediment.	
Sand and gravel extraction	United States of America	Comprehensive review of impacts from dredging operations identifying the most severe effects: entrainment of benthic organisms; destruction of essential habitat; increased turbidity affecting sensitive fauna like corals and suspension-feeding organisms.	Michel et al., 2013
Sand and gravel extraction	Moreton Bay, Australia	Alteration of the existing tidal delta morphology by the removal of a small area of shallow banks. In most cases, the prevailing sediment transport processes would result in a gradual infill of extraction sites.	Fesl, 2005
Sand and gravel extraction	Puck Bay, Southern Baltic Sea	Benthic re-colonization at a site formed by sand extraction was investigated some 10 years after the cessation of dredging. The examined post-dredging pit is one of five deep (up to 14 m) pits created with a static suction hopper on the sandy, flat and shallow (1–2 m) part of the inner Puck Bay (the southern Baltic Sea). Organic matter was found to accumulate in the pit, resulting in anaerobic conditions and hydrogen sulfide formation. Macrofauna was absent from the deepest part of the pit and re-colonization by pre-mining benthic fauna was considered unlikely.	Szymelfenig et al., 2006
Diamond mining	Benguela Region, Africa (offshore of Namibia and South Africa)	Cumulative impacts of seabed diamond mining assessed over time and as a combination of numerous operations. Four to 15 years for benthic recovery, biodiversity altered in favour of filter feeders and algae, resulting in decreased biodiversity but increased biomass.	Pulfrich et al., 2003; Pulfrich and Branch, 2014
Diamond mining	Offshore Namibia, Orange Delta	Changes in surficial sediment grain size composition from unimodal to polymodal, with increased coarse sand and gravel.	Rogers and Li, 2002
Tin mining	Bangka-	Hundreds of makeshift pontoons	IDH, 2013

	Belitung Province Indonesia	operate alongside a fleet of 52 dredgers belonging to P.T. TIMAH. The island coastline has been altered by tailing dumps, and up to 70 per cent of coastal ecosystems, particularly coral, sea-grass and mangroves, are degraded.	
Gold mining	Norton Sound, northeastern Bering Sea, United States.	Mining with a bucket-line dredge occurred near shore in 9 to 20 m during June to November 1986 to 1990. Sampling a year after mining ceased indicated that benthic macrofaunal community parameters (total abundance, bio- mass, diversity) and abundance of dominant families were significantly reduced at mined stations	Jewett et al., 1999

Several studies have looked at the restoration of seabed habitat after mining activity (e.g., Cooper et al., 2013, Kilbride et al., 2006, Boyd et al., 2004). In the OSPAR region, where damage to protected species and habitat occurs, restoration is identified within the obligations of the Convention for the Protection of the Marine Environment of the North-East Atlantic, various European directives, and in various United Kingdom marine policy documents, (Cooper et al., 2013). A study on seabed restoration identified three issues central to decisions about whether to attempt restoration following marine aggregate dredging. They include: (i) necessity (e.g. a clear scientific rationale for intervention and/or a policy/legislative requirement), (ii) technical feasibility (i.e. whether it is possible to restore the impacts), and (iii) whether is it affordable (Cooper et al., 2013).

A recent study of the Thames Estuary, United Kingdom, an area of aggregate extraction, used the estimated value of ecosystem goods and services to determine if seabed restoration was justifiable in terms of costs and benefits; they concluded that in this case it was not (Cooper et al., 2013). The proposed restoration involved levelling the seabed and restoring the sediment character for an estimated cost of over 1 million British pounds. In order to determine if this expenditure could be justified, the authors assessed the significance of the persistent impacts on the ecosystem goods and services and the cost and likelihood of successful restoration. While the site-specific cost benefit analysis precluded restoration, they suggest that the approach taken could be used at other sites to determine if restoration is practical and effective.

In the United Kingdom a research fund, (the Aggregate Levy Sustainability Fund), was established in 2002 and ran until March 2011, using revenue from the Aggregates Levy introduced in 2002 - a tax of 2.00 British pounds per ton on primary aggregate sales (including land- and marine-derived aggregates; Newell and Woodcock, 2013). There was intense public criticism when the Fund was discontinued in 2011, as previously 7 per cent of the Fund had been directed to communities, non-governmental organizations and other stakeholders to fund projects delivering conservation, local community and other sustainability benefits (e.g., BBC 2011; MPA 2011). Cooper et al., 2013 also suggest that the fund could have been used to finance seabed restoration projects.

3.2 Social impacts

Social impacts of offshore mining are likely to be complex and different and generally less than that for terrestrial mining (Roche and Bice, 2013). Table 4 details potential social impacts from offshore mining. In countries where offshore mining is relatively new and untested (like Australia), societal expectations set higher standards for its acceptance, particularly with regard to environmental protection and strengthening of the national economy (Mason et al., 2014).

Table 4. Positive and negative potential social impacts identified (after Tillin et al, 2011; Roche and Bice, 2013)

Impact	Effect
Environmental degradation	Loss of ecosystem services that negatively affects livelihoods.
Provision of material	For coastal defence and beach replenishment.
Revenue	Revenue to industry, government and community; Foreign exchange earner.
Reduced pressure on land based resources	Avoidance of social impacts for resource extraction on land, including competing resources, community relocations.
Employment	Employment for local community, accompanied by influx of people to new industry; particularly for small island communities.
Cultural impacts	Loss of cultural sites; changes/loss in resource distribution (food, territory, etc.); ignoring of/loss of traditional knowledge.
Governance and policy	New regulatory regimes; implementation of policy; social and environmental degradation can lead to conflict.

Regional initiatives, targeted at developing a holistic approach to decision-making, that incorporate social, environmental and economic evaluation and stakeholder engagement, are outlined in Table 5. In some areas, such as the Pacific Islands region, emphasis is on making informed decisions about deep-sea mining. Countries which decide to engage in deep sea mining can obtain assistance from the Secretariat of the Pacific Community to develop national regulatory frameworks (offshore national policy, legislation and regulations) in close collaboration with all key stakeholders and in particular, local communities (SPC-EU, 2012). Elsewhere, the framework is focused more on the sustainable management of the marine environment, including non-living resources, and includes ecosystem-based approaches and valuation of ecosystem services affected by human activity. For example the European Union Marine Strategy Framework Directive (2008) advocates a transition from a sector-specific policy landscape to a system-based one, in which activities are regulated in concert, based on shared space and time across boundaries. Uncertainty remains, however, about how to value coastal assets and quantitatively measure social impact (Beaumont et al., 2007).

Awareness is increasing of the potential social impacts of marine and coastal extractive mineral industries, such as coastal dredging for aggregates and beach re-nourishment schemes (e.g., Austen et al., 2009; Drucker et al., 2004). Strong public sentiments about environmental and social issues already exist around land-based mining (e.g., Mudd, 2010). However, there is currently not the same level of understanding and informed debate around offshore mining (Mason et al., 2014). As offshore mining becomes more commonplace, information and data on the marine environment and impacts will be collected, and it is important that this information is disseminated to stakeholders. It is worth noting that the value of stakeholder participation in developing and implementing policy was included in Principle 10 of the Rio Declaration, which states that: “environmental issues are best handled with the participation of all concerned citizens, at the relevant level...”

Studies suggest that for an informed society to accept a nascent offshore mining industry, stakeholders require: better information (particularly rigorous scientific analysis of potential impacts, costs and benefits); a transparent and socially responsive management process within a consistent and efficient regulatory regime; and meaningful engagement with stakeholders (Boughen et al., 2010; Mason et al., 2010).

Table 5. Relevant regional and national initiatives

	Initiative
European Union	MSFD (2008): “Directive 2008/56/EC on establishing a framework for community action in the field of marine environmental policy” This directive provides a transparent legislative framework for an ecosystem-based approach to the management of human activities; supports the sustainable use of marine goods and services; and integrates the value of marine ecosystem services into decision making.
United Kingdom	Marine Environment Protection Fund 2010: Framework to allow marine aggregates extraction options to be analysed using socio-economic information. The framework analyses the interactions between different uses of the marine environment at both local and regional levels (Dickie et al., 2010)
Pacific Islands	SPC-EU DSM Project (2011-2016): Technical assistance and advisory service for Pacific Island countries choosing to engage in deep sea mining to help them improve governance and management in accordance with international law, with particular attention to the protection of the marine environment and securing equitable financial arrangements for their people.
United States	Executive Order 13547- Stewardship of the Ocean, Our Coasts, and the Great Lakes. The Order adopts the recommendations of the Interagency Ocean Policy Task Force, except where otherwise provided in this Order, and directs executive agencies to implement those recommendations under the guidance of a National Ocean Council. Based on those recommendations, this Order establishes a national policy to ensure, amongst other things, the protection, maintenance, and restoration of the health of ocean and coastal ecosystems and resources.

3.2.1 Case Study: Kiribati

A recent study by Babinard et al. (2014) examined the potential social impacts of offshore aggregate mining in South Tarawa (see section 2.1.3). The authors determined that as the ESAT (Environmentally Safe Aggregates for Tarawa) dredging operation develops, it could have adverse consequences for the welfare of those Kiribati residents who are either sellers or users of aggregates. Sellers of aggregates rely on beach mining for their livelihood (they currently receive 1 Australian dollar per bag). A 2006 household survey found that 206 out of 280 households surveyed were involved in some form of beach mining (Pelesikoti, 2007). There is widespread belief that they are acting within their rights as customary owners of the land, and they will likely lose economic opportunities as a result of the offshore dredging operations. For users of aggregates on the island, the main issue is whether they will be legally able to continue to mine aggregates from their own beaches. Residents argue that the customary rights to mine are included in the Foreshore Amendment Act of 2006 (Pelesikoti, 2007).

3.3 *Economic benefits from marine mining*

The economic benefits from near-shore mining are difficult to estimate. Marine aggregates are often sourced locally and reporting is scattered, but the marine sector is often distinguished from the land sector, so the value of the resource can be estimated. In contrast, commodities like tin and diamonds are part of a global market, which does not distinguish between land-derived and marine-derived materials. Table 6 gives estimated values where reported.

Table 6. Estimates of marine aggregates and minerals

Locations	**Resource**	**Quantity**	**Revenue**	**Employment**	**References**
European Union, United Kingdom, Japan, United States (minor)	Aggregate	~ 50-150+ million m^3 / year (can vary strongly year to year depending on demand)	1-3+ billion US dollars)	5,000–15,000 (estimate)	Ifremer, 2014 Herbich, 2000 Marinet, 2012 Newell and Woodcock, 2013
South Africa, Namibia, Australia (Inactive)	Diamond Placers	1.1 million carats (2012).	3.5 billion US dollars	~1,600	NAMDEB, 2010 NAMDEB, 2014
Indonesia, Malaysia, Thailand; Australia (inactive)	Tin	19,000 tons /yr tin	Indonesia 500 million US dollars	Indonesia ~3,500 Malaysia & Thailand N/A	Timah, 2012
New Zealand (inactive)	Iron Sands	0	0	0	
United States, South America, Australia, New Zealand, Africa, Portugal, India (all inactive)	Phosphates	0	0	N/A	
Mexico (inactive)	Phosphates	Total of 327.2 million ore tons at 18.5% P_2O_5	0	N/A	Don Deigo (2015)
United States (now inactive)	Sulphur	0	0	0	

4. Developments in other forms of seabed mining: current state and potential scale

4.1 Phosphate mining

Phosphorites are natural compounds containing phosphate in the form of cement-binding sediments in tropical to sub-tropical regions (Murton, 2002). They are widely distributed on the continental shelves and upper slopes, oceanic islands, seamounts and flanks of atolls. Deposits have been found off the west coast of Tasmania, Australia; Congo, Ecuador, Gabon, Mexico, Morocco, Namibia, New Zealand, Peru, South Africa, and the United States. They are usually located in less than 1,000 m of water and their formation is linked to zones of coastal upwelling, divergence and biological productivity.

Currently proposals to mine phosphate are under consideration in New Zealand, Namibia and Mexico. In New Zealand, the Ministry of Business, Innovation and Employment has granted a 20-year mining permit to Chatham Rock Phosphate Ltd. for the extraction of rock phosphate nodules from an 820-km2 area of the Chatham Rise (Figure 7). Before mining can commence, the company still needs to obtain consent from the Environmental Protection Authority. At the time of publication of this report the Authority had refused an application by Chatham Rise Phosphate limited for a marine consent to mine phosphorite nodules on the Chatham Rise (NZ EPA, 2015). The decision-making committee found that that “the destructive effects of the extraction process, coupled with the potentially significant impact of the deposition of sediment on areas adjacent to the mining blocks and on the wider marine ecosystem, could not be mitigated by any set of conditions or adaptive management regime that might be reasonably imposed.” They also concluded that the economic benefit to New Zealand of the proposal would be modest at best.

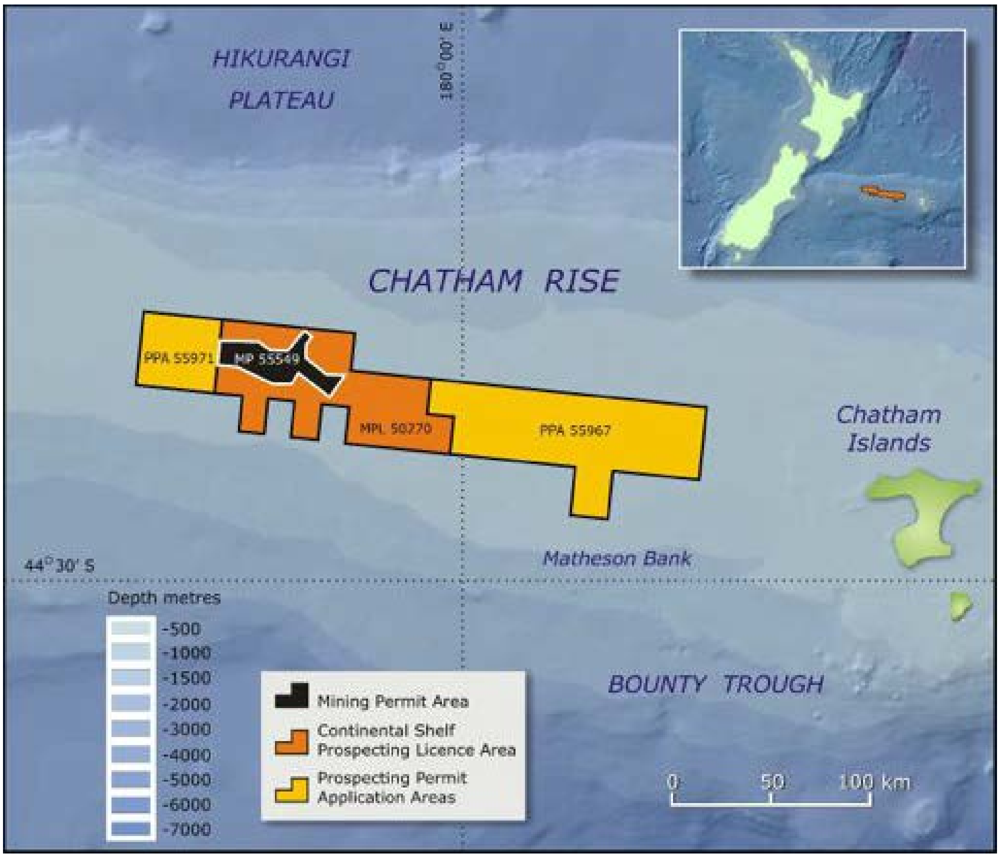
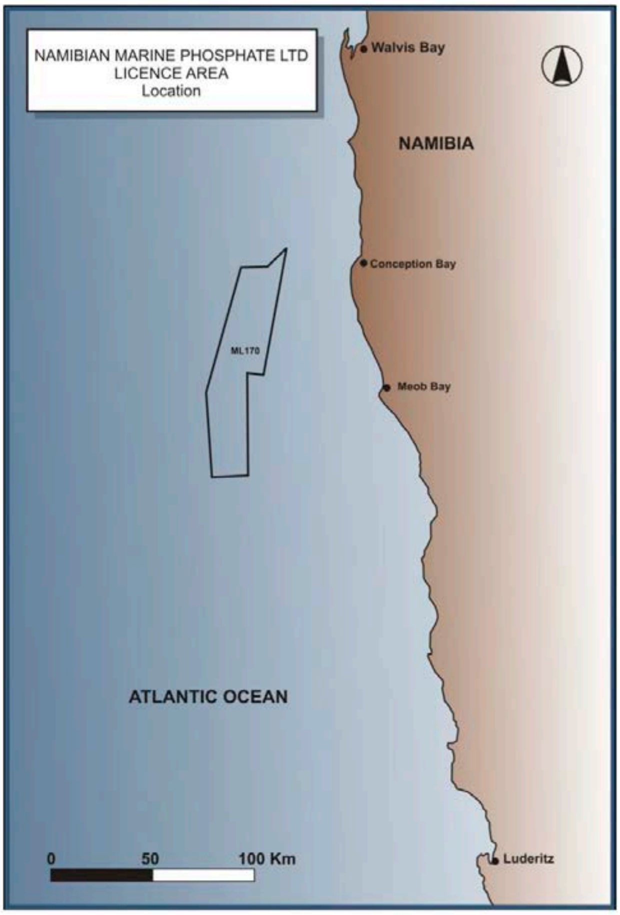


Figure 7. Location of Chatham Rise phosphate project area (RSC, 2014).

In Namibia, an Environmental Impact Assessment Report and an Environmental Management Plan were submitted in March 2012 for the Sandpiper Phosphate Project (Figure 8), which proposed to dredge phosphate-enriched sediments south of Walvis Bay, Namibia, in depths of 180-300 m (Midgley, 2012). The company planned to extract 5.5 Mt of phosphate-enriched marine sediments on an annual basis, for over 20 years. The environmental impact assessment (EIA) identified low-level potential adverse impacts including biogeochemical changes, benthic habitat loss, loss of biodiversity and cumulative impacts (Namibian Marine Phosphates, 2012; Midgley, 2012; McClune, 2012). No official decision has been issued on the Sandpiper Phosphate Project application as yet, however in September 2013, an 18-month moratorium on environmental clearances for bulk seabed mining activities for industrial minerals, base and/or rare metals (including phosporites) was declared by the Government of Namibia. During this period the Ministry of Fisheries and Marine Resources is required to make a strategic impact assessment on the potential impacts of the proposed phosphate mining on the fishing industry. While the Ministry of Mines and Energy is allowing marine phosphate exploration activities to continue during the moratorium period, such activities are not currently being undertaken in areas within the national jurisdiction of Namibia.



The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 8. The Sandpiper Project (license area shown) includes the zone of highest regional phosphate concentration (Namibian Marine Phosphate, 2012).

A proposed Mexican underwater phosphate mine, the Don Diego project, is located in 60-90m water depth, approximately 40 km off the cost of the Bay of Ulloa, on the west coast of Baja California. The permit area is 912 km^2 and it is estimated that if the project proceeds the area dredged annually would be around 1 per cent (1.7 km^2; Don Diego, 2015). Phosphorite resources at the Don Diego deposit have been estimated to total 327.2 million ore tons at 18.5 per cent P_2O_5. Odyssey Marine Exploration has lodged an environmental impact assessment for the recovery of the phosphate sands with the Mexican Secretary of Environment and Natural Resources and is awaiting a decision (Odyssey Marine Exploration, 2014). Local non-governmental organizations including WildCoast, Centro Mexicano Derecho Ambiental (CEMDA), Grupo Tortuguero, Vigilantes de Bahia Magdalena and Medio Ambiente Sociedad have been vocal in their opposition to the project (Pier, 2014).

4.2 Deep-Sea Mining

Although commercial deep-sea mining has not yet commenced, the three main deep-sea mineral deposit types – sea-floor massive sulphides (SMS), polymetallic nodules and cobalt-rich crusts – have been the subject of interest for some time (see SPC 2013a,b,c,d). Recent announcements make it seem likely that SMS mining will begin in the Manus Basin of Papua New Guinea (Nautilus Minerals, 2014a and b). Other Pacific Island States (e.g., Fiji, Solomon Islands, Tonga and Vanuatu) have issued exploration licenses to various companies to evaluate the commercial feasibility of mineral resources development in their exclusive economic zones. The economic interest in SMS deposits is their high concentrations of copper, zinc, gold, and silver; polymetallic nodules for manganese, nickel, copper, molybdenum and rare earth elements; and ferromanganese crusts for manganese, cobalt, nickel, rare earth elements, yttrium, molybdenum, tellurium, niobium, zirconium, and platinum.

In addition, the International Seabed Authority (ISA), which regulates deep-sea mining in the Area (the seabed, ocean floor and subsoil thereof beyond the limits of national jurisdiction) has entered into 15-year contracts for exploration for polymetallic nodules, SMS and cobalt-rich ferromanganese crusts in the deep seabed with 26 contractors (composed of companies, research institutions and government agencies) plus 1 contract pending ISA Council action in July 2015 (ISA, 2000; ISA 2001; ISA 2010; ISA 2013).

Seventeen of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone (CCZ, 16) and Central Indian Ocean Basin (1). There are six contracts for exploration for SMS in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and four contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean (3) and Atlantic (1) (ISA 2015a). These licences allow contractors to explore for seabed minerals in designated areas of the Area.

The ISA has called for comments on draft regulations for exploitation licensing in the Area (ISA 2015b). The decision to commence deep-sea mining in the Area will depend in part on the availability of metals from terrestrial sources and their prices in the world market, as well as technological and economic considerations based on capital and operating costs of the deep-sea mining system.

5. Gaps in capacity to engage in offshore minerals industries and to assess the environmental, social and economic aspects.

Despite the importance of marine extractive industries in many developing countries, the environmental, social and economic aspects are often not adequately understood. Therefore it is necessary to strengthen the approach to planning and managing these activities. This includes implementing the precautionary principle and adaptive management, as well as transparent monitoring. There is also a lack of consensus on what is an acceptable condition in which to leave the seabed post mining. Increasing public awareness and engendering a custodial and stewardship attitude to the environment may help curb the most damaging practices.

Unregulated mining often occurs in parallel to regulated mining activities. For example, numerous small operators participate in the marine sector of the tin mining industry in Bangka and Belitung, Indonesia. Many of the practices associated with these workers are unsafe and miners are killed or injured every year; local news reports refer to over 100 fatalities per year (Jakarta Post, 2010). The lack of regulation or the lack of enforcement of regulations, allows mining to take place in critical marine habitats and extensive damage has been done to coral reefs and mangrove environments (IDH, 2013). Improved licensing, regulation, enforcement and monitoring, in conjunction with social programmes to find alternative sources of revenue, would be needed. How the industry is being regulated would also need to be considered. The export data, published by the Bangka Belitung regional administration, showed that P.T. Timah, which owns 473,800 hectares of concession areas, exported 8,899 tons of tin in 2009, and privately owned smelters, which operate concession areas of 16,884 hectares, exported 13,867 tons. These discrepancies highlight the magnitude of the problem. The penalties provided by mining and/or environmental legislation may need to be strengthened to stop these practices.

For any State or company planning resource development, integrating coastal and marine ecosystem services into the development process is important; however, information on the services provided or the value of these services is often scarce. In many developing countries the interface between governments and offshore minerals industries needs to be strengthened. Deficiencies exist in the information available and in the institutional capacity to manage non-living marine resources. In summary, the following gaps can be identified:

- Increased capacity in coastal and marine geosciences information systems (including social, cultural, economic, ecological, biophysical and geophysical information) to improve geoscientific advice for management and monitoring of coastal environments to meet the requirements of ecosystem-based management and sustainable development;
- Development and implementation of robust regulatory frameworks for marine mineral extraction industries, which include environmental impact assessments, environmental quality and social laws, environmental liability, and monitoring capacity;
- Increased public awareness of the vulnerability of coastal environments, the benthic habitats and the fishery nursery grounds that may be affected by marine mining; and
- Technology transfer and skills development to ensure best practice in marine mineral extraction.

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