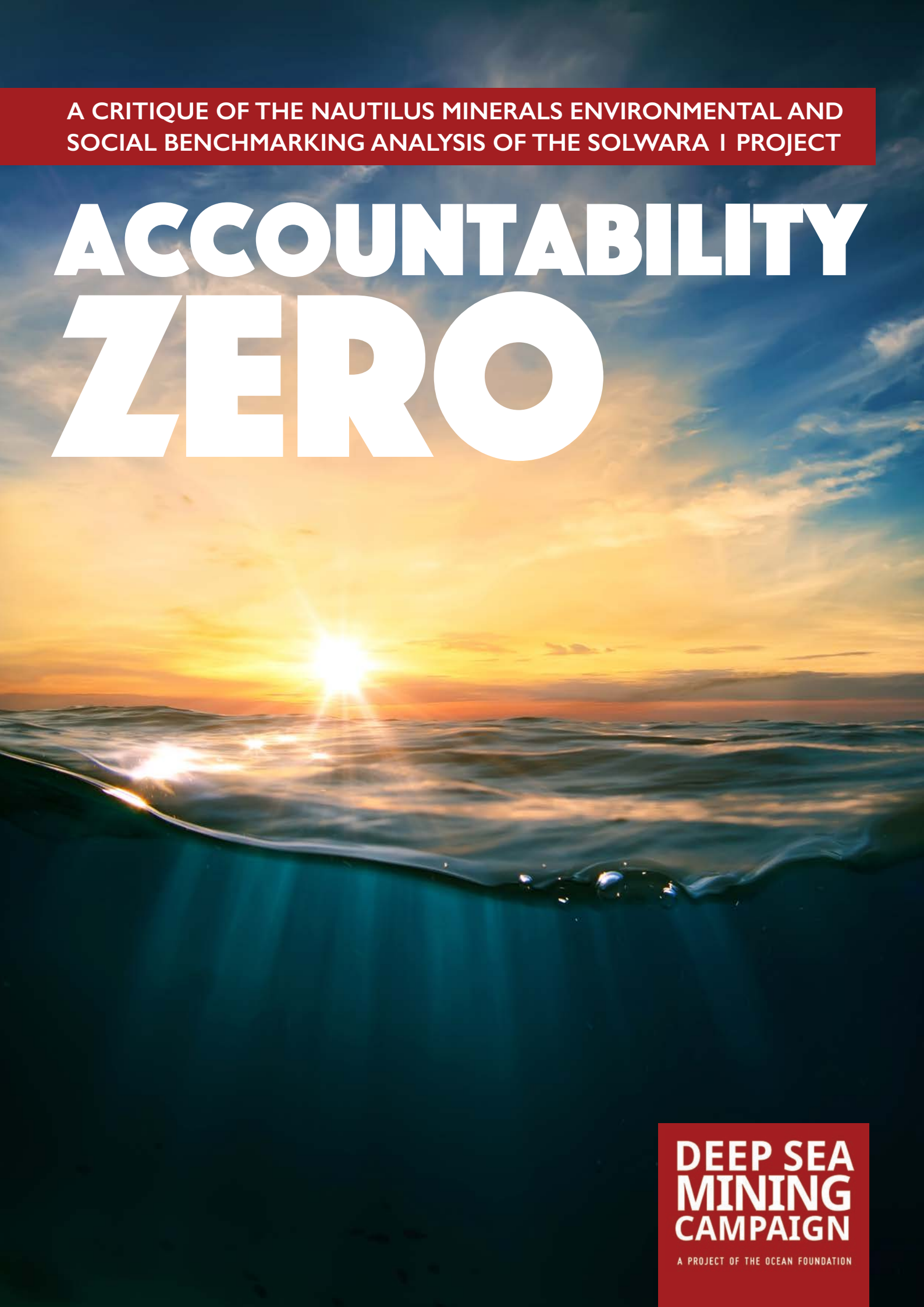
A CRITIQUE OF THE NAUTILUS MINERALS ENVIRONMENTAL AND SOCIAL BENCHMARKING ANALYSIS OF THE SOLWARA 1 PROJECT

# ACCOUNTABILITY ZERO



DEEP SEA MINING CAMPAIGN

A PROJECT OF THE OCEAN FOUNDATION

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The **Deep Sea Mining (DSM) Campaign** is an association of non-governmental and community based organisations and citizens from the Pacific Rim Region who are concerned about the impacts of DSM on marine and coastal ecosystems and human communities.

As an emerging threat, DSM has not been widely discussed beyond mining and technical circles. A key aim of the DSM campaign is to raise the profile of issues amongst government and the general populace. We seek to generate critical thinking and thus informed debate about the risks and costs of this new mining industry.

We have produced several articles, fact sheets, two science-based reports, made a submission to the International Seabed Authority, conducted advocacy and participated in discussions on DSM at international, Pacific regional and national levels. All materials and resources are downloadable at our web site.

*The Deep Sea Mining Campaign is a project of The Ocean Foundation*

Established in 1989, **Economists at Large** are a team of economists working to create a sustainable economy, society and environment. We are like 'economists without borders', working where economics is least represented, using the tools of economic analysis to ensure the true value of the environment and society is fully recognised. We work frequently with the not-for-profit sector, applying the tools of economics to natural resource management, environmental conservation, animal welfare tourism and general public policy analysis.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| DSM | Deep Sea Mining |
| CBA | Cost-Benefit Analysis |
| EE | Earth Economics |
| EEZ | Exclusive Economic Zone |
| EIA | Environmental Impact Assessment |
| EIS | Environmental Impact Statement |
| EPA | Environment Protection Authority |
| ESBA | Environmental and Social Benchmarking Analysis |
| NGO | Non-Governmental Organisation |
| NZ | New Zealand |
| OECD | Organisation for Economic Co-operation and Development |
| PNG | Papua New Guinea |

# 1 OVERVIEW OF CONCERNS REGARDING THE ENVIRONMENTAL AND SOCIAL BENCHMARKING ANALYSIS OF THE NAUTILUS MINERALS SOLWARA 1 PROJECT

The Canadian mining company, Nautilus Minerals Inc. (hereafter Nautilus) is set to embark on the unprecedented extraction of metals from the sea floor. The mining project, known as the Solwara 1 project, proposes to extract gold and copper from the floor of the Bismarck Sea in the New Guinea Islands Region of Papua New Guinea (PNG). It is the first of a potentially large number of deep sea mining (DSM) projects within the Pacific Islands Region, including a number of other nearby tenements granted to Nautilus.

Globally, interest in DSM is burgeoning, with new areas being opened up to exploration almost monthly. The Indian Ocean, the Red Sea and the Clarion Clipperton Zone (58,000 km$^2$ of international waters between Hawaii and Mexico) are just some of the world's exploration hot spots.

Over the past decade, the Pacific Islands Region has also witnessed a frenzy of seabed exploration. Over 1.5 million km$^2$ of ocean floor in the south-west Pacific alone is under exploration leasehold to private companies and Government-company joint-ventures within both territorial and international waters.

Despite issuing exploration licences (and in the case of Solwara 1 an exploitation licence), Governments and the International Seabed Authority still lack the regulatory frameworks and decision making tools to ensure the well being of coastal and island communities and the marine ecosystems they rely on.

Nautilus commissioned United States based consultancy firm, Earth Economics (EE), to produce the Environmental and Social Benchmarking Analysis (ESBA) of the Solwara 1 project. Published in May 2015, Nautilus and the consultants consider the report a groundbreaking analysis of DSM using natural capital accounting and an ecosystem goods and services framework.

According to the ESBA report, the primary goal of the analysis is to measure the social and environmental impacts of the Solwara 1 project in comparison to three terrestrial copper mines, as a tool for good decision making. In the words of EE:

*"This study provides a social and environmental review of the Solwara 1 project. It provides a preliminary framework that examines the ecosystem goods and services that may be enhanced, degraded, or consumed by the Solwara 1 project in Papua New Guinea. This study also sets out the first ever natural capital accounting and ecosystem goods and services framework for seabed mining. The Solwara 1 project is compared to modern existing and proposed terrestrial copper mines. Increased recycling and replacement of copper as alternatives to mining and the smelting process are also examined."*

However, as we explain below, the ESBA falls well short of its own stated goals and does not provide the critical analysis needed for strengthened decision making. While it employs a structure adapted from an internationally recognized natural capital accounting process, it fails to meet the well accepted requirements of a cost-benefit analysis (CBA). A CBA would identify major social and environmental concerns associated with Solwara 1 and attempt to quantify impacts as meaningfully as possible. It would seek to estimate the net benefits of the proposed deep sea mine against its net impacts. Without a CBA, the

ESBA is of little value to public policy and DSM decision-making.

Furthermore, the ESBA contains serious methodological and logical inconsistencies including:

- The use of natural assets, ecosystem services and values that describe terrestrial environments but bear no relevance to deep sea and marine environments. As a result, the ESBA undervalues, or values at zero the ecosystem goods and services provided by deep sea and marine ecosystems;
- A failure to account for the social, cultural and economic values of oceans;
- The failure to account for the cumulative impacts of the several deep sea mines Nautilus intends to operate in the Bismarck Sea;
- A questionable comparison with selected terrestrial mines that fails to build a picture of the natural assets and ecosystem services associated with the Solwara 1 site;
- A partial and incomplete analysis that rests its case entirely on copper production and omits the analysis of gold production.

The ESBA is based on scientific information provided by Nautilus, principally the Solwara 1 Environmental Impact Statement (EIS). It is therefore limited at the outset by the company's own incomplete assessment of the impacts of the proposed mining process. In particular, The ESBA lacks reference to the risks examined in well substantiated reviews of the Solwara 1 EIS.

> The use of this framework for decision making purposes would lead to very poor public policy outcomes. The risk of unexpected costs and losses due to unpredicted environmental and social impacts is high and could leave coastal and island communities carrying a long term burden.

# 2 INADEQUATE IMPACT ASSESSMENT STARTS WITH THE SOLWARA 1 EIS

Scheduled to begin commercial production in 2018, Solwara 1 is the world's first licensed deep sea mine. Nautilus was issued with all necessary permits by the Government of PNG despite a flawed EIS, inadequate consultation with civil society and the absence of the Free Prior and Informed Consent of local communities.

> Three independent science-based reports have comprehensively analysed the Solwara 1 EIS. These detail deficiencies in the science and the modelling employed by Nautilus[1]. Nautilus has neither disproved the concerns raised by reports nor has it provided for public scrutiny additional research that may allay them.

Whilst Nautilus has collaborated with leading scientists to document species at hydrothermal vents at the Solwara 1 and other sites, this work is relatively straightforward and not controversial. More complex and of wider public concern are the potential impacts of the proposed Solwara 1 mine on these species and on others both at depth and in more shallow waters.

Many significant risks were poorly addressed in the Solwara 1 EIS. These include:

- Sea water pollution from spills of oil or ore slurry from vessels at the surface, leakage from the riser or discharge pipes, and sediment plumes generated during the mining process and through the return of the discharge water;
- Seismic events or storm surges causing spills, breakages and leakage;
- Vertical (upwellings) and horizontal currents transporting sediment plumes and pollutants shorewards and into contact with marine food chains;
- The bioavailability and toxicity to marine species of DSM related heavy metals contaminating marine water;
- The contamination of marine and human food chains resulting from sea water pollution and associated health impacts for coastal communities;
- Impacts on artisanal and commercial fisheries and on sea based tourism (e.g. game fishing, diving) and associated economic and social implications including for local food security, cultural practices, and livelihood opportunities;
- Light and noise under water and on the ocean's surface generated by the seafloor mining tool and surface support vessels and the physiological effects on marine species and sea birds;
- The destruction of unique and endemic ecosystems at hydrothermal vents. This is of particular concern as limited information exists about the capacity of, or timescale, for hydrothermal vent systems to re-establish following widespread vent field destruction, and whether any new vent systems will be as biologically diverse. As emphasised by Professor Van Dover, no one can predict the effects of scraping away 5000 years of mineral deposits across a whole vent field.[2]

The ESBA relies on the Solwara 1 EIS for scientific and technical information relating to the proposed mine. Thus the omissions and flaws inherent in that document flow through to the ESBA and are further compounded by the unsound logic employed by EE, as discussed below.

# 3 FUNDAMENTAL ERRORS IN THE LOGIC OF THE SOLWARA 1 ESBA REPORT

The rationale provided by EE for conducting the ESBA is to strengthen DSM decision-making by quantifying and valuing natural capital assets and ecosystem services. Tables 3 and 4 of the report respectively claim to describe these properties at the Solwara 1 site and the extent to which they will be impacted by mining in comparison to three terrestrial mines.

However, these tables and the analyses that underpin them contain serious logical inconsistencies. These render the conclusions reached by EE incorrect and misleading.

> Consequently the ESBA is not fit for its intended purpose i.e. it fails to provide a framework to assist decisions about the advisability of Solawara 1 or any other DSM project.

The sections below describe the more glaring of the errors in EE's logic.

## 3.1 FLAWED COMPARISONS WITH TERRESTRIAL MINES

EE's comparison of the Solwara 1 project with three terrestrial mines raises serious methodological questions. Not only are terrestrial and marine ecosystems extremely different, but while much is known about the existing and potential impacts of mines on land, there is no equivalent information for the marine environment, as no deep sea mine has yet been developed.

The environmental impacts of the two existing terrestrial mines chosen (the Bingham Canyon mine, Utah, USA, and the Prominent Hill mine, South Australia) are extremely high and very well documented. The proposed Intag mine in Ecuador selected by EE is located in a biodiversity hot spot and has been the subject of years of opposition by the local community, to which EE itself has contributed.[3]

EE advocates against the development of the Intag mine, having conducted research with the goal of confirming "that copper mining in unique ecosystems like the Intag Region of Ecuador is uneconomic, ill-advised and that the preserved natural resources in the region are worth far more than the extracted resource could ever be."[4] The reality is that both the Bismarck Sea and the Intag region contain natural resources that are valuable and ecosystems that are worthy of protection.

Given the emphasis on isolation from human populations on the natural capital values assigned by EE to Solwara 1, terrestrial mines further removed from human populations may have been more relevant comparisons. Six of the world's 10 most productive copper mines are located in the desert of Chile, including an underground mine.[5] These could be expected to have less impact on ecosystems services than the mines selected.

Alternatively, a comparison with other mines in PNG discharging waste into marine environments[6] could have offered greater congruence and provided for a more meaningful analysis.

## 3.2 SELECTIVE AND INCOMPLETE FOCUS ON COPPER[7]

The ESBA relies heavily on an analysis of copper as facing steadily increasing demand, being essential to human development, and decreasing in terms of economic deposits on land. The ESBA then argues that recovery of the high grade deposits that Nautilus is seeking to mine is important for human development.

Leaving aside the current collapse in demand and prices for copper, it should be noted that hydrothermal vents are not abundant, and hydrothermal vents that are economic to mine even less so.

While the metal grades in hydrothermal vents are higher than most metal grades on land, the total metal content of hydrothermal vents is lower than that of terrestrial ore deposits "it is therefore unlikely that the marine mining of massive sulphides will have a significant impact on global resource supply."[8]

In other words, terrestrial mining will continue. Should DSM become a reality then the harm caused by terrestrial mining will be augmented by the harm imposed on the marine environment. It is therefore in society's interest to ensure that the environmental and social impacts of terrestrial mining are minimised rather than to embark upon the destruction of ecosystems which until now have not been exposed to mineral resource extraction and are so remote from the public eye that monitoring impacts will be extremely difficult.

In addition, the ESBA does not factor in the capacity of technological developments to significantly enhance the extent to which recycling is likely to contribute in the future to global supplies of copper and other metals, including rare earths. The "urban mining" of the world's already huge and growing stockpiles of electronic and other wastes would provide for economic, social and environmental win-win outcomes. Research efforts to commercialise this are in progress and attracting investment.[9]

> A more economically, socially and environmentally sustainable future would be one in which metal recovery and recycling is prioritised and supplemented, if necessary, by a small number of well managed terrestrial mines.

It is notable, that the ESBA focuses its analysis on the copper to be mined by the Solwara 1 project and ignores the significant production of high grade gold that Nautilus anticipates mining. This is in spite of the fact that at current prices gold will contribute to almost 40% of the project's total revenue.[10]

The ESBA argues in favour of Solwara 1 based on the global need for new sources of copper for industrial uses, whereas gold is primarily used for jewellery. Gold is an extremely lucrative commodity and a primary driver of new mining exploration worldwide. Completely ignoring an analysis of gold in the ESBA is not consistent with sound economic analysis and creates an impression that the ESBA has been conducted in a selective manner so as to favour Solwara 1.

## 3.3 USE OF INAPPROPRIATE TERRESTRIAL METRICS

A rigorous natural resource accounting framework would enable a reader unfamiliar with the location to gain an accurate picture of the ecosystem services provided by Solwara 1 and the degradation that these are likely to experience as a result of mining. However no such understandings are provided by the ESBA.

Standard cost-benefit analysis (CBA) as implemented by a wide range of agencies, including the World Bank, requires a 'baseline' case to be described. This case would describe all services that are being provided by the underlying asset. This baseline case would act as a reference point against which to compare the effects if the project went ahead.[11]

Given the continuous nature of the marine environment, sound natural resource accounting would also weigh up the scope and scale over the long term of indirect impacts on important natural assets and ecosystem services. For example, what are the impacts of the plumes of metal-bearing sediment to be generated by the mining

process on all values, including sea water quality, fisheries, tourism, cultural, environmental and social values?

Based on scientific information provided by Nautilus, the ESBA presents an incomplete picture of ecosystem services, potential impacts, and how, if at all, these can be contained and mitigated in the marine environment. Further to this, the ESBA uses sets of ecosystem services that are relevant for terrestrial locations but inappropriate for the deep sea.

By *comparing apples to oranges*, it is hardly surprising (but meaningless) that Solwara 1 is rated by EE as having a lower impact than the selected land-based mines on terrestrial values such as ground and fresh water quality, air quality, pollination, soil formation and retention, recreational activities such as hiking and bike riding, and loss of agricultural land.

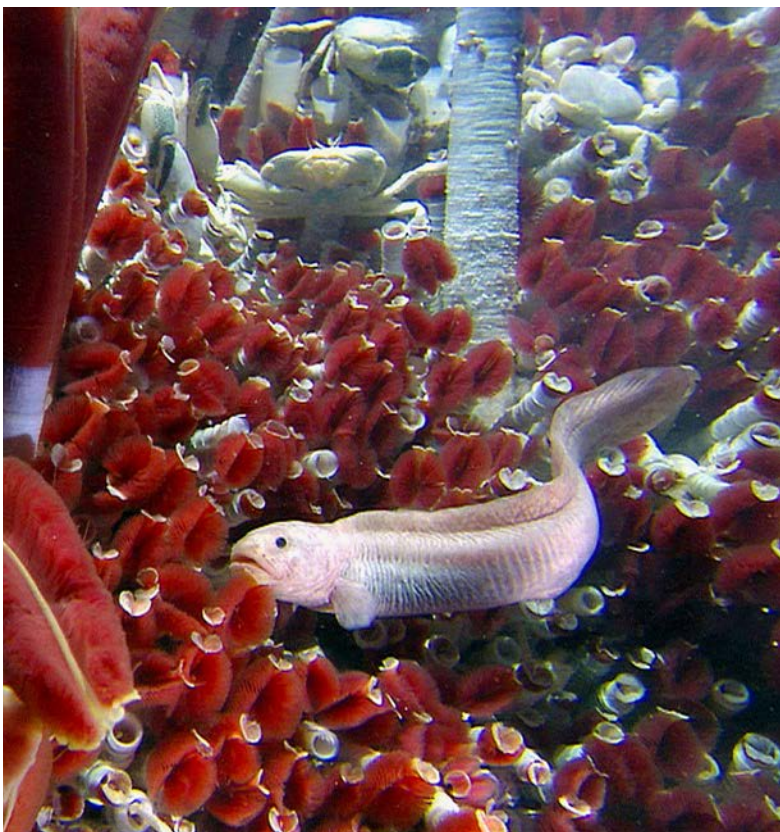
The comparison of Solwara 1 to selectively chosen land-based mines and the use of terrestrial metrics to evaluate the significance of the ecosystem impacts of the Solwara 1 project seriously questions the credibility of the ESBA review.

The absence of an economic analysis of Solwara 1's likely impacts on sea water quality, marine ecosystems, other marine values and their associated social impacts is astonishing in a study purporting to be a groundbreaking natural capital analysis of deep sea mining.

Little is known about the properties of the deep sea and studies identifying ecosystem services and establishing their values are lacking. However, the Organisation for Economic Co-operation and Development (OECD) has made clear that: "When evaluating any project or policy in which an environmental asset is destroyed or depreciated, the Total Economic Value of the lost asset needs to be determined."[12] Thus, proponents are expected to seek and to incorporate the best available, meaningful impact and valuation data.

In order to do this, a sound natural accounting framework would have drawn on a range of information sources (not only Nautilus's data) to assess the impacts on deep sea ecosystems, sea water quality, the sea bed, artisanal and commercial fisheries, marine and bird species, tourism, local livelihoods and culture, as per the risks identified in Section 2 of this paper. The ESBA could have utilised data relating to gas and oil drilling (from which Nautilus has adapted its deep sea mining technology) as well as other maritime development activities such as military use, bridge construction, dredging and deep sea bottom trawling.

Moreover, the ESBA should have incorporated ecosystem services relevant to the deep sea even if it is necessary to note the absence of impact data. Indeed, an impartial and independent analysis would have highlighted the risks associated with these gaps in knowledge, the research required to fill them, and the consequent need to adopt a precautionary approach towards the development in question.



## 3.4 THE SOCIAL, CULTURAL AND ECONOMIC VALUES OF OCEANS

Marine ecosystems provide critical fisheries, coastal protection, and cultural benefits to communities worldwide. A recent study using an interdisciplinary social-ecological systems approach estimated the social, economic, and cultural values of a small scale fishery in the Hawai'i Islands. In doing so, it accounted for important food security functions and its contribution to the maintenance of social relationships and social cohesion.[13]

Just as the Solwara 1 EIS fails to adequately assess many of the project's environmental impacts, it also falls short in its consideration of social impacts. To date no studies exist in the public domain into the full scope of social, cultural and economic effects of the proposed Solwara 1 mine.

For surrounding coastal communities, the Bismarck Sea underpins local culture and provides sources of food and livelihood opportunities. Typically in PNG, small scale fisheries provide nutrition for families, with surplus sold at local markets contributing to material family needs and the cash economy. The pattern and nature of artisanal fishing around the Bismarck Sea and the effects of the Solwara 1 project on this and family livelihoods are yet to be determined.

However, the ESBA asserts that the proposed Solwara 1 mine will not affect food supplies, culture, spiritual and historical connections. This is ill-informed and contradicts findings in New Zealand (NZ) last year. Here the Environment Protection Authority (EPA) rejected NZ's first two applications[14] to mine within the Exclusive Economic Zone (EEZ) in recognition of insufficient scientific information to identify the scope and significance of impacts on the environment and on existing commercial and community interests. In a nutshell, the EPA decided against issuing the licences because according to their estimation of costs and benefits, the risks outweighed the economic benefits.[15]

In PNG, due to uncertainty surrounding the impacts of seabed mining, Solwara 1 has been met with opposition from communities, churches,[16] NGOs, scientists, fishery scientists, academics and student associations.[17]

Contrary to EE's conviction that the project will have no cultural impacts, local communities have used traditional practices to ban the entry of Nautilus from the ocean surrounding the Solwara 1 site.

IMAGE: Grassroots resistance to deep sea mining. A New Irelander puts up a "gorgor" near the Solwara 1 site in the Bismarck Sea of Papua New Guinea to prohibit the entry of Nautilus Inc. According to customary law New Irelanders have the right to destroy vessels entering their waters without permission.

## 3.5 SCALE, TIMEFRAME AND CUMULATIVE IMPACTS

The ESBA states *"All mines present a risk to downstream ecosystems; however, the scale of Solwara 1 is small".*

Nautilus holds approximately 420,000 km$^2$ of exploration leasehold on sea floor in the western Pacific, largely in PNG, the Solomon Islands, Fiji, Vanuatu and Tonga, as well as in international waters in the eastern Pacific. Twelve Solwara

tenements have been identified in the Bismarck Sea with several being proposed as follow-on projects after the 2.5 year life expectancy of Solwara 1.

It is therefore misleading to imply that the social and environmental impacts for the communities of the Bismarck Sea will be confined to the 11 ha Solwara 1 mine alone. It is equally disingenuous of the ESBA to compare the impacts and the land size of only Solwara 1 with the three much longer-lived terrestrial mines when in fact a succession of Solwaras are planned.

Because DSM is proposed as a rolling series of small scale, short-lived mines, the ESBA framework should have accounted for the cumulative effects over time of the several mines Nautilus intends to operate. The impact footprint of each individual seabed mining operation is likely to be larger than the proposed mine site. The interactions between currents, weather and seismic events means that the spread of pollution and its impacts cannot be contained nor readily predicted. The high level of uncertainty and risk associated with many individual projects could accumulate and compound in unknown ways as DSM activity increases.

## 3.6 IMPACTS OF PLUMES

If it proceeds, Solwara 1 will generate plumes of sediment during the mining process and as a result of the discharge of waste water just above the sea floor. Depending on upwellings, currents, and tides, the plumes could travel considerable distances. Pollution may also occur at shallow depths through surface spills or leakage from the riser or discharge pipes.

Nautilus is yet to conduct comprehensive studies into the bioavailability and the toxicity to marine organisms of the heavy metals that will be carried in the plumes and how these properties may change with depth and temperature. Thus, the extent to which metals derived from Solwara 1 may poison marine species and the coastal communities that rely on them is not yet known. However the limited toxicity testing that Nautilus has conducted indicates that Solwara 1's waste water would be toxic to shallow water species and would need to be diluted 700 times to lose toxicity to these species (EIA 9.4).[18]

Furthermore, the independent oceanographic review of the Solwara 1 EIS found that vertical and horizontal water movements around the Solwara 1 site could carry the sediment plumes shoreward towards the west coast of the main island of New Ireland Province and possibly towards the island of East New Britain.[19]

The ESBA dismisses the impacts of plumes, claiming that the emission of the adjacent undersea volcano exceeds the sediment plume expected from the Solwara 1 mine. However in order to validate this claim the ESBA should quantify and compare the background level volcanic emission and its chemical composition with that of the mine derived sources of pollution and their likely ecological effects. The ESBA also does not consider the cumulative effects of the Solwara projects in addition to the volcanic activity.

Without such information, claims that the impact of sediment plumes is negligible are not valid.

## 3.7 EVALUATING IMPACT AND COST- BENEFIT ANALYSIS

The overall conclusion drawn by EE is that Solwara 1 has the potential for far fewer social and environmental impacts than the existing terrestrial mines examined. In the sections above we demonstrate the errors in logic that render their conclusions invalid.

In addition, it should be noted that a rigorous economic analysis would not emphasise the number of impacts, but the value of impacts on natural assets and ecosystem services and then compare this value to the value of Solwara 1's total output. It is a CBA such as this that would assist decision making about deep sea mining.

The production output of Solwara 1 is very small at 0.7% - 6% of the output of the terrestrial mines included in the study (refer to pxiii ESBA). A CBA could well indicate that the potential benefits of Solwara 1 are outweighed by the costs of its impacts. Indeed, this is the basis of the NZ EPA's decision last year to reject two applications to mine within NZ's EEZ (see section 3.4 above).

Factored into a CBA would be the significance and rarity of deep sea hydrothermal vent ecosystems. It is estimated that there may be 500 to 5,000 deep sea hydrothermal vent sites (often associated with Seafloor Massive Sulphide deposits) in the world's oceans.[20] If one estimates that each of these vent sites covers an average of 1 $km^2$, the global total area covered by deep sea hydrothermal vent ecosystems would be 500 $km^2$ to 5,000 $km^2$. This is relatively small compared with, for instance, the more than 6 million $km^2$ of tropical forest habitat globally, or the 100+ million $km^2$ of abyssal plain in the world's ocean (where another type of DSM deposits, poly-metallic nodules are found).

In fact, deep sea hydrothermal vent ecosystems are one of the rarest ecosystem types in the global biosphere. Thus, disturbance or removal of deep sea hydrothermal vent habitat through DSM activities would remove proportionately a much greater percentage of the global total of this habitat, than would mines of similar output in abyssal plain or tropical forest habitat.[21] In addition, these deep sea vent ecosystems are home to some of the only species known that rely on chemosynthesis, representing unique life forms relatively new to science.[22]

According to marine specialists at the Woods Hole Institute, "No two vents discharge exactly the same mixes of fluids, so no two vents are colonized by exactly the same life forms. Researchers continue to find new vent species just about every time they look for more. (...) So little is known about them that if vents are mined, we may never know what species have been lost.[23]

Furthermore, these same marine experts note that not only species unique to a particular mined vent will be lost, but biodiversity critical to ecosystem resilience as a whole is at risk: "The result could be the subsea equivalent of replacing an old-growth forest with a field of dandelions. (...) Too little research has been conducted to know for sure."[24]

**The monetised value of the destruction of such rare ecosystems would necessarily be high.**

# 4 CONCLUSIONS

The ESBA utilises partial data inappropriate to the marine environment to argue that the social and environmental impacts of the proposed Solwara 1 are lower than those of three of the world's most destructive terrestrial mines - the Bingham Canyon mine in Utah, USA, the Prominent Hill mine in South Australia and the proposed Intag Mine in Ecuador.

As described in Section 3, the report contains serious methodological and logical inconsistencies including:

- The use of natural assets, ecosystem services and values that describe terrestrial environments but bear no relevance to deep sea and marine environments. As a result, the ESBA undervalues, or values at zero the ecosystem goods and services provided by deep sea and marine ecosystems;
- A failure to account for the social, cultural and economic values of oceans;
- The failure to account for the cumulative impacts of the several deep sea mines Nautilus intends to operate in the Bismarck Sea;
- A questionable comparison with selected terrestrial mines that fails to build a picture of the natural assets and ecosystem services associated with the Solwara 1 site;
- A partial and incomplete analysis that rests its case entirely on copper production and omits the analysis of gold production.

Most notably, the ESBA fails to ask key research questions vital to good decision making about DSM such as:

- What are the net costs and benefits across environmental, social and economic dimensions over time and

- Do the net benefits outweigh the costs of impacts?

It is doubtful that a rigorous cost benefit analysis would determine in favor of Solwara 1 over the existing and potential future uses of the Bismarck Sea.

It is acknowledged that there is a paucity of data about the impacts of DSM, the properties of the deep sea, and its ecosystem services. However, it is incumbent upon researchers to incorporate the most meaningful impact data available. This was not done in the ESBA.

A sound and independent natural accounting framework would have drawn on a range of information sources (not only Nautilus's own data) from other development activities in the sea (e.g., gas and oil drilling, military use, bridge construction, bottom trawling and other coastal developments) to assess the impacts on deep sea ecosystems, sea water quality, the sea bed, artisanal and commercial fisheries, marine and bird species, tourism, local livelihoods and culture, as per the risks identified in section 2 of this paper. Moreover, it would draw attention to the deficiencies in impact data, gaps in knowledge requiring further research, and alert readers to the consequent need to adopt a precautionary approach.

By dismissing the risks associated with Solwara 1, Earth Economics commits what it itself describes as the greatest error in monetising impacts – "that of omission, or not valuing important assets at all" (p79, ESBA). "For when natural capital assets and ecosystem services are not considered in economic analysis, they are effectively valued at zero" (p37, ESBA). Thus even by its own measure, the ESBA fails to deliver a credible natural resource economic analysis of the proposed Solwara 1 mine.

**In conclusion, the ESBA is not fit for its intended purpose. It fails to provide a framework to assist decisions about the advisability of Solwara 1 or of any other DSM project.**

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10. Nautilus plans to process ore at an annual rate of more than 1.3 million tonnes, producing about 80,000 tonnes of copper and 150,000-200,000 ounces of gold per year over the estimated 2.5 year life of the mine. At August 2015 prices, the project will generate annually around US$245 million in gold (at US$ 1,225/ounce) and US$397 million in copper (at US$ $4,958/tonne).

11. 'Cost Benefit Analysis in World Bank Projects', Independent Evaluation Groups (IEG), World Bank, IFC, MIGA, 2010, https://openknowledge.worldbank.org/bitstream/handle/10986/2561/624700PUB0Cost00Box0361484B0PUBLIC0.pdf?sequence=1

12. Total Economic Value is the total value of all services provided by any asset. In the case of environmental assets this includes "Non-use values" which refer to environmental assets that people will not actually use themselves but may want to preserve for others (altruism), for future generations (bequest values), or simply because they attach a value to its very existence (existence values)." OECD, (2007:3), Policy Brief, Assessing Environmental Policies, OECD, Paris, 2007, http://www.oecd.org/env/tools-evaluation/38208236.pdf

13. Kittinger JN, Teneva LT, Koike H, Stamoulis KA, Kittinger DS, Oleson KLL, et al. (2015) 'From Reef to Table: Social and Ecological Factors Affecting Coral Reef Fisheries, Artisanal Seafood Supply Chains and Seafood Security'. PLoS ONE 10(8):e0123856. doi:10.1371/journal.pone.0123856, http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0123856

14. The EPA in New Zealand refused Trans-Tasman Resources Ltd (TTR) marine consent for seabed mining in June 2014, https://ramumine.files.wordpress.com/2014/06/trans_tasman_resources_decision_17june2014.pdf and refused Chatham Phosphate's marine consent in February 2015, http://www.epa.govt.nz/eez/EEZ000006/EEZ000006_CRP%20Final%20Version%20of%20Decision.pdf

15. 'EPA refuses marine consent application by Chatham Rock Phosphate Ltd', 11 February 2015, http://www.epa.govt.nz/news/epa-media-releases/Pages/EPA-refuses-marine-consent-application-by-CRP.aspx

16. 'Lutherans in PNG against seabed mining', see video http://www.deepseaminingoutofourdepth.org/video-lutherans-join-fight-against-seabed-mining-in-png/

17. '24,000 petitioned against seabed mining in PNG', see video http://www.deepseaminingoutofourdepth.org/video-24000-petitioned-against-sea-bed-mining/

18. Quoted in Coumans, Catherine 'Deep Sea Mining – A new frontier for ecosystem destruction', Mining Watch Canada, July 2015, http://www.miningwatch.ca/blog/deep-sea-mining-new-frontier-ecosystem-destruction; For the Environmental Impact Assessment see http://www.cares.nautilusminerals.com/Assets/Documents/Main%20Document%20Text.pdf

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21. The point we make above is not that forest ecosystems or abyssal plains should be mined in preference to hydrothermal vents. We advocate the maximisation of metal recovery and recycling, the minimisation of mining effort, and improving the management of environmental and social impacts of all mines.

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23. Quoted in Coumans, Catherine 'Deep Sea Mining – A new frontier for ecosystem destruction', Mining Watch Canada, July 2015, http://www.miningwatch.ca/blog/deep-sea-mining-new-frontier-ecosystem-destruction; 'What is seafloor mining?', Woods Hole Institute. Accessed July 2, 2015. http://www.whoi.edu/main/topic/seafloor-mining

24. Ibid.


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