



Executive Summary

The primary goal of the analysis was to measure the environmental and social impacts of the Solwara 1 project in comparison with three terrestrial mines.

Nautilus Minerals Inc. (Nautilus) is a seafloor resource exploration and development company that intends to commercially explore the seafloor for copper-, gold-, silver- and zinc-rich seafloor massive sulphide deposits and for manganese, nickel, copper and cobalt nodule deposits.

On 11 December 2014, Nautilus formed a joint venture with Eda Kopa (Solwara) Limited, a wholly owned subsidiary of Petromin PNG Holdings Limited, which is the nominee entity of the Independent State of Papua New Guinea for the Solwara 1 Project. Located in the Bismarck Sea of Papua New Guinea (PNG), the Solwara 1 project will be the world's first deep seabed mining project for copper minerals.

Earth Economics was commissioned by Nautilus to conduct an independent environmental and social benchmarking analysis of Nautilus' proposed deep seabed mining project. The primary goal of the analysis was to measure the environmental and social impacts of the Solwara 1 project in comparison with three terrestrial mines. This goal was achieved, as the analysis was sufficiently comprehensive to clearly identify critical social and environmental concerns and potential project benefits.

This analysis utilized a natural capital accounting approach that is internationally recognized based on improvements to the Millennium Ecosystem Assessment (MEA)¹ and The Economics of Ecosystems and Biodiversity (TEEB)² methods. The review has provided a comparison of the Solwara 1 project to three terrestrial copper mines, two existing and one proposed.

In this report, the importance and environmental implications of copper mining are discussed and a primer is provided on natural capital accounting and the value flows of environmental goods and services. The report analyses and conclusions are included on the following pages.





▲ Copper coil
Image credit: Pixabay

Report Analyses and Conclusions

Four analyses were completed as follows:

- 1 Analysis I examined the continued need for copper mining and the potential for recycling or substitution to replace copper mining in the future.
- 2 Analysis II reviewed 22 natural capital categories of goods and services present in the mining sites at Solwara 1 and the three terrestrial copper mining projects.
- 3 Analysis III delivered a quantitative analysis of input and effluent physical measures per metric ton of copper produced, again comparing three terrestrial copper mines with Solwara 1.
- 4 Analysis IV reviewed the potential monetized natural capital accounting impacts of Solwara 1 and the terrestrial mines for 14 of the 22 identified natural capital categories, with results provided in dollar values.

This report also presents a discussion of the Tongling Non-Ferrous Metals Group (TNFM) copper smelter, the smelter that has agreed to purchase the Solwara 1 copper product.

The concentration of copper in terrestrial ore deposits is declining, increasing the financial, social, and environmental costs associated with production.

Copper and the Environment: A Nano-History

- 1 Over 7 billion people use copper. It is essential to achieving human development goals.
- 2 Copper is vital for producing numerous forms of electrical power, clean water, and technology.
- 3 Terrestrial copper mining has significant social and environmental impacts. Risks of terrestrial mining include displacement of communities, water contamination, and damage to downslope communities from waste rock and tailings.
- 4 The concentration of copper in terrestrial ore deposits is declining. This decline is increasing financial, social, and environmental costs associated with production, on a cost-per-metric ton basis.

Copper recycling is important, but recycling alone cannot fulfill current and projected copper demand.

Analysis I: Copper Recycling and Substitution

- 1 Copper recycling prices are high, with brisk, robust copper recycling markets. However, there is a limit on idle copper available to be recycled.
- 2 Copper recycling is likely limited to around 30% of global supply, and the substitution of other materials and technologies for the currently in-use copper stock will not be realized in the near future, thus, demand for copper ore will remain high and copper mining will likely expand globally.
- 3 Even if recycling a significant portion of the current global built capital stock became feasible, copper ore mining would still be required in order to meet global demand.

The State of Knowledge of the Bismarck Sea Deep Seabed

- 1 The deep seabed is not generally well understood; however, the Solwara 1 proposed mine site, the North Su volcano, and the South Su conservation site are well studied. The Solwara 1 project environmental impact statement and 35 independently published papers document the area to a degree that would compare very favorably with similar studies for terrestrial mining projects.
- 2 The Solwara 1 mine site is adjacent to the active North Su undersea volcano, which produces volcanic emissions that far exceed the sediment plume that the Solwara 1 mine is expected to produce.

The final three analyses each provide a comparison of the impacts of the proposed Solwara 1 deep seabed mining project and three terrestrial copper mines: Bingham Canyon (Utah, USA), Prominent Hill (South Australia, Australia), and Intag (a proposed mine in Intag Province, Ecuador). These mines have been chosen for comparison with Solwara 1 for the following reasons:

- The Bingham Canyon Mine is typical of the large scale terrestrial copper porphyry deposits that currently account for most of the world's copper supply;
- The Prominent Hill Mine holds a copper deposit that yields a similar annual amount copper as the projected copper yields for the Solwara 1 Project;



- The proposed Intag Mine is located in an area containing cloud forest that is considered to be a unique and sensitive terrestrial ecosystem with significant species endemism. Similarly, the vent ecosystems of the deep sea are also considered a unique and sensitive ecosystem with notable species endemism.

The results of these analyses are as follows:



▲ Bingham Canyon Mine
Image credit: Spmusick via Wikicommons

Analysis II: Identification of Copper Mine Impacts for Bingham Canyon, Prominent Hill, Intag and Solwara 1

- 1 Two terrestrial mines (Prominent Hill and Bingham Canyon) and one proposed terrestrial mine (Intag) were ranked with Solwara 1 across 22 identified environmental and social impact categories. These categories included resource, water, climate, soil, habitat, and cultural values. Rankings were devised using publicly available data such as Global Reporting Initiative, Environmental Impact Assessments, and Annual Report documentation.
- 2 When ranked across the 22 categories of natural capital accounting, deep seabed mining of the high grade copper material in the 14-hectare Solwara 1 site would involve far fewer impacts than operations at any of the examined terrestrial mines.
- 3 People will not be displaced by the Solwara 1 deep seabed copper mine.
- 4 Food production, fresh water supply, disaster risk reduction, pollination, soil formation, erosion, freshwater regulation, recreation, historic, and cultural values will not be impacted by Solwara 1. These natural capital categories are often negatively impacted by terrestrial mines (as in the case of the three comparison mines examined).
- 5 Raw materials, biological control, climate stability, air quality, waste treatment, habitat and nursery, nutrient cycling, genetic resource values, and science and education values will be impacted by Solwara 1, but less so than for the terrestrial copper mines examined. It is highly likely that the majority of terrestrial mines would have similar impacts as the terrestrial mines examined in this study.

Across 22 categories of ecosystem services, deep seabed mining of copper at the Solwara 1 site would involve fewer potential impacts than operations at any of the examined terrestrial mines.

The following table (also found in Analysis II) summarizes the impacts of each mine site. A description and explanation of the values presented in this table is found in Analysis II.

► Level of Ecosystem Service Impact by Mine. Level of impact ranges from 0 (lowest) to 3 (highest).

| Key | |
|-----|--------------------|
| | Low impact |
| | Moderate impact |
| | Significant impact |
| | High impact |

| Ecosystem Service | Level of Impact (0 = lowest, 3 = highest) | | | |
|-----------------------------------|---|----------------|----------------|-------|
| | Solwara 1 | Prominent Hill | Bingham Canyon | Intag |
| Provisioning Services | | | | |
| Food | 0 | 1 | 3 | 3 |
| Medicinal Resources | 0 | 1 | 1 | 3 |
| Ornamental Resources | 0 | 0 | 0 | 1 |
| Energy & Raw Materials | 3 | 3 | 3 | 3 |
| Water Supply | 0 | 1 | 3 | 3 |
| Regulating Services | | | | |
| Biological Control | 1 | 3 | 2 | 2 |
| Climate Stability | 1 | 1 | 2 | 3 |
| Air Quality | 1 | 0 | 1 | 1 |
| Moderation of Extreme Events | 0 | 1 | 3 | 3 |
| Pollination | 0 | 1 | 1 | 3 |
| Soil Formation | 0 | 3 | 3 | 3 |
| Soil Retention | 0 | 3 | 3 | 3 |
| Waste Treatment | 1 | 2 | 3 | 3 |
| Water Regulation | 0 | 1 | 3 | 3 |
| Supporting Services | | | | |
| Habitat & Nursery | 2 | 2 | 3 | 3 |
| Nutrient Cycling | 1 | 2 | 3 | 2 |
| Genetic Resources | 1 | 3 | 3 | 3 |
| Cultural Services | | | | |
| Natural Beauty | 1 | 1 | 3 | 2 |
| Cultural and Artistic Information | 0 | 1 | 2 | 3 |
| Recreation and Tourism | 0 | 0 | 3 | 3 |
| Science and Education | 1 | 3 | 1 | 2 |
| Spiritual and Historic | 0 | 3 | 1 | 3 |



Analysis III: Quantification of Copper Mine Impacts for Bingham Canyon, Prominent Hill, Intag, and Solwara 1

Producing one metric ton of copper results in far less freshwater use, mineral waste, energy use, area of disturbance and CO₂ emissions in Solwara 1 compared with terrestrial mines.

- 1 The mining impacts of Solwara 1 were quantified per copper ton produced for freshwater use, mineral waste, energy use, disturbed area and CO₂ emissions, and were then compared with the two operating mines and one proposed mine.
- 2 Producing one metric ton of copper requires far less freshwater, mineral waste, energy use, area of disturbance and CO₂ emissions in Solwara 1 than in any of the terrestrial mines examined.
- 3 The risk of downslope or offsite impacts to human communities is present in all terrestrial mines that dispose of large volumes of waste and tailings materials on the surface. There is no downslope risk to human communities from Solwara 1.
- 4 All mines present a risk to downstream ecosystems; however, the scale of Solwara 1 is small. The site is also a naturally dynamic area due to the influence of the seafloor volcano, and downstream risks to deep seabed ecosystems are thus greatly reduced relative to the far greater threat of terrestrial copper mines to downstream terrestrial and coastal marine ecosystems.

▼ Mine Comparisons for Inputs Required for 1 Metric Ton of Copper Output

The following table is also found in Analysis III with a fuller explanation and discussion of the values presented.

| | Measure | Annual Cu Production | Total Cu Production | Freshwater Use | Energy Use | CO ₂ Emissions | Mineral Waste | Area of Disturbance |
|-----------------------------------|---------------------------|----------------------|---------------------|--------------------------------------|-----------------------------------|--|--|---|
| | Unit | Metric tons | Metric tons | Liters per metric ton of Cu produced | MWh per metric ton of Cu produced | Metric tons of CO ₂ per metric ton of Cu produced | Metric tons of tailings & waste rock per metric ton of Cu produced | Square meters per metric ton of Cu produced |
| COMPARISON MINES | IMPACT TYPE | | | | | | | |
| Solwara 1 (proposed) Total | Mine + Refinery | 77,760 | 127,186 | 0 | 4.0 | 3.6 | 1.9 | 5.4 |
| <i>Solwara 1 Mine</i> | <i>Mine</i> | | | <i>0</i> | <i>4.0</i> | <i>3.6</i> | <i>1.9</i> | <i>1.1</i> |
| <i>Tongling Refinery</i> | <i>Refinery</i> | | | <i>Data not available</i> | <i>Data not available</i> | <i>Data not available</i> | <i>0</i> | <i>4.3</i> |
| Prominent Hill Total | Mine + Refinery | 73,362 | 2,046,000 | 83,831 | 15.3 | 5.4 | 36.3 | 7.2 |
| Bingham Canyon Total | Mine + Refinery + Smelter | 194,000 | 19,000,000 | 21,041 | 24.8 | 7.7 | 11.5 | 5.4 |
| Intag (proposed) Total | Mine | 484,437 | 9,906,472 | <i>Data not available</i> | <i>Data not available</i> | <i>Data not available</i> | 11.5 | 5.4 |



▲ The Prominent Hill Mine
Image credit: Geomartin

Analysis IV: Monetization of Copper Mine Impacts for Bingham Canyon, Prominent Hill, Intag, and Solwara 1

- 1 The economic value of some ecosystem services impacted by copper mining can be monetized. Not all of the social and environmental impacts can be monetized, therefore the findings of this analysis should be considered an underestimate of the full social and environmental impacts.
- 2 The monetary damages of the three terrestrial mines and Solwara 1 were estimated across a subset of social and environmental impacts.
- 3 The magnitude of annual damages was calculated to be USD 1.9 million/year for Prominent Hill; USD 42.9 million/year for Bingham Canyon; USD 8.8 million/year for Intag; and USD 0.025 million/year for Solwara 1.
- 4 A net present value of impacts for each mine was also calculated, in which Solwara 1 (based on expectations as of the date of this report) would outperform the terrestrial mines. These values do not consider the downstream impacts, which are difficult to quantify, but including these impacts would substantially widen the differential between Solwara 1 and terrestrial mines.
- 5 Mining in the deep seabed (assuming the creation of sufficient biodiversity conservation sites) has fewer identified, quantified and monetized impacts than terrestrial mining.

▼ Present Value of Ecosystem Service Impacts to Solwara 1 and Comparison Mines

The following table is also found in Analysis III with a fuller explanation and discussion of the values presented.

| Mine | Annual Value of Ecosystem Service Impacts | Net Present Value of Ecosystem Service Impacts | Total Copper Production for Lifetime of Mine (metric tons) | Relative Impact on Ecosystem Services per Ton of Copper Produced |
|----------------------|---|--|--|--|
| Solwara 1 (proposed) | \$24,724 | \$605,871 | 127,186 | 1.0 |
| Prominent Hill | \$1,919,065 | \$47,026,675 | 2,000,000 | 4.9 |
| Bingham Canyon | \$42,864,859 | \$1,050,403,319 | 17,000,000 | 13.0 |
| Intag (proposed) | \$8,797,585 | \$215,584,802 | 9,906,472 | 4.6 |



Copper Concentration, Smelting and Environmental Impacts

- 1 Though not responsible for the mineralized material at the smelter, Nautilus has chosen one of the world's newest and most efficient smelters, operated by Tongling Non-Ferrous Metals (TNFM) in China to reduce smelting environmental impacts.
- 2 The TNFM smelter has a closed system, which is more efficient and can better capture pollutants and useful by-products.

Overall Conclusion

The Nautilus Solwara 1 copper mine has the potential to significantly reduce the social and environmental impacts of copper mining.

The Nautilus Solwara 1 copper mine has the potential to significantly reduce the social and environmental impacts of copper mining.

The deep seabed at the Solwara 1 mine is a remarkably advantageous choice of mining site for a number of reasons. First, no people live at the proposed mine site, and there are no cultural or historical claims to the site. The mine site itself is quite small, covering only 14 hectares of seabed. Natural resources are less impacted by operations at this site as surface or groundwater freshwater resources will be not used or contaminated at Solwara 1. In addition, there is limited overburden covering mineralized material, resulting in very little waste rock material. Finally, the proposed mine operation wastes will be dwarfed in comparison to the impacts of a nearby erupting underwater volcano. Even excluding these by-product credits, the mineralization copper grade alone is approximately 7%,³ a remarkably high percentage which will lead to numerous efficiencies.

The overall conclusion is that Solwara 1 has the potential for far fewer social and environmental impacts than the existing terrestrial mines examined. Based on this analysis, it is highly likely that Solwara 1 would have far less overall impact per ton of copper produced than the currently operating Prominent Hill, Australia, and Bingham Canyon, USA, mines and the proposed Intag, Ecuador, copper mine. Indeed, Solwara 1 may well have far less overall social and environmental impacts than any currently producing copper mine.

Solwara 1 presents an opportunity for PNG to receive mining royalties that will support the national budget for education, health, and other expenditures while achieving significantly fewer social and environmental impacts compared with terrestrial mining. The impacts of terrestrial mining are well demonstrated in the existing PNG mines and elsewhere in the world, and this analysis reveals a potential alternative to the heavy impacts of terrestrial mining.

The mineralization copper grade at Solwara 1 is 7%, a remarkably high percentage that will lead to numerous efficiencies.

Currently, there are several other Seafloor Massive Sulphide (SMS) deep seabed mining proposals moving forward under the auspices of various companies. As the first company to commercially explore the seafloor for SMS, Nautilus has to date defined the standards for deep seabed mining at the national and international scales. As the first proposed deep seabed mining project, Solwara 1 will set a high sustainability standard as an example for all followers. Solwara 1 is likely to surpass many of the International Finance Corporation (IFC) social and environmental standards for mining practices.

Importantly, Solwara 1 has set a high bar for social and environmental management, study of the seabed, establishment of vent habitat conservation areas, collaboration with the scientific community, transparency, and collaboration with unaffected, but nearby communities for development.

While recognizing Nautilus' efforts to date, the authors also wish to encourage the company to continue to show this high level of responsible leadership in this emerging industry.

As with any planned project that has yet to enter production, uncertainties remain. Further analysis should be undertaken as Solwara 1 commences operation in order to better understand and record the impacts of deep seabed mining, the post-mining recovery process, and the importance and effectiveness of establishing deep seabed conservation areas.

Copper is an essential element for the 21st century global economy, and it is a critical element in securing a high quality of life for the world's population. With the implementation of appropriate controls and management measures, seabed mining could play a catalytic role in transforming global copper mining into a more sustainable, less damaging, and less risky industry.

Most of the Earth's crust is below the ocean's surface. Opening up this area may reveal higher copper concentrations that have the potential to significantly contribute to global copper supplies and greatly reduce the environmental and social costs of copper mining. Solwara 1 appears to be a well-planned, carefully developed project with a clear opportunity to dramatically reduce the social and environmental impacts of copper mining.



