In Analysis IV, the impacts on ecosystem services are monetized for Bingham Canyon, Prominent Hill, Intag, and Solwara 1.

In Section A, the impact associated with a mine's area of disturbance is estimated using land cover-based ecosystem service valuation. Section B presents calculations for the impact associated with carbon emissions.

Section A. Monetizing Impacts to Ecosystem Services

The monetization of natural capital assets requires three key elements: the identification and quantification of assets, methodologies for valuation and a framework for bringing diverse values together. Modern financial analysis commonly tackles the problem of comparing firms with differing units of production (cars, metric tons of wheat, geological services) by translating these units into monetized values. The scientific and sustainability communities are often less familiar and comfortable with monetization; however, comparing monetary values can be an important tool that assists with decisions to allocate monetary resources.

The monetization of natural capital has the same pitfalls as the monetization of built capital assets. Markets and values may change quickly, but natural capital values are often far less volatile than financial assets such as stocks and bonds. Both the cost and price of water is less volatile than real estate, for example. Natural capital accounting and valuation are important tools for assisting many investment decisions, even if they do face the same valuation pitfalls that beset built capital.

One of the greatest potential errors in valuation is that of omission, or not valuing important assets at all. Without monetization, natural capital values are often tallied at zero.

One of the greatest potential errors in valuation is that of omission, or not valuing important assets at all. Over valuing or double counting natural capital assets is a far less common problem. Without monetization, natural capital values are often tallied at zero. Failing to account for the value of natural capital can lead to decision-making that is not fully informed. This document provides a preliminary valuation of natural capital impacts from copper mining in the four cases studied. This analysis largely errs on the side of undercounting the natural capital damage from terrestrial copper mining because many of the natural capital assets identified as clearly degraded by mine wastes or land clearing cannot be not monetized. This is either due to a lack of data, a lack of economic studies to establish the values, or a lack of valuation methodologies.

In the case of Solwara 1, data limitations required the use of terrestrial values to provide an estimate of the value of the seabed. With the exception of copper valuation, there are no existing studies that have established the economic value of deep seabed natural capital goods and services.

Because Solwara 1 is so remote, the potential for ecosystem service beneficiaries is low. In addition, many of the potential impacts found in a surface mine, such as freshwater quality and quantity, are not present at Solwara 1.

In the case of Solwara 1, there are no "comparable" valuation examples because ecosystem service valuation studies of deep seabed ecosystems do not yet exist. Ecosystem services valuation relates directly to the natural system's economic contributions to human economies. Because Solwara 1 is so remote, the potential for ecosystem service beneficiaries is low. In addition, many of the potential impacts found in a surface mine, such as freshwater quality and quantity, are not present at Solwara 1. To address the lack of comparable valuation studies, estimates of the economic damage to deep seabed ecosystems for Solwara 1 were based on terrestrial values identified for cloud forests in the Intag region as both regions are considered unique and sensitive ecosystems with similar qualities.

Overall, the monetization of natural capital assets and natural capital accounting is a rapidly expanding field. Natural capital accounting is increasingly being required by governments and firms to help inform project- and program-related decisions. Earth Economics is recognized as a leader in this field.

This analysis follows the methods of the United Nations Environment Program (TEEB and MEA) in utilizing a landscape and seascape approach to natural capital valuation based on the land cover type and area disrupted.

First, a land cover analysis of Solwara 1 and the three comparison mine sites was conducted. Within the areas directly impacted by each mine site, the total number of hectares of each land cover type was identified. For Solwara 1, the total area of disturbance was estimated based on Nautilus documents. For Bingham Canyon and Prominent Hill, the area of disturbance was estimated using GIS analysis, which is based on satellite imagery combined with company GRI reporting. The area of disturbance for the proposed Intag mine was estimated based on a mine study carried out by the Japanese International Co-operation Agency (JICA).

Next, the original distribution of land cover for each area of disturbance and its value was estimated using benefit transfer methodology. The loss of natural capital (e.g. forest, shrub and other vegetation) was assumed to be complete in the direct footprint of each mine, as open pit copper mining clears the landscape of vegetation, and goods and services such as food, water filtration, biodiversity and storm buffering are completely lost. The dense forest within the

This study uses a highly cautious and "conservative" approach to valuation of Solwara 1 impacts, in the sense that it is more likely to result in an overestimate of impacts than an underestimate.

Intag mine site, for example, will be completely removed with a full loss of the ecosystem goods and services that the forest once provided. Each dollar value in the tables below is tied to a specific valuation study. Appendices A and B provide full references for values in the tables. All values are presented in 2014 US dollars.

Tables 7-10 show dollar estimates for the value of each ecosystem service related to the land cover types occurring at Solwara 1, Bingham Canyon, Prominent Hill, and Intag. All estimates are expressed as dollars per hectare per year. These per hectare values were then summed for each land cover type across the ecosystem services valued for that land cover type, to give an estimate for the total annual value of each land cover type.

It should be noted that the values that were used for Solwara 1 were based on values used for cloud forests, due to the lack of available valuation studies conducted on the deep sea bed. This approach assumes that the deep seabed is at least as valuable as cloud forests in terms of biological control, habitat & nursery, and genetic resources. As cloud forests are some of the most productive and biodiverse ecosystems on the planet, this represents a highly cautious and "conservative" approach to valuation of Solwara 1 impacts, and is more likely to result in an overestimate of impacts than an underestimate.

Just as in the ecosystem services Table 3 in Analysis II, blank cells indicate that impacts to that service are not possible due to lack of presence at the site. Green cells indicate that the ecosystem service is present, and green boxes with a dollar value indicate that appropriate valuation studies were found for that specific service/ land cover combination. Based solely on the number of green cells below and in Analysis II, it can initially be seen that Solwara 1 has fewer potential impacts to ecosystem services (i.e. more blank cells).

	Seabed (based on Intag Cloud Forest values)
Ecosystem Service	**Value ($/hectare/year)**
Food	
Medicinal Resources	
Ornamental Resources	
Energy & Raw Materials	
Water Supply	
Biological Control	**$26**
Climate Stability	
Air Quality	
Moderation of Extreme Events	
Pollination	
Soil Formation	
Soil Retention	
Waste Treatment	
Water Regulation	
Habitat & Nursery	**$1,464**
Nutrient Cycling	
Genetic Resources	**$277**
Natural Beauty	
Cultural and Artistic Information	
Recreation and Tourism	
Science and Education	
Spiritual and Historic	
Total	**$1,766**

Table 7. ▲
Annual Ecosystem Service Impacts of Solwara 1 (proposed) Mine by Ecosystem Service and Land Cover

	Mixed chenopod, samphire
Ecosystem Service	**Value ($/hectare/year)**
Food	
Medicinal Resources	
Ornamental Resources	
Energy & Raw Materials	
Water Supply	
Biological Control	
Climate Stability	**$23**
Air Quality	
Moderation of Extreme Events	
Pollination	
Soil Formation	
Soil Retention	
Waste Treatment	
Water Regulation	
Habitat & Nursery	**$828**
Nutrient Cycling	
Genetic Resources	
Natural Beauty	
Cultural and Artistic Information	
Recreation and Tourism	**$481**
Science and Education	
Spiritual and Historic	
Total	**$1332**

▲ **Table 8.**
Annual Ecosystem Service Impacts of Prominent Hill Mine by Ecosystem Service and Land Cover

Key	
	Ecosystem Service Not Present
	Ecosystem Service Present but No Valuation
$	Ecosystem Service Present with Valuation Studies

▼ **Table 9.** Annual Ecosystem Service Impacts of Bingham Canyon Mine by Ecosystem Service and Land Cover
Source: Derived from Thurber et al., 2014, Table 1. Key on facing page.

	Developed, Open Space/M-low Density	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub	Grasslands	Pasture/Hay	Cultivated	Woody Wetlands	Emergent Herbaceous Wetland
Ecosystem Service	**Value ($/hectare/year)**									
Food			$78	$39		$90		$22,560		$877
Medicinal Resources										
Ornamental Resources										
Energy and Raw Materials		$48	$10	$29				$356		
Water Supply										
Biological Control										
Climate Stability										
Air Quality	$579	$670	$410	$540				$251		
Moderation of Extreme Events	$319		$1,682	$841					$18,270	$7,694
Pollination										
Soil Formation										
Soil Retention			$2	$1		$18	$15	$325		
Waste Treatment			$516	$258					$14,064	$38,684
Water Regulation	$1,083					$4		$121	$2,644	$6,503
Habitat & Nursery			$9,496	$4,748	$828	$87	$12	$736	$35,791	$14,688
Nutrient Cycling										
Genetic Resources										
Natural Beauty	$57,805	$1,217		$609			$13	$217	$17,683	$15,559
Cultural and Artistic Information										
Recreation and Tourism		$742	$15,922	$8,332	$481	$285		$68	$18,646	$13,121
Science and Education										
Spiritual and Historic										
Total	$59,785	$2,678	$28,116	$15,397	$1,309	$484	$40	$24,634	$107,097	$97,126

Table 10.
Annual Ecosystem Service Impacts of Proposed Intag Mine by Ecosystem Service and Land Cover

Key	
	Ecosystem Service Not Present
	Ecosystem Service Present but No Valuation
$	Ecosystem Service Present with Valuation Studies

Ecosystem Service	Agricultural Lands	Pasture	Bamboo	Native Andean Alpine Grasslands	Cloud Forests Value ($/acre/year)	Rivers and Lakes	Pasture and Agricultural
	Value ($/hectare/year)						
Food	$11,459			$62	$2,899	$742	$94
Medicinal Resources							
Ornamental Resources							
Energy and Raw Materials	$2,753		$498		$3,732		
Water Supply			$613	$16	$12	$742	
Biological Control				$36	$26		$37
Climate Stability	$844		$670	$433	$679		
Air Quality							
Moderation of Extreme Events							
Pollination	$457			$39	$714		$31
Soil Formation	$15	$742	$737	$2	$16		$2
Soil Retention	$15			$48	$1,045		
Waste Treatment			$251	$137	$283	$742	
Water Regulation				$5	$84	$742	
Habitat & Nursery			$624	$3	$1,464	$742	
Nutrient Cycling	$59				$1,468		
Genetic Resources					$277		
Natural Beauty							
Cultural and Artistic Information							
Recreation and Tourism	$79				$835	$56,242	$69
Science and Education							
Spiritual and Historic							
Total	$15,681	$18	$3,393	$782	$13,531	$81,947	$232

Tables 11-14 show the acreage value of each land cover type within the mine area examined, the total monetized value for all ecosystem services valued per hectare for that vegetation type and the total value (acres multiplied by ecosystem service value per acre).

Table 11. Total Annual Ecosystem Service Impacts of Solwara 1 (proposed) Mine

Land Cover Type	Area (hectares)	Value ($/hectare/ year)	Value of Impacts to Ecosystem Services ($/year)
Seabed	14	$1,766.03	$24,724
Total	**14**		**$24,724**

Table 12. Total Annual Ecosystem Service Impacts of Prominent Hill Mine

Land Cover Type	Area (hectares)	Value ($/hectare/ year)	Value of Impacts to Ecosystem Services ($/year)
Mixed chenopod, samphire	1,466	$1,332	$1,952,330
Total	**1,466**		**$1,952,330**

Table 13. Total Annual Ecosystem Service Impacts of Bingham Canyon Mine

Land Cover Type	Area (hectares)	Value ($/hectare/ year)	Value of Impacts to Ecosystem Services ($/year)
Open Water	4	$0	$0
Developed, Open Space	129	$59,785	$7,697,270
Developed, Low Intensity	205	$59,785	$12,262,929
Developed, Medium Intensity	183	$0	$0
Developed, High Intensity	49	$0	$0
Barren	179	$0	$0
Deciduous Forest	242	$2,678	$648,584
Evergreen Forest	524	$28,116	$14,724,095
Mixed Forest	1	$15,397	$12,282
Shrub/Scrub	838	$1,309	$1,096,636
Grassland/Herbaceous	242	$484	$117,206
Pasture/Hay	302	$40	$12,153
Cultivated Crops	96	$24,634	$2,364,458
Woody Wetlands	27	$107,097	$2,862,971
Emergent Herbaceous Wetlands	11	$97,126	$1,066,274
Total	**3,031**		**$42,864,859**

▶ **Table 14.**
Total Annual Ecosystem Service Impacts of Intag (proposed) Mine

Land Cover Type	Area (hectares)	Value ($/hectare/year)	Value of Impacts to Ecosystem Services ($/year)
Agricultural Lands	33	$15,681	$522,791
Bamboo	18	$3,393	$62,635
Cloud Forests	592	$13,531	$8,013,450
Native Andean Alpine Grasslands	42	$782	$33,238
Pasture	184	$18	$3,266
Pasture and Agricultural	329	$232	$76,230
Rivers and Lakes	1	$81,947	$85,975
Total	**1,200**		**$8,797,585**

0.08 – 0.2

RELATIVE IMPACT OF SOLWARA 1 ON ECOSYSTEM SERVICES PER TON OF COPPER PRODUCED COMPARED WITH BINGHAM CANYON, INTAG, AND PROMINENT HILL

Tables 11-14 show there are a number of ecosystem services present but not monetized for each mine site. In other words, there is a lack of valuation studies (comparable areas with peer reviewed valuation studies) to apply to the sites. These gaps imply that the estimates may be underestimates of the true natural capital values per hectare for each land cover type.

In addition, the calculation of impacts to ecosystem services for Prominent Hill, Bingham Canyon, and Intag conservatively assumes there are no off-site environmental impacts. However, many previous examples show that downstream impacts can be significant if rock waste and mine tailings are deposited downstream (as in the PNG Ok Tedi copper mine),[117] or if an earthen tailings/waste rock retention dam fails (as in the Marinduque copper mine).[118]

From these annual losses, a net present value of these losses can be calculated and is shown in Table 15 with a discount rate of 4% over 100 years (Nobel laureate economists advise lower discount rated for natural capital net present value analysis[119]).

▼ **Table 15.**
Present Value of Ecosystem Service Impacts to Solwara 1 and Comparison Mines

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