



Managing the Freshwater Impacts of Surface Mining in Latin America

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Acronyms

ESIA	Environmental and Social Impact Assessment
BDO	Biodiversity Offsets
DOC	Dissolved Organic Carbon
EN	El Niño
ENSO	El Niño-Southern Oscillation
ESIA	Environmental and Social Impact Assessment
GDP	Gross Domestic Product
GNI	Gross National Income
LAC	Latin America and the Caribbean
LN	La Niña
SAM	Small-Scale and Artisanal Mining
TSS	Total Suspended Sediments

Abstract

The path to better gold mining practices in Latin America and the Caribbean (LAC) is rife with challenges due to the complex linkages between the high value intensity of gold, its spatial concentration in specific geological formations, and the social and economic conditions that render it one of the most financially attractive yet damaging land use activities in the region. Its uncontrolled spread across many lowland river basins of LAC continues to leave a record of significant environmental impacts, cultural change, social unrest, and human health concerns. At its best, however, the mining sector can play a significant role in the near-term development of regional economies by boosting employment, increasing public revenues, supporting business growth, and building public-purpose infrastructure, such as roads and power facilities. But over the long term, poorly managed and regulated mining can create significant environmental and social costs that are simply passed on to future generations. This is the case in particular when proceeds from mining are not effectively reinvested by governments in improving social and environmental conditions.¹

This paper provides a brief overview of the linkages between the primary factors driving gold mining, how these interact with regional geology to concentrate impacts on specific river basins, and the primary environmental and social impacts that can erode the economic benefit delivered from gold production if it is left unmanaged. We consider these impacts in the context of operational scale and the regional differences in background hydrological conditions with a view to identifying freshwater systems that are most inherently vulnerable to the effects of mining and that thus have the greatest impact of additionality. The paper concludes by considering ways in which these impacts might be averted or mitigated through a mix of approaches aimed at normalizing mining processes, structures, and relationships through tailored, incentive-based policies and actions.

¹ Hartwick 1977.

1. What Is Driving Growth in Gold Mining and Its Impacts on Freshwater Systems?

Global Price and Demand

Over the past 40 years, gold's role in the global economy has transitioned from one of currency support to commodity to currency hedge as many of the major sovereign balance sheets have accumulated debt and as global savings rate disparities have sharpened. Expansion of financial instruments aimed at offering exposure to gold, but partially underpinned by bullion reserves, have further catalyzed real demand. Speculation in futures markets has abetted this real hedge demand, driving nominal gold prices to a record high.

Rising gold prices and expanding global demand has consequently seen explosive growth in mining. The overwhelming bulk of new supply arrives through large-tonnage facilities, mainly in China, the United States, Australia, and South Africa. But LAC—in particular the Guiana Shield countries of Venezuela, Guyana, Suriname, French Guiana, Colombia, and Brazil—have experienced some of the highest growth rates in production since 2000.² LAC has become a major supplier to the international gold market and is set to increase its market share toward the mid-millennium. As of 2012, 22 percent of the global pool of very large-tonnage (> 1 metric ton per annum) gold mines were found in LAC countries. In addition, of the 22 very-large tonnage operations currently in their planning phase worldwide, more than half are located in LAC. More than 85 percent of current and planned large gold mining operations in the region are open pit operations³—and about half of these are in lowland tropical locations. This pattern of mining is shadowed by a rapid growth in mining permits, concessions, and exploratory leases and by an increasing proportion of watersheds that these occupy.⁴

The rapid rise in gold prices over the last decade has also seen a resurgence of growth in small (artisanal) and medium-scale mining operations across LAC and elsewhere. Today, more than a tenth of declared gold supply worldwide is estimated to arrive via small-scale operations. In major gold-producing countries in the LAC region, this proportion is believed to be much higher, in the range of 20–60 percent of production.

² Hammond et al. 2007.

³ Analyzed using data on world mine sites derived from InfoMine.

⁴ Hammond 2005a; Bebbington and Bury 2009.

Employment, Income, and Artisanal Mining

The extremely high value intensity of gold has always propelled small-scale production—more so than virtually any other mineral commodity apart from gemstones. A very small amount of production can yield a very high income relative to other income-earning opportunities. This is particularly true for gold-producing countries such as Nicaragua, Guyana, Honduras, Bolivia, Suriname, Ecuador, and Peru, where in 2011 less than five troy ounces of production was enough to exceed the per capita gross national income (GNI at purchasing power parity). Less than 10 ounces exceeded per capita GNI for every gold-producing country in the region.⁵ Official unemployment rates in gold-producing countries have also averaged in the double digits over the last decade,⁶ underpinning a relatively low opportunity cost of labor and adding to the economic attraction of gold to the prospective small-scale miner. This represents a simplification of the factors shaping participation rates for small-scale mining. But increasing price combined with the value intensity of gold, stagnant job growth, and little access to capital in many areas have been critical drivers in the intensification of mining in lowland river basins.

Estimates of the number of people directly involved in small-scale mining annually in the LAC region over the last decade range from 750,000 to 1.5 million, with three to four times as many involved indirectly through provision of support goods and services to the mining community.⁷ Some countries, such as Brazil, have seen a decrease in participation rates as alternative livelihood opportunities and government actions have made clandestine mining less attractive. But many small-scale Brazilian *garimpeiros* previously operating in the northern states have also moved to neighboring countries, where they often operate undocumented. This provides the outward appearance of policy success in Brazil, but to a large extent it has merely transferred the environmental and social impacts of mining to neighboring countries.

2. Where is Gold Mining of Greatest Concern?

The mining of precious metals and gemstones has been taking place in Latin America and the Caribbean since pre-Colombian times, and the land alterations attached to this practice are

⁵ Gross national income per capita (at PPP) versus average gold price. GNI data source: World Bank Development Indicators.

⁶ Unemployment rate (percent labor force), WBD and Latin American and Caribbean Macro Watch 2002–2011 (www.iadb.org/res/lmw).

⁷ Hentschel et al. 2002; GOMIAM (www.gomiam.org); CASM (www.artisanalmining.org); Departamento Administrativo Nacional de Estadística (DANE) (www.dane.gov.co).

visible in virtually every country.⁸ However, modern mining technologies have expanded the mineral environment rapidly to cover vast areas not previously known. As a consequence, most of the major gold or polymetallic ore-bearing rock formations are now, or have been, under some level of exploitation. These formations are, of course, the primary spatial determinants of mining activity at all operational scales. They can be crudely depicted as broad zones, or provinces, attached to the geologic history of the region. These can be seen in Figure 1 as the Andean and Precambrian Shield provinces. The extension of the main volcanogenic arc belts is similarly coincident with gold mining activity through Central America and the central highlands straddling the Haiti-Dominican Republic border. More than 95 percent of all gold mining activity in LAC is attached to these broad structural features (see Figure 1). The intervening deep Phanerozoic sediment basins are not strongly indicative of economic gold deposits, although they are the primary target of other mining activities, most notably hydrocarbons. Understanding the geological control on natural resource systems is critical for understanding the nature and extent of land use impacts on environment and society.⁹

Some countries in the region have been more intensively exposed to gold mining than others as the result of intersecting geopolitical and geological boundaries. This is particularly true of many smaller countries—Guyana, Suriname, Honduras, Panama, and Ecuador—where mining activity has affected a relatively large proportion of the watersheds flowing through their national land areas. A number of nationally and regionally important basins have experienced particularly intense activity in their upstream catchments, as shown in Figure. Most notable among these is the Rio Magdalena Basin in Colombia (No. 9), the Essequibo Basin in Guyana/Venezuela (No. 10), the Marowijne Basin in Suriname/French Guiana (No. 16), and with increasing intensity most of the southern tributaries in the Orinoco Basin in Venezuela (No. 3) and the headwaters of the Rio Negro Basin in Colombia, Venezuela, and Brazil (No. 1).

The headwaters of many large subbasins of the Amazon River (No. 1) that drain the eastern slopes of the Andes and the northern rim of the Brazilian Shield complex have also experienced intense gold mining activity. These include the Tapajós (No. 1A) and vast Madeira (No. 1B) watersheds in Brazil and, by extension, the major subcatchments of the Madre de Dios (No. 1C) and Beni (No. 1D) rivers that course from the montane forests areas of northern

⁸ See, e.g., Machado and Figueirô 2001.

⁹ Hammond and Zagt 2006.

Bolivia/southern Peru into the Brazilian Amazon.¹⁰ Similarly, the headwater reaches of the Napo (No. 1E) and Marañon-Santiago (No. 1F) subbasins in Ecuador have been subject to an intensification of gold mining over the last several decades. The western slopes of the Andes are drained by a multitude of small watersheds that are characterized by excessively steep topography. Many of these have also been affected by gold mining, particularly in southern Ecuador and the much drier Ayacucho region of Peru.

Similar to this region, the relatively small watersheds draining Central American and Caribbean countries are easily affected by intensive gold mining activities. Modern mining activity is concentrated in a number of important areas, including the upper reaches of the region's largest river, Rio Coco (no. 21), and its adjacent watersheds (nos. 22, 31, and 38). These collectively drain the Bosawás (Nicaragua), Río Plátano (Honduras), and Tawahka-Asagni (Honduras) Biosphere Reserves that straddle the frontier region between the two countries. Together, these reserves represent the largest remaining area of contiguous tropical forest north of the Amazon Basin. Other important lowland forest basins—such as the Chucunaque (no. 32) and Atrato (no. 18) in the Darién region of Panama and Colombia—have also seen long-standing artisanal and gold mining activity in the highland reaches feeding the main lowland rivers.

Watersheds in most Caribbean island nations are not affected by gold mining, with the exception of the Dominican Republic. Extensive, mainly large-scale, polymetallic mining operations are located at various locations in the highlands of the Cordillera Central. Polymetallic deposits are being examined through exploratory leases that cover a much larger fraction of the island's upper watersheds. These deposits extend across the international border into Haiti, offering opportunities for much-needed national revenue generation, but also the risk of further degradation to the country's freshwater resources if poorly managed.

3. How Do Gold Mining Operations Affect Freshwater Systems?

Gold mining is intrinsically inefficient. Compared with many other common metals—such as iron or nickel—it produces a much greater level of processed waste for each unit of refined product. The methods used in processing and disposal of these wastes fundamentally shape the

¹⁰ Barthem et al. 2004.

nature, intensity, and duration of gold mining impacts on lowland freshwater systems in the LAC region. The methods used depend on operational scale.¹¹

Generally speaking, scales of operation are categorized by the amount of ore processed, the net smelter return, the revenue generated, the level and type of technology or working capital used, the number of employees, and/or the structure of the entity undertaking the work—whether this be formal or informal, licensed or unlicensed. Applying this basket of attributes to actual field operations normally identifies three, sometimes four, natural scales of operation.¹² Categorizing operations as small, medium, or large appears adequate in differentiating most environmental and social impacts and benefits. (See Table 1.)

Small-scale and artisanal mining (SAM) operations are characterized by a very large number of miners working independently or in cooperatives. They typically work placer and palaeo-placer deposits created through weathering of upstream auriferous rock formations and then transported downstream. Hard rock operations—such as those at Serra Pelada in north Pará, Brazil—still can be found, but many of these deposits are now owned and operated by much larger mining companies. SAM employs a basket of basic techniques, ranging from simple comminuting and panning to the use of hushing and small hydraulic jet devices to remove overburden and liberate the deposited gold layers. The gold itself is typically separated from the parent material using both gravity and mercury techniques. SAM operators, on average, are more likely to have no or little alternative income, few years of formal education, poor access to health care and no operational support and to suffer from malnutrition and disease. They are also more likely than is typical at larger operational scales to be women or children. SAM is more often carried out without formal rights, licensing, or permits. The likelihood of remediation is practically zero.

Medium-scale operations can evolve from successful SAM cooperatives, but they are more commonly developed by small business owners seeking to invest in alternative income-earning ventures. Often these are owned by a pool of investing partners. They often work the same floodplains as SAM operations, but more typically they have formal claim to a site. Hard rock deposits abandoned by large-scale miners are sometimes reactivated by medium-scale operators who require less auriferous ore to support their investments. They use larger and more sophisticated equipment, such as floating hydraulic dredges or multi hydraulic jet pontoons, that

¹¹ Hammond et al. 2007.

¹² McMahon et al. 1999; Hammond et al. 2007.

allows them to process much larger volumes of sediment than SAM workers can handle. Both amalgamation and mechanical separation techniques are used to liberate the gold. Operations at this scale consist of small teams working in shifts and supervised by an experienced operator, and they include skilled workers, such as mechanics, with some form of head office support. They are typically directed or advised by a professional engineer and geologist, but often without an environmental and social impact assessment (ESIA) or remediation plan. The likelihood of remediation is low.

Table 1. Main Features of Gold Mining Scales of Operation

Feature	Small-scale/Artisanal (SAM)	Medium-scale	Large-scale
Number of operations	100,000s	1000s	100s
Labor force	1–5	5–25	50–100s
Ore processed	< 50 t pa	50-500,000 t pa	> 500,000 t pa
Ownership	Individuals; families	SAM cooperatives; family businesses; domestic investors	Corporations; domestic and international investors
Investment	US\$1k to 10k	US\$10k to 250k	US\$1000k to 100,000k
Equipment	Shovel, hammer mill, pan, sluice, metal detector	Hydraulic monitor, gravel dredge, missile dredge, sluice, bulldozer	Bucket wheel excavator, compact spreader, bulldozers, loaders and other heavy equipment
Separation chemistry	Hg	Hg	NaCN, KCN
Effluents	Sediments, Hg	Sediments, Hg, fuels	Acid mine drainage; tailings pond failure (sediment, cyanide)
Infrastructure & Support	Little or none	Transport, fuel, room & board (TFRB)	TFRB, health care, safety, training, recreation

The largest operations are almost exclusively undertaken by dedicated national and international mining companies, often in partnership. Their primary targets are entirely hard-rock deposits, often those sourcing the downstream placer deposits worked by smaller-scale operators. They process vast volumes of gold and polymetallic ores, relying on metal commodity prices and economies of scale to offset the considerable capital investments that can often include roads, housing, and other ancillary infrastructure. Open-pit mining at this scale involves a sophisticated heap-leaching process that uses sodium cyanide as the primary gold-separating reagent. It

requires large volumes of water and creates similarly large amounts of waste effluent and ore waste (tailings). These operations are worked, supervised, and directed by highly trained professionals who receive very good salaries, health care, and extensive head office support. Normally these operations require an extensive ESIA along with a wide range of permits and management and operational plans. The likelihood of some remediation is higher, but contingent on governments establishing and enforcing appropriate regulations and on operators overcoming the technical hurdles attached to large-scale remediation of tropical lowland environments.

Direct Impacts

The lowland LAC region is one of the world's largest contributors to surface freshwater discharge, contains more plant and animal species than any other region of similar size, and houses the planet's largest above-ground carbon store. Thus it is no surprise that it also plays a critical role in hemispheric and global biogeochemical cycling, ecosystem productivity, and biodiversity. Changes in the storage and transfer functions of regional lowland freshwater systems will see adjustments in other global compartments and their interlinking pathways as a consequence of mass balance equilibration. Land use changes, such as mining, that alter the rates and storage capacities thus have environmental consequences at a wide range of spatial scales.

Suspended Sediments

At small scales, placer and palaeo-placer mining techniques consume, process, and release riverbed and consolidated riverbank sediment. Coarse sediments and intercalated rock dislodged from banks and beds are redistributed as in situ tailing piles, while clay, silt, and carbon elements suspend in the water column to be redeposited downstream. This process—repeated along river mainstems and feeder streams within affected basins across LAC—rapidly accelerates erosion and alters the type and relative abundance of aquatic micro-habitats. In many instances, a vast number of small-scale mining operations working adjacent segments of streams and small rivers simply ablate all hydrological function by occluding or redirecting water flow, creating small pools of poorly drained residual effluent where little if any vertebrate aquatic life survives. Where hydrological function is impaired but not extinguished, the greatest and most consistent impacts of sediment loading have been found immediately downstream, where a plume of elevated turbidity has been documented for most waterways with active gold mining operations.

In some rivers, the release of sediments from mining increases downstream turbidity by a factor of 100 or more relative to background averages.¹³

These levels of increased sediment loads and higher turbidity can have a profound impact on the spectral attributes of the water light field. Suspension of clay particles actively attenuates light penetration through scattering, filtering out important components of the photosynthetically active radiation spectrum.¹⁴ Loss of this portion of visible light has a negative impact on photosynthetic capacity through the water column and primary productivity—such as phytoplankton and vascular plants—that underpins the broader trophic structure of aquatic and riverine terrestrial habitats alike.¹⁵ The abrasive properties of suspended sediment in high velocity flows can also affect primary production by scouring periphyton growth on large rock components of streams and rivers. Conversely, the broad deposition of suspended sediment on the riverbed reduces substrate texture critical in maintaining a diverse macro-invertebrate community.¹⁶

While an abundance of studies have documented the impacts of sediments on primary production and invertebrate communities,¹⁷ impacts on fish communities and other larger vertebrates, such as aquatic birds, are less clear. Contraction of underlying aquatic productivity can affect fish population stability and community structure in theory, but there is a dearth of studies conducted in a manner that would reveal the true extent, if any, of this loss in the lowland waterways in the LAC region. Sediment loading by gold mining operations along a tributary of the Approuague River in French Guiana appeared to affect a shift in the trophic structure of the downstream fish community, but not reductions in biomass or diversity. Recent studies in neighboring Suriname did detect a loss of diversity due to gold mining effluent.¹⁸ Suspended sediments have been shown to impair fish foraging behavior, particularly among apex predators, by altering visibility and impeding cardiovascular performance.¹⁹

The role that gold mining plays in sedimentation should be set against a background of naturally occurring suspended sediment loads and the important role that these play in delivering nutrients and affecting energy delivery vital to the long-term maintenance of aquatic life.

¹³ See, e.g., Mol and Ouboter 2004; Brosse et al. 2011.

¹⁴ Davies-Colley et al. 1992.

¹⁵ See, e.g., Guenther and Bozelli 2004; Tudesque et al. 2012.

¹⁶ See, e.g., Vasconcelos and Melo 2008.

¹⁷ Kemp et al. 2011 and references therein.

¹⁸ Brosse et al. 2011; Mol and Ouboter 2004.

¹⁹ Mol and Ouboter 2004; Kemp et al. 2011.

However, most lowland LAC freshwater systems are characterized by strong seasonal changes in suspended sediment loads that parallel changes in precipitation and discharge volumes. In contrast, placer mining along rivers and streams is typically most active at times when natural loading of sediments would be at its lowest—during dry seasons, when access to target deposits is at its greatest due to lower river stage height and when working conditions are optimal. This is an important consideration, since highly active mining faithfully carried out over consecutive dry seasons can subject downstream habitats to long periods of elevated turbidity and sedimentation, disrupting normal seasonal cadences in productivity, reproduction, and growth.

Factors governing basin-wide sediment loads and their downstream environmental impacts are complex. A prime example is the Rio Magdalena basin in northeast Colombia (No. 9 in Figure 1), characterized by a sediment yield that is the highest in the LAC region and tenth highest globally and that has been increasing since the 1990s.²⁰ The activity of numerous operators along different waterways within a number of contributing catchments combine to elevate suspended sediment loads downstream and to increase sediment flux to coastal margins. Yet while not all of the catchments within the basin are affected by mining, some of those unaffected yield similar or larger amounts of sediment to downstream reaches. Thus, the marginal impact of mining on sediment fluxes in the Magdalena basin is much smaller than its absolute impact. In contrast, an analysis of sediment flux at the main stem of the Orinoco River over 20 years showed very little change²¹ despite increased mining activity in the headwaters regions along the Ventuari and Caroni rivers.²²

Mercury Pollution

The processes driving heavy metal contamination of freshwater systems are fewer than those attached to suspended sediments: many of these metals, such as lead, cadmium, and arsenic, are naturally found in trace quantities only and their abundance is not strongly affected by other land use practices. Medium- and large-scale operations targeting polymetallic ores that may include gold are the most common point sources for heavy metal pollution worldwide, particularly where effluent from sulfide mineral tailings is poorly managed.²³

²⁰ Restrepo and Syvitski 2006.

²¹ Laraque et al. in press.

²² Trujillo et al. 2010.

²³ See, e.g., Tarras-Wahlberg and Lane 2003.

Mercury is also not commonly found to occur at naturally high concentrations, but it is the most critical heavy metal pollutant attached to gold mining across the LAC region. Ease of use and low cost has made mercury amalgamation the method of choice among small and medium-scale operations. The amount of mercury used for each kilogram of gold produced—the emission factor—varies but realistically ranges from one to five. The emission factor depends primarily on ore grades—the amount of gold per ton of sediment or hard rock—and on whether recovery technologies, such as retorts, are used. Consequently, unlike suspended sediments, the amount of mercury making its way into the environment runs collinear to the volume of gold produced.

Mercury has been used to refine gold and silver in the LAC region since the 1550s, and it is estimated that nearly 200,000 tons of mercury were released into the environment from 1560 to 1900.²⁴ Conservatively estimating mercury release based on gold production estimates from 1900 to 2010 and an emission factor of 1.5²⁵ yields a total estimated release of 203,700 tons of mercury. Considering the total land area of the LAC region including Mexico (a major silver and gold producer in the sixteenth through the eighteenth centuries) this amounts to an accumulated release of just over 10 mg Hg m⁻²—a disturbing level that has no geological antecedent. Mercury is a highly stable element that can cycle in the global environment for thousands of years once released from the lithosphere.²⁶ Small-scale gold mining is a major contributor to this global mercury cycle. This sector is estimated to account for 60–75 percent of mercury emissions in LAC alone.²⁷

During gold mining, mercury is released through two primary pathways: it is flushed into freshwater systems along with the treated tailings and emitted into the atmosphere as vapor during the final refinement phase, when it is burned off to yield the raw gold. Both pathways inject mercury into the lowland environment, albeit at different spatial scales. Flushing creates a pollution point source in the immediate vicinity of mining operations, while the atmospheric path acts as a non-point source, dispersing across a much larger geographic area, where it is deposited at lower but more uniform concentrations. These two pathways—along with the long legacy of

²⁴ Nriagu 1994.

²⁵ Lacerda 2003.

²⁶ Sellin 2009.

²⁷ *Ibid*; the other major sources of mercury are coal-fired power plants, cement production, and electroplating industries.

mercury use in the region—may help explain why several studies have shown elevated mercury levels in non-affected waterways.²⁸

Elemental mercury making its way into creeks and rivers is relatively inert with very few toxicological effects. In the water column, however, it undergoes a process of oxidation and methylation to form an organometallic complex that is available for uptake by plankton and plants. This process opens the door for mercury to proliferate through the freshwater trophic structure, a process known as biomagnification. Most studies have shown that fish species preying on other fish or benthos are more contaminated than those that feed on plants or are omnivorous. Mercury also consistently increases with fish length and weight. Consequently, the oldest predaceous individuals within the fish community tend to have the highest mercury loadings.

Ideal conditions for methyl-mercury formation occur in relatively slow-moving or stagnant waters, characterized by a relatively low pH and in the presence of high concentrations of dissolved organic carbon (DOC). These conditions are typically found in lakes, reservoirs, oxbow lakes (*ciénagas*, *cochas*), and river inlets in lowland LAC and where black-water rivers systems are prevalent. Mercury concentrations in fish have been shown to reach extremely elevated levels within these particular freshwater features, with particular cause for concern aimed at fish populations in lowland reservoirs and other artificial impoundments.²⁹ The dense clusters of floating aquatic plants, such as water hyacinth (*Eichhornia* spp.) or marsh rush (*Oxycaryum cubense*), that are commonly found in these locations can act as important methylation zones. They provide ideal conditions for sulfate-reducing bacteria—an important mediator of methylation—to interact with mercury in the presence of high levels of DOC and low pH.³⁰ They also provide a superior nursery habitat for juvenile fish and amphibians.

The contamination of freshwater fish communities with mercury from mining in LAC is extensive. Studies have consistently shown elevated³¹ mercury concentrations in fish from rivers affected by gold mining across the region, including the Magdalena (No. 9 in Figure1), Cuyuni-Essequibo (No. 10), Caroni-Paragua, Caura, Ventuari, and upper Orinoco-Casiquiare (No. 3), Marowijne (No. 16), Tartarugalzinho, Amapá state in Brazil, Tapajós (No. 1A), Madeira (No. 1B), Madre de Dios (No. 1C), and the Napo (No. 1E).

²⁸ Da Silva et al. 2009; Howard et al. 2011; Ouboter et al. 2012.

²⁹ Povari 1995; Mol et al. 2001; Barbosa et al. 2003.

³⁰ Achá et al. 2005.

³¹ Above the baseline levels of 0.2 µg Hg kg⁻² fish body weight.

There is relatively little known about the subsequent impact of heavily contaminated fisheries on birds, mammals, and reptiles that rely heavily on these resources for growth and reproduction. Many species, such as giant river otters, feed extensively on fish, but the few published results are inconclusive.³² More-extensive studies on the effects of mercury on aquatic wildlife conducted outside the region indicate that mercury is most detrimental during the early development stages. This leads to lower reproductive success, abnormal growth, and impaired function.³³

Deforestation

At local scales, the impact of gold mining on riverine forest cover depends on the density of mining sites, since individual operations typically restrict forest removal to the targeted deposit and an adjacent area needed for storage and—in the case of large operations—housing and other infrastructure. Stretched over hundreds of mining sites, annual forest cover losses due to mining range from 200 to 400 km² per year in the Guiana Shield region alone. The cumulative impact can be significant, as in the case of Suriname, where it is estimated that 750–2,300 km² of forest have been removed for mining.³⁴ Additionally, riparian forests absorb a disproportionate portion of losses, although these contribute unique value to landscape-level biodiversity and play a critical role in maintaining freshwater fish diversity and abundance.³⁵ These are the direct impacts of forest clearance to access deposits. Indirect losses also occur as a consequence of mining operations igniting forest fires, particularly during dry phases of strong El Niño-Southern Oscillation (ENSO) events.³⁶

Despite these losses, early-stage forest regeneration appears robust after small-scale mining, as long as there is a significant residual source of tree seeds adjacent to the affected area.³⁷ But large areas are less likely to recover quickly and may ecologically succeed toward grass and scrubland habitats.³⁸ Inactive deep surface mines, such as Serra Pelada, often fill with water over time to form artificial lakes. Many of these can contain mine tailings or exposed sulfide deposits that alter the biochemistry of the waters, impeding long-term successional processes.

³² See, e.g., Gutleb et al. 1997.

³³ Wolfe et al. 1998.

³⁴ Peterson and Heemskerk 2001.

³⁵ Rosales 2001.

³⁶ Hammond and ter Steege 1998.

³⁷ Rodrigues et al. 2004.

³⁸ Hammond 2005a.

Deforestation from mining also poses challenges to some countries, such as Suriname or Guyana, that are seeking environmental service payments under negotiated REDD+ agreements, particularly where agreed reference emission levels are established in a manner that appropriately reflects the historical absence of this type of deforestation in these countries.

Indirect Impacts

Many other non-operational activities attached to mining can create significant impacts. The level of operational support and capital investment plays an important role in discriminating the indirect effects of gold mining operations on freshwater systems. These include environmental impacts originating from access roads and the bushmeat trade and fish catch that can arise as part of an informal gold mining service economy.

Foremost among indirect impacts are those attached to forest road-building. Primarily developed by large mining, timber, or hydroelectric operations, the creation or improvement of roadways places enormous pressure on freshwater systems. Road access simplifies the logistics of setting up and running a gold mining operation, encouraging less-experienced miners to take on the significant challenges involved in successfully operating a profitable mining venture. Roads also create point sources for sediments at bridge crossings, occlude drainage where inadequate culverting occurs, and encourage road-based hunting and agricultural encroachment.

Many small and medium-scale miners are unable or unwilling to invest the operating capital necessary to support and maintain themselves or their workers without weighing on resources *in situ*. Road access plays an important role in facilitating this approach. In part as a consequence of this, there is often an influx of commercial hunting and fishing operations aiming to supply these operations from local resources or—as an ancillary—to harvest bushmeat and fish in commercial quantities for export to urban markets. Often medium-scale operators will attempt to offset some of their running costs through this reverse supply chain. Commercial operators use techniques, such as gill nets and use of sodium cyanide, that are highly efficient at harvesting but are wasteful due to the high level of bycatch. Overharvesting has been shown to be the primary reason for collapse in fisheries and local forest bird and mammal populations in tropical lowland locations in LAC and elsewhere.³⁹

³⁹ See, e.g., Redford 1992.

4. What Are the Social and Economic Consequences of Freshwater Impacts?

Human Health

The occupational health risks of lowland gold mining are well known, ranging from malnutrition, dysentery, and infection with insect-borne or sexually transmitted disease to development of silicosis and other respiratory and skin ailments associated with long-term exposure to dust and industrial chemicals.⁴⁰ SAM operators who contract these ailments typically have little access to proper medical care.

Of overwhelming long-term importance, however, is the impact that contamination of freshwater fish resources is having on the health of residents in the region. Numerous studies have documented the disconcertingly high levels of mercury in people residing in the region and relying on its freshwater systems for livelihoods.⁴¹ A detailed analysis of the mercury risk attached to consuming fish from several Colombian and Venezuelan tributaries in the Orinoco Basin reported that more than 70 percent of samples taken from 27 species were above the U.S. Environmental Protection Agency's accepted limits for methyl mercury consumption.⁴² Given the very high proportion of fish in their diets, the incidence of mercury poisoning and the neurotoxicological toll that it is taking on mainly rural- inhabitants is widespread, and it remains largely unabated. The development of regional and national fish markets based on commercial exploitation of freshwater catch from the region's rivers can extend significant health risks to urban consumers⁴³ as well as economic losses from market contraction due to restrictions placed on the sale of mercury-contaminated fish.

Ecosystem Services

Fisheries and bushmeat are one example of critical provisioning services delivered to local community residents in lowland forest areas where agriculture cannot provide adequate protein for survival. Across the Amazon, two-thirds of rural residents' protein intake is derived from freshwater fish (45 percent) and bushmeat (20 percent).⁴⁴ Mining, through sediment and mercury contamination and appropriation of local resources through overfishing and hunting, deeply impairs the value of these services at the local scale.

⁴⁰ See, e.g., Heemskerk 2004.

⁴¹ See, e.g., Maurice-Bourgoin et al. 1999; Webb et al. 2004; Fréry et al. 2001; Ashe 2012.

⁴² Trujillo et al. 2010.

⁴³ See, e.g., Alvarez et al. 2012.

⁴⁴ Rushton et al. 2005.

Gold mining operations also transfer the cost of mitigating these impacts downstream to other water users, often impairing value of hydrological services at national scales. In particular, potable water suppliers and hydroelectric facilities absorb costs attached to increased sediment loads since these increase the cost of water treatment and reduce the operating life of reservoirs and turbines. At international scales, the prolific use of mercury at thousands of gold mining sites across LAC and its seepage into the environmental pool contribute to the erosion of the regional economic value of fisheries as mercury works its way into large river and offshore marine ecosystems and into important commercial fish species. The export of elevated sediment to coastal marine environments, such as in the Magdalena basin,⁴⁵ can also lead to major changes in important offshore ecosystems, such as coral reefs and sea-grass beds. These coastal marine systems contain significant economic value through their regulating and provisioning services, such as coastal protection, tourism, and fishing. For some Caribbean and Central American countries, the ecosystem service value of these systems can account for 10–30 percent of gross national product.⁴⁶

5. Impact Additionality and Geographic Effects

An environmental impact could be considered as a negative deviation caused by a human activity that exceeds normal variation in some background state condition. Where background state conditions differ, the magnitude of the negative deviation consonant with an impact should be adjusted accordingly. This is the case with land uses, such as gold mining, that are practiced over a broad portion of the LAC region. Adjusting for differences in background conditions allows identification of freshwater basins that are perhaps most critically affected by gold mining, all else being equal.

Background Freshwater Conditions

Applying this concept to the region-wide occurrence of gold mining identifies basins draining the Guiana Shield region as the ones most critically affected. Only Precambrian Shield, Andean Cordillera, and Central American/Caribbean volcanic arc-belt formations yield extractable gold deposits within the region, but there are substantial differences in the background state condition

⁴⁵ See, e.g., Restrepo and Kjerfve 2004.

⁴⁶ See, e.g., Cooper et al. 2009.

of freshwater systems between these areas.⁴⁷ River chemistry typically agrees with basin geology,⁴⁸ and systems draining the Andes—such as the Beni, Madre de Dios, Madeira, Marañon, Napo, and Magdalena rivers—naturally contain significantly higher suspended sediment loads and turbidity levels than those draining the Guiana or Brazilian Shield areas. (See Figure 2.) In addition, the background loadings of the regions differ considerably in their ratios of particulate and dissolved carbon, inorganic and organic carbon constituents, relative fraction of various clay types constituting suspended sediments, average pH, flow velocities, and stream sinuosity. These differences fundamentally shape how long sediments and heavy metals produced through gold mining can be expected to remain in the regional systems, affecting freshwater resources long after mining activity has ceased.

Climate Variation

Strong ENSO events significantly alter rainfall regimes across the LAC region, but to varying degrees and in different ways.⁴⁹ Severe drought, flooding, and fire are strongly coincident with the fluctuations in this coupled oceanic-atmospheric circulation. Strong El Niño events have most consistently shown a strong negative impact on rainfall in the eastern Brazilian Amazon and Guiana Shield regions, the Cauca-Magdalena region of Colombia, and southern Panama since 1950. (See Figure 3.) Conversely, this same phase of ENSO brings a high likelihood of increased rainfall to Pacific-draining basins of coastal Ecuador and northern Peru. The opposite phase, commonly called La Niña, also shows consistent but inverse precipitation responses in the northern coastal regions of South American, but less so elsewhere. (See Figure 3.) The Guiana Shield region has one of the most consistent ENSO-precipitation signals globally.

The effects of past ENSO fluctuations on sediment loading in many affected systems is well documented.⁵⁰ But it is not fully clear how changes in the climatological conditions in the Pacific that trigger severe ENSO responses will change, if at all, as a consequence of accelerated greenhouse warming. However, the strong sensitivity of the Magdalena and Guiana Shield systems makes them particularly vulnerable to any intensification of these events and the amplification of impacts associated with widespread gold mining.

⁴⁷ Hammond 2005b.

⁴⁸ Stallard 1980.

⁴⁹ Ropelewski and Halpert 1987.

⁵⁰ See, e.g., Tarras-Wahlberg and Lane 2003; Restrepo and Kjerfve 2000; Hammond 2005b.

Tropical hurricanes similarly account for the greatest seasonal and interannual changes in the discharge of terrigenous sediments from affected Caribbean islands.⁵¹ The volume of sediment disgorged from rivers in the Caribbean is strongly tied to deforestation levels. Mining activity in the headwater reaches of the main watersheds in Dominican Republic, the primary source of gold mining in the Caribbean, increases erosion susceptibility and sediment loading where open-cast operations do not adequately prepare for the magnitude of rainfall attached to hurricane events. Accelerated greenhouse warming has led to an increase in sea-surface temperatures in the Atlantic Ocean, and some climatological models have indicated that this additional energy might increase the size and/or number of hurricanes arriving in the Caribbean.⁵² While the certainty of this trend remains inconclusive, severe hurricane regimes would challenge precautions taken to avoid mass-wasting of exposed upland soil under normal operating conditions, with significant consequences for offshore ecosystems, particularly coral reefs.

Land Use Dynamics

There are also significant differences in the relative presence of different land use activities in the region. For example, the Magdalena river basin clearly is a hotspot of gold mining activity, but it also has suffered significant sediment delivery through deforestation from agriculture and urban expansion.⁵³ The same set of circumstances has similarly affected sediment loadings in other basins, such as the Beni River in Bolivia. The proportional amount of sediment delivered, or forest cover loss, due to gold mining in these circumstances is considerably lower than along the Marowijne River in Suriname or Essequibo-Cuyuni in Guyana/Venezuela, where the presence of gold mining would explain a much higher proportion of the total variation in these impacts. In a similar frame, mining can have disproportionate impacts on riparian or gallery forests and the rivers they shadow, since these act as concentrated repositories of biodiversity and local community resources in areas of savanna-forest mosaic found in the Brazilian and Guiana Shield regions.

⁵¹ See, e.g., Warne et al. 2005.

⁵² Goldenberg et al. 2001.

⁵³ Restrepo and Syvitski 2006.

6. What Can Be Done to Reduce Impacts?

Gold mining is significantly affecting freshwater environments throughout LAC, but impact additionality is probably greatest in the Guiana Shield region, due to its low-energy freshwater systems, relative absence of competing land uses, high levels of forest cover, and high incidence of oligotrophic black water systems. The changing face of the global economy has created significant uncertainties, and gold will remain an important means of hedging this uncertainty in international markets. This will grow demand. Many countries in the LAC region derive a significant portion of their GDP from mining, and an even larger—and perhaps more important—fraction of their foreign-exchange earnings from gold exports. These trends are set to continue throughout this decade and beyond. Consequently, mining activity is only likely to expand and intensify across areas containing significant gold deposits. The global experience with gold mining in lowland tropical systems suggests a number of opportunities to improve practices and reduce impacts on freshwater systems and the people who rely on these for their livelihoods.

Coordinate Land-use Planning across Natural Resources and Resource Use Sectors

Gold typically represents one of many existing natural resources under some form of exploitation in most LAC countries. There is a critical need to support the establishment of land-use planning systems that better integrate the use of terrestrial and aquatic resources across mining, agriculture, forestry and protected areas sectors. Mining concessions, claims, and licenses variously overlap with protected areas, timber concessions, indigenous reserves, and agricultural leases in most countries because surface and subsurface rights are treated as distinct entities under most land law provisions.

These land use conflicts can create significant challenges to businesses seeking to deliver products certified as sustainable. For example, countries with large tracts of national land area allocated to timber production, such as Guyana, Venezuela, Peru, and Belize, have made considerable advances in reducing impacts of timber extraction on freshwater systems by requiring waterway buffer zones to be included in harvest plans. Certification of timber products from these areas are often contingent on protection of these intercalated waterways. At the same time, gold mining licenses are often allocated within these buffer zones, leading to intensive impacts on areas explicitly targeted for protection under forestry planning statutes.

Similarly, gold mining concessions allocated upstream of installed hydroelectric facilities risk reducing the operational life of these facilities and, *inter alia*, lowering internal rates of return through increased sediment loading. Additional stresses placed on operational performance of these facilities through poor control of upstream water quality can ultimately lead to increased power supply prices as generation costs begin to exceed projections. This lack of coherence in the laws and policies governing surface and subsurface resource use, as well as under-resourced land use planning divisions, continues to impede the sustainable use of lowland watershed resources.

Tailor Gold Mining Regulations and Standards to Background Environmental and Land Use Conditions

A process of review, consultation, and adaptation of gold mining regulations and standards to better account for background conditions prevailing in LAC countries would reduce the broader environmental, social, and economic risks attached to operations. Some of these conditions are inherent to the shaping influence of geology and soils on freshwater systems. Systems sourcing from the Guiana Shield and Brazilian Shield need to account for the significant additionality of impacts delivered by alluvial gold mining operations in these sensitive regions. Standards should also reflect the cumulative impacts of all land uses in complex environments, such as the Magdalena basin, where mining accounts for a smaller fraction of the total contamination of freshwater systems or riverine habitat losses.

Conditions can also differ due to vulnerabilities attached to catastrophic changes in rainfall regimes and their interaction with the effects of mining. ENSO-sensitive regions, such as the Guiana Shield and Magdalena basin, require different regulations and standards that address how operations are conducted during periods of severe drought and flooding largely governed by this climatological system. Hurricane-prone areas in the Caribbean with existing or prospective gold mining operations, such as the Dominican Republic, Haiti, and Belize, would increase the net benefits derived from gold mining by provisioning operational protections needed to prevent catastrophic sediment loading during these severe events.

Support Uptake of Mitigation Technologies to Reduce Sediment and Mercury Loading

As is the case with many lowland land use activities, the technical components needed to effectively avoid and mitigate most long-term impacts of gold mining—sedimentation, mercury contamination, overharvesting of local resources—are well known. But there is a need for

institutional programs designed to offset or reduce the cost of implementing standards in order to increased adoption rates by small and medium-scale mining operations. Without uptake, the effect of well-crafted standards and regulations is negligible. Facilitating uptake of impact-mitigating procedures and technologies could occur through various pathways. For example, establishment of equipment leasing bodies that provide the tools, practical training, and follow-up support necessary to encourage operations toward profitability while meeting regulatory standards has met with broad success in agricultural and forestry sectors in many LAC countries. Offering low lease rates and service support would encourage poorly educated, poorly capitalized miners toward greater uptake. Additionally, simple technologies made from available materials have proved very effective in reducing some impacts. For example, the introduction of basic retorts made from locally available scrap metal can significantly reduce the emission and exposure to highly toxic vapor mercury as it is released during gold refinement.

Encourage Small Operators to Form Collectives to Normalize Interactions and Increase Visibility

Uptake of impact-reducing procedures and equipment has been slow in part due to the administrative effort required to effectively deliver such support to a vast pool of small and medium-scale operators. In many gold-producing countries, such as Suriname, Brazil, and Bolivia, small operators have formed collectives to improve their negotiating power in obtaining legal rights to extract minerals, but these could also act as important conduits for increased uptake of impact mitigation technologies. Programs aimed at specifically encouraging and financially supporting the formation and administration of cooperatives where these are needed, such as Guyana, would improve the visibility of the largest part of the mining community. It would also decrease the transaction costs of normalizing institutional relationships and coordinating stakeholder collaboration.

Internalize the Environmental Costs of Impaired Water Quality and Biodiversity Loss

Reducing the operational impacts of mining through normalization of the industry will alleviate some of the effects on downstream users of freshwater resources. Even when it is managed at its best, however, gold mining intrinsically affects freshwater systems through sediment discharge and forest loss, particularly where large numbers of small operators work in close proximity. A reduction in water quality impairs the use of freshwater by downstream users. Consequently, their loss of use is effectively subsidizing mining operations that are not paying for the effects of

the pollution that they generate. There is a clear need to compensate downstream communities and businesses that use freshwater resources for this impairment.

Development of a system of collective water quality rights could help mitigate the transfer of environmental costs from gold mining operations to local communities and businesses. These rights would formalize negotiations, avoid many land use conflicts, and allow communities and businesses to recoup the cost of impairment to their “normal” use of freshwater resources since these stakeholders would become an implicit component of the decision to mine. This would also internalize the environmental costs of mining. Having institutions help in developing a pilot system of water quality rights issuance and administration could go a long way to reconciling some inevitable short-term environmental impacts attached to mining and the loss of ecosystem services.

Adoption of biodiversity offsets (BDO) has played a central role in mitigating wetland loss in the United States for the past 40 years and is increasingly being considered as a creative tool in addressing inevitable impacts of large-scale extractive operations in the lowland tropics. This approach recognizes that a loss of natural habitat is intrinsic to mining and that some aspects cannot be cost-effectively replaced through restoration techniques. BDOs ensure the integrity of areas with equal or greater biological value by providing long-term financial support for their protection and management. The use of BDOs and the modalities of their implementation might be further explored as a key provision for large-scale operations and an opportunity to normalize SAM and medium-scale operating clusters where these have been organized under legal mining rights.

Examine Approaches to Pay for Increased Mitigation, Monitoring, and Compliance

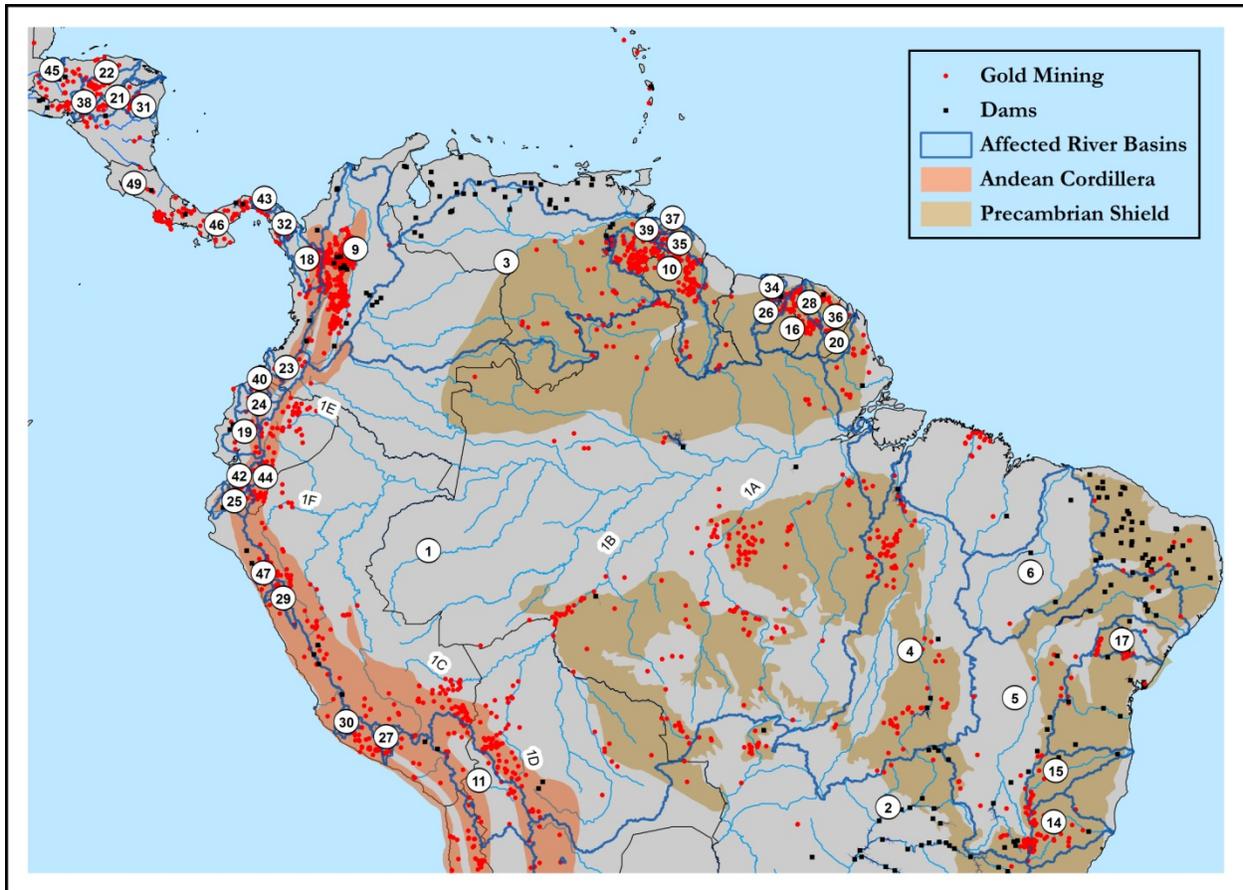
Arrangements for sustainably financing protected areas are currently being considered in many LAC countries. An assessment of how best the lessons learned from their experience in achieving long-term funding for protected areas could help in identifying the best mix of revenue sources and applications needed to normalize the small and medium-scale mining sector. For example, a pool of Caribbean nations that includes Belize, the Bahamas, Jamaica, and others have concluded that a pooled conservation trust fund is the most cost-effective means to deliver the necessary financial support for maintaining the integrity of regional protected areas.

Revenues from mining royalties and fees have reached record amounts in most of the LAC countries housing hotspots of gold mining activity. Contributing a small fraction of these

proceeds to well-managed trust funds to support reductions in mining impacts on regional freshwater resources would offer an important basis for attracting contributions from other national and international sources. It would also allow for better coordination of activities that are currently carried out by a wide range of supporting institutions that include government agencies, nongovernmental organizations, mining companies, banks, and scientists.

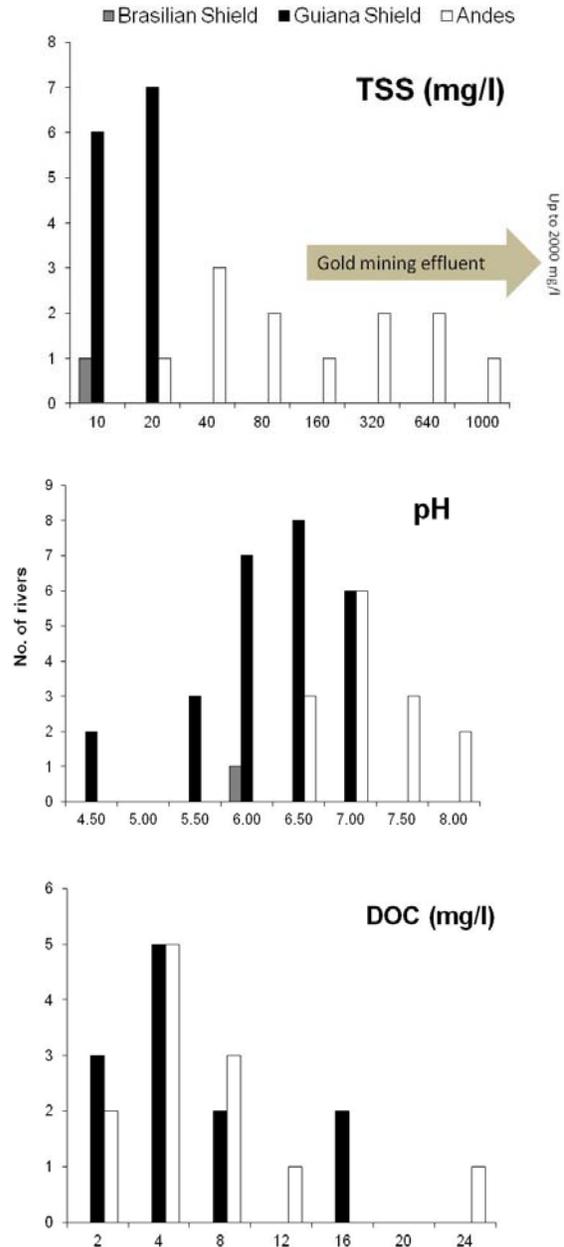
Figures

Figure 1. Indicative spatial distribution of LAC gold mining activity since 1970 in relation to geologic province, hydrological basin, and hydrodam facilities. Numbers identify major basins affected by gold mining, represent rank size in descending order, and are used as a reference guide in text.



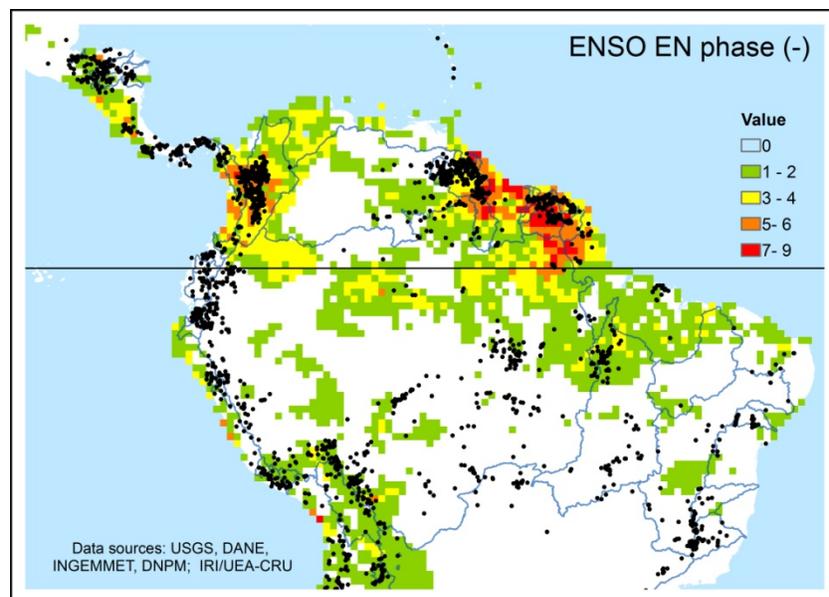
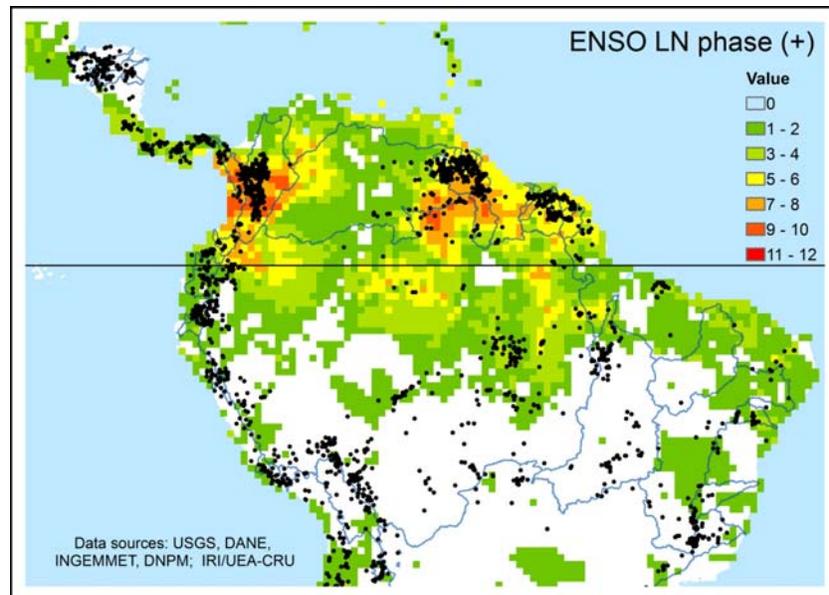
Sources: Hammond et al. 2007; USGS, 2011; CPRM-PNPO, 2011; INGEMMET, 2012; InfoMine 2012.

Figure 2. Total suspended sediments (TSS), water pH, and dissolved organic carbon (DOC) values of lowland river locations categorized by headwater source region (see Figure 1). The range of TSS values attributed to gold mining effluent is given for comparison to background levels.



Source: Hammond (2005a) and references therein.

Figure 3. Consistency of precipitation anomalies during the 12 strongest La Niña (LN) and El Niño (EN) events between 1950 and 2010 in relation to the spatial distribution of gold mining activity detailed in Figure 1. Only positive anomalies during LN events and negative anomalies during EN events. Value is the number of these events (0.5° x 0.5° grid) based on methods detailed in Mason and Goddard (2001).



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