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Challenges to measuring, monitoring, and addressing the cumulative impacts of artisanal and small-scale gold mining in Ecuador

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ABSTRACT

Portovelo-Zaruma, Ecuador is an artisanal and small-scale gold mining (ASGM) region with approximately 6000 gold miners working with mercury and cyanide. Although artisanal gold mining (AGM) has taken place in Portovelo-Zaruma for centuries, highly mechanized small-scale gold mining (SGM) processing plants capable of increased throughput began being built in the 1990s. While there are benefits associated with ASGM, there are also negative impacts experienced by the miners and the surrounding communities. To take advantage of ASGM as a poverty-alleviating mechanism while reducing unwanted externalities, the cumulative impacts must be understood. Numerous challenges to measuring, monitoring, and addressing ASGM impacts result from the complexity of the impacts themselves, the nature of the gold mining as an informal industry, and the shortfalls in the current regulatory framework. These are discussed in the context of ongoing, unresolved issues including efforts to address trans-boundary water pollution, management of mining waste, and conflicts regarding priorities, ambiguities, and enforcement of existing regulations and policies. Internationally, interventions to address both AGM and SGM impacts have typically focused almost exclusively on technological changes through the elimination of mercury use. Our analysis suggests that to better address ASGM and their cumulative impacts in Ecuador, it will be beneficial to revisit the legal definitions of AGM and SGM. Additionally, promotion of information-based strategies including educational outreach programs and cross-scale and cross-level mitigation methods may also be beneficial. The success of these strategies to reduce ASGM-related cumulative impacts will depend on sufficient funding and the commitment of stakeholders.

Introduction

ASGM in Ecuador

Artisanal and small-scale gold mining (ASGM) produces 10%–15% of gold mined in the world (Telmer and Veiga, 2008; Street et al., 2013) providing income for many impoverished communities. In addition, ASGM is associated with numerous negative impacts such as exposure to pollutants for both the miners and communities adjacent to and downstream of mining activities (see Table 1). While relatively small in each instance, this poverty-driven activity uses straightforward technologies including mercury amalgamation and/or sodium cyanide leaching to extract gold from ground ore. Since the technology used for ASGM is accessible and affordable, it is used in many locations around the world including Latin America, Sub-Saharan Africa, and Asia (Veiga and Baker, 2004). Given that gold is immediately fungible in local and international economies, ASGM operations begin largely as entrepreneurial efforts driven by immediate profits. For this reason, strategies designed to address the cumulative impacts of large-scale mining operations including international conventions, voluntary codes of conduct, consumer-based pressure groups, and government regulation may not necessarily be applicable or sufficient.

Although Ecuador's formal extractive economy has primarily been based on development of petroleum resources, ASGM is well established in Ecuador and has been a central economic activity

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Table 1
Positive and negative impacts associated with ASGM

Negative impacts	Positive impacts
1. Water, air, and soil pollution now and in the future.	1. Jobs for miners and financial support for families; source of poverty alleviation.
2. Land-use change and landscape changes.	2. Generation of revenue through attracting people in areas close to mining centers.
3. Ground instability and landslides.	3. Creation of a sense of identity and culture of people/community.
4. Forced relocation of communities.	4. Improvement of local infrastructure.
5. Increased dryness and dust.	5. Heightened awareness of the importance of safety among the population.
6. Exposure of miners to occupational hazards, including death.	6. Encouragement of the entrepreneurial spirit.
7. Increased exposures and related diseases of miners, current residents, downstream communities, and future generations to chemical toxicants.	
8. Increased rates of infectious disease, violence and crime.	
9. Increased health-care costs.	
10. Loss of biodiversity.	
11. Child labor and de-emphasis on education.	
12. Economic impact on lost opportunity: agriculture, fisheries, land productivity.	
13. Lack of community and worker empowerment.	
14. Population-wide distrust of government officials.	
15. Stressed political relationships with Peru.	
16. Inability to invest mining earnings to benefit the community.	

among individuals for hundreds of years. Ecuador has four ASGM districts; the largest and most active is the Portovelo-Zaruma district in the Puyango-Tumbes River Basin (Fig. 1). ASGM has evolved and changed significantly over time in Ecuador. Indigenous people and African slaves mined gold in the Portovelo-Zaruma district using strictly artisanal, rudimentary techniques in the 1500s (Lane, 2004). In 1880, the mineral wealth of the region became internationally recognized and large companies moved in to develop the resources beginning with the British-owned Zaruma Gold Mining Company Limited. By 1896, the American-owned South American Development Company (SADCO) bought out Zaruma Gold and operated profitably until 1951 when several labor strikes crippled the company and tax disputes with the Ecuadorian Government led to bankruptcy. SADCO was bought out by Ecuadorian Compañía Industrial Minera Asociada (CIMA) and continued to operate until 1978 when poor management and high rates of inflation led to another bankruptcy (Sandoval, 2002; Velásquez-López et al., 2010). Artisanal gold mining (AGM) was revived during this period. In the early 1980s, with industry no longer present and gold valued at over USD $800/ounce, a gold rush began providing livelihoods for former industry employees and bringing fortune-seekers to Portovelo-Zaruma. Despite this inflation in gold price being temporary, prolonged AGM continued since there were not viable employment alternatives.

In contrast to the way ASGM is carried out in most parts of the world, in the 1990s entrepreneurs built small processing centers to be rented by miners to crush large quantities of ore and process gold through the use of gravity separation and mercury amalgamation. Because gold recovery using mercury amalgamation is less than 40%, processing center owners profit by reprocessing amalgamation tailings left behind by artisanal miners. Using more refined techniques including cyanidization, flotation, and smelting, processing center owners recover the remaining 60%–70% of gold (Velásquez-López et al., 2010). Accordingly, a unique business model developed whereby processing center owners who employed less efficient small-scale gold mining (SGM) techniques for crushing and amalgamation generated greater profit.

Over the last five years, Ecuadorian authorities have sought to address ASGM-related concerns in response to an expansion of the ASGM sector and related impacts (Velásquez-López, 2010). With gold now trading at over USD$1600/ounce and a greater national emphasis placed on growing the mineral resource sector as Ecuadorian petroleum reserves dwindle, more than 100 processing plants are estimated to be active in the Portovelo-Zaruma region producing approximately nine tons of gold annually (Velásquez-López, 2010). All of these processing centers use mercury, sodium cyanide, or both to extract gold. Currently, mining activities support a local population of over 20,000 with an estimated 80% of the population involved in or reliant on ASGM for income (Velásquez-López, 2007). Although ASGM operations provide economic opportunity and a source of pride for the people of Portovelo-Zaruma, they also have spurred a variety of negative impacts.

ASGM-related impacts

It is necessary to understand ASGM-related impacts and associated complexities to optimize the benefits of mineral development while reducing harm to miners and communities.[1] While

[1] There is an underlying assumption built into this discussion that ASGM should be optimized. Individuals in the developing world deserve an opportunity to provide for themselves and their communities. The development of gold resources is historically a major factor in national development and economic growth, as evidenced in the histories of the United States and Australia. In these cases, however, because of the richness of deposits, ASGM was quickly overtaken by larger scale industrial activities and regulated by government. The promise of ASGM as a driver of development is not fully realized in Ecuador. However, ASGM does play a large role in poverty reduction and likely will continue to help improve the economic and social outlooks for populations. According to information collected by the Ecuadorian National Institute of Statistics and Census (INEC), Portovelo-Zaruma has approximately 50% less poverty than similar neighboring

Fig. 1. Map of the Puyango-Tumbes River Basin—Portovelo-Zaruma is the most concentrated region for ASGM in Ecuador, with the majority of processing plants on the Puyango River and its three tributaries: the Calera, Amarillo and Pindo. Once into Peru, the Puayngo becomes the Tumbes River, a critical water source for Northern Peru.

each of the impacts of ASGM are significant, it is the successive, incremental, or combined effect of the impacts, defined as *cumulative impacts*, that must also be measured, monitored, and addressed (Brereton et al., 2008; Franks et al., 2011).

The environmental impacts associated with ASGM relate primarily to the degradation of water quality and aquatic ecosystems. ASGM reduces water quality in four major ways: (1) contamination caused by the runoff of mining waste from tailings piles and tailings ponds, (2) pollution caused by illegal dumping of mine waste into rivers, streams and other water systems, (3) gradual contaminant drainage caused by improperly sealed waste management sites, and (4) increases in soil erosion associated with land-use change. In Portovelo-Zaruma, all of these problems are present (SGAB-Prodeminca, 1998). Many of the processing plants have pipes that empty directly into the Puyango River and its tributaries and there are tailings piles with high levels of toxic metals including mercury, cadmium, copper, manganese, lead, and arsenic situated on the river banks. Also, regular "night dumping" occurs in which truckloads of tailings and other ASGM waste, including cyanide pulp, are transported from more remote locations and dumped into the Puyango River system. Many of these pollutants undergo chemical changes as they interact with other constituents in the environment that can influence their transport and fate. For example, mercury can interact with sulfur (see review: Fitzgerald and Lamborg, 2003) and cyanide (Guimarães et al., 2011) to form complexes that can be transported far downstream. In addition to increasing the turbidity of the river itself far from the mining center (Tarras-Wahlberg and Lane, 2003), ASGM practices have a drastic impact on the entire ecosystem: they have toxic effects on fauna and contaminants can be transported downstream via river sediments and suspended particulate matter (Guimarães et al., 2011; Tarras-Wahlberg et al., 2001). In addition, the infusion of toxic metals into soils due to the use of mine-polluted water for the irrigation of crops may have secondary effects on soil and crop quality, even in areas that are far from mining sites (Appleton et al., 2001). ASGM may also interact with factors described above to decrease biodiversity and increase habitats for disease vectors such as mosquitoes and black flies (Sandoval, 2002).

Since ASGM has such large impacts on environmental and ecosystem health and reduces population access to potable water, it has an adverse influence on population health. The most well-characterized and well-studied health-related impact of ASGM in Ecuador pertains to exposures of mercury vapor among occupational populations (Velásquez-López et al., 2011) and exposures of downstream populations to metals, including mercury, manganese and lead (Betancourt et al., 2005). Although there have not been any longitudinal studies conducted in this area to determine the long-term health impacts associated with these exposures, Betancourt et al. (2012) suggested these exposures result in a significant cognitive decline among children. Additionally, there is a perception among both Ecuadorian and Peruvian populations that pollution of the Puyango-Tumbes River results in high levels of contaminants in shrimp, fish, rice and bananas that could over time result in health-related consequences. However, only limited studies of the food-web have been conducted that weakly support these perceptions (SGAB-Prodeminca, 1998; Sandoval, 2002; Chincheros, 2007). In addition, the sociology of ASGM may also contribute to increased disease risk due to movement of non-immune populations who have limited access to health services (Hilson, 2002).

ASGM also has many social and cultural impacts. Since exposures to toxic metals and ASGM chemicals can increase population morbidity, ASGM can lead to a loss of productivity across the population. Additionally, involvement of children in Ecuador's mining regions has resulted in decreased school attendance,

(*footnote continued*)
towns without ASGM. It is the opinion of the authors that inequality and poverty can be viewed as an environmental problem. For this reason, addressing environmental problems without consideration of factors leading to poverty and inequality is unlikely to succeed. Consistent with this view, we assert that the negative cumulative impacts associated with ASGM in Ecuador should not be ignored, though it would be wrong to dismiss the role of ASGM in helping individuals to achieve their aspirations and to meet their needs. On balance, because equality is a prerequisite to environmental sustainability, the advantages of optimized AGSM outweigh the disadvantages.

perpetuating the reliance on ASGM as an economic necessity (Sandoval, 2002; ILO-IPEC, 2003). Since ASGM can lead to ground instability through the extraction of ore, and since mining operations do not require the approval of land owners in Ecuador, it can cause population displacement and conflicts between land owners and concessionaires. Displacement of populations has an entire class of socio-cultural consequences of its own lifestyles, relationships, and cultures of entire communities that have existed for generations need to be re-built (Franks et al., 2011). Further, since communities do not need to approve of mining activities prior to the issuance of exploration and mining licenses, there is a great deal of resentment and distrust towards the government to help sustainably grow the mining sector while protecting community interests (CONAIE, 2009).

There are many political and economic challenges associated with responding to ASGM impacts. First, governments can struggle to balance the need for continued expansion of the ASGM sector with constitutionally-mandated and internationally-supported sustainable development and social justice goals. Because ASGM-related impacts are visible, and development of this sector often conflicts with community property ownership and access to food and water, the lack of government actions to address ASGM issues has the potential to de-legitimize government and has led to regional protests (UNHCR, 2011; BBC, 2012—see Section Addressing land-use and resource ownership in the context of ASGM). Second, pollution of shared water resources, which is perceived to be caused by ASGM upstream, has increased political tension between Ecuador and Peru. Multiple complaints have been filed against Ecuador on behalf of Peru through the Ministry of Foreign Affairs and recently there have been workshops between Ecuadorian and Peruvian governments to begin working towards resolution (see Section-The challenge of trans-boundary water pollution (spatial impacts)).

Along with impacts that effect the general population, there are also occupational impacts specific to the miners and laborers directly involved in ASGM. Workers are exposed to chemical hazards including dust, cyanide, mercury, and other metals and chemicals. In addition, there are exposures to safety hazards including noise, vibration, heat, lack of oxygen, confined spaces, slips, trips, falls, over-exhaustion, and psychosocial stress. Due to these inherent hazards, along with a lack of engineering expertise, capital, and appropriate protective equipment, there are accidents that can cause severe injury and even death (Jennings, 1999). Reliable statistics on occupationally-related injuries are often severely under-reported in Ecuador and official numbers are not available (ILO, 2006). However, as in many Latin American and Caribbean countries (Giuffrida et al., 2002), mining-related injuries and deaths likely make up a significant portion of workplace fatalities in Ecuador. In Portovelo-Zaruma specifically, deaths are most often reported to result from cave-ins of underground mines. While miners participate in ASGM out of choice, there are very few other economic opportunities outside of the sector. The inability of miners to find jobs elsewhere, combined with a relative lack of government intervention and regulation of the workplace, enables plant owners to take advantage of miners by not compensating them fairly or providing a safe workplace. Since artisanal miners are not officially employed and are working on a unit-production basis, they are not subject to work benefits and have no effective means to organize or collectively bargain for improved workplace conditions, as is often the case in Latin American and Caribbean countries (Giuffrida et al., 2002). Additionally, mistreatment of workers and lack of governmental regulations also fuels the use of inefficient technologies for gold extraction and the mishandling of mining waste and tailings. This greatly contributes to the outlined environmental, socio-cultural, economic, and political consequences.

Experiences in responding to ASGM in Portovelo-Zaruma, Ecuador

Cumulative impact assessment is typically related to the *ex-ante* assessment of single projects subject to formal government approval (CEAA, 2008; Connaugh, 2005; Court et al., 1994; Walker and Johnston, 1999). In contrast to traditional cumulative impact assessment that takes place as part of the formal environmental impact assessment process, assessment of ASGM-related cumulative impacts in Portovelo-Zaruma, Ecuador requires a joint evaluation of the effects of gold processing taking place at over 100 gold processing centers and plants and countless artisanal gold mining sites that have operated with minimal to no oversight for decades. For these reasons, measuring, monitoring, and addressing cumulative impacts of ASGM-related impacts in Portovelo-Zaruma is highly complex relative to other situations discussed in the cumulative impact literature.

In this section, the challenges to measuring, monitoring, and addressing cumulative impacts are discussed in the context of ongoing experiences in Portovelo-Zaruma, Ecuador. Despite the increased application of cumulative impact assessment in recent years, some have suggested current cumulative impact assessment methods fail to adequately address variation of impacts over multiple scales (Therivel and Ross, 2007). Consistent with this view, we first argue ASGM impacts in Portovelo-Zaruma vary over temporal, spatial, and jurisdictional scales. This variation imposes an information problem on policy and decision makers that is not accounted for with traditional policy tools including emission standards or market-based solutions. Second, we argue that recent legislative and constitutional changes in Ecuador do not provide the necessary tools to grow and regulate the ASGM sector or to effectively measure, monitor, and respond to ASGM-related impacts.

Accounting for the complexities of ASGM-related impacts

The challenge of trans-boundary water pollution (spatial impacts)

Although most studies focusing on ASGM-related impacts focus on localized effects, some impacts are observed far from the center of mining activity and extend across political boundaries. Among the most contentious issues resulting from ASGM in Portovelo-Zaruma is pollution on the shared waters of the Puyango-Tumbes River. In 2001, concerned Peruvian citizens filed official complaints regarding the water quality of the Puyango-Tumbes River through the Peruvian Foreign Affairs Ministry. These complaints alleged poor water quality of the Tumbes River in Peru was due to Ecuador's ASGM and lack of waste management upstream on the Puyango. Thus, they claimed ASGM was harmful to Peruvian agriculture and fisheries. Tensions have intensified over the past decade. In December of 2012 Peruvian representatives not only expressed extreme discontent with the continued, unrestricted pollution of the Puyango-Tumbes River, but also officially requested compensation on behalf of Tumbes citizens for the negative impacts they have incurred due to Ecuadorian mining. A formal request was also made for Ecuadorian officials to inform Peruvian representatives of specific actions that will be taken to protect populations living downstream of Portovelo-Zaruma from ASGM-related pollution (MRECI, 2012). The ongoing conflict between Peru and Ecuador with regard to the pollution of the Puyango-Tumbes River highlights a variety of challenges that hinder measuring, monitoring, and addressing cumulative impacts that extend across spatial and jurisdictional scales.

Since the environmental impacts associated with ASGM in Portovelo-Zaruma, Ecuador extend far beyond the location of the mineral resource development, there are substantial debates regarding the origin of the pollution. Although Peruvians contend that the pollution is related to the Ecuadorian mining operations, Ecuadorians claim a significant portion of the pollution far downstream on the Puyango-Tumbes could be related to geological characteristics of the region and erosion caused by deforestation and land-use change occurring in Peru. Additionally, it has also been suggested that pollution from ASGM in Portovelo-Zaruma cannot travel far downstream and that pollution may be the result of AGM taking place on the Peruvian side of the border. The inability to directly differentiate between impacts associated with a geographically distant activity like ASGM and other sources including deforestation and land-use change is a barrier to assessing and responding to cumulative impacts (Franks et al., 2011). This demonstrates how information can be perceived differently depending on one's position since there may be distinct factors contributing to what is considered important, credible, or valid (Cash et al., 2006). This challenge in differentiating between pollution sources as it relates to ASGM is also discussed in the scientific literature (Adler Miserendino et al., In preparation; Canuel et al., 2009; Wasserman et al., 2003).

Cumulative impacts tend to require consideration from multiple disciplines. For example, in the trans-boundary pollution situation between Peru and Ecuador, many Peruvian and Ecuadorian ministries need to be consulted to investigate and respond to water quality concerns including those ministries responsible for regulating mining, water, agriculture, fisheries, tourism, the environment, and foreign affairs. Thus, simple tasks, such as collecting information to understand the impacts of ASGM on various stakeholder groups or jointly monitoring known problems, are not straightforward. To address jurisdictionally varying impacts, there must be an institutional arrangement that requires an agreement on the hierarchical structure of rules and norms (Ostrom et al., 1999), which can be difficult to derive.

An additional difficulty in addressing jurisdictional disputes is cost distribution. Since 2001, there have been numerous bilateral negotiations and workshops between Ecuador and Peru; however, none have been successful in producing bilateral agreements to address waste management upstream or the shared water pollution problem of the Puyango-Tumbes River. Instead, existing funded programs focus on the development of large-scale water infrastructure. For example the Puyango-Tumbes Project, scheduled to commence during 2013, has primarily focused on building a dam and other irrigation infrastructure without addressing the pollution problem directly. The straightforward solution to this problem of cost-sharing seems to be the “polluter pays” principle. This principle holds those who are responsible for producing, permitting, or causing pollution liable for cleanup costs caused by the pollution. Challenges in determining who polluters are and the absence of multi-lateral enforcement mechanisms has limited its application in this case.

The challenges of tailings and waste disposal (temporal impacts)

Ongoing efforts to address tailings management and waste disposal in Portovelo-Zaruma (Tarras-Wahlberg et al., 2000) highlight a problem that spans multiple temporal levels. The national and provincial governments have led an effort to develop a community-based strategy for miners to dispose of mining waste. This plan has focused on establishing a site where mine wastes and tailings could be transported, deposited, and safely stored over the next 15 years. In addition, through the development of a waste management site, officials expect this effort to reduce water pollution.

There are many unanswered questions that threaten the success of this plan pertaining to the time-scale over which this solution should remain viable. While the candidate site was selected to minimize anticipated damages while accommodating ASGM waste, the plan does not account for the long-term site maintenance, environmental, socio-cultural, and economic impacts and associated costs. Lack of expertise in designing tailings dams and lack of agreement between authorities and processing plant owners have led to four-year-long discussions about the feasibility of the project and have threatened to stop the project altogether. Interventions on behalf of the Ecuadorian National Research Institute and international experts on tailings management have enabled the project to continue. Currently, the national government has allocated financial resources for the preliminary phase of the tailing dam; however, the proposed plan fails to establish who bears the responsibility for costs into the future. Furthermore, there has not been a plan established to share or re-invest potential profits of secondary processing of tailings delivered to the communal site to benefit future development of Portovelo-Zaruma and the betterment of the community. The failure of the proposed waste management plan to account for the aforementioned factors is reflective of several classic dilemmas in addressing time-varying impacts, all of which greatly complicate the selection, design, and implementation of policies or management solutions.

There are technical difficulties in determining or projecting future impacts of the proposed waste management plan due lack of local expertise. There is no clear plan or time-line for current and future mining development. Furthermore, there is a lack of knowledge about the carrying capacity for tailings in the selected site with an expected increase in the number of operations and throughput in the area over time. Additionally, local officials have a lack of experience with designing tailings dams for ASGM and have not been sufficiently trained to monitor or manage disposal and storage of mineral residues and tailings.

There remains a discrepancy over how to account for the costs of the projected tailing management plan and future impacts through the policies and decisions made today. Since policy decision makers have present-biased preferences, impacts at present are a higher priority than those anticipated in the future. Therefore, commitments made today to address future problems are often broken or postponed (O'Donoghue and Rabin, 1999). To account for time-varying impacts, the projected cost of future impacts should be discounted. However, there are many theories regarding how to most appropriately select a discount rate to take into account the true cost associated with future impacts, along with the “value” placed on that impact by today's policy and decision makers (Pindyck, 2007; Weitzman, 1998). Since there is great uncertainty regarding the magnitude of future impacts associated with a particular plan, in this case a tailing and waste management plan, and since these future costs are typically discounted, estimates of future costs are often significantly under-estimated.

Due to the lack of planning as well as technical and economic knowledge, there is a difficulty in determining cost distribution among stakeholders over time. There are many options for how future costs could be distributed, each of which introduces a unique set of strengths and vulnerabilities. If costs were treated as an upfront fee to miners and processing plants on a per-unit basis, there would be a disincentive for miners to bring their tailings and waste to disposal facility. This price-structure is likely to lead to continued illegal dumping into the river or storage of unprotected tailings. This would result in an additional cost to the general community either in terms of the impacts associated with the dumping or in additional cost of enforcement to ensure compliance with the new waste management and waste disposal framework. If a fee were collected on a per-ton of ore processed or per-gold production basis, there would be an incentive for all actors to under-report their production figures. On the other hand, if the costs were borne through local taxes, the burden of caring for the waste would not be borne by the polluters, antithetical to principles outlined in the Ecuadorian Constitution. As an alternative, the future impacts could be dealt with through liability, to be paid for either by all miners and processing plants or society as a whole after the impacts manifest. This approach has the downside of being unable to locate responsible parties to cover costs, having unnecessary litigation costs to be able to acquire necessary funds to address the problems, or having some impacts that are no longer able to be fixed.

As another challenge to regulating time-varying impacts, even once measurement and information-based challenges are dealt with and decisions are made with regard to how to distribute costs over time, there are still challenges with consistent enforcement. While a policy maker today can establish policies, future policy makers can modify or change them. This, in part, speaks to the present-biased preferences in which policy and decision makers may neglect the commitments made by predecessors (Horowitz, 1996). Hence, even if these issues are able to be dealt with now, there is a high likelihood of having to revisit the issues. No single policy maker or group of policy makers can regulate over the time-scale relevant to a "long-term" problem.

Environmental and mineral policy in Ecuador

In 2008 and 2009, under the leadership of President Raphael Correa, the Government of the Republic of Ecuador re-shaped many policies to encourage growth of the mineral sector. Under this legislation, ASGM is primarily regulated by four documents: (1) the Constitution of the Republic of Ecuador (Constitución, 2008; (2) the Mining Act (Ley de Minería, 2009; (3) Presidential Decree 119, the General Mining Regulations (Decreto Presidencial, 2009a; and (4) Presidential Decree 120, the Special Regulatory Rules for ASGM (Decreto Presidencial, 2009b). Collectively, these documents provide the framework for the ASGM sector to operate through the various stages of natural resource development including exploration, development, and production. As a significant departure from previous legislation, the Mining Act and the Special Regulatory Rules for ASGM acknowledge the importance of ASGM as a national priority for economic development. However, with the mineral sector in its infancy, and a general lack of knowledge regarding the cumulative impacts of ASGM, the current legislation fails to provide a clear vision for the development of the sector. In particular, the current laws do not clarify how ASGM can be pursued in tandem with the progressive aspects of the Ecuadorian Constitution that emphasizes the right of all people to live in *sumak kawsay*, harmony with oneself, society, and nature (Art. 3, 14, 72, 275). This is due to a lack of specific, enforceable definitions of artisanal and small-scale mining that leads to difficulties in regulating the ASGM sector and to inconsistency regarding land-use, resource ownership, and the role of the community in approval and execution of development projects. These are discussed below in greater detail.

Definitional challenges in ASGM policy

One of the primary differences between ASGM and industrial gold mining is that ASGM is informal and decentralized, whereas industrial mining has well established chains of command. As an acknowledgment of this difference, the Mining Act and the Special Regulatory Rules for ASGM delineate separate regulations pertaining to artisanal, small-scale, and industrial mining and establish plans for developing training programs to promote sustainable development of the ASGM sector. Although, in principle, the differences between artisanal, small-scale, and industrial mining are recognized, there is a difficulty in classifying particular miners and particular operations as artisanal, small-scale, or industrial based on existing definitions. In many cases, these classifications of mining and related legislation serve as a disincentive for miners to become organized or to truthfully report their activities.

Although classifying ASGM as legal activities of national importance empowers the Ecuadorian Government to regulate the sector, there is an unintended side effect of the special regulatory rules. Certain provisions afforded to artisanal gold miners encourage the unplanned nature of small-scale operations, preventing miners from becoming more organized and efficient. ASGM in Ecuador takes place through the work of two distinct populations: (1) artisanal miners who extract ore from mines, perform amalgamation in processing centers to recover 30%–40% of total gold, and leave amalgamation tailings as part payment for the rental of equipment and (2) small-scale miners, generally owners of small processing plants or small companies that process amalgamation tailings or mineral extracts through amalgamation, cyanidation, flotation, smelting and refining. Many government policies fail in the attempt to solve the various problems created by ASGM since these two groups are often mixed and are mutually dependent on each other.

Although there is a classification of small-scale versus artisanal mining according to tonnage of ore processed and income generated in the current mining law (Art. 14; 134), the regulations have a conceptual gap. Differentiating between these groups is non-trivial and fuels resentment and non-compliance on behalf of small-scale miners who want the privileged status afforded by the Special Regulatory Rules for ASGM to artisanal miners. For example, by providing significantly less stringent permitting and taxation policy towards artisanal mining as compared to small-scale and industrial mining, the rules create an incentive for individuals to work for subsistence rather than to grow operations into more productive, sustainable enterprises. Specifically, the Mining Act of 2009 requires all new industrial and small-scale mines to acquire a mining title through the Ministry of Non-Renewable Natural Resources, to perform an Environmental Impact Assessment (EIA), to obtain an environmental license through the Ministry of Environment, and to obtain a resource development contract. The act also requires industrial mining companies pay a 5% royalty on sales and small-scale operations to pay a 3% royalty in addition to income tax, windfall taxes, and value added tax (Art. 93). In contrast, under the general regulations artisanal miners fill out a form to acquire an exploration license (Art. 61) and under the special rules are not required to undergo an EIA and are not taxed (Art. 19).

Under this operating model, which discourages honest reporting, accounting for the cost induced though ASGM-related impacts by individual miners or processing plants is difficult. The number of ASGM firms and the lack of centrality make it difficult to directly observe their actions, track pollution and other impacts, and calculate production costs. Accordingly, with the information deficit and a lack of capacity for government officials to effectively monitor each operation, to enforce environmental regulations, or to establish regulatory measures to encourage efficient use of technologies, compliance with health and safety regulation is difficult.

To encourage improved waste minimization and gold recovery efficiency across the ASGM sector, it may be worthwhile to consider changing the definitions of artisanal versus small-scale gold mining to be based on technologies used during the gold extraction process and not simply the throughput of processed ore and income generated. This change would greatly reduce the incentives for miners to choose less efficient technologies for gold recovery or to falsely report their profits. As an added benefit, this change would enable regulatory officials to differentiate between AGM and SGM operations by quick visual inspection since technologies used during these processes are visibly different. Thus, enforcement of existing policies would not reply only on the reporting from miners or plant owners.

Addressing land-use and resource ownership in the context of ASGM

The Ecuadorian Constitution is primary to other "ordinary" laws (Art. 133; 425). However, there are several topics including land and property ownership, access to food and water, and community approval of mining projects that some suggest are not handled according to the Constitutional guidelines since the Mining Act declares itself supreme (Final Disposition 2). This has been the root of social upheaval and unrest within Ecuador, particularly among Indigenous communities in the Southern regions rich in gold and other minerals. Since 2009, there have been numerous country-wide and regional protests (UNHCR, 2011, BBC, 2012). As a testament to the level of acrimony associated with these legal discrepancies, CONAIE brought a case against the state that challenges the constitutionality of the Mining Law (CONAIE, 2009). The case was heard in 2010 and has gained attention world-wide since it was alleged that current mining laws violate the UN Declaration of the Rights of Indigenous Peoples, the American Convention of Human Rights, the Additional Protocol of the American Convention of Human Rights in Matters of Economic, Social and Cultural Rights, and the International Pact of Economic, Social, and Cultural Rights (CONAIE, 2009). Although this case primarily dealt with industrial mining, several key concerns also relate to ASGM and remain to be addressed are outlined.

The Ecuadorian Constitution establishes that, although all non-renewable natural resources are a strategic sector at the official discretion of the government to manage and regulate (Art. 313), communities must be consulted prior to the establishment of extraction projects (Art. 400) and given the right to object (Art. 98). The Ecuadorian Mining Act, however, stipulates that communities living within mining concessions only need to be consulted after the exploration license is granted, and that agreement of the land owners and communities is not required to move forward with mineral resource development. This is true no matter how long individuals and their ancestors have lived in the region and no matter if they own the land officially or through ancestral rights. Typically, there is no contract between the land-owner and the miner, leaving the land-owner to either illegally mine on his own land or to make an informal agreement with the concessionaire.

Additionally, the Constitution stipulates that all individuals have the right to access quality food and water resources (Art. 3; 13; 32). The Mining Act and the Special Regulatory Rules for Artisanal and Small-Scale Mining state that in situations in which the land is deemed as a "public utility," the government has the authority to allow mineral exploration and development, even if the mining may interfere with communal access to quality food and water (Special Rules art. 14; Mining Law art. 15; 28). Moreover, the Mining Act also states sanctions can be placed against individuals or groups that aim to disrupt or prevent mining activities from going forward (Art. 100).

The lack of agreement among the land owners and communities living within mining concessions and resistance to mining activities indicate challenges in regulating the accessibility of mineral resources, community planning, the rights of individuals and communities, and the economic development in the Mining Act. In addition, by allowing government agencies to declare community resistance to mining as a disruption without clear definitions of what constitutes a disruption, the law permits the criminalization of concerned community members for seeking to fulfill their Constitutional entitlements to own property and to have access to clean food and water (UNHCR, 2011).

Recommendaitons to improve measuring, monitoring, and adressing ASGM-related impacts

Given the numerous complexities associated with ASGM in Portovelo-Zaruma Ecuador, it is clear no single policy or program will immediately simplify the process of addressing ASGM-related impacts. An improved vision of how the mineral resource development sector in Ecuador can take advantage of ASGM to grow the economy while empowering communities is necessary. We suggest multi-stakeholder educational outreach and training activities targeted towards both miners and community members may be the logical first step to empower the community and pave the way for comprehensive future-changes to official government policies and sector-wide improvements. As a longer-term solution, the legal definitions of AGM and SGM need to be revisited as described in Section Definitional Challenges in ASGM Policy, and cross-scale and cross-level mitigation techniques should be considered to more efficiently address management of ASGM-related impacts across spatial, jurisdictional, and temporal scales.

Using information strategies to address ASGM cumulative impacts

Regulatory approaches to prevent ASGM-related impacts in Ecuador have failed due to a dearth of knowledge regarding the complexity of ASGM-related impacts, lack of clarity of the policy framework, limited resources, and a lack of capacity to control mining activities to bring about change. Other alternatives to reduce environmental pollution and occupational risks, such as market-based approaches, only work when there is an entity to charge and available resources to design, implement, and enforce the market-based solutions. In the case of ASGM this is challenged by its decentralized nature (see Section Definitional Challenges in ASGM Policy). When more "traditional" approaches for pollution and hazard control, such as regulatory or market-based solutions, are either too difficult to enforce or too costly, information strategies are a viable option (Tietenberg and Wheeler, 1998).

Unlike many other approaches to reduce ASGM-related impacts, information-based strategies could be used in combination with ongoing regulations to work across multiple stakeholder groups within relatively short time-scales in three ways. (1) Engagement of stakeholders is useful to raise public awareness about ASGM-related impacts, enabling individuals to take immediate action to reduce their own risk factors. (2) Once individuals are aware of the unavoidable risks they face due to ASGM, they are more likely to advocate for improvements in ASGM-related legislation, regulation, waste management, and remediation efforts. (3) Outreach to and direct engagement of miners and ASGM-impacted communities would greatly help reduce the sense of helplessness and lack of control felt by communities and miners and could result in the creation of a new social norm that favors more communication and greater transparency.

Over the longer term, training and education of miners may further allow for greater social change, sector-wide improvements, and application of other more "traditional" policy approaches. For example, once miners are trained and educated on techniques for optimal gold recovery, they are more likely to collectively identify and avoid poorly designed processing plants with sub-optimal gold recoveries (30%–40%) in favor of processing plants with more sophisticated, efficient designs. Small-scale and artisanal gold miners around the world have readily accepted and applied new techniques after effective demonstrations (Barry, 1996; Hinton et al., 2003). Accordingly, miners are likely to pay higher prices to process ore in exchange for greater efficiency in gold recovery to "punish" owners of less efficient processing plants who would be perceived as "free-riders," even if it means lower marginal profits (Fehr and Gächter ,1999). Thus, training miners to use more efficient technologies will likely result in more efficient plants, less pollution, and adoption of business models that are less reliant on social-hierarchies of abuse.

Unionization or organization of miners in some capacity is a critical step towards bringing about large-scale, sector-wide change through placing collective pressure on plant owners. However, before miners will organize, they must have sufficient awareness to recognize unfair work conditions and to motivate themselves to work together for a collective benefit, which can be obtained through training or educational outreach. The legal classification of ASGM in Ecuador, along with the explicit support for organization of miners in the Special Regulatory Rules for ASGM, allows for the possibility of an organization of miners in some capacity, which could facilitate efficient communication between miners, regulatory bodies or community stakeholders, encourage adherence to safety protocols, and promote more awareness of the impacts of ASGM.

There are many examples in which information-based strategies have been utilized to engage communities and workers to reduce environmental and occupational impacts. The United States Environmental Protection Agency Toxics Release Inventory (TRI), a database that includes information regarding toxic chemical emissions from factories, is one well-known example in which the disclosure of information has motivated improvement in corporate compliance with environmental regulations through community-based pressure. Although the success of the TRI is not by any means uniform, (Lynn and Kartez, 1994; Doshi et al., 2012), it is generally accepted that the TRI has been a success in motivating firms to reduce their toxic emissions (Stephan, 2002). Improvements have also been observed in the United States occupational environment as a result of the Occupational Safety and Health Administration Hazard Communication Standard (OSHA HCS). By mandating that employees are educated regarding occupational hazards in the workplace, workers are empowered to reduce their own risks, to better seek compensation in situations in which they are harmed, and to use information they are given to advocate for positive change. The success of the OSHA HCS, however, is largely dependent on the effectiveness of worker training programs and educational outreach and not simply on the dissemination of information (Fagotto and Fung, 2003).

The joint education and organization of miners has been attempted in the Portovelo-Zaruma Region on a small-scale, and has been successful at reducing occupational hazards and environmental pollution (Velásquez-López et al., 2010). During this effort, miners and mineral processors were linked into single operations to provide the incentives to improve recovery of residuals. The success of this project indicates that training and education of miners may achieve similar results on a larger scale provided communication of pertinent information to miners is effective. For a broader impact, these efforts could be incorporated as a part of future educational programs that will be developed under the Special Regulatory Rules for ASGM, which have not been initiated.

Efforts are ongoing to build the International Training Center for Artisanal Miners (ITCAM) or Centro Internacional de Entrenamiento de Mineros Artesanales (CIEMA). This center will serve as a state-of-the-art gold processing center and educational facility for both Peruvian and Ecuadorian miners. The overarching goal is to use education and state-of-the-art technologies to improve environmental stewardship of the sector, increase profit margins, reduce poverty, and improve quality of life among miners and ASGM affected communities. Since this project is a collaborative effort between universities, the Ecuadorian Government, NGOs, other international organizations, larger industry, and artisanal and small-scale gold miners and since the project will be made possible through local coordination and leadership, it will serve as a hub for a global network dedicated to resolving ASGM impacts in Ecuador and more broadly. This incorporation of local leadership is identified as a critical factor of program success in previous studies of ASGM in other regions (Hilson, 2006).

Although education of miners is central to sector-wide improvements in ASGM, acquiring sufficient capital to support sustained programs is required. Without sustained funding, miners will not have access to the necessary equipment and training (Velásquez-López, 2010). Micro-financing through partnerships between miners and industry or micro-credit programs through government lending programs are unlikely to raise the necessary funds to support the necessary changes in production and gold recovery (Veiga, 2011). One of the defining features of this ITCAM project is that it will be fully operational, allowing it to generate revenues to support its mission through gold extraction. By having these educational and training programs coupled to government and NGO programs, while also generating revenue, the educational mission of the ITCAM will have sustained funding and trained personnel to help achieve long-term objectives.

Cross-scale and cross-level policy reform to address ASGM impacts

Since the impacts of ASGM differ across spatial, jurisdictional, and temporal scales and levels, there is an outstanding need to enable better coordination between communities and governmental organizations and across political boundaries. Previous research targeted towards understanding the impact of scale on policy making suggest having common responses to deal with scenarios is advantageous (Ostrom et al., 1999). Cash et al. (2006) discuss multiple cross-scale and cross-level policy mitigation approaches which could, over the long-term, be applied to help improve responses to ASGM and related impacts in Ecuador.

Co-management refers to arrangements that rely on sharing or distributing power and responsibility across governments and communities (Cash et al., 2006). In Portovelo-Zaruma, co-management between community groups and government organizations could be a viable way of managing the future ASGM waste-storage site since having both community and government stakeholders involved would add to the credibility and legitimacy of the selected management solution. To achieve the best dynamics between the government and community as a part of a co-management solution for addressing waste management, there are several factors that should be considered including: (1) building shared vision, leadership, and trust; (2) enabling legislation to create political opportunities; (3) monitoring the environment; (4) combining different kinds of knowledge; and (5) supporting collaborative learning (Olsson et al., 2004). Taking these factors into account is critical in a place such as Portovelo-Zaruma where communities have, for so long, been left out of the decision making process. Educational outreach programs (described in Section using information strategies to address ASGM cumulative impacts) are also likely to help support the success of this approach.

Situations can be perceived very differently across different levels. Therefore, addressing issues that span over multiple jurisdictions, such as the trans-boundary water pollution of the Puyango-Tumbes River, may sometimes be handled most efficiently through the creation of boundary organizations. These boundary organizations are developed to focus explicitly on playing an intermediary role in facilitating knowledge and agreements between two competing sides. By insuring there is a team working on assessing the water pollution and water quality issue that has accountability on both sides of the boundary, there is likely to be mutual trust and respect from both Peru and Ecuador which will enable more focused solutions. It is possible that existing organizations, such as the Comisión Técnica Binacional (Binational Technical Commission), could help serve this purpose; however, the organization will need resources and authority for decision making.

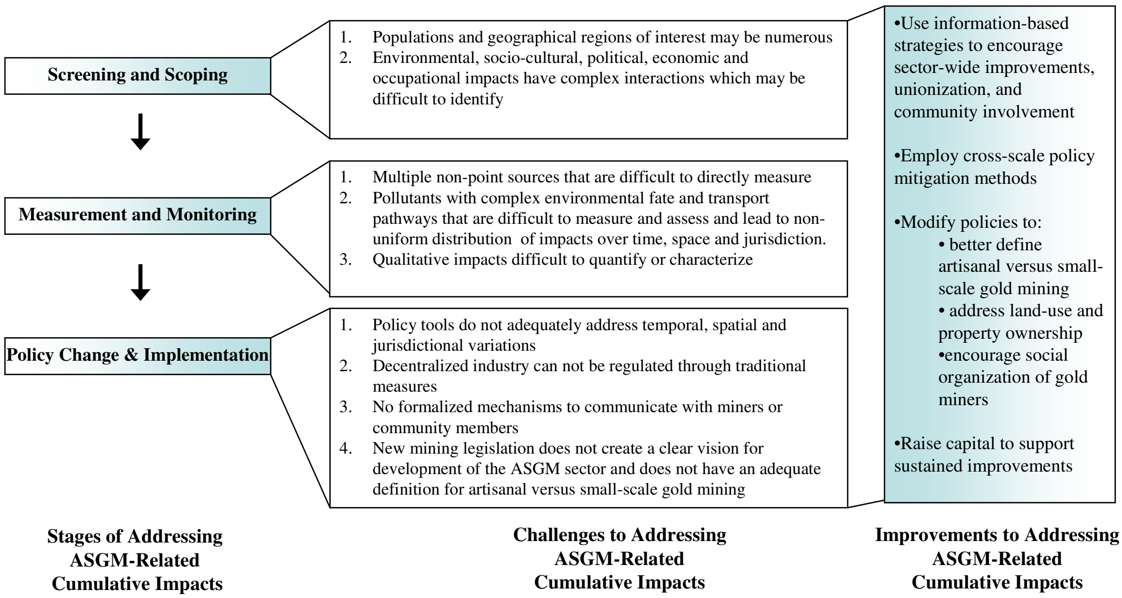

Fig. 2. Challenges and suggested improvements for addressing ASGM-related cumulative impacts at different stages.

Increased stakeholder participation is generally regarded as a helpful step in improving sustainability of mining operations (James, 1999; Labonne, 1999). Inclusion of cross-level and cross-scale stakeholder participation is credited with bringing about sector-wide improvements in other mining regions (NPRC, 2005; CEAA, 2011). Of course, the use of cross-scale and cross-level policy mitigation methods in combination with information-based strategies could be used jointly to help maximize the impact of collaboration between stakeholder groups to bring about sector-wide improvements in ASGM.

Conclusions

The cumulative impacts associated with ASGM are complex and present a variety of complications for measurement, surveillance and remediation (Fig. 2). Since ASGM-induced cumulative impacts are driven not only by existing mining and mineral resource policy but also by complex social factors including but not limited to poverty and lack of alternative economic opportunity, solutions will necessarily involve broad, systematic regulatory and social change driven through non-traditional policy tools. As such, significant improvements in assessing and reducing cumulative impacts associated with ASGM cannot be obtained without substantial efforts on behalf of government, regional or international bodies, and the scientific community to bridge critical information gaps, revisit the definitions of small-scale versus artisanal gold mining, and to provide new management strategies that will address problems over temporal, spatial, and jurisdictional scales. Furthermore, efforts to employ information-based strategies and cross-scale and cross-level policy mitigation methods have great potential to lead to sector-wide improvements and policy change. The success of these strategies is dependent on commitment of all stakeholders, sustainable funding mechanisms, and an understanding of ASGM and its complexities.

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