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Development of a site-specific system for the rehabilitation of legacy mines: The challenges of social, geological, hydrological, and biological data integration

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Abstract

Successful rehabilitation of legacy mines continues to be challenging due to the tensions between legal requirements, current practices, and host communities' aspirations. Previous rehabilitation efforts have often focused on technical and environmental aspects, leading to their narrow focus that usually creates resistance from the host community and, thus, are usually unsustainable. To address these issues, particularly the lack of community engagement, we developed the Biodiversity Positive Mining for The Net Zero Challenge (Bio+Mine) project, which focuses on the abandoned Sto. Niño copper mine (Tublay, Benguet, Philippines). Before undertaking site sampling, our Social Science Team embarked on an extensive community engagement program to secure permits from the local inhabitants and the associated administrative and regulatory units.

The relationships built in this process resulted in a wealth of historical data about the evolution of the post-mining landscape and the community's social structure, which enabled us to better target the baseline sampling campaign. A key aspect of our work is developing a pragmatic approach using a mixed methodology. We collected historical (document analysis) and socio-economic-demographic (interviews and surveys) information, including the community's views, perceptions, knowledge, and skills about mine rehabilitation. We have used and developed the social-ecological-technological system framework to examine the intersections of these data with geological (geochemical and mineralogical), biological (hyperaccumulator plants and earthworm diversity, DNA sequencing of soil and rhizosphere and water microbiomes), hydrological (water quality, pollutants, clean-up strategies), and remote sensing (drone) data. However, significant challenges have been encountered integrating social data into and with the geological/hydrological/biological data that describe the physical site. In this paper we explore the potential of Situational Analysis as method to rigorously analyse social data and integrate it with the geological/hydrological/biological datacube. A high-level challenge identified is the contrasting research paradigms between the social sciences and sciences which can lead to undervaluation of certain data types. More practical challenges are focused on the needs to preserve the anonymity of participants and the transformation of non-numerical data and contexts into the datacube. Our preliminary Situational Analysis mapping demonstrates that it is possible to achieve meaningful integration of the disparate data types generated by the project. This integration enables a more effective pathway for collaborative working with local communities to co-design site specific systems for legacy mine rehabilitation.

Keywords: *social characteristic, mine rehabilitation, site-specific system, multi-disciplinary approach*

1 Introduction

Each legacy mine represents a unique intersection of social, economic, and environmental parameters that demands site-specific rehabilitation strategies and implementation plans. Effective management of these sites necessitates effective characterisation of the hazards and specification of the risks posed by these materials longitudinally to achieve positive rehabilitation outcomes (Moyo et al. 2023; Proto et al. 2023). The failure to do this may result in ecosystem degradation, negative human health impacts, policy issues, financial risks and widespread distrust that has catalysed the formation of political movements in some parts of the world (Mills 2022). Whereas the methods for the comprehensive spatial parameterisation of the physiochemical characteristics of the waste, soil, sediments, rock, waters and landscapes to inform potential ecosystem responses are achievable (Kavehei 2022); the effective integration of social information with these data is both complex and elusive.

The mining process frequently results in the traumatic modification of the existing supporting ecosystem services, implicitly impacting the original and existing dependent ecological interactions of a land area (Ngungi et al. 2018). Thus, part of the social responsibility of rehabilitating a legacy mine is the intent to revert a post-mining area to a state deemed safe for alternate land uses such as agriculture, agroforestry, and leisure activities (Lima et al. 2016; Bennett et al. 2021; Tongway and Lugwig (2011). Government and private landowners are frequently left accountable for managing abandoned or orphaned legacy mines. This inherited responsibility can pose significant practical and reputational risks where these parties are committed to achieving future sustainability goals (Unger et al. 2015). Despite the increasing literature and evidence base, the unique nature of each legacy mine site means that there are no widely accepted guidelines for techniques and criteria to implement achievable rehabilitation programs (Erskine & Fletcher 2013). This has significant implications for formulating policies and supporting infrastructure for legacy mines where local communities redevelop/repurpose orphaned sites.

In this paper we present a possible method by which social science data from a local community can be integrated with hydrological/biological/geological data to produce datacubes to inform and monitor rehabilitation strategies. It is hoped that the described method will deliver a more holistic approach to the rehabilitation of an occupied legacy mine that places the social dimension at its centre.

1.1 The context of the study: the Bio+Mine project

The Biodiversity Positive Mining for the Net Zero Challenge Project (Bio+Mine) is a 3-year program focused on the former Sto. Niño copper mine situated in the Ambassador Barangay, Tublay Municipality in Benguet Province, Philippines (Figure 1). In year 1, the project assessed the current legacy issues, and in collaboration with the local community is co-devising/co-producing a programme of interventions that seek to mitigate against the identified legacy problems and potentially valorise problematic waste materials.

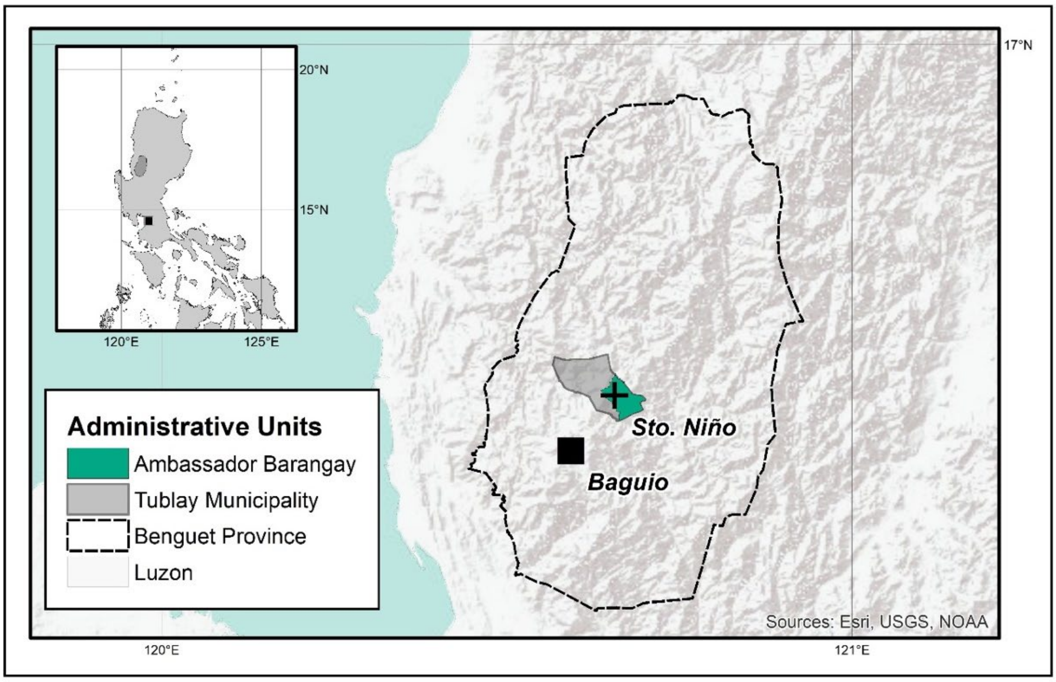

Figure 1 The inset map shows the position of the Sto. Niño mine site in respect to Luzon, Philippines. The main map shows the site's positioning within the administrative unit structure of Barangay, Municipality and Province

The baseline data (reported in Herrington et al. 2023) are used to inform and develop a strategy for the future reconstruction of functioning and sustainable ecosystems to support the local community's agricultural activities and the biodiversity of uncultivated land areas. The aspiration of the project is that these works will allow the development of a full-scale system of intervention (year 2 focus). A key element of this will be the formulation for the assessment and quantification of the natural capital of Sto. Niño. Ultimately, the project will develop site-specific strategies underpinned by the local community's knowledge, skills, and practices, with the potential for the knowledge gained to be deployed for other legacy mine sites in the Philippines. Year 3 of the project will focus on building capacity within the community to implement and sustain the co-produced site-specific strategies.

1.2 Questions

As outlined in the project's protocol paper (Alonzo et al., 2023), the overarching research questions of the project are:

1. What are the requirements (social, technical, and economic) that need to be met to ensure the development of successful biodiversity and human positive solutions in legacy mines?

2. How can the Sto. Niño mine site be explored as a natural laboratory to reconstruct the ecosystem, inform the development of sustainable nature-positive bioremediation strategies, and support ongoing agricultural activities by the local community?
3. How does the project ensure that interventions lead to positive outcomes and how are the impacts of the identified solutions quantified?

1.3 Theoretical framework

From the perspective of the social science element of Bio+Mine we required a theoretical framework with which to develop our methodology. The Social-Ecological-Technological Systems Framework (SETS) originates in Pickett et al.'s (2001) analysis of the linkages of ecology, physical and socio-economic environments in an urban setting and meets the project's needs. The embedding of ecosystem services as an integral part of the total system was formalised in the SETS framework for several urban systems where (S) socio-economic-demographic; (E) ecological; and (T) infrastructure, technical, and technological (Grimm et al., 2015; Depietri & McPhearson, 2017; Frantzeskaki et al., 2019). Previously, the SETS framework has been used with respect to Environmental and Social Impact assessments (ESIA) for mining project (Nilsson et al., 2021). The application of SETS to the Sto. Niño site is arguably even more appropriate than that of ESIA, as the site has a protracted history of a community reclaiming a total system not only in terms of its abandoned infrastructure but the use of the resulting ecosystem for socio-economic benefits. In developing SETS for Sto. Niño a key step for further data integration was the identification of the 5 main stakeholder groups, the people who live on or near the mine site; the individuals and organisations associated with the mining operation and abandonment; the local government and regulatory units; professional individuals and groups such as the police, teachers and researchers and; civil society groups such as NGOs and activist networks.

2 Methodology

2.1 Research design

We used the exploratory sequential, mixed-method design (Tashakkori & Teddlie, 2003). We started with the qualitative phase to explore the communities' views, beliefs, perceptions, aspirations, knowledge and skills about mining and rehabilitation of legacy mines. The qualitative analysis of these data was used to frame and develop a quantitative survey tool to assess if the wider community shared the views of the initial participants. In the final step, both the results of the qualitative and quantitative phases were integrated to address our research questions. This data was supplemented by the environmental data collected by the other Bio+Mine work packages reported in Herrington et al. (2023).

2.2 Ethical considerations and permissions

A vital tenet of Bio+Mine is that of working in collaboration with the local community. As the project is working with Indigenous Peoples (IPs) in the Philippines, it is obligatory to comply with requirements set by the Indigenous Knowledge Systems and Practices (IKSPs) and Customary Laws (CLs) Research and Documentation Guidelines of 2012. This is a national policy of the Philippines implemented by the National Commission on Indigenous Peoples (NCIP) to promote and protect the rights of Indigenous Cultural Communities/Indigenous Peoples (ICCs/IPs). The project received ethical approval from the NCIP regional office in Benguet and the University of Mindanao (UMERC-2022-289).

2.3 Study setting

The Sto. Niño mine sites sits immediately to the south of the town of Ambassador, the Barangay's administrative centre. Physio-geographically, it is in the steep-sided valley that runs to the south within terrain typical of Northern Luzon's Cordillera Central mountain range. The recorded mining history of the area includes claims documented from 1907, with the larger-scale mining operations taking place from 1972 to 1981. The mining of the latter period exploited two ore bodies: the Southwest ore body, which was exploited by an open pit operation, and the Northeast ore body that utilised an underground block cave operation. The primary commodity produced was copper, with some credits of gold and molybdenum (MGB, 2010). The majority of the comminution infrastructure and thickeners are located proximal to the Northern limits of the open pit operation (Figure 2), with a tunnel used to transport waste to a tailings storage facility to the north. A significant volume of non-milled waste was placed in a series of dumps to the south of the original pit. The site was abandoned in 1982, and since then, the area has been used by the local community, who have established domestic dwellings and subsistence and cash crop agricultural plots in and around the open pit and mine dumps. The Sto. Niño area has been subject to frequent landslip events caused by typhoons or seismic activity on both the non-mined and mined landscapes. The footprint of the mine and the local agriculture, stands of the primary undisturbed ecosystem are still present on steeper grounds. For more than four decades, no comprehensive rehabilitation programme was implemented despite the significant post mining hazards.

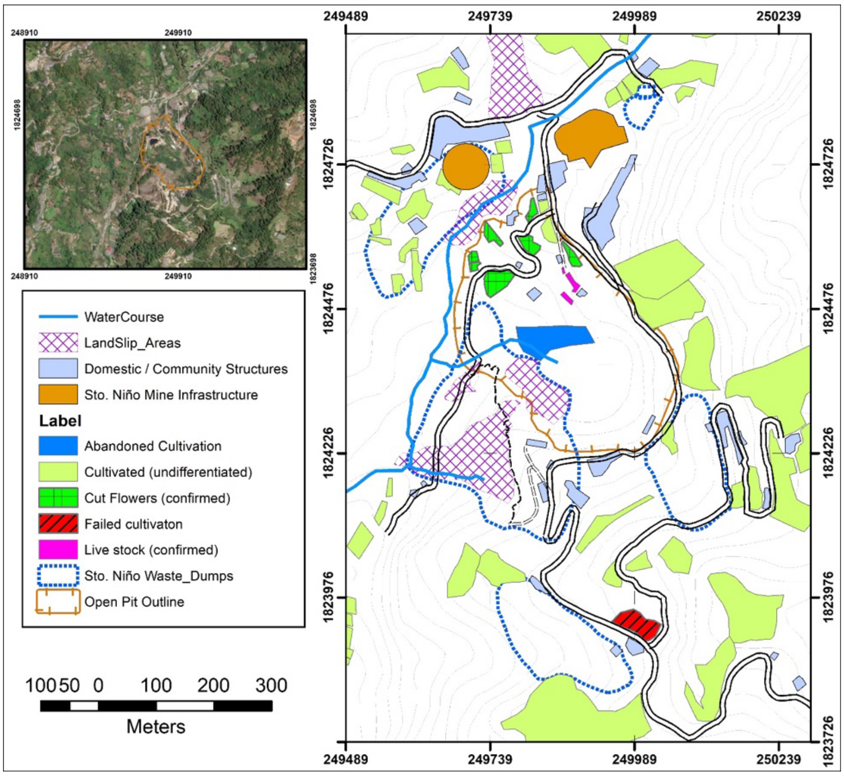

Figure 2 A preliminary sketch map of the central Sto. Niño Mine site illustrating the distribution of the original mine workings, mine infrastructure and post-mining land use

The interpretation of the map is based on image interpretation and field-based observations. The area of Failed Cultivation refers to a previously rehabilitated area for future agriculture that has failed to thrive. The identified livestock areas consist of structures built upon previous mine benches.

2.4 Participants

The project team interviewed a total of 44 individuals (men = 9, women =11, out-of-school youth = 1, people with disability = 3, small-scale miners = 3, LGU = 6, IP leaders =5, professional groups = 6), with the survey questionnaire being returned by 381 individuals (men = 126, women =131, high school. students = 34, out-of-school youth = 20, people with disability = 2, small scale miners = 12, LGU = 22, IP leaders = 9, professional groups = 25). The categories used reflect the complexity encountered in terms of occupation, status and recognition within the IP community and the wider administrative infrastructure. The categories men and women are used to identify people external to the other categories. The category “small scale mining worker” refers to individuals currently engaged in small-scale artisanal mining in the area. IP leaders are individuals recognised as "Elders" by the community. The data collection focused on the broad themes outlined in section 2.1. In addition, questions were iteratively refined with further contextual questions as the other science-focused teams moved across the site. These questions focused on the unwritten history of the site relating, for example to the decision to grow cut flowers as opposed to food crops in particular areas, the timing and cause of landslips on the mine dumps and the valley sides, and the targeting of artisanal mining activity.

2.5 Individual interview

Semi-structured interviews were used to allow for open conversation to gain in-depth information (Bryman, 2016). Using the interview guide as topic prompts (Alonzo et al., 2023), an individual's view around the themes outlined was explored. These were organised under the topics of People, Culture, Goals, Technology, Infrastructure and Ecology. All interviews were audio-record and transcribed. The transcribed data were anonymised to remove all information that might identify the individual participant.

2.6 Survey

The data resulting from the interviews was used to construct and refine a survey tool. The Survey tool development followed both theoretical (DeVellis, 2003) and empirical approaches (Worthington & Wittaker, 2006). The theoretical approach allowed the construction of individual items from the thematic analysis of the interview data. The tool was then validated by three experts, ensuring that it effectively measured the intended information. The empirical approach investigated the tool's reliability (α =.97) and factor structure. The questionnaire comprised of two broad sections, part 1 collected demographic information about the participant. The second part consisted of a series of scaled responses where participants were asked to score the importance of the presented statement and their confidence in their response. The areas of part 2 corresponded to the theme and topic areas identified in the Semi-Structured Interviews. The final section of part 2 of the questionnaire consisted of 6 questions targeted towards administrative officials.

2.7 Approach to data analysis

Seeking a method of data analysis that allows the holistic investigation of disparate data types is challenging. The data analysis must be capable of preserving the context of the data whilst allowing the direct exploration of the relationships and dependencies that may exist between the social, ecological, and technological domains. As a physical entity, a mine-site can be quantified across geological, biological, and hydrological domains by spatially attributed samples of rocks, soils, waters, biota and remote-sensing data. An initial difficulty that researchers and practitioners must overcome is interpolating discrete point data (geological and biological samples) with continuous data delivered by remote sensing platforms (drones and satellites). Hydrological parameters illustrate the need for the inclusion of a temporal dimension in any site characterisation. i.e., variations in oxygenation, pH, flow rate and chemistry across the seasons.

Although complex, the relationships, dependencies, and ecological interactions can be explored across these multidisciplinary datasets. Whereas some relationships may directly reflect biophysical necessity or adaptation, for example acidophile prokaryotes and low pH (Quatrini & Johnson, 2018) or the fern *Pteris vittata* as an arsenic- hyperaccumulator (Xie et al., 2009), other data sources offer the opportunity to extend point data knowledge into continuous spatial data sets, for example, plant species mapping via automated drone imagery interpretation (Kattenborn et al., 2019).

Geographical Information Systems (GIS) enable the researcher to overlay these data types in space, thus allowing geospatial analytical methods to be applied. Ultimately, these parameters will be integrated into a datacube, a multi-dimensional array of values, that allows the description and analysis of the Sto. Niño site (Figure 3). Datacubes are now relatively commonplace in exploration geology where they facilitate the integration of geophysical, geochemical, mineralogical and remote sensing data as part of the geological model development for an area or region (Abedi & Norouzi, 2012; Piippo et al., 2022; Data et al. - Open Geospatial Consortium (ogc.org)). Well constrained and populated datacubes are essential for the future deployment of digital twins of mine sites undergoing rehabilitation (Hazrathosseini & Afrapol, 2023). However, integrating the data from social science studies is not easily incorporated into such datacubes.

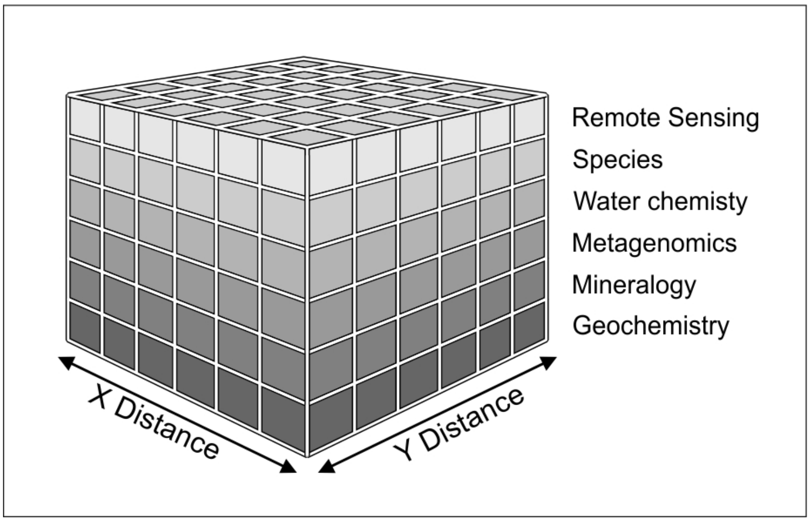

Figure 3 A conceptual illustration of Sto. Niño datacube that is registered in space from the perspective of empirical environmental values

Variables that are acknowledged but not illustrated in the figure are those of altitude (Z) and time (seasonality). Spatially attributed demographic data can be included as a parameter; however, this data may allow the identification of individuals. The datacube concept allows for the inclusion of models, which in this case may include relationships between actors and actants, for example access to 'safe' water.

Several facets and conditions of the social science data make integration with science data challenging; for example, the fundamental contrast in research paradigms, the use of qualitative data (semi-structured interviews), and the requirement for anonymity, which precludes presentation of spatial data that allows individuals/family units to be identified. Therefore, a method of data analysis is required to analyse quantitative and qualitative social science data rigorously. Additionally, the analysis method must address the inherent subjectivity of not just the source data, the views of the interviewee but the potential subjectivity of the analyst's method. Grounded Theory is a method of data analysis that seeks to empirically assess qualitative data using "coding" and inductive reasoning (Bryant, 2009; Glaser, 2007). The methodology does not restrict itself to specific data types but considers everything as data, including associated quantitative data such as demographic data (Glaser, 1998; Chun Tie et al., 2019). Situational Analysis (SA) (Clarke, 2005) is a method that has evolved from the Grounded Theory Method (GTM). Previously, SA has been deployed across complex interdisciplinary settings addressing public health systems (Martin et al., 2016), pollutant biomonitoring in humans (Washburn, 2013), environmental activists use of scientific data (Fähnrich, 2018), and integrative conservation for biosphere reserve in Mexico (Alonso-Yanez et al., 2016).

SA enables the researcher to capture the heterogeneous and complex nature of a social environment and its intersection with the physical environment. The methodology has several features that are useful in analysing the Sto. Niño namely:

- The understanding that the context or conditions are a part of the situation under examination (Mathar, 2008); i.e., the contained contexts are not separate to the situation but are an intrinsic part of the overall Situation (Clarke & Friess, 2007).
- The consideration of the individual and collective actors, physical, legislative, and discourse actants within a system, and the 'mapping' of these elements to each other. These are termed "Situational Maps" (Clarke et al., 2018)

- The analysis of the interplay of the social worlds and arenas present, where social worlds are defined as where collectives share a common discourse / world view and social arenas are representative of the larger system encompassing where the identified social worlds will intersect (Clarke et al, 2018).
- The generation of positional maps where the sites of stated and non-stated positions are identified (Clarke et al, 2018).

The identification of the actors and the actants, and the interplay of these is key to the process and is exemplified by the categories suggested by Clarke and Friese (2007, p.375). A significant characteristic across the categories, is whether the actor/actant is human/non-human and has recognition and/or is visible to the individual actors. This can be considered as influences or controls that an individual does not directly experience but are active in the system. The concept of an actor/actant being “implicated” in the social world/social area builds on this notion of direct visibility. These can be considered actors/actants that are only discursively present or silenced (Clarke et al., 2018, p76). Conceptually this is important for the Sto. Niño system as it allows the generation of theory describing the relative power present in the social world / social arena. The process of centring a map around a specific actor or actant allows the relationships and discourses to be examined for a specific actor/actant with respect to the other actors/actants and gauge the relative importance of that relationship to the actors/actants' existence. This process is iterative, with multiple “Situational Maps” generated from the viewpoint of each key actors/actants. The relationships and interactions generated from the Situational Maps allow the identification of the discrete Social World's within the system and where commonalities or adjacencies exist. Once assembled, the larger Social Arenas can be compiled where the smaller Social Worlds intersect (Mathar, 2008). The final mapping stage of SA is positional maps, where the perspectives of the differing collectives present in the situation can be assessed. Clarke et al’s (2018) assertion that these positional maps should not include individuals or groups appears somewhat counterintuitive, though these positions should emerge from the situational map. This separation of actors from positions allows the identification of drivers that may evolve within in changing system, such as a rehabilitation programme. An identified potential benefit of SA positional maps in the context of the Sto. Niño programme is the derived anonymity of specific individuals and groups.

The theory and models derived from SA of the Sto. Niño social data will inherently address the physio-chemical-biological dimensions of the site as non-human actants, temporal elements and spatial elements. These models can then be further integrated into the datacube or considered in parallel for generating coherent strategy and policy decisions.

3 Preliminary deployment of situational analysis at Sto. Niño

For illustrative purposes we will focus on the collective human actor of Family Units who Farm (FUWF). This preliminary SA will take the process through to Social World Maps and a discuss an example of a positional map.

3.1 Identification of actors, actants and discourses at Sto. Niño

The adoption of the SETS theoretical framework, in addition to the approval processes (see section 2.2), identifies several key sets of individual, group and non-human actors and actants at Sto. Niño. As the field sampling progressed, refinements and additions could be made to these categories. This was largely informed by the interviews, the survey tool and incidental engagement with the community by the Bio+Mine project team “on the ground”. Additional insights arose from the reflections of the field workers as they completed the field work. A particularly valuable data source was the exchange of oral histories detailing the development of the site and events effecting the site as written sources are limited. The collation of the actors, actants, discourses and elements in play at Sto. Niño, as derived from “Messy Maps” is presented in Figure 4.

Individual Human Elements/Actors	Nonhuman Elements/Actants	Collective Human Elements/Actors	Implicated/Silent Actors/Actants
• Local inhabitants • Farmers • IP leaders • Church leaders • Local consultants • Researchers • Municipal Mayor • Barangay Captain • Cooperative leaders • Teachers • Health professionals	• Geosphere, Hydrosphere & Biosphere • Transport infrastructure • Livestock and Crops • Basic public services • Mine infrastructures • Access to knowledge • Technology • Power supply • Access to knowledge • Job opportunities	• Families • Research institutions • Regulatory bodies • Council of Elders • LGU/BLGU • Associations and cooperatives • Media • Political parties • SMEs • NCIP	• Children • Bodies of Water • Terrain • Agriculture • Potential eco-tourism • Farm to market road • Weather and climate • Resources • Displaced workers • Plant and animal health • Topography

Discursive Constructions of Human Actors	Discursive Constructions of Nonhuman Actors
• Support for small-scale mining activities • Influence of IP leaders versus political leaders • Stereotypes of researchers • Influences of regulatory bodies • Community's attachment to the land • Community's adoption of new practices • External activism	Concepts and understanding of: • Rehabilitation • Biodiversity • Ecosystem activities • Water quality and availability • Landscape stability

Political/Economic Elements	Sociocultural/Symbolic Elements	Temporal Elements	Spatial Elements
• NCIP legislation • Environmental and natural resources legislation • Government system and hierarchy • Community/project agreements • Economic conditions • Tenancy agreement	• IP rituals and practices • Religious organisations • Political history • Local dialects and ethnicity • Gender roles • Migration pattern of IP groups • Social dynamics	• Mine closure • Disasters (typhoon, earthquake, landslides, extreme temperatures) • Economic conditions • Seasons • Legislations • Mining legacies • Power Supply	• Land use • Agricultural infrastructure • Mine infrastructure • Transport infrastructure • Built environment • Geosphere • Hydrosphere • Biosphere

Major Issues/Debates (Usually Contested)	Related Discourses (Historical, Narrative, and/or Visual)
• Water and soil quality • Outsiders are involved • Land stability and mitigation • The Middlemen/Gatekeepers • Rehabilitation strategies • Indigenous knowledge/beliefs versus outside knowledge/beliefs	• People's connection to their land • Perception of mining • New business opportunities • Rehabilitation versus restoration versus non-intervention • Agricultural productivity

Other kinds of Elements *As found in the situation*
• Opening of the mine • Closure of the mine • Scientific attention to mine site rehabilitation • Environmental legislation

Figure 4. A simplified Ordered Situational Map for the Sto. Niño site This represents an earlier simplified of the in-depth Situational Map derived from the Bio+Mine Field campaign

These situated maps demonstrate multiple actors and actants at the Sto. Niño site. However, significant human and non-human actors/ actants though influential on the community and the site, are not geographically present within the site; therefore, their degree of visibility to the community is uncertain. The geological, biological, and hydrological domains fall into the non-human actants categories and have various levels of visibility to the human actants. This is exemplified by concerns expressed in the water use and land use discourses.

3.2 Situating family units who farm: initial situational analysis

The FUWH represents a key stakeholder collective for the site as they are the most impacted by the existing legacy and any future rehabilitation strategy/implementation. Figure 5 represents a "Relational Analysis Map" where the FUHF perspective is centred. These human actors include other family units and the local "decision makers" for both practical and spiritual matters, for example, local officials of the BLGUs, IP leaders and elders, and church leaders. Sources of knowledge that relate to / influence the family unit include community knowledge, the media, project researchers and local consultants. The individual and collective human actors of the regulatory bodies (i.e., National Commission on Indigenous Peoples, Department of

Environment and Natural Resources, Department of Agriculture) are less spatially associated and potentially less visible to the community.

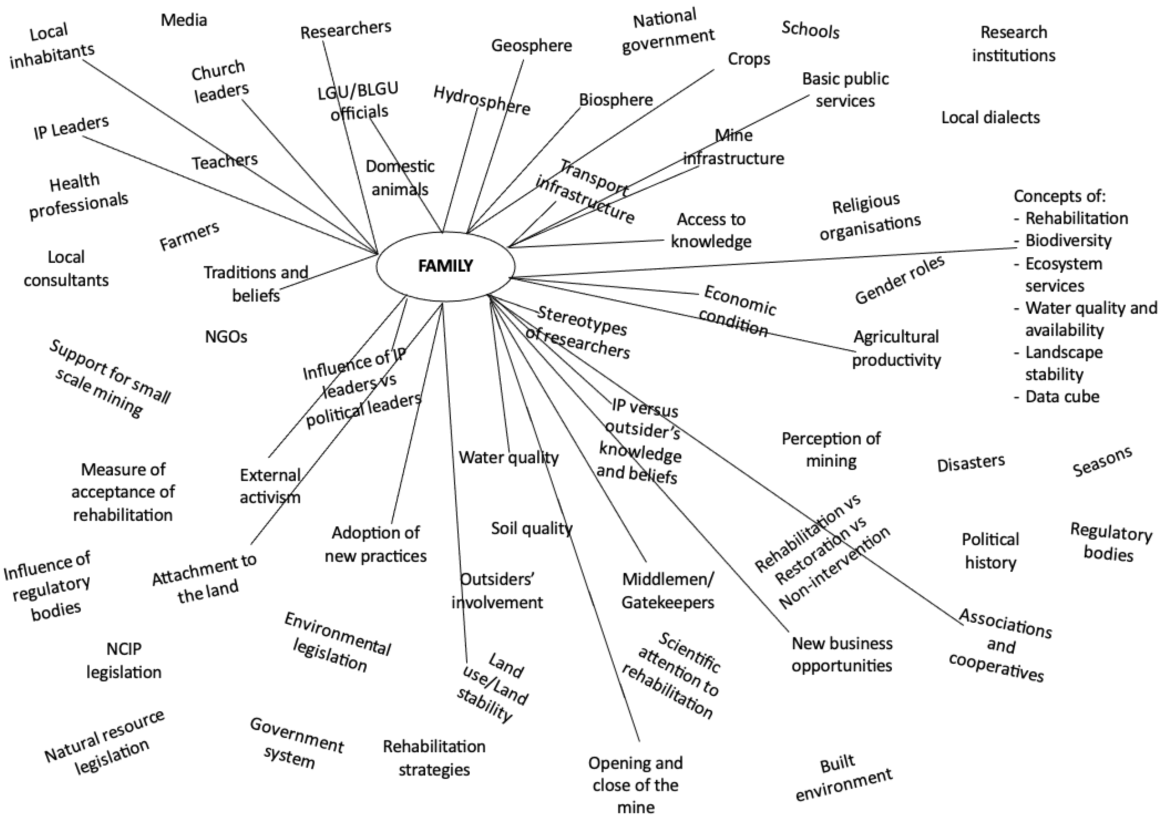

Figure 5. Preliminary Relational analysis based on a 'Messy Situational Map' on rehabilitating the Sto. Niño legacy mine. In this map, the relationships are plotted from the perspective of the family unit

The connection with non-human actants within the Sto. Niño site have varying degrees of spatial and temporal influence. These include public transport, road access, education, crops, water, soil, and job opportunities. The silent actors in the site include the power supply, geological formations, the mineralization, the indigenous flora and fauna (non-disturbed biodiversity). The FUWF are influenced by discourses on many issues, including competing views about mining, the role of IP leaders and BLG. A significant discourse for the project is the perceived lack of commitment of researchers to deliver their target outcomes, the influence of external activism, and the enthusiasm of the community for rehabilitation activities. Discourses relating to non-human actors appear variably influential for the FUWF. These include the availability of safe water, the need for scientific investigation/intervention to use the land and other resources available, farming practices, and threats to the transmission of indigenous knowledge and practices down the generations. Building on the "Relational Analysis Map" (Figure 5), initial Social World maps can be constructed to examine how the FUWF is situated and relates to the community at the local scale and the regional/national scale. In the first iteration (Figure 6) the non-human actants that represent the physical nature of the site are purposefully omitted. This in part to further understand the social structure and interactions that are present and develop an understanding of the relationships and the power balance of the interactions.

The interrogation of the interview and survey data indicate that FUWF are strongly patriarchal, where the husbands are the key income earners via farming activities. The wives run the household as well contributing to farming activities. There is an expectation that the family's children will also assist in the farming activity.

The farm is a family enterprise and frequently multi-generational with all individuals contributing. A degree of variability exists across the FUWF, for example, family elders residing in the household, and what is the family's tenure to the land they farm. The family unit exists in the broader community alongside other family units and other actors/actants that influence their farming enterprises, such as the farmers' cooperatives, IP leaders and middlemen. The visibility of the administrative units, Local Government Units, and other regulatory bodies directly or indirectly influence the family's activities, with the degree of perceived influence to some extent being a function of proximity to the family unit/community. Outside the community, there are human actors that are present occasionally; the research institutions, researchers, funding agencies, and consultants whose presence can influence all three domains. They either enhance or disrupt their views, beliefs, societal norms, knowledge, skills, and practices by introducing new knowledge, skills and farming methods, financial assistance, partnerships, and possibilities.

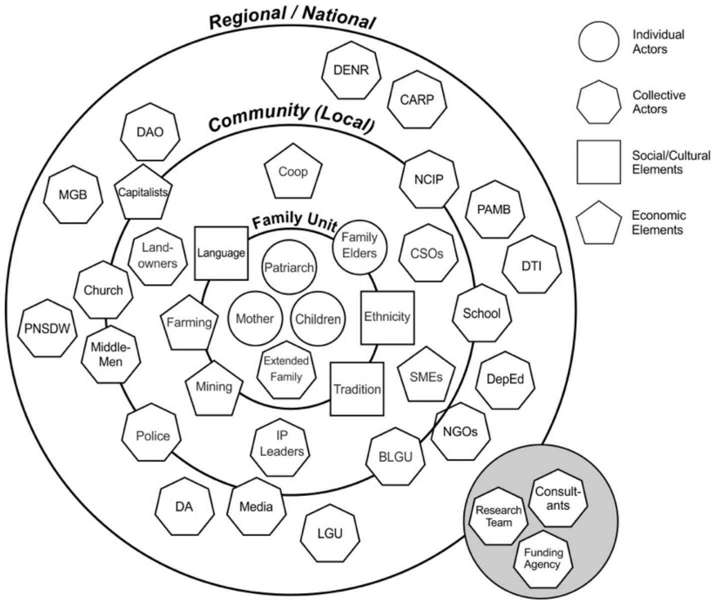

Figure 6 An initial Social World map/ecogram from the perspective of the family unit who farm

In this diagram, the social world is organised into domains of proximity: the family unit, the local community and the regional/national domain. Additionally, the project actors are presented. Note that the non-human actants of reflecting the physical site are not presented. Some actors and elements are positioned as traversing the domains, indicating that those actors/elements are not clearly assigned to one domain. A key function of this social world map is to understand from the semi-structured interviews and the survey tool data the visibility of an actor/element to the family unit. This will contribute to developing an understanding of the power balance embedded in the relationship present.

3.3 Incorporating situated social data in the Sto. Niño datacube

The situational maps and social world maps are not spatially constrained in a way that allows straightforward integration in the project datacube as they frequently describe social constructs. The final mapping stage of Situational Analysis is that of Positional maps, which separate actors and actants from the positions held within the system. An example from Sto. Niño relates to the access of FUWF to safe water. Two immediate positions that are emergent here are the quality and reliability of water sources versus protecting water sources from human activities such as domestic sewerage and agricultural run-off. In both positions, the spatially controlled scientific data provides information for the community to make informed decisions. However, other spatial elements are in play, for example, land ownership/tenure of water sources and the informal infrastructure used to move water from source to usage point around Sto. Niño. The latter introduces an additional level of spatial complexity in that the spatial adjacencies are disrupted by human intervention. As Clarke et al. (2018) allude to, each position has variable intensities, which can be cast relative numerical scales for the purposes for incorporation into the datacube. For this work, these can be informally termed as the social tensors within the project's datacube.

4 Conclusions

The development of rehabilitation strategies co-produced with the communities living there requires multi-disciplinary data. The first year of the Bio+Mine project demonstrated that the social sciences provide valuable insights that allow further contextualization of ecological, hydrological, and geological data that physically describes the Sto. Niño legacy mine site. However, the contrasting nature of these data types poses significant challenges in terms of data integration.

4.1 The challenge of contrasting research paradigms

Differences in philosophical orientations and contrasting ontological perspectives of the Sto. Niño datasets pose significant challenges to their integration. The social data and analysis seek to understand the social constructions that are the Sto. Niño communities' experience of rehabilitation. This social construction is not fixed and is influenced by many internal and external factors such as subjective experiences, knowledge, and cultural norms. In contrast, technical data are often considered to have an objective existence and operate according to natural laws. Therefore, significant epistemological differences exist; where the social data seeks to explain people's experiences the technical data seeks to describe and quantify the bio-physical environment that constitutes Sto. Niño site. Thus, a purely logical positivist approach to developing the datacube is inappropriate as applying natural science principles to explain social causation and relationships does not adequately capture the subjectivity of the communities' experiences.

The multi-disciplinary nature of the Bio+Mine research team brought together researchers from positivist and pragmatist approaches. The tensions between these contrasting theoretical orientations were exemplified by our attempt to embed qualitative data from the interviews as opposed to pursuing purely quantitative survey tool that could be statistically interrogated. The resulting qualitative data provided a more nuanced understanding of the variations present in the communities' dispositions, knowledge, and skills regarding the historical, current, and future rehabilitation of the site. This enhanced understanding of the community provides an additional framing of the quantitative environmental data that describes the Sto. Niño site.

4.2 The addressing challenges of incorporation of social data into quantitative datacubes

The social data generated in the Bio+Mine project consists of qualitative data derived from semi-structured interviews and interactions with the community at site, and demographic and scaled questionnaire responses from the survey tool. The nature of this data presents two significant challenges to integration with a quantitative datacube.

Firstly, ethical compliance requires that no individual can be externally identified from data placed in the public domain i.e., the data must be anonymised. Therefore, the use of spatially attributed social data is challenging as individuals can be identified by their physical address yet the individuals' experiences and relation to the physical entity of the site are dominated by their location. For example, in the limited geographical of the Sto. Niño site even the simplest spatial plotting of demographic categories maybe problematic. Secondly, qualitative data that frames the social constructs and experiences is language based and subjective. Therefore, it is not readily machine readable within the confines of datacube. Yet the nuances captured by this data are important to developing informed rehabilitation strategies for Sto. Niño site.

4.3 The potential of situational analysis

The adoption of Situational Analysis with its foundations in Grounded Theory allows the rigorous analysis of multiple types of social science data. The SA's generation of non-spatially attributed maps that reveal and describe both the social and physical interactions and dependencies of individuals and collectives with the physical attributes of the site. The initial development Situational and Social Arena maps allow the generation of numerous Positional Maps that capture the intensity of these interactions and dependencies. These positional intensities are amenable to transformation to categorical data which may be incorporated into the datacube for further analysis alongside the geological, hydrological, and biological data. Situational Analysis therefore has potential as a method for the effective integration of Social Science and Environment Data to allow further develop of SETS theoretical framework for the development, implementation, and monitoring of mine site rehabilitation strategies.

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