DISSERTATION

HEALTH-LIVELIHOODS-ENVIRONMENT INTERACTIONS: HEALTH AND CULTURE IN LIVELIHOOD DECISION-MAKING AND CONSEQUENCES FOR THE ENVIRONMENT IN INDONESIA

Submitted by

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ABSTRACT

HEALTH-LIVELIHOODS-ENVIRONMENT INTERACTIONS: HEALTH AND CULTURE IN LIVELIHOOD DECISION-MAKING AND CONSEQUENCES FOR THE ENVIRONMENT IN INDONESIA

This research examines the role of perceived health status in the livelihood decision-making of rural households and associated impact on the environment. I drew on three social-ecological frameworks to conceptualize relationships between health, livelihoods, and environment. The primary hypothesis examined is that changes in health status result in livelihood strategies that depend on increased natural resource extraction.

Qualitative and quantitative data were collected in twelve villages of the Dumoga Valley, North Sulawesi, Indonesia from 2015 to 2016. These data were used to develop an agent-based model that acts as an experimental context to examine health-livelihood-environment over a longer timeframe than was captured through field data collection.

Illegal, artisanal gold mining is the primary resource extraction activity included in livelihood strategies. A surprising effect identified in qualitative data analysis was that different ethnic groups in the study site display different responses to health status change and have distinct livelihood strategies. Quantitative data analysis demonstrates a relationship between landlessness and engagement in illegal gold mining, but no relationship between mining and health. Dynamics in the agent-based model suggest that health does affect both the number of miners and amount of land cleared. In addition, the model suggests that natural resources play an important role in short-term livelihood strategies developed in times of ill health.

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1.1 Introduction

Natural resources and ecosystem services are foundational components of human well-being and livelihoods (Chapin & Kofinas, 2009; Díaz et al., 2018; MEA, 2005; Heather Tallis, Guerry, & Daily, 2013). The purpose of this research is to analyze the relationship between health, a component of human well-being, and household engagement in natural resource extraction. In this study, health is measured in terms of occurrence of illness that are subjectively categorized as mild to severe by participants. This study focuses on detecting whether changes in health moderate the livelihood pathway linking health and well-being to ecosystems using qualitative interviews, quantitative surveys, and simulation modeling. It examines whether changes to a household's health condition results in changes to human decision-making related to natural resources exploitation as part of a household's livelihood strategy. The primary hypothesis guiding this research is decreases in health condition at the household level increase reliance on livelihood strategies that rely on natural resource extraction. This study tests specific contextual factors that are hypothesized, in various literatures, to influence interactions between health, livelihoods, and natural resources. Quantitative data are used to test the hypothesis that there are socio-demographic factors such as household size, age and education associated with inclusion of extractive natural resource activities in a livelihood strategy.

I employ a social-ecological systems approach and use multiple methods to understand the context and nature of this relationship in an agricultural community comprised of 54 number of different ethnically homogenous villages in Indonesia. An ancillary goal of this research is to demonstrate a method to develop a new conceptual model that brings together lessons from multiple disciplines including medical anthropology, political economy, ecosystem ecology, and biodiversity conservation for empirical analysis of a practical issue.

Ensuring human well-being and sustainable livelihoods requires sustainable management of natural resources and conservation of biodiversity. Striking a balance between maintenance of ecosystem function carried out by a biophysical system and resource exploitation by a social system has spurred the development of the concept of the social-ecological system (SES). In SES research, human-environment interactions are complex, non-linear and operate at different temporal and spatial scales (Preiser, Biggs, De Vos, & Folke, 2018; Smith et al., 2007; Walker, Holling, Carpenter, & Kinzig, 2004).

Although our understanding of complex dynamics that influence human-environment interactions has grown rapidly over the past half century, many questions remain. The term "wicked problems" (Balint, Stewart, & Desai, 2011) has been used to describe issues that arise in SESs. Wicked problems are perpetuated by the dynamic and complex nature of systems in which there are nested problems, each with their own, potentially conflicting, desired outcomes. They require that challenges are managed constantly rather than solved definitively. To this end, an SES framework takes different perspectives on complex issues. Each perspective sheds light on various components of the wicked problem and asks different questions about the system in question.

Approaches to managing wicked problems generally espouse involvement of interested parties in a process that identifies outcomes and tradeoffs of actions. Simulation modeling is one technique used to facilitate this type of management. Advances in computational power allow researchers to develop various models that can simulate outcomes of decision-making processes. However, parameters included in models, for example, agents that are considered and the processes that describe their behaviors, can be stronger if based on empirical observations, such as those presented here.

Aside from direct benefits of nature such as breathable air, drinkable water and the mental health benefits of exposure to nature, livelihoods represent the primary pathway linking human health and well-being to nature. In the next section I review the literature on social-ecological systems frameworks and link them to health-environment framings. I develop a conceptual model that is the frame for the research to follow.

1.2 Literature Review of Social Ecological Frameworks and Health-Environment Framings

I draw concepts from several SES frameworks to develop a conceptual framework to guide this research. Many different frameworks have been employed to analyze SES depending on the subject system and the questions being addressed. The diversity of frameworks allow researchers to select a framework that is best suited to link essential components of the SES of interest (Binder, Hinkel, Bots, & Pahl-Wostl, 2013; Scholz, 2011). The epistemological orientation of different SES frameworks is informed by its disciplinary origin. They vary in terms of conceptualization of human systems, environmental systems and the relationships between them.

The *Sustainable Livelihood Approach* (SLA, Scoones, 1998, 2009) contributes the concept that household livelihood decisions take place within nested vulnerability contexts. The SLA does not provide structure for analyzing vulnerability context, so I draw on the Vulnerability framework (Turner, Kasperson, et al., 2003) to which I add the concepts of learning and human agency drawn from the Human Environmental System (HES, Scholz & Binder, 2003). This section describes these frameworks and the conceptual model that I develop from them.

1.2.1 Social-ecological systems

Social-ecological systems (SESs) frameworks emerged to structure interdisciplinary thinking about complex issues. SESs are one type of complex system, the analysis of which requires consideration of more than the interactions of component parts. For example, application of SES frameworks to examine both social and economic institutions as well as their interactions with one another and the environment. SE has provided new insight into use of common pool resources (humans extracting natural resources) that previous economic or sociological approaches lacked. Ostrom (2009) developed an SES framework that helped understand underlying structures that influence sustainability of common pool resources.

Social-ecological system (SES) thinking builds upon the tenets of complex systems and incorporates concepts developed in disciplinary studies of both human social systems and ecological systems. Cilliers et al. (2013) summarize the features that distinguish complex systems. They are composed of many interacting parts and the interactions between parts are characterized as non-linear, short-range (meaning direct influence occurs between immediate neighbors and not with all parts simultaneously) and offer the potential for feedback mechanisms. They are open systems with boundaries that are permeable. Social influences, policies, changing climate, pollution and other system components can flow between the target system and other scales of the system. Complex systems are not in equilibrium but are constantly adapting to stimuli to retain core functional attributes of the system. The final characteristic of complex systems is that individual interactions between components lead to the emergence of system-wide phenomena that are not observed in any isolated interaction. The brain is an example of a complex system that exemplifies this phenomenon. Individual interactions between neurons cannot be aggregated to predict the emergence of thought. Thought emerges as a characteristic of the entire system.

The concepts of non-linearity and emergence present in complex systems provides the foundations for a developing an approach to science that draws from knowledge generated through reductionist experiments, but “does not expect disproof by experiment and ultimate agreement by the scientific community” (Abel, 1998, p. 7). Complex systems research necessitates an interdisciplinary approach and facilitates discourse across disciplines about a common topic with the understanding that each disciplinary perspective remains valid.

One of the major contributions of ecology theory to social-ecological systems thinking is the idea of emergence, or the concept that dynamics observed at one level of aggregation do not predict dynamics observed at other scales (Schlüter et al., 2019). In the natural world, vegetation communities demonstrate resilience dynamics that are distinct from the resilience of individual component species. Extant research on health-poverty, health-environment and environment-poverty interactions frequently does not embrace complex interactions that yield very different patterns at different levels of resolution. Even though these disciplinary approaches (health-poverty, health-environment and environment-poverty interactions) have formed the basis of knowledge about human-poverty-environment interaction, new epistemologies and technologies are empowering researchers to tackle complexity and gain new insights about the interactions between poverty, environment and human health.

1.2.2 Sustainable Livelihoods Approach

The SLA, from which I borrow the concept of livelihood decision-making taking place in a vulnerability context, forms the core of my approach. The SLA conceptualizes livelihood generation as a key interaction between human systems and environmental systems. Poverty elimination through achievement of socially, economically, and environmentally sustainable livelihoods is a fundamental tenet of the United Nations' Sustainable Development Goals (UN, 2020) as well as the activities of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES, Díaz et al., 2015).

Livelihoods research has traditionally been the domain of development researchers and rural sociologists. As such, it evolved to understand smallholder agricultural societies and frequently takes an economic or institutional perspective. Early livelihoods research assumed limited livelihood resources, which facilitated an economic or institutional approach. We now understand that many smallholders diversify livelihoods as a source of resilience to income and other changes in economic well-being, which are referred to as shocks (Wunder, Angelsen, & Belcher, 2014).

SLA (Ashley & Carney, 1999; Scoones, 1998) was used to guide collection of household data and conceptualize livelihoods and wealth in poverty reduction efforts. The approach takes a bottom-up view of the creation and modification of household livelihood. Household assets are building blocks of livelihood strategy choices that occur within a vulnerability context and are facilitated through transformative structures and processes with the goal of achieving livelihood outcomes (such as income, health, and well-being). Each of these components is discussed below.

SLA evaluates household livelihood in terms of five sources of capital. Household needs are met by exchanging sources of capital between categories. Human dependence on natural resources is incorporated as natural capital into household asset evaluation. Wage labor can be conceptualized as exchanging human capital (education, physical and intellectual capability) for financial capital. Natural capital and physical capital can be used as savings to be converted to financial or social capital when needed.

In SLA, household livelihood strategies are developed within a vulnerability context consisting of factors that influence households but are beyond their control. Operationalized versions of SLA (e.g., UK DFID, 2001) generally limit factors evaluated in the vulnerability context to trends, seasonality and shocks. Trends can include changes in population, politics, resource condition, technologies, and economics. Seasonality includes variations in prices, employment opportunities, health, and agricultural production. Shocks are sudden disruptions of income brought about by changes in human health, environment, economic and security conditions.

Transformative structures and processes include infrastructure, access to credit, economic and social policies and institutions. This component of the framework governs how households can convert assets into livelihood outcomes. For example, lack of infrastructure to bring products to market will inhibit a household's ability to convert human capital into financial assets by selling products generated by investment in farm labor.

SLA is still widely employed (e.g., Apine, Turner, Rodwell, & Bhatta, 2019; R. T. Shackleton, 2020) and many of the foundational concepts and components of the framework continue to be refined and examined as sustainability science has emerged. In particular, large literatures focusing on capitals and transformations have emerged. Natural and social capitals and their role in sustainable livelihoods have generated global research initiatives such as The Natural Capital Project (www.naturalcapitalproject.stanford.edu) and literature that examines how these forms of capital interact to support or hinder sustainable livelihoods. Mbiba et al., (2019) use SLA to evaluate the role of natural capital and social capital in supporting livelihoods when negative income shocks occurred. They determine that both capitals are important, but access to natural capital in their study context had a larger effect.

Transformative structures, or, more generally, transformations toward sustainability, have also generated their own literature. Although the term "transformative structures" is used in SLA, the concept employed in recent literature on transformations necessary to achieve sustainability is broader than described in a SLA foundational document (e.g., UK DFID, 2001). Patterson et al. (2017) determine that transformations are "fundamental changes in structural, functional, relational, and cognitive aspects of socio-technical-ecological systems that lead to new patterns of interactions and outcomes" (p. 2). Transformation occur at multiple spatial and temporal scales within an SES, and are inherently political because they necessitate a shift in power and access to new forms. Scoones et al., (2020) define three inter-related approaches to transformation that can serve to guide application of the SLA. Structural transformations focus on "a complete overhaul of the ideological underpinnings of social systems writ large" (Scoones et al., 2020, p. 66). Systemic transformations draw heavily on SES thinking and focus either on interactions of system components (e.g., social institutions and political systems) or on the functioning and role of the component itself. Finally, enabling approaches to transformation emphasize human agency and developing capacity to act to support sustainable livelihoods. The authors recognize that these approaches can be complementary, and, for this research, I focus primarily on enabling transformational processes at the household level, but also examine, to a lesser extent, transformational structures from a systemic perspective.

Of particular interest to this research is the inclusion of health as a component of the vulnerability context in both seasonality and shocks. Health is an input to livelihood strategy as a component of human capital as well as a livelihood outcome. Despite the appearance of health in multiple components of this framework, health is rarely considered exclusively in SLA analyses. Scoones (2006) criticizes implementation of SLA for failing to fully incorporate all components of the vulnerability and transforming contexts.

Within the SLA, households make decisions to use various assets[1] to develop livelihood strategies that achieve desired livelihood outcomes, such as health and well-being. Natural resources are included as an asset that can be mobilized as part of the livelihood strategy. Household livelihood strategies are influenced by a vulnerability context, which is described in detail below.

Health is the only component of the SLA that is conceptualized as both an input to livelihoods (as a component of human capital) and a livelihood outcome. This emphasizes potential for a feedback cycle between human health and ecosystem health mediated through livelihood strategies.

In SLA, vulnerability consists of shocks such as crop failures or health shocks, and seasonality and trends, including history and socio-economic trends, that act upon households and transformative structures (such as infrastructure and policies) that influence how assets can be used in livelihood strategies. However, trends, shocks and seasonality influence not only household vulnerability, but also SES system vulnerability. Transformative structures in the SLA comprise social structures and norms, physical infrastructure, socio-economic policies, and other structures that influence how livelihood strategies choices are made, what strategies are viable

[1]SLA describes five categories of assets or capitals associated with household livelihood strategies. Human capital includes health, education, capacity to work and skills/experience. Natural capital are the natural resources and ecosystem services that can be accessed and exploited. Social capital represents access to decision-making, networking opportunities, trust, social support and other pathways through which livelihood opportunities are obtained and executed. Physical capital includes infrastructure, tools, machinery and other built items. Financial capital includes not only household savings and income sources, but also access to fair credit (Chambers & Conway, 1992; Serrat & Serrat, 2017; UK DFID, 2001).

and how livelihood strategies stabilize or destabilize the vulnerability context. The components of the SLA vulnerability context give rise to policies, infrastructure, and path-dependencies within the transformative structure. Therefore, this analysis combines the vulnerability context and the transformative structures and processes of the SLA.

1.2.3 Vulnerability Framework

SLA is not clear on how the vulnerability context is evaluated and how the role of transforming institutions is assessed, and, therefore, these key contexts for analysis are often ignored (Scoones, 2009). To fill this gap, I draw, secondly, on concepts from the *Vulnerability Framework* presented by Turner et al. (2003). This framework invites evaluation of processes (exposures) that differentially influence components of the SES based on the component's inherent sensitivity to that process. In this framework, overall system response to exposures and sensitivities is attenuated or exacerbated by a system's ability to respond to changes while maintaining essential function, referred to as its adaptive capacity. The *Vulnerability Framework* recognizes feedbacks between adaptations in the social and biophysical systems but does not offer specific pathways for how these feedbacks are incorporated into system response.

In SES research, a system's vulnerability is assessed in terms of the stresses (exposures) that it experiences, the sensitivity of the system to those stresses and the system's ability to adapt (Adger, 2006). The *Vulnerability Framework* proposed by Turner et al. (2003) emerged from risk-based research that focused on stressors as static entities acting upon systems. These approaches failed to incorporate the resilience of the system, or the constant change inherent in effects of stressors as the system adapts.

A vulnerability framework expands the concepts of risk and hazard to stressors and perturbations that result in different outcomes based on system functions, which can exacerbate or ameliorate stressors. Dynamic elements of the stressor, such as timing (e.g., sudden or sustained) and intensity (e.g., acute or chronic) result in different system responses. The amount of change that a system experiences to a given stressor is a complex and fluctuating function of the interaction of stressor and system attributes. Turner et al. (2003) also emphasize the need to consider multiple interacting exposures that can happen simultaneously or sequentially

The system's sensitivity is determined by conditions of social and biophysical components and their linkages. The state of these elements determines how stressors change the system and how these changes move through the system. A system that is not sensitive to a specific stressor, or a set of stressors, will not experience as much change as a system that is sensitive.

The ability to absorb change, or to change in response to change, while retaining its core social and ecological functions is the system's adaptive capacity. High adaptive capacity contributes to a system's resilience. Adaptive capacity on the social side of a system can be measured in terms of institutional capacity, social capital, and the set of coping mechanisms available. Adaptive capacity of ecosystems often derives from having multiple groups of organisms capable of carrying out critical ecosystem functions (such as decomposition and photosynthesis) or functional redundancy, In an ecosystem with functional redundancy, the loss of any given group of organisms can be compensated by other organisms that can perform the same function. Social and biophysical adaptations can influence one another and create feedbacks that augment or diminish a system's vulnerability.

The question at the center of this research is fundamentally related to human decision-making, so I thirdly draw from the *Human-Environment System* (HES) framework (Scholz & Binder, 2003) that focuses on the ability of human agents to perceive and act on signals from the biophysical system. This is characterized as environmental perception and is key in evaluating how feedbacks from the biophysical system are incorporated into decisions made in the social system.

1.2.4 Human-Environment Systems

The *Vulnerability Framework* does not fully incorporate the role of human agency in determining a system's vulnerability. Humans can react to and change behavior in response to changing conditions within the vulnerability context. For this work, the concepts of perception of environmental change and learning are borrowed from the HES (Scholz & Binder, 2003) to capture human agency in the conceptual model. The is an analytical structure that proposes a set of postulates that provide a more robust theoretical and epistemic grounding for SES analysis. The framework can incorporate diverse levels of hierarchical systems and focuses on a process in which human agents and environmental systems interact through such variables as goal setting, strategy selection, action, environmental reaction and strategy revision depending on the problem at hand. This framework emphasizes the agency of human system components, but also leaves room for revision of humans' goal-based strategies (strategies for food security, health, well-being, etc.) in response to environmental feedback. Unlike frameworks where human goals are immutable, this framework recognizes that human goals for well-being are created and can be revised using information gathered from both human and environmental systems. The framework also acknowledges that environmental feedback will be incorporated into strategy selection based on the level of environmental awareness in the human system (Scholz, 2011; Scholz & Binder, 2003).

The framework is a heuristic for organizing thinking about SES. Despite the functional nature of the framework, it is built upon a strong theoretical foundation "derived from integrative modeling, system theory, basic cybernetic feedback loop modeling, cognitive sciences, and decision research" (Scholz & Binder, 2003, p. 791). It is both a process and a structure guided by seven postulates. Several of the postulates focus on the need for social systems to receive and be aware of environmental feedbacks to make decisions that support core functional capacities of the SES, or to intentionally support transformation of the SES to a new structure.

It is this emphasis on decision-making and incorporating decision-making towards potentially conflicting goals at various scales within the human system that makes this model fit well with the current research. The SES framework underscores the role of human agency and the importance of social systems being cognizant of environmental conditions as well as having the ability to act upon that awareness.

1.3 Health, poverty, and environment linkages

The complex nature of the questions of this research requires use of an interdisciplinary framework and a broad analytical perspective. SES approaches embrace transdisciplinarity. They do not simply seek to combine knowledge from various social and natural science disciplines, but they seek to generate new knowledge that transcends traditional disciplinary constraints and recognizes the need for new epistemologies to address complex interactions between humans and environments (Choi & Pak, 2007).

This section provides a brief overview of contributions from various fields to understanding of health-poverty, poverty-environment, and environment-health interactions. Health-poverty, health-environment and environment-poverty relationships have been extensively explored and debated by various disciplines (e.g., Myers et al., 2013; Salafsky, 2011; Singh & Singh, 2008; Tallis, Goldman, Uhl, & Brosi, 2009; Wagstaff, 2002; Zivin et al., 2010). Poverty-environment research has a strong foundation in economic development (Mcsweeney, 2005; Wunder, Angelsen, et al., 2014). Health-poverty interactions are explored obliquely. For example, health shocks and ability of households to change consumption patterns is a topic covered in micro-economic literature (Leive & Xu, 2008; Mitra, Palmer, Mont, & Groce, 2016; Wagstaff, 2007). Health-environment research has been largely conducted from environmental health and ecosystem services perspectives (Díaz et al., 2015; Tallis et al., 2013; WHO, 2015), which emphasizes ecosystem impacts on human health. Strong contextual effects stymie theory generation in each of these areas. Geographic location, cultural traditions, household demographics and even weather patterns have all been linked to livelihood strategy development, reliance on natural resources and responses to health crises.

Livelihood strategies are the combined tactics that households use to meet their consumption needs. In rural communities, strategies often rely on natural resource-based activities such as agriculture, forestry, mining, and fishing. Strategies available to households are determined by natural and socio-economic conditions present (Peng et al., 2017). A livelihood choice can only be available and viable if required natural resources are available. In addition, non-subsistence livelihood choices require physical and financial infrastructure to transport and market extracted resources. In developing countries, households often include multiple income sources in their livelihood strategies to help increase resilience to income shocks (Peng, Zheng, Robinson, Li, & Wang, 2017; Vedeld, Angelsen, Bojö, Sjaastad, & Kobugabe Berg, 2007). "Geographical location, natural capital, household structure, labor quality, and ecological policies are the main factors affecting choice of livelihood strategy" (Peng et al., 2017, p. 1). To this list, Rakodi (1999) adds economic policy and the household's situation within the economic system.

When facing health shocks, the poor lack savings to cope with out-of-pocket expenses even in countries with socialized health systems (Mitra et al., 2016; Sparrow et al., 2014). A growing body of literature, primarily based in rural communities in Africa, has identified health as an issue that changes how households adopt livelihood strategies to meet consumption needs (Damon, Zivin, & Thirumurthy, 2015; Shackleton & Shackleton, 2012; Zivin et al., 2010). These studies suggest that when poor households experience a health shock ("unpredictable illnesses that diminish health status" (Leive & Xu, 2008, p. 849)), household consumption needs are met through increases in natural resource extraction.

Illness may reduce the resource extractive effort of a single individual, but health shocks may cause a household to change livelihood strategies to compensate for reduced capacity of one member. In rural, resource-dependent communities, the options for generating financial capital to meet healthcare needs often involve natural resource extraction, either through direct liquidation of natural capital or by seeking employment in extractive industries.

Conceptually, health shocks are different than economic shocks such as crop failures or natural disasters (Wagstaff & Lindelow, 2014). Economic shocks stress multiple households simultaneously, affect all members of a household and are normally short-lived. Health shocks strain an individual household and can be addressed by a shift in labor within a household if other healthy, productive adults are available and can persist.

Research has demonstrated a strong relationship between development of human capital (e.g., skills, education, health status), which is influenced by morbidity, and dependence on natural resources (de Sherbinin et al., 2008). Sudden reduction in available human capital will require exploitation of natural, social, asset or financial capitals. These changes can result in higher risk/higher reward resource extraction such as illegal logging or illegal mining that degrade the environment. Fiorella et al. (2017) documented that fishermen were 69% more likely to use an illegal fishing method when experiencing physical or mental illness.

However, relationships identified in site-specific studies are influenced by context and may not be generalizable (Wagstaff & Lindelow, 2014). Although health shocks have been demonstrated to lead to changes in natural resource use in some contexts (Damon et al., 2015; Fiorella et al., 2017; Sedda et al., 2015), effects on resource use are likely to be dependent on natural capital stocks and alternative employment opportunities. It is expected in the context of this study that health shocks will lead to increased exploitation of natural capital as a source of income or employment in extractive activities to smooth household consumption.

SES frameworks frequently examine ecosystem services that influence human well-being as well as the ability of humans to affect ecosystem function through exploitation and conservation. Clean air and water are essential for daily survival. Healthy soils allow us to grow food, the ozone layer protects us from the sun, and nature-based recreation is beneficial to physical, mental and emotional health. Historically, the natural system is conceptualized as a purveyor of services and the human system the exploiter of those services (Díaz et al., 2018; Guerry et al., 2015). Recently, the Millennium Ecosystem Assessment employed the concepts of ecosystem services, defined as "the benefits that humans obtain from ecosystems" (Tallis et al., 2013) to examine human well-being. This assessment categorized four types of ecosystem services: provisioning, regulatory, cultural, and supporting. The cultural category, which encompasses numerous intangible and essential benefits humans derive from nature, was included in the Millennium Ecosystem Assessment to show the relationship between humans and environments. Following the Millennium Ecosystem Assessment, the IPBES has expanded the breadth of people-nature relationships to recognize that context and values governs the type and magnitude of the benefits and applied a revised term, Nature Contributions to People (NCP).

A healthy ecosystem is required for healthy humans (Lebel, 2003) and as such, health and ecosystems should be approached using systems thinking. Despite calls for inclusion of environmental factors in considering health and health outcomes, most research still focuses on the role of ecosystems in supporting human health, and little attention has been paid to how human health and well-being affects ecosystems.

> We accept that the environment influences human health, but we know little about how human health affects the environment. However, millions of people around the world rely on natural resources for food and livelihoods and confront a high burden of illness. Experience of illness may change people's physical capacities, outlook, and planning horizons and shape how they engage with the environment. (Fiorella et al., 2017, p. 1)

Human activities, including local livelihood pursuits, can degrade ecosystems and result in impacts to human health. The health impacts of environmental degradation tend to disproportionately impact the poor, who then exploit additional natural resources and increase degradation. This dynamic has been observed in Africa within communities stricken with HIV/AIDS. Households with an HIV positive member may face both debilitating illness as well as stigma that prevents them from earning an income (Damon et al., 2015; Shackleton & Shackleton, 2012). Research has demonstrated that they can cope with loss of livelihood by turning to natural resources. Health changes increasing reliance on natural resources has been documented as well as in countries of Southeast Asia (Wagstaff, 2007; Wagstaff & Lindelow, 2014).

Literature on health and conservation generally focuses on impacts of environmental conditions on health, but there is growing recognition of the need to address human health and ecosystem health as part of an integrated whole (Bremner, Carr, Suter, & Davis, 2010). Using a social-ecological systems perspective on health and environment encourages exploration of feedback mechanisms, interactions, and non-linear dynamics. The conceptual model I developed from the SES frameworks and the literature on health, livelihoods and the environment follows. It is useful for understanding the complex interactions and for guiding my research questions.

The conceptual model in Figure 1 presents linkages that are explored in this research. Health is both a resource drawn on to develop a livelihood strategy as well as an outcome of that strategy. Livelihood strategies influence natural resources either through extraction/use or through conservation. Natural resources in turn influence health and future livelihood choices. For this research, I draw a distinction between a natural resource, a source of natural capital, located at the local and regional levels and cross-scale environmental conditions. Local natural resources of interest in this analysis are primarily forest and water. However, regional, and global environmental conditions, such as global and regional climate patterns, influence condition of the local natural resources on which livelihood strategies depend. Likewise, markets, prices, policy, etc. also affect use and the state of local natural resources. All these interactions occur within vulnerability contexts at different scales.

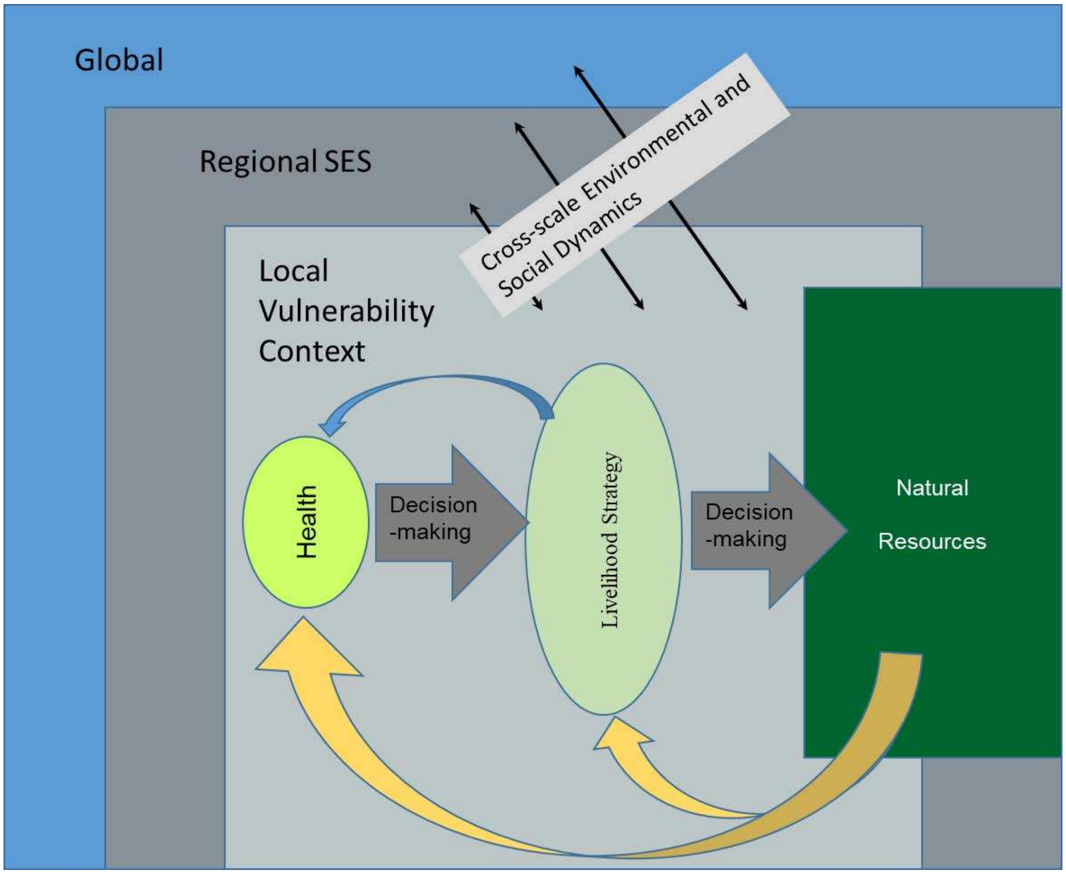

Figure 1. Conceptual Model

1.4 Structure of the dissertation

The remainder of this dissertation seeks to take this perspective by using fundamental relationships described by the disciplinary literature cited above. This chapter has outlined the broad concepts and theoretical foundations of this research. Chapter two describes the environment and history of the study site and provides a description of the households that participated in the study. Chapter three examines the vulnerability context by evaluating qualitative data collected through formal and informal interviews with site residents and local and regional government officials. Chapter four quantitatively evaluates household dynamics and health in determining livelihood strategy. Chapter five draws on findings from chapters three and four to develop and evaluate an agent-based model that represents health-livelihood-environment dynamics over a longer timeframe than can be captured with survey data. Chapter six presents discussion, conclusions and next steps based on the material presented in chapters three through five. In this final chapter, I revisit the frameworks and apply the findings of qualitative, quantitative, and model analysis.

Chapter 2 Study Site and People

The purpose of this chapter is to outline the historic and cultural context of the Dumoga Valley of North Sulawesi, Indonesia, and to present the descriptive data collected from households included in the study about issues related to health, livelihoods and environment in the study site. I begin by describing the history of the study site and people of the area. Then I provide a descriptive analysis of the four main ethnic groups included in this study (Minahasa, Mongondow, Balinese, and Jaton) using data gathered from two rounds of surveys that were conducted in 2015 and 2016. Households representing each of the ethnic groups in twelve randomly selected villages were visited in 2015 and asked about household characteristics, livelihood choices, and how households faced economic difficulties. In 2016, we returned to as many of these same households as could be located to ask the same questions to identify changes in livelihood, health, and natural resource use. Data were collected from different seasons in 2015 and 2016 to help understand the effects of seasonality on livelihood and health status. Data were collected in 2015 at the end of the harvest, or rainy, season, while the 2016 data were collected at the end of an abnormally long dry season. Advanced analyses of the data are presented in Chapter Four.

2.1 Study Site

The Dumoga Valley is in the Indonesian province of Northern Sulawesi on the Minahasa Peninsula. Prior to 1950, the broad, flat Dumoga Valley was covered with lowland rainforest renowned for its high levels of biodiversity and endemism. In the 1950s, households began to colonize the thickly forested valley floor. The population grew slowly due to lack of infrastructure and outbreaks of malaria and dengue fever that occasionally forced settlers to retreat from the area. In the 1970s, the Indonesian government began the "*transmigrasi*", a process relocating 960 families from the more populated islands of Java and Bali to the so-called outer islands (Wells, Guggenheim, Khan, Wardojo, & Jepson, 1999). The Dumoga Valley was a center for relocation and as a result the population swelled from approximately 8,000 in 1960 to over 50,000 by 1980 (Wells et al., 1999).

Several World Bank projects supported population growth in Dumoga Valley. In 1973, the World Bank began the construction of a two-lane highway from Manado, the capital of North Sulawesi Province, to the Dumoga Valley (Conroy & Litvinoff, 1988). In addition, by the early 1980s the Kosinggolan and Toraut dams had been constructed in an effort to expand wet rice agriculture. Expansion of rice production spurred spontaneous immigration, mainly from the neighboring region of Minahasa, and further fueled the population boom in the Dumoga Valley (Marsden, 1989).

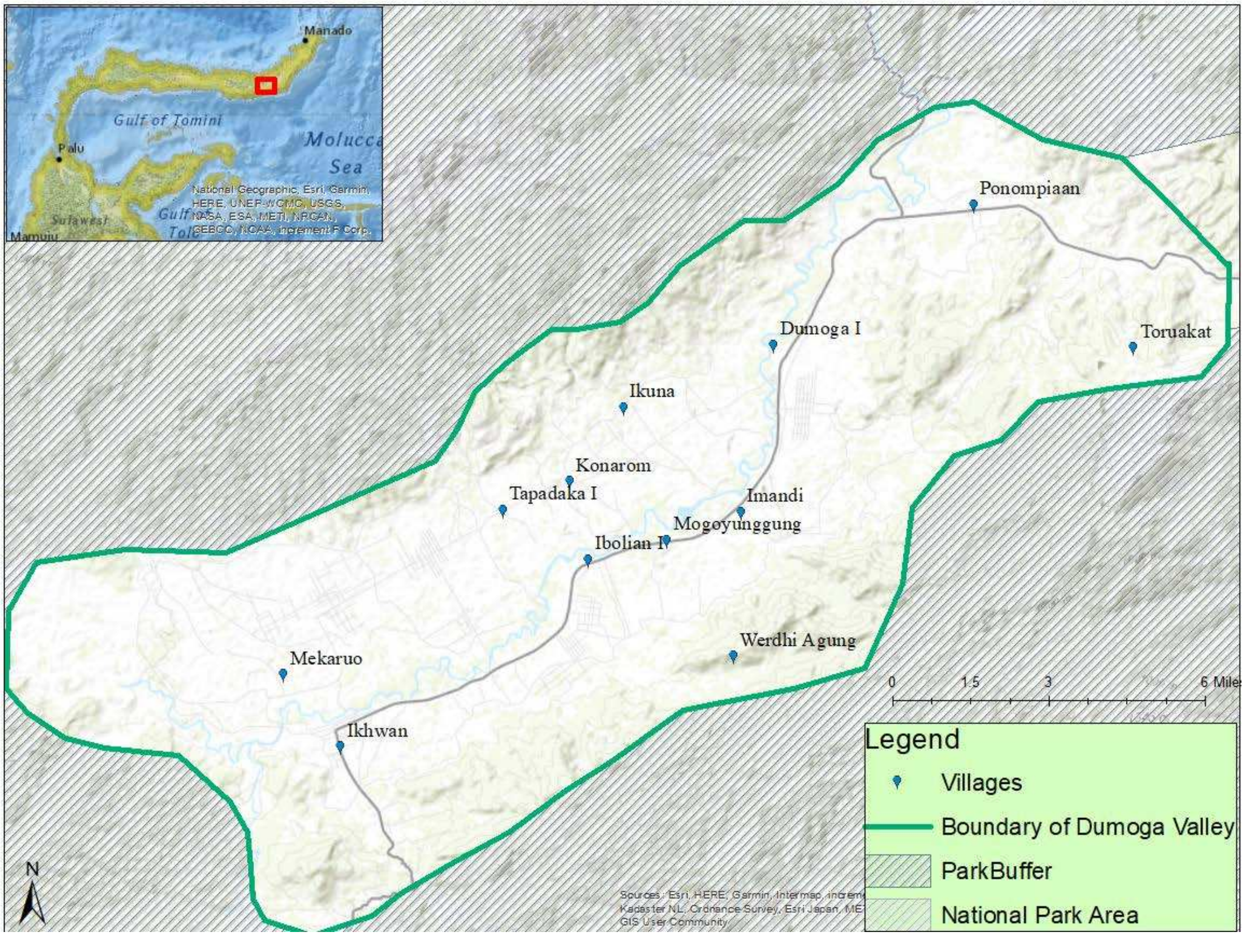

Figure 2. Study site

2.1.1 Bogani Nani Wartbone National Park

Toraut dam sits adjacent to the village of Toraut in the northwest corner of Dumoga Valley and the Kosinggolan dam is in the southwest corner of the valley. When the dams were completed, they provided irrigation to approximately 8,500 farmers on 11,000 hectares (Wells et al., 1999). The dam projects rely on a steady water source, but the Dumoga Valley sits in a rain shadow caused by the high surrounding mountains. Protection of the forest is essential for water provision to the irrigation scheme. International environmental groups saw potential for significant conservation while also supporting economic development. Therefore, concurrent with the construction of the two dams, the Dumoga Bone National Park (now called Bogani Nani

Wartbone National Park) was created to protect the catchment area that feeds the irrigation system. Although the environmental organizations that contributed to the creation of the park tout it as one of the earliest conservation and development projects, in practice, the purpose of the park was primarily to feed the irrigation system. Biodiversity conservation was an ancillary goal (Wells et al., 1999). In addition, the creation of the park and dams primarily benefited transmigrants from Bali and Java that had practiced wet rice agriculture for generations.

The 300,000-hectare Bogani Nani Wartabone National Park borders the Dumoga Valley on three sides (Kawuwung, 2012). When the park was created, there was a population of approximately 50,000 people living within the park and its five-kilometer buffer zone (Wind & Sumardja, 1988). Most of these residents were resettled outside the park, but one large community persists illegally within park boundaries.

In interviews, residents reported that establishment of the park was confusing. Park officials claim they conducted numerous events (*sosialisasi)* to inform landowners of the importance and location of the park, eventually adding clear markers around the park boundary. However, residents are still confused or willfully ignorant of the park and its land uses. Residents reported in interviews that, initially, there was sufficient government enforcement and sufficient land to prevent significant encroachment at the park boundary. However, upon the discovery of gold in the 1980s in the park, the lure of windfall profits quickly outweighed potential repercussions of being caught at an illegal mine. People came from the Dumoga Valley and beyond to make a living mining gold. This was a new livelihood strategy available to the poor and landless. In the early days of the gold rush, park officials conducted *operasi* (enforcement operations) and expelled encroaching miners. Today, land use enforcement is lax and the boundaries of the park are frequently violated for agriculture, animal poaching, and artisanal gold mining.

Together, the two irrigation schemes comprising the dams and the national park have brought significant success toward meeting broad economic goals. Increased rice production in Dumoga Valley contributed to shifting North Sulawesi from a rice importer to a rice exporter. However, these economic gains were accompanied by large-scale social and environmental changes.

> "The [conservation and development] project essentially failed in social terms while delivering substantial economic gains. Negative impacts clearly resulted from a failure to fully appreciate the effects of the complex interactions between the indigenous population and the recently arrived migrants and transmigrants. The original, or at least pre-1980, Dumoga valley inhabitants, being accustomed to rain-fed agriculture and shifting cultivation, did not adapt rapidly to the more intensive and profitable irrigated rice cultivation. While some were forced to sell their land for transmigration projects, others sold their land for very low prices to speculators, absentee landlords, and others. These people then moved into the forest within the new national park, attempted to carry on with a traditional way of life that had suddenly became illegal, and were thrown out. The beneficiaries of the project (the transmigrant rice farmers) did not represent a biodiversity threat to the park." (Wells et al., 1999, p. 98)

Concurrent processes of infrastructure development, government-supported migration, land clearing, and the creation of the national park have generated social dynamics that continue today.

2.2 People of Dumoga Valley and their Livelihoods

Very early in data collection, differences in livelihood strategies, desired livelihood outcome and responses to health-related disruption to livelihood strategies between ethnic groups began to emerge. Literature indicates that informal livelihood activities such as hunting, food collections and home gardens are important for food security in rural areas (Wunder, Börner, Shively, & Wyman, 2014). I attempted to collect data on informal livelihood activities of the communities in this study, but this data was not reliable as many respondents denied participating in these activities despite visible evidence of forest products, home gardens, and other non-market goods in households. During data analysis, the impressions that I formed about the effect of culture on health-livelihood-environment interactions was confirmed. In the following chapters, I discuss these differences in detail. However, although ethnic group differences were not anticipated in the research design, and were not identified in the literature, the differences are so fundamental to the findings and results presented here, that much discussion is structured in terms of ethnic group. In this chapter, I introduce livelihoods and household demographics of the four main ethnic groups, their commonalities, and their differences.

Most of the valley's residents regard themselves as agriculturalists. In Indonesia, one chooses an official occupation from a limited number of categories (farmer, soldier, doctor, government worker, tradesman, etc.). Although many households survive through diverse income generating activities, they view their official occupation as their primary identity regardless of the percentage of their income that profession provides. Rice, corn, and coconut are the main agricultural products, but high value, slow-growing crops such as chocolate, nutmeg and cloves are also important sources of income. Farmers also earn wage income working in numerous grain mills (*gilingan*) in the valley that are used for dehulling rice and drying corn, however agricultural processing infrastructure is limited to small-scale operations. Non-farm income options are limited. There are a few government and military positions, and some small-scale local trade, but the primary source of off-farm income is through engagement in illegal gold mining in the mountains surrounding the valley.

During the height of transmigration era (1950s to 1980s), the government bought or appropriated land from the Mongondow people who had initially settled the area. Government-supported migrants received free land as well as agricultural infrastructure that permanently shifted the valley from rain-fed crops to wet rice production. Wet rice producers benefited greatly from government support such as irrigation and improved rice varieties. They earned higher prices for rice than rain-fed crops such as corn and coconut cultivated by the Mongondow and Minahasa. Preferential support and higher prices helped establish income inequality between the original residents and transmigrants.

As the population of the valley grew, deforestation accelerated. Mongondow and some early Minahasa settlers began to clear away forest to cultivate for a few years before eventually selling to the wealthier migrants. Their land was more valuable as wet-rice production than dry agriculture, so the highest and best economic use was not consistent with the agricultural practices of the Minahasa and Mongondow farmers.

> The prospect of irrigation for rice production pushed land prices up and promoted speculation and more deforestation, since land had to be cleared to obtain legal possession. Clearing in anticipation of increased land values was practiced by original settlers as well as by the proxies of absentee landlords. (Gradwohl & Greenberg, 1988)

The best option for original settlers was therefore to sell land to the relatively well-off migrants. This clear-plant-sell strategy was repeated until the valley floor was almost completely cleared of forest. Many Minahasa and Mongondow farms moved to the steep hills beyond the valley where irrigation was not feasible. The ability to clear new land as needed was halted with the creation of the Bogani Nani Wartabone National Park. Initial demarcation of park boundaries did wind around some existing plots, but the creation of the park left many Mongondow and

Minahasa farmers without land. Despite risk of up to three years in jail, the landless continued to cultivate in the national park.

In 1983 when the Kosinggolan dam did not reach projected discharge levels, the government enacted a large-scale effort to control deforestation, remove the then-illegal settlers and reinforce national park boundaries (Wind & Sumardja, 1988). This step further marginalized the original valley inhabitants. When gold was discovered in mountains now within the park, a lucrative new livelihood source was available to those excluded from the planned development in the valley below.

In 1990, the government conducted a massive *operasi* that removed all miners from the protected area. This led to widespread civil unrest in the villages of the Dumoga Valley. Hundreds of people, mostly men, lost their only source of livelihood. Unemployment, drinking and unsettled disputes that had originated at the mining region led to theft and violence. As a result, the government now conducts fewer enforcement operations and tacitly approves mining encroachment. Mining settlements have grown from a few men in tents whose fires were only visible from the valley floor at night, to makeshift villages with roads clearly visible on the slopes within the park.

Residents of the Dumoga Valley developed a unique system of illegal artisanal gold mining in Bogani Nani Wartabone National Park. When a prospector finds a gold vein, they claim a *lubang* (literally "hole" in English). They may mine the hole themselves, but more often, they establish a *kongsi* or share that consists of several miners who will work the hole for a period and share any profits. A group of 10 to 12, mostly men, but occasionally women, will extract ore for a period of 10 days to 2 weeks. They live at the mine site within the park, and living expenses are provided by the owner of the *lubang*.

Once the group has collected sufficient ore, the group pays for rental of processing equipment. Processing takes place mainly in the valley, but more recently, processing facilities have been moved to the mining area. If processing is taking place in the valley, the group members will transport bags of ore via motor bike down from the mountain and to a *tromol*[2] to be processed using liquid mercury or, in rarer cases, larger vats with cyanide. Both forms of amalgamation leave toxic residue and threaten human health.

Mining groups can work weeks on end and find no gold. Even when they do find gold, after they have paid a portion to the *lubang* owner, reimbursed living costs, and rented the *tromol* for amalgamation, an individual's share may not be appreciable. However, the hope of income and the lack of other sources of wage income for the landless make gold mining an attractive option despite its inherent danger.

> Illegal gold mining yields only modest rewards, is arduous and dangerous (involving unprotected use of mercury), and carries a penalty of three years in prison if the miner is caught. But its continuing popularity strongly suggests a lack of economic alternatives for the unemployed and landless in North Sulawesi, where considerable hardship has been caused by the collapse of the clove and coconut industries." (Wells et al, 1999, p.97)

No research has been conducted on specific effects of artisanal gold mining in terms of ecosystem function or health. Miners used, and continue to use, hand tools and low-tech methods to find, extract and process gold. Many miners do not recognize the impact of mining on forests because they often leave the forest intact above the mineshaft. Construction of roads to reach the

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[2] *Tromols* are a system of steel drums that are filled with river rock, liquid mercury, ore and water and then churned either using water or a gas engine. The mercury amalgamates the gold, and when the churning cycle is complete, the waste rock, river rock and water are discarded, and the liquid mercury and gold amalgam collected. In contrast to the Balinese who decreased the number of income sources in 2016, there is a trend among the Mongondow to increase income sources. sing a piece of cloth, the mercury and gold amalgam is strained to remove excess liquid mercury. The remaining product is a solid ball of mercury and gold. The final step in processing is to burn off the mercury in an open fire leaving pure gold.

mining area and temporary settlements with no sanitation infrastructure leave the forest far from pristine and protected. Although artisanal gold mining does not denude large swaths of land like commercial mining, impacts to forest ecosystems are evident. In Dumoga, mining sites are readily seen from the valley floor. In a few years, the sites grew from a few isolated locations that could be identified only by the fires they lit at night, to a cleared area that resembles a village high on the sloped wall of the valley.

Human health implications of mining have been of great concern for decades in Indonesia, but no research on health impacts of mining has been conducted in the Dumoga Valley. The government does not monitor for mercury or cyanide, a less common means of amalgamation, in streams and irrigation systems. The area is not sanctioned for mining, and therefore, there should be no mercury or cyanide present.

2.2.1 People in this study

The Dumoga Valley is divided into six districts: North, South, East, West, Central and Southeast Dumoga. Villages in Dumoga are primarily ethnically homogenous. There are five well-represented ethnic groups in the Dumoga Valley: Mongondow, Minahasa, Balinese, Jaton, and Javanese. The Mongondow and Minahasa are native to North Sulawesi. The illustrations that follows presents demographic data for the dominant ethnic groups in the study: Minahasa, Mongondow, Balinese, and Jaton.

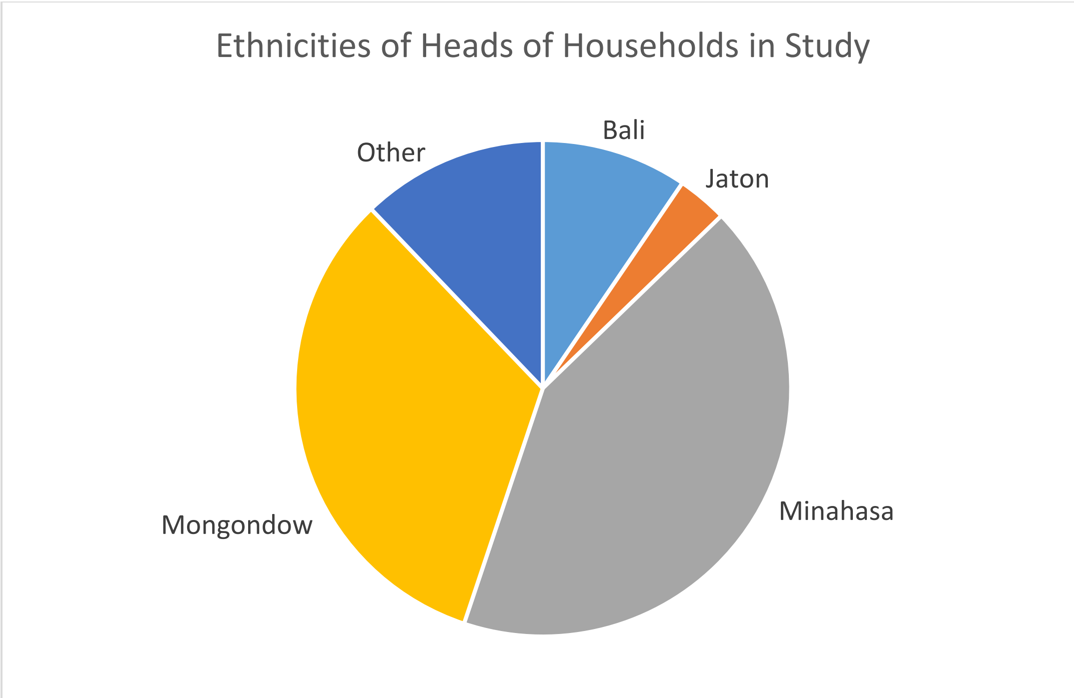


Figure 3. Distribution of household ethnicities represented in survey responses.

2.2.1.1. Minahasa

Minahasa households have largely migrated spontaneously from the neighboring state of Minahasa to the Dumoga Valley. Early migrants were drawn by the potential of cheap land and government investment in agricultural infrastructure. Later immigrants have been drawn by potential for mining profits.

Minahasa heads of households have an average age (49.7) with an average of 3.4 members. Over 90% of Minahasa households are Christian. Minahasas have higher levels of education than the other ethnic groups in this study. They have the highest percentages of individuals whose education terminated after middle school, high school or college.

Currently a large proportion of Minahasas earn a living through wage labor. Figure 4 and Figure 5 show the distribution of household income strategies in terms of percent of Minahasa households that engaged in the activity in 2015 and 2016. There is no significant difference in the livelihood distribution between 2015 and 2016. Households can engage in more than one income activity, so the total percentage of households in the figure is more than 100 percent. Most of the valley's wage labor is related to agriculture, either through field work planting and harvesting rice or working in rice/corn processing mills. Additionally, there are limited seasonal opportunities such as construction. The first survey in 2015 showed nearly five percent of Minahasa households earned income from mining and this increased to seven percent in the second survey. One-third of Minahasa households indicated that they have earned income from mining at some point.

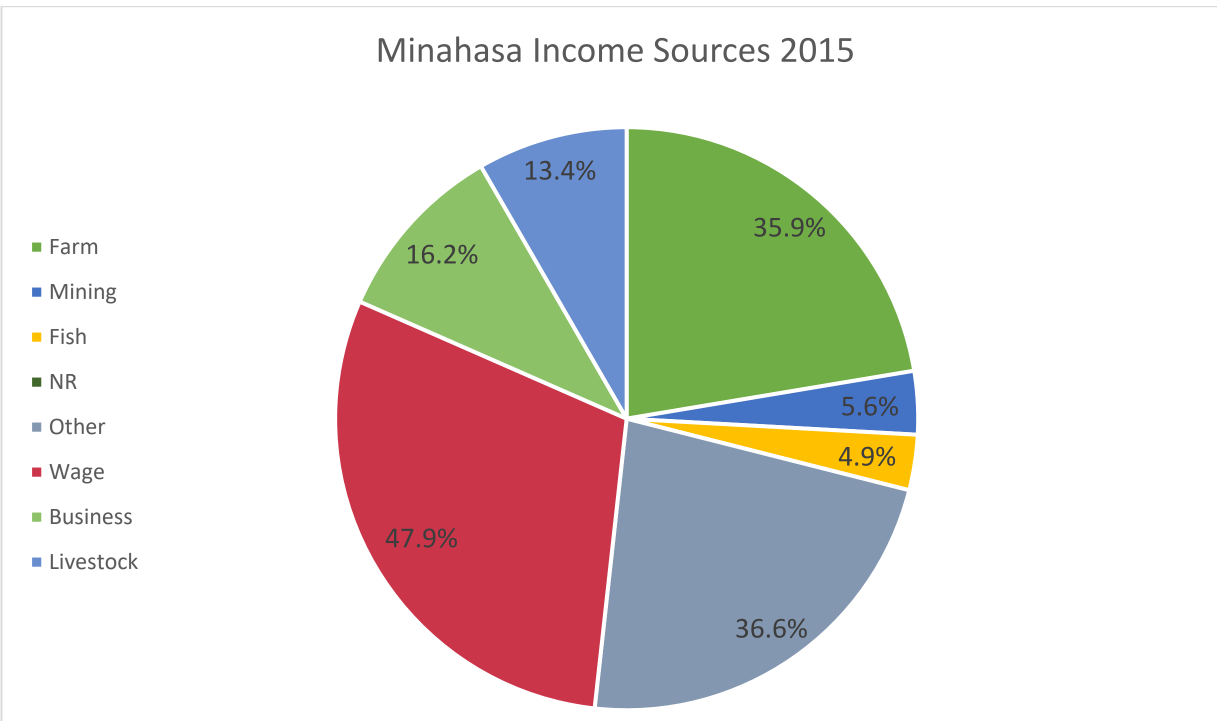


Figure 4. Distribution of Minahasa household income activities in 2015. Percentages total more than 100% because households can have more than one income source.

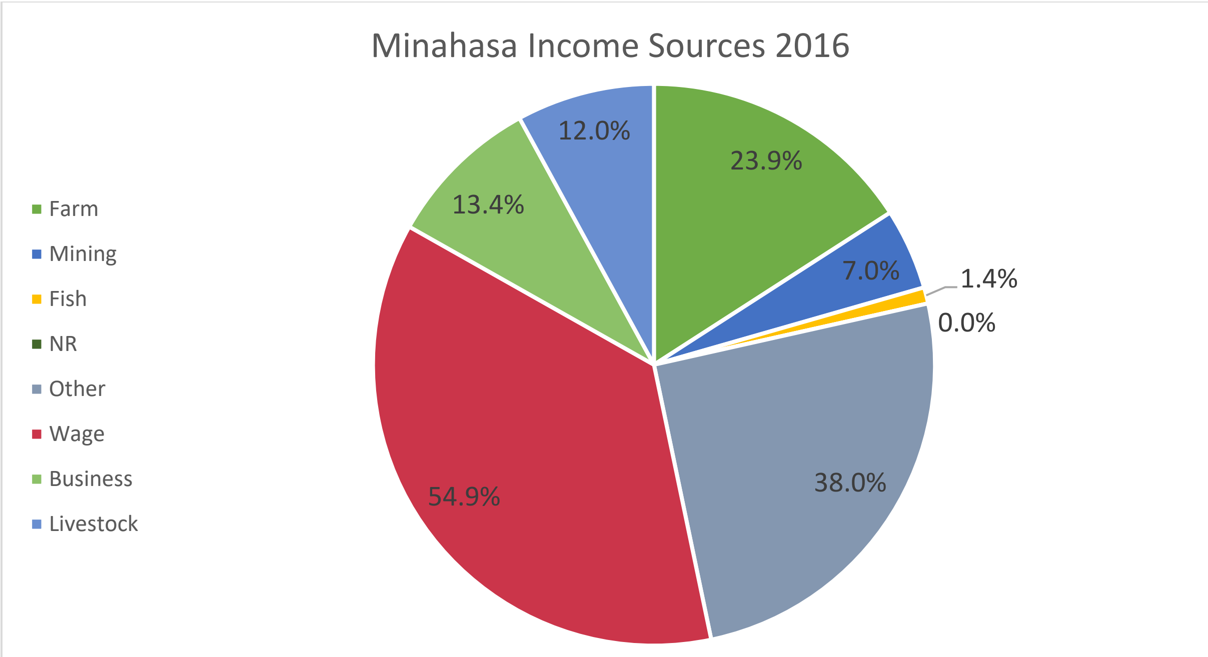


Figure 5. Distribution of Minahasa household income activities in 2016. Percentages total more than 100% because households can have more than one income source.

In both 2015 and 2016, more than half of Minahasa households relied on one income source, and there was little change in the number of income sources per household between years and these changes were not statistically significant. In 2016, fewer households reported having no income (Figure 6) and there were no increases in any of the income activity categories. The manitude of changes was not statistically significant, but is provided here to demonstrate representative values for the two time periods.

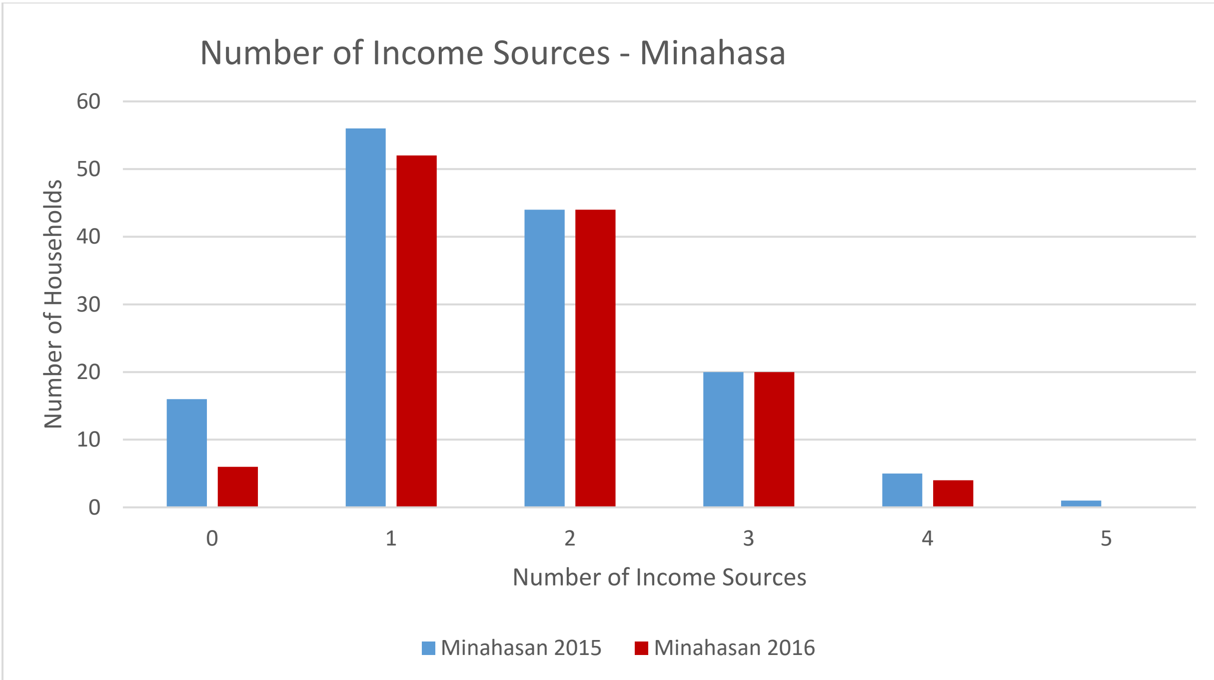


Figure 6. Number of income sources of Minahasa households in 2015 and 2016.

The measure of landownership was expanded between the 2015 and 2016 surveys. Upon review of the 2015 results, it became clear that the question on land access was not specific enough. Sharecroppers, people who cultivate land in exchange for a portion of the profits, had not been considered in the survey design. During the 2015 survey, some responded that they had land and others responded that they did not. In the 2016 survey, sharecropping was coded as a type of landownership. At the time of the 2015 survey, over 59% of Minahasa households did not have access to land for agricultural production. In the 2016 survey, just under 50% of households had no land. A larger percentage of households indicated less secure types of land tenure than outright land ownership. Less secure land access included borrowing land (ususally from family members) or share cropping. Eight Minahasa households indicated they had previously sold land. Four had done so to pay school fees for their children, one to buy other land, one for capital, one for household needs and one to pay for health care.

Minahasa households in 2015 had savings both in liquid cash (16%) as well as assets such as gold (13%). A lower percentage of Minahasa had debt in 2015 (Figure 7). Thirty-nine percent of Minahasa households had debt in 2015, and a high percentage (16%) of them responded that their debt fell into the highest category of debt on the survey, roughly equivalent to two months' salary. In 2016, the same percentage (16%) of Minahasa households had the same level of cash savings, but the percentage of households with asset savings increased to 19%. The percentage of households with debt decreased slightly to 38% in the 2016 survey (Figure 7). None of these differences were statistically significant.

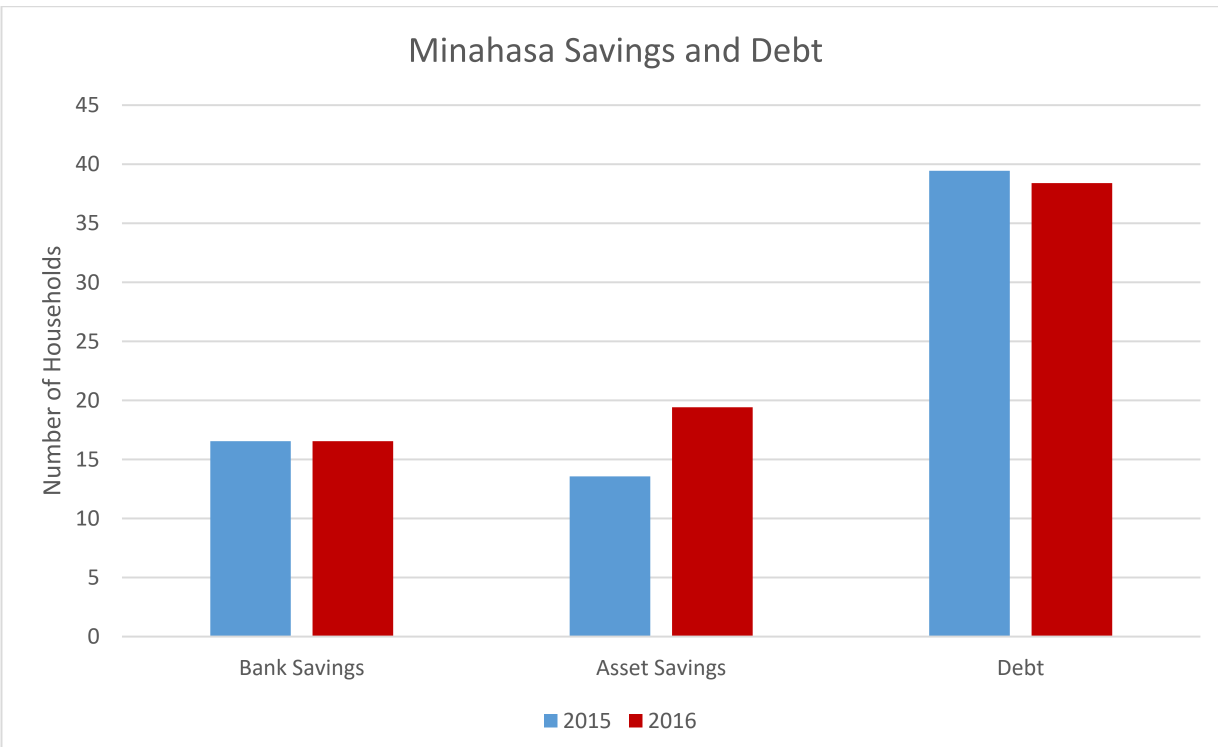


Figure 7. Savings and Debt in Minahasa Households

Minahasa households reported the lowest percentage of illness overall in 2015 and 2016. However, they had the highest percentage of both minor illness (such as cough or flu) and fatal illness (stroke or cancer). They had the lowest rates of chronic or acute illness.

Crop failure and illness were the two most common economic shocks to Minahasa households. In 2015, 18% of households reported crop failure and 12% indicated that their household economy was impacted by major illness. In 2016, 23% of households suffered crop failure that impacted their household incomes and just over 9% experienced major illness to an extent that household income was impacted.

2.2.1.1. Mongondow

The Mongondow people are the original settlers of the Dumoga Valley, but are not indigenous to the valley. The average age of Mongondow household heads was 45.5 years, with an average of 3.5 members. Over 85% of Mongondow households are Muslim. Mongondow households in the sample have the highest percentage of individuals who have only completed a primary school education and the lowest percentage of individuals who have completed high school or above.

Responses in both 2015 and 2016 indicate that most Mongondow households rely on wage labor (Figure 8 and Figure 9). Mongondow have the highest proportion of households who earn income from businesses such as small convenience stores (*warungs)* and trade. The number of households earning income from mining remained steady at just under 5% in the two survey periods. While only 4% of Mongondow households reported income from mining in 2015 and 2016, 31% indicated that they had been involved in mining at some point. There was not a statistically significant difference between income source distribution in 2015 and 2016.

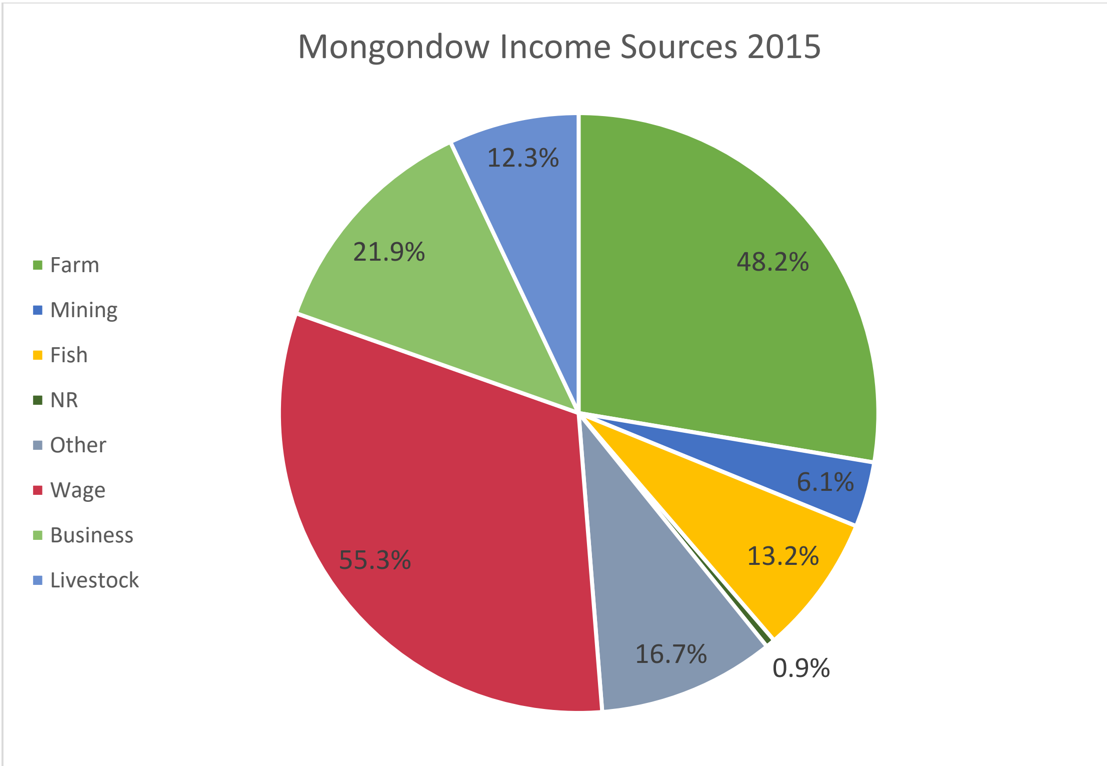


Figure 8. Distribution of Mongondow households engaged in income activities in 2015. Percentages total more than 100% because households can have more than one income source.

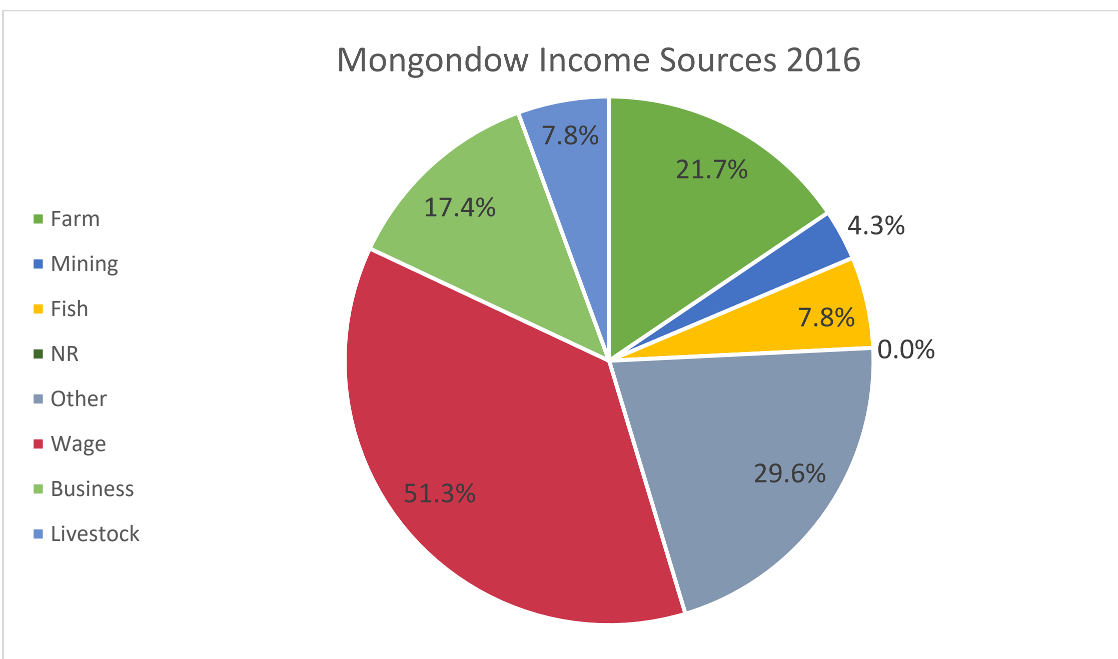


Figure 9. Distribution of Mongondow households engaged in income activities in 2016. Percentages total more than 100% because households can have more than one income source.

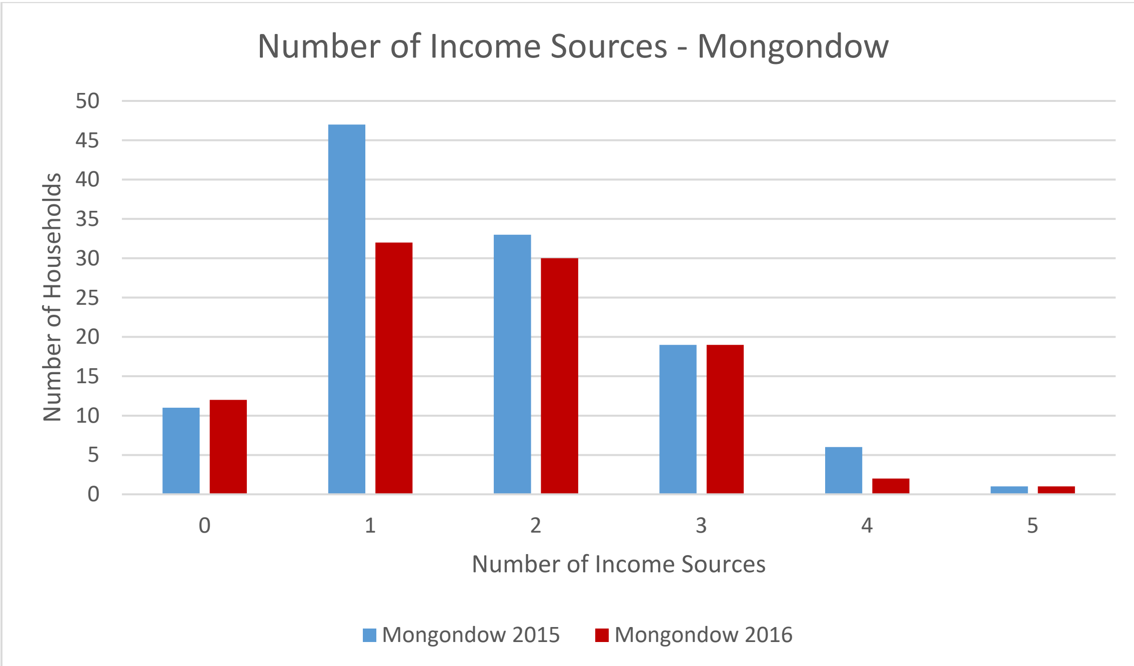


Figure 10. Number of income sources of Mongondow households between 2015 and 2016

In both 2015 and 2016, the largest percentage of Mongondow households relied on one source of income (Figure 10). In 2016, the number of income sources per household tended to decrease, and a higher percentage of Mongondow reporting no income at all, but this change was not significant.

In the 2015 survey, 63% of Mongondow had access to agricultural land, and in the second survey this rose to 68%, due to an additional 5% of Mongondow having land access through sharecropping. The majority of Mongondow households who have access to land own their own land. Mongondow were the only group that acknowledged any use of government land, meaning they acknowledged encroaching upon the protected area of Bogani Nani Wartabone National Park. Eleven households had sold land. Four of the households said that they sold land to acquire land elsewhere, which is consistent with the trend of clearing and selling land. Three households sold land to pay school fees and three sold land to pay for health care.

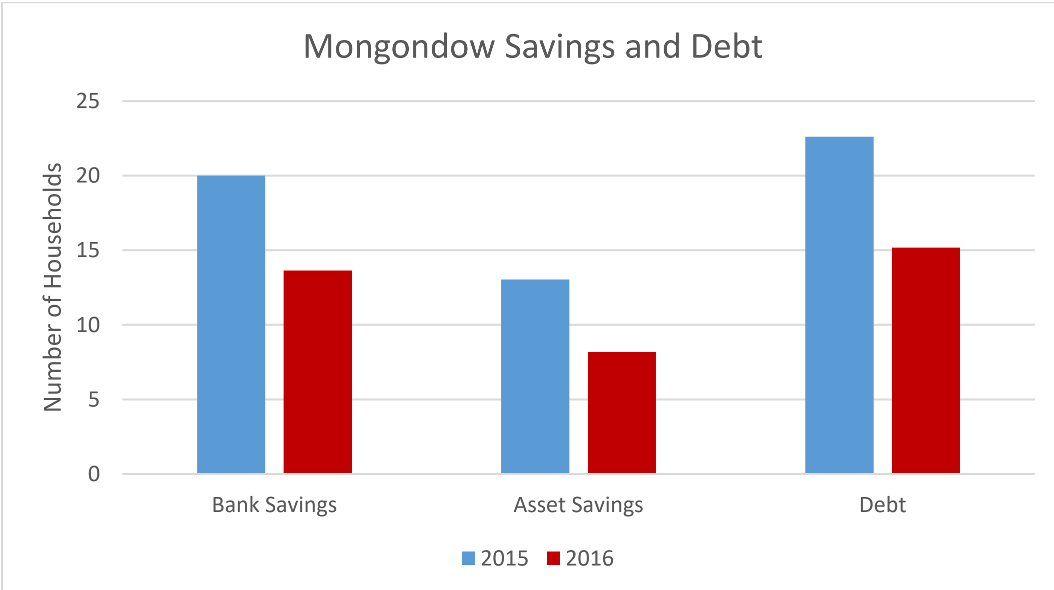


Figure 11. Savings and Debt in Mongondow Households

Mongondow households had the highest percentage (20%) of cash savings among all ethnic groups in 2015 and 13% of households also had asset savings. Twenty-two percent of Mongondow households had debt in 2015 that was categorized as approximately 2 months' salary. In 2016, cash and asset savings as well as debt decreased. None of the differences between 2015 and 2016 were statistically significant.

Mongondow households had the highest percentage of reported illness across all groups in 2016 when data from both years is combined. When asked about unexpected crises that impact household income, Mongondow households report crop failure and serious illness as the main disruptions. Crop failure stayed relatively consistent at around 13% in both time periods, but serious illness increased from approximately 12% in 2015 to 17% in 2016.

2.2.1.2. Balinese

Over forty years after transmigration, many Balinese families continue to live in villages that are ethnically homogenous. Almost all of the Balinese households in the study reside in the village of East Werdhi Agung (*Werdhi Agung Timur*). East Werdhi Agung is an independent village that has broken off from the original transmigrant village, Werdhi Agung. One of the unique aspects of Werdhi Agung and the villages that have subdivided from it, is that the transmigrants were all relocated from the same village in Bali following the destruction of their home village in Bali by a volcanic eruption. Previous research has noted that the culture in this village remains particularly uniform as there is no mixing of cultural practices from different parts of Bali prior to migration (Hoey, 2003; MacAndrews, 1978).

Balinese heads of households in the sample had an average age of 47.9 years, and the average number of residents of Balinese households in the study is 3.2. Balinese families are majority Hindu although two families converted to Islam and one family identifies as Christian. The one Balinese family that is Christian does not live in Werdhi Agung and is the only case of a Balinese head of household married to a non-Balinese wife. The Balinese population in the study had the highest percentage of people with no education or a primary school education.

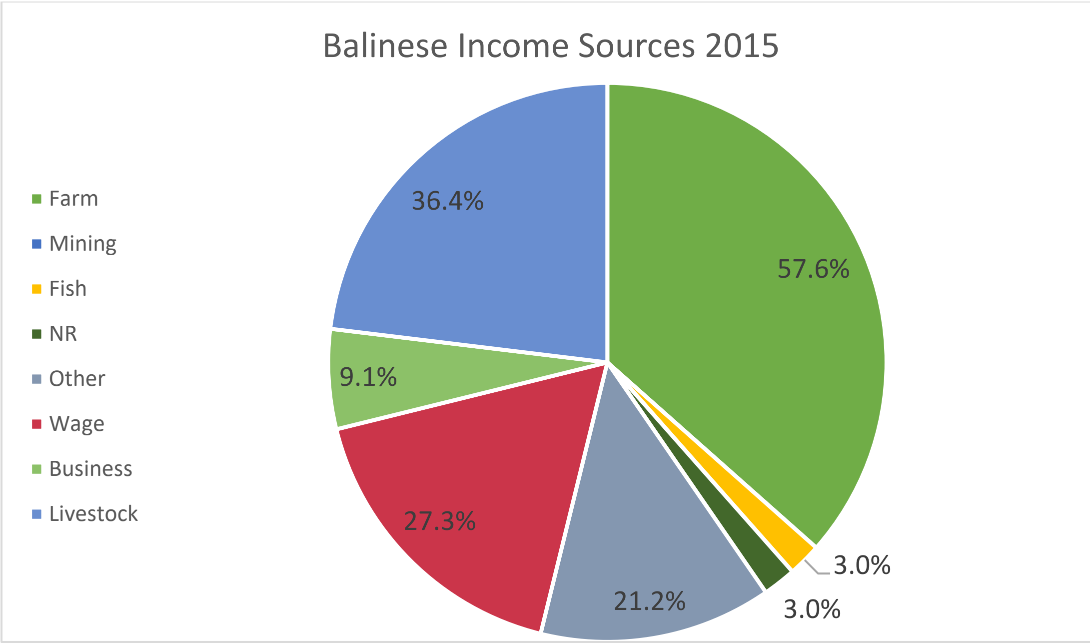


Figure 12. Percentages of Balinese Households Engaged in Income Activities in 2015. Percentages total more than 100% because households can have more than one income source.

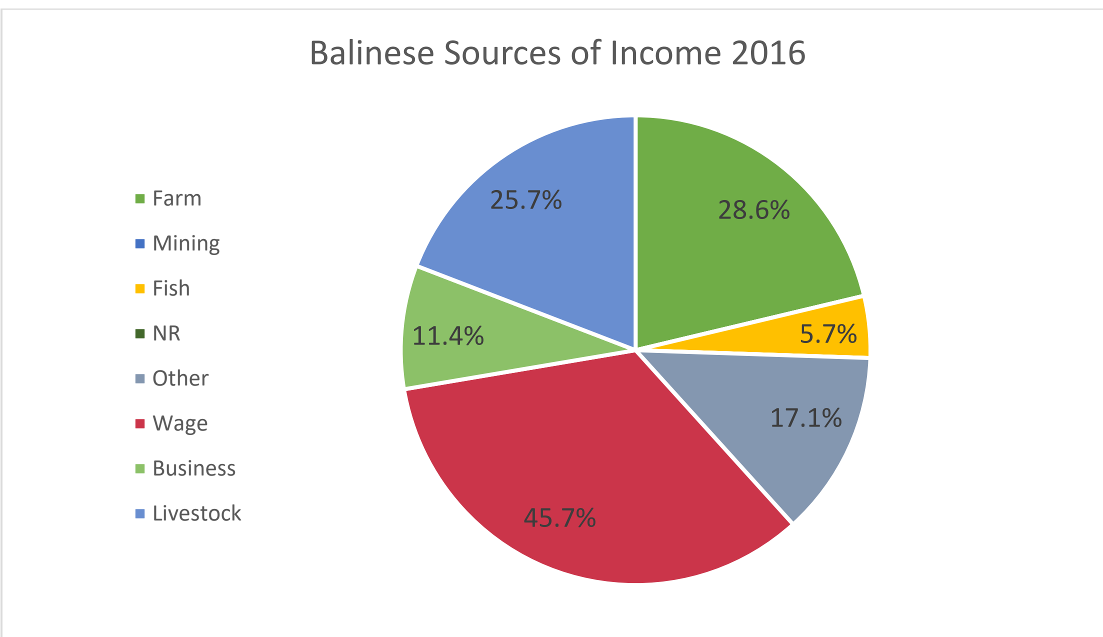


Figure 13. Percentages of Balinese Households Engaged in Income Activities in 2016. Percentages total more than 100% because households can have more than one income source.

Livelihoods of the majority of Balinese households in 2015 and 2016 are related to agricultural crop production (Figure 12 and Figure 13). There were also high percentages of

Balinese households that earned income through livestock production and wage labor. There was not a statistically significant difference between income source distribution in 2015 and 2016. Agricultural income in Balinese households primarily engaged in wet rice production with significant proportions engaged in corn, coconut and chocolate production as well. No Balinese household indicated that they had ever earned income through mining.

Most households report multiple sources of income such as agriculture and livestock (Figure 14). In both years of the survey, more Balinese households had two or more sources of income. Households had generally decreased the number of income sources in 2016, but the change was not significant.

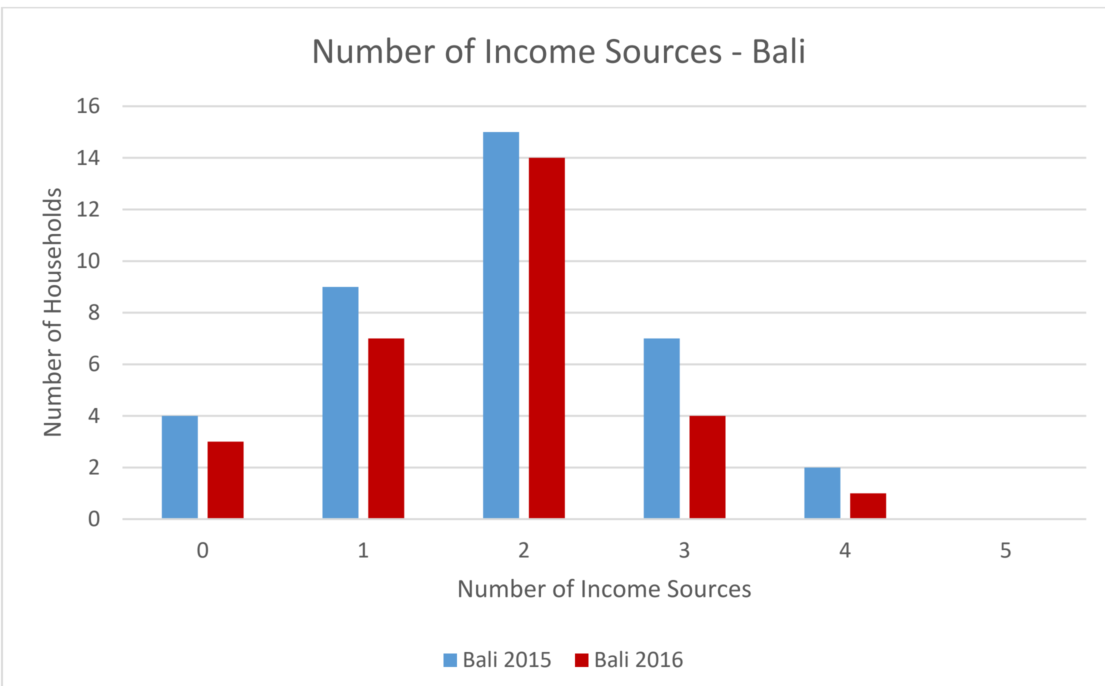


Figure 14. Number of income sources of Balinese households in 2015 and 2016

Over 70% of Balinese households have access to land. The majority own their own land, and a few households rent or borrow land. Only one Balinese household indicated that they had cleared forest in the past five years, and this household had subsequently abandoned that land

and are now landless. Seven households indicated they had previously sold land. Three households sold land to send children to school, two to buy other land, one to meet household needs and one to pay healthcare costs. Of these seven, only the household that sold land to pay healthcare costs is currently landless. The sale of land is a last resort for most families.

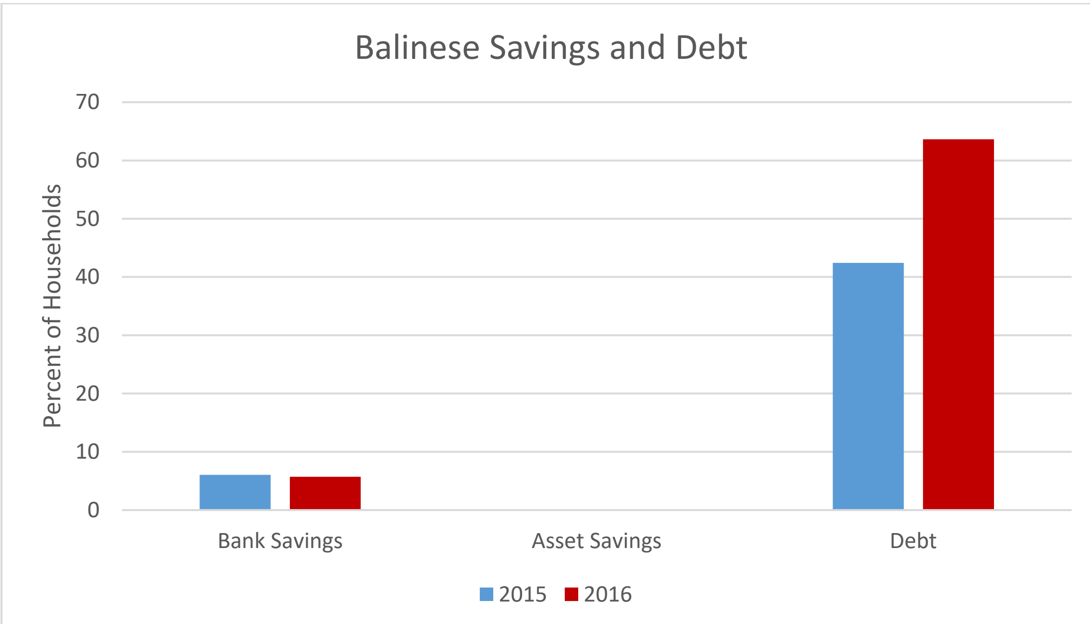


Figure 15. Savings and debt in Balinese households

In 2015, only 6% of Balinese households had savings of any kind and 42% had debt (Figure 15). The few households that had savings had the equivalent of between one and five months' salaries. In 2016, the total percentage of households with savings dropped only slightly, but the number of households with debt increased to over 63%. Balinese households frequently incur debt to obtain seed and other agricultural supplies. The intent is to pay back the debt upon harvest, making crop failure potentially catastrophic for households. The changes in savings and debt among Balinese households were not statistically significant.

Crop failure and illness were the most commonly reported economic shocks in Balinese households. In 2015, 24% of Balinese respondents indicated they had suffered a crop failure and an equal percent indicated that the household had suffered from serious illness. In a Balinese household, when one member is ill, even severely ill with, for example malaria, other members of the household will continue to work. This contrasts with Minahasa and Mongondow families.

Although many of the health care workers in the valley are Balinese, the population is not healthier than other ethnicities. Balinese experience roughly the same percentage of illness as other ethnicities. In 2015, Balinese households reported the largest percentage of serious or fatal illness in contrast to 2016 when Balinese households reported the lowest percentage of serious or fatal illness.

2.2.1.3. Jaton

Jaton is a contraction of Java Tondano. They are people who trace their roots to political exiles that were sent to settle in the Tondano from the Minahasa Region of North Sulawesi. The community started with a small group of Muslims that were exiled by Dutch colonists over 150 years ago. Unlike the transmigration of entire villages from Bali and Java in the Indonesian *transmigrasi,* these exiles arrived in small groups periodically over a long period of time. Today Jaton people retain their adherence to Islam, but do not use the Javanese language. Most exiles were male, and they intermarried with local Minahasa women. Jaton have lost their connection to Javanese culture in most ways. Religion is the primary distinguishing feature between Jaton and the predominantly Christian Minahasa people.

Heads of Jaton households show the oldest average age, 50.7 years, and an average size at 4.5 members. Jaton households have a similar education level distribution as Minahasa households. A little over one-third (35%) of household members in the sample have grade school education, 28% have middle school education and over 26% have high school education. Ten percent of Jaton household members have education beyond high school.

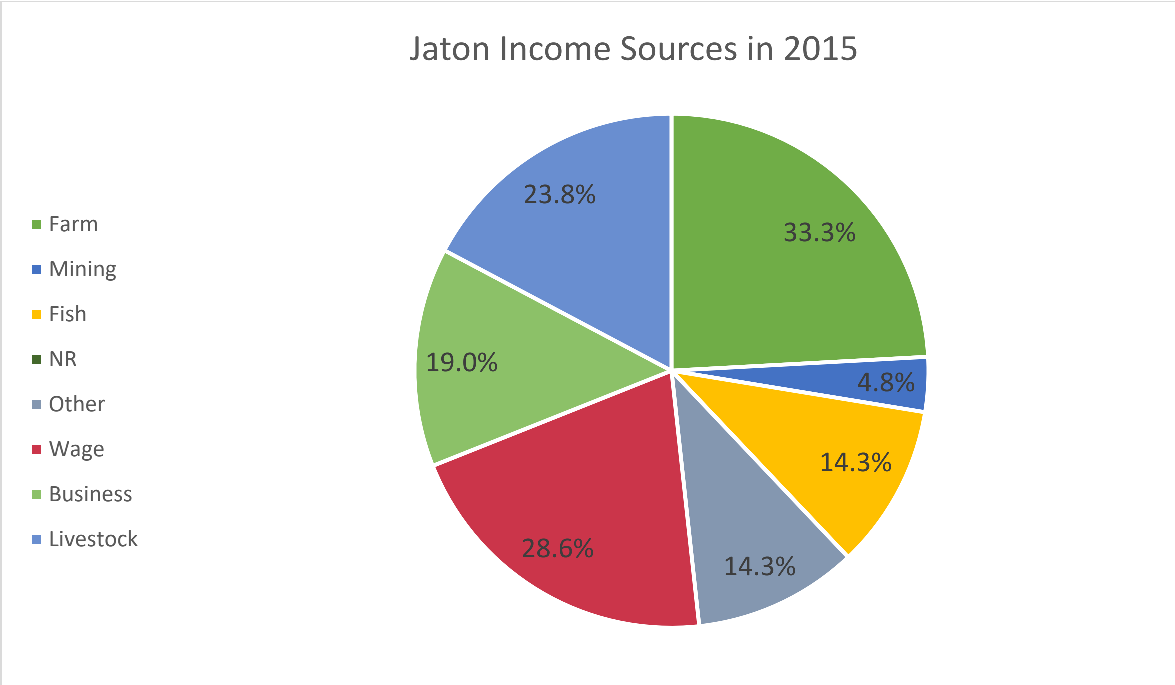


Figure 16. Distribution of income activities of Jaton households in 2015. Percentages total more than 100% because households can have more than one income source.

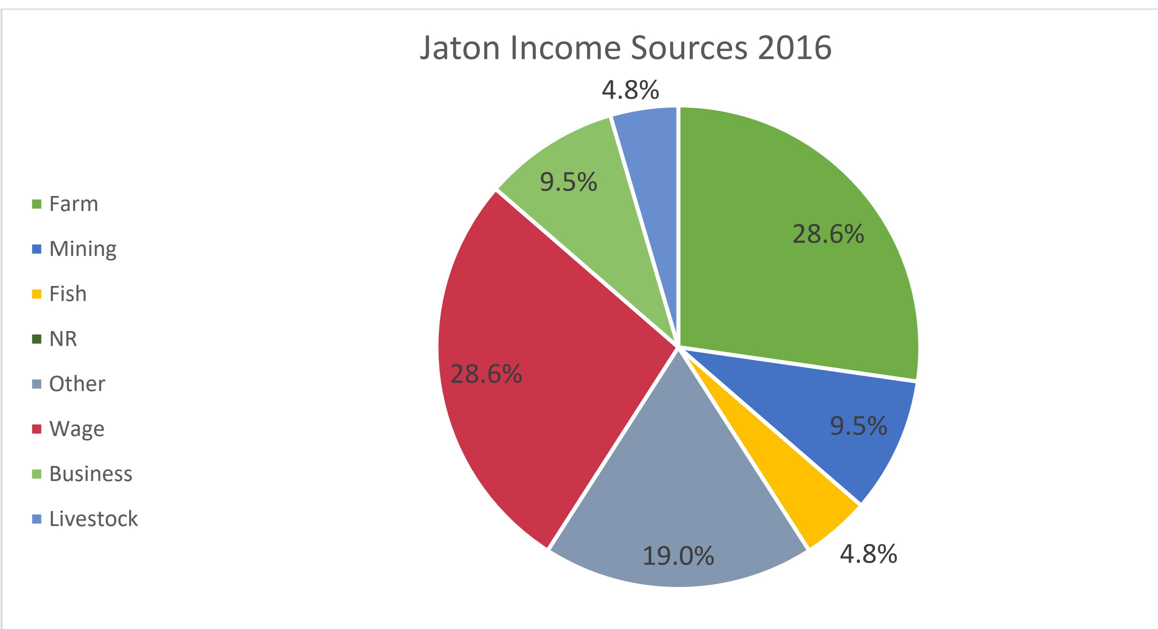


Figure 17. Distribution of income activities of Jaton households in 2016. Percentages total more than 100% because households can have more than one income source.

In 2015, Jaton households chose livelihood strategies that included agriculture, business, livestock, and wage labor in similar proportions. Mining, fishing, and other income sources were a smaller proportion of income, but also roughly equal. In 2016, however, households relied heavily on wage labor and agricultural income. There was not a statistically significant difference between income source distribution in 2015 and 2016.

The majority of Jaton households had a single source of income in both 2015 and 2016 (Figure 18). Households appear to show decreased numbers of income sources between 2015 and 2016. No households had more than three income sources in 2016, and the number of households with two income sources remained the same. More households indicated a single income source in 2016 than 2015 and fewer households had no income. Although it could appear that households with no income gained in income sources, further analysis suggests that the increase in households with a single source of income derives from loss of income sources from 2015 to 2016. The decrease in households with no income is likely the result of poor households not being available to participate in 2016. The changes between 2015 and 2016 were not significant.

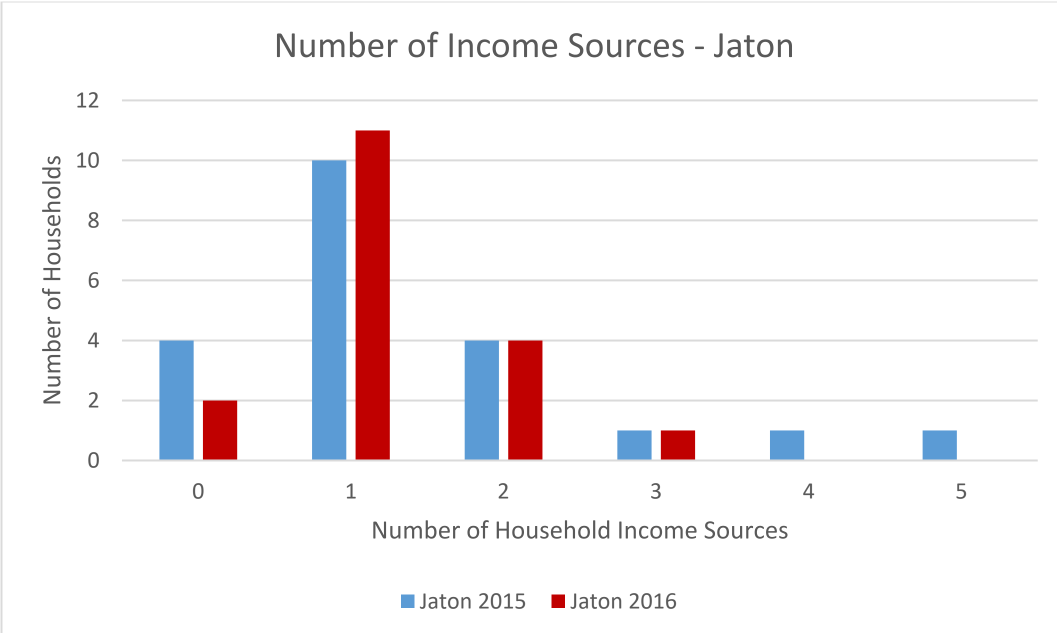


Figure 18. Number of income sources in Jaton households in 2015 and 2016.

In 2015, 57% of Jaton households were landless. Only Minahasa households had lower land ownership in 2015. In 2016, the percentage of landless Jaton households decreased to 50%, but that decrease is due to withdrawal of landless households from the study. The only Jaton household to indicate that they had sold land had sold it in 2014 to send children to school.

Compared to other ethnicities in the study, Jaton households reported relatively high levels of savings and low levels of debt. In 2015, percentage of households with bank savings (19%) was slightly lower than Mongondow, who had the highest rate of bank savings. Like the Balinese, Jaton households do not seem to emphasize asset savings. In 2015, only two households (9.5%) reported having minimal amounts of asset savings and in 2016, no households reported asset savings. In 2016, the percentage of households reporting bank savings dropped to 14%, which was second highest in the sample after Minahasa households. Debt decreased from two households (9.5%) to none between 2015 and 2016 (Figure 19). However, these changes were not statistically significant.

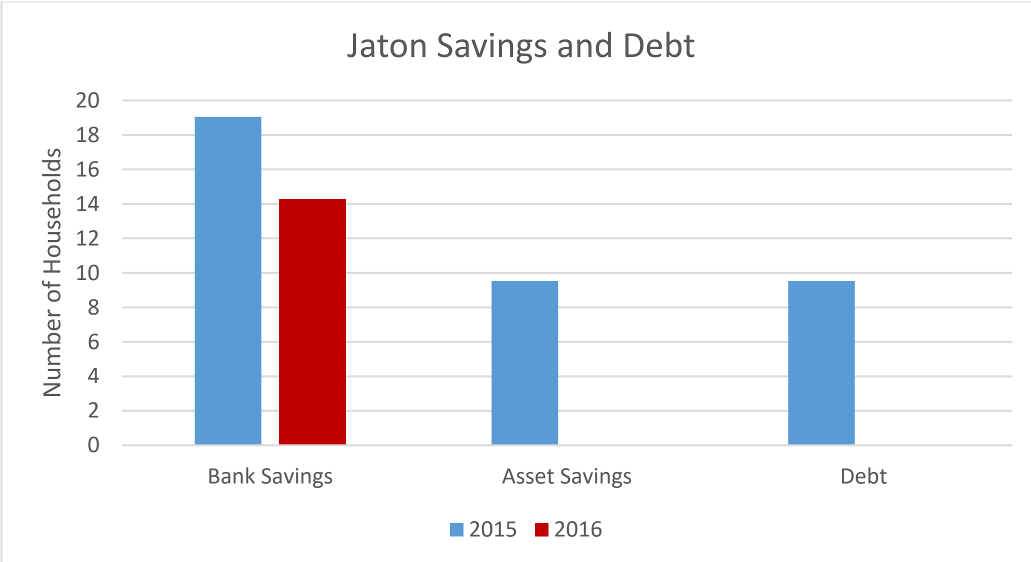


Figure 19. Savings and debt in Jaton households in 2015 and 2016.

Jaton have the highest level of illness occurrence. In 2015, 66% of households reported illness, including several fatal and severe illnesses. However, most of the illnesses were minor ailments such as a cough or cold. In 2016, 77% of households reported illness, but again, during this period, most illnesses were minor.

In 2015, Jaton households reported lower levels of unexpected crisis expenditures, primarily crop failure, than other ethnicities. In 2016, Jaton households showed a dramatic increase in crises and as a result, they had the highest proportion of households that experienced crises among all ethnicities. The crises included crop failures and serious illness

2.3 Summary

As new immigrants and transmigrants arrived in the Dumoga Valley, and government policies supported changes in agricultural practices, the landscape in the valley changed. Today the Dumoga Valley is home to multiple ethnic groups, each with their own culture, livelihood strategy and relationship with their environment. Households in the Dumoga Valley rely on natural resources and ecosystem services, particularly provisioning of water, for livelihoods.

However, their income activities also have potential to degrade those natural resources.

Table 1. Summary of Data

	HH 2015	HH 2016	Religion	HH Size	HHH Age	% Land	% Illness Combined
Bali	33	28	Hindu	3.24	47.94	72.73	60.66
Minahasa	142	130	Christian	3.45	49.70	40.56	61.17
Mongondow	114	96	Islam	3.48	45.45	62.93	71.79
Jaton	21	18	Islam	4.48	50.74	42.86	56.13

HH 2015 – Number of households in 2015 survey. HH 2016 – Number of households in 2016 survey. Religion – predominant religion of ethnic group. HH size – average number of members in a household. HHH Age – Age of the head of household. % Land – Percent of households with access to land. % Illness combined – Percent of households that experienced any illness during both survey periods.

Literature suggests that household demographics influence livelihood strategy development (Ellis, 2008; Peng et al., 2017). The overview data from this study demonstrate that ethnic groups differ in factors that have been associated with natural resource extraction as a component of livelihood, such as household size, age of head of household, education and land ownership. For example, Balinese households tend to have more diversified livelihood strategies, but they do not engage in mining. The 2015 survey occurred at the end of the productive rainy season, and the 2016 survey occurred during an abnormally long dry season. Fewer households of all ethnicities were able to earn agricultural income in 2016. However, their income substitution patterns differed. Balinese and Minahasa households increased engagement in wage labor while Mongondow households sought other forms of income. These included finding work as drivers, motorcycle taxi operators, or mechanics. A few Jaton and Minahasa households turned to mining as well. The next chapter will examine the statistical differences in household factors and seek to identify which factors explain variation between resource extractive behaviors. The remaining chapters of this dissertation explore the system-wide implications of these differences.

Chapter 3 Assessing vulnerability

This chapter focuses on the influence of vulnerability context on household livelihood strategies in resource-dependent communities of the Dumoga Valley. This chapter first explains the conceptual foundation of vulnerability analysis from an SES perspective. I draw on the vulnerability assessment framework suggested by Turner et al. (2003) to structure this analysis. Then I describe methods used for data collection and analysis and present themes related to the components of the vulnerability framework that emerged from those data.

3.1 Conceptual model of vulnerability context

Vulnerability is the extent to which perturbations or changes experienced by the human or environmental component of a system disrupt its function (Turner, Kasperson, et al., 2003). The vulnerability context encompasses social, economic, environmental, institutional, and demographic conditions that influence the sustainability of the social-ecological system. Analysis of vulnerability is fundamentally place-based (Eakin, Winkels, & Sendzimir, 2009; Turner, Kasperson, et al., 2003), and dominant factors influencing vulnerability vary by system (Turner, Matson, et al., 2003). This research used qualitative interviews with households and local and regional government officials to explore components of vulnerability in the Dumoga Valley.

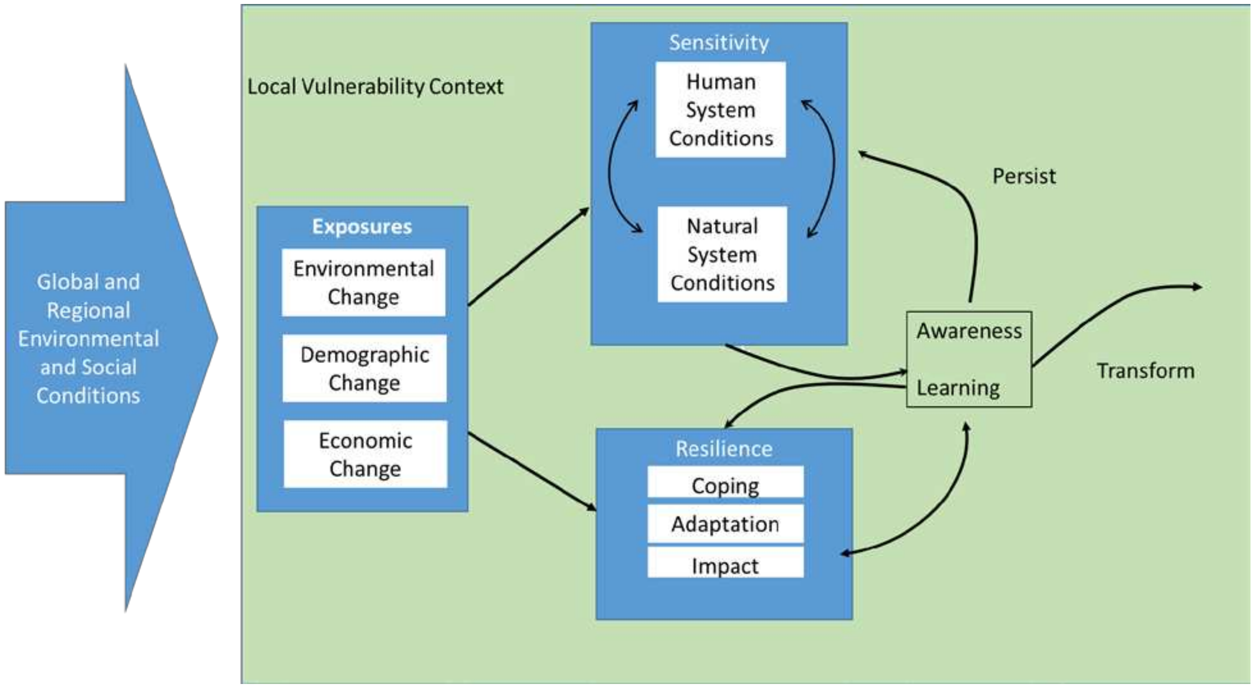


Figure 20. Conceptual model of local vulnerability context

Figure 20 depicts the conceptual model that forms the foundation of this chapter. It is a detailed depiction of the factors that comprise the local vulnerability context, nested within the regional and global contexts presented in the conceptual model in Chapter 1 Figure 1. The vulnerability of a system is determined by the sensitivity of the combined human and natural components of the SES, the types of exposures or stressors that affect the system, and the system's ability to cope with or react to those exposures (Chapin, Kofinas, & Folke, 2009; Turner, Kasperson, et al., 2003). Sensitivity arises from the conditions of the human and natural components of the system; degraded or stressed conditions increase sensitivity to many types of exposure. Resilience derives from the system's ability to cope with, adapt to, or react to exposures and either ameliorate or exacerbate the effects. Responses that ameliorate are adaptive and those that exacerbate are maladaptive. Responses are influenced by awareness of exposures as well as how learning and adaptation incorporate feedbacks between human and natural systems. Dynamic interactions between exposure, sensitivity and resilience determine if the system will persist or if it will transform.

3.2 Methods

Data for this chapter are drawn from semi-structured interviews conducted between August 2015 and February 2016 in villages of the Dumoga Valley. I interviewed village leaders, healthcare workers, cooperative leaders, environmental activists, and other village members. Although interviews started with specific individuals, others frequently joined in and formed ad hoc focus groups. I completed twenty-nine interviews and approximately 55 individuals participated in these interviews. Although I intended to interview participants one at a time, often family members or curious passersby would join interviews resulting in ad hoc focus groups.

Interviews were structured to obtain information about environmental, social, and institutional contexts in which households develop livelihood strategies and the use of natural resources in them. In addition, interviews focused on eliciting perceptions of health, health care and the environment. I did not provide a definition of health or environmental change in the interviews or in the quantitative surveys that are discussed in the next section. As suggested by the conceptual model (Figure 20), perceptions of health and perceptions of environmental change affect decision-making. These perceptions may or may not be based on objective data and may vary from one respondent to another. Therefore, while clear illness diagnosis or quantification of environmental change would be helpful for decision-making by policy makers, households make decisions based on their perceived health condition, and they respond to perceived environmental changes.

I conducted all interviews in Indonesian and recorded them for transcription later. A local research assistant attended all interviews to assist with translating the local language if

Indonesian was not sufficient for communication. All interviews were transcribed and analyzed in Indonesian; the only translations that I conducted were for statements quoted in this chapter.

To analyze the data, I used a modified framework approach (Ritchie, Lewis, Nicholls, & Ormston, 2013). I first developed a set of a priori codes based on the concepts that interviews were designed to explore. These codes were also informed by literature, and they were developed to complement factors explored in quantitative surveys and provide context for interpretation of the quantitative results presented in Chapter 4. Initial codes included broad topics such as the environment, social change, mining, farming, cultural differences, and health. Because I conducted the interviews personally, I also noted any additional themes that emerged during data collection. These themes were also added to the a priori codes.

After conducting interviews, I reviewed transcripts of the interviews in Indonesian and applied the established codes manually using NVivo 12 (released 2019). Because all data were analyzed in Indonesian, computer-assisted coding was not possible. The software was used to help me apply codes and collate data as is done in manual qualitative data analysis. During data analysis, I added additional codes from themes that emerged, which related to exposures, sensitivity, and resilience. For example, the initial framework included feedbacks between environment and livelihood choice. As data were coded, the nature of this feedback was refined, and I added a category for environmental perception. Once the codebook was fully developed, I sorted the data by code and developed narratives to describe important components of the vulnerability context.

3.3 Results

3.3.1 Health

A key difference that emerged from the data was that response to illness in the household is radically different between Balinese and Minahasa or Mongondow households. In the Balinese households, the ill person will stay home, and the rest of the household will continue with regular activities. In the Minahasa or Mongondow households, however, when one member of the household is ill, the rest of the household suspends usual activities. One Minahasa civil servant explained that if his wife or child were sick, he would be unable to work because he would be too concerned and distracted to work. Therefore, the impact of illness on livelihood activities varied by ethnicity.

It was very difficult to obtain clear answers on health conditions or the severity of illness. Quantitative surveys, discussed in the next chapter, attempted to quantify type of illness and length of time that the household's income activities were affected by illness. However, these data were not reliable or clear because enumerators led respondents in order to get any time of answer to these questions. Often, illnesses were not clearly diagnosed by healthcare workers. Healthcare workers at local, government-funded community health centers retained data only on illnesses that are predetermined by the central government. This prevented them from obtaining support to track novel illnesses and biased them toward diagnosis of the most common illnesses on that predetermined list.

General respiratory illness was very common and could be related to mining. A regional healthcare worker identified that tuberculosis (TB) proliferates where there is a higher percentage of miners. He explained that miners often pass a single air hose back and forth when in the mine and this can facilitate the spread of TB. Other illnesses such as stroke and diabetes were also frequent. Furthermore, several respondents indicated that they were completely debilitated by diseases such as asthma or high blood pressure that would be manageable with medications that were not available to them.

Residents understood that there is a connection between their health and village environmental conditions. A Village Head indicated that health in the village had improved because people are now aware of *kebersihan lingkungan* or cleanliness of the environment. A health center nurse described the installation of public latrines in one village as a cause of improved health. However, connections between environmental conditions and health at a larger spatial scale (e.g., air and water quality) were not drawn by any respondents.

3.3.2 Environmental Change

Several indicators of environmental change emerged from the interviews. Frequent examples of environmental changes that impacted livelihoods included expansion of agricultural land through forest clearing, decrease in irrigation water, and changes in the dry season. Some long-time residents described the area as "still" forest when they arrived. They have witnessed the Dumoga Valley change from impenetrable jungle filled with malaria and dengue fever to the complex agricultural matrix that exists today. Several respondents described the arduous journey to the area from Kotamobagu, the nearest city: "To get here, you had to walk because if you took a vehicle, it would take longer. There were no roads…"

Residents also described more recent changes to the environment. Frequently, respondents spoke of drastic decreases in discharge capacity of the dams. For example, one respondent said, "Environmental change can be felt strongly now. The dry season is different than it used to be. Before, the dry season could last eight months and we would still have water [from the dams], but now, that has decreased drastically." Another villager lamented, "We farmers feel a great loss because the water that could usually irrigate 48,000 hectares can't irrigate that anymore because the dam has little water. In the end, some are forced to not be farmers anymore."

All respondents who spoke about the irrigation system described decreased water availability. Respondents indicated that though three rice harvests per year were common in the past, that had decreased to two or, according to some, one harvest per year due to lack of irrigation water available to be discharged from the dams. The dry season of 2015 stretched well beyond what respondents expected, and many indicated that there was no work because of the dry season. Without water to irrigate crops, they were unable to work their own land or find employment working the land of others.

There were also indications of a perceived change in water quality. One environmental activist in Ikhwan-- a farmer who has some education in conservation and who has worked with conservation groups to educate other farmers-- indicated that the quality and amount of water had changed, but there has not been testing to prove the change. He said, "There has been a change from cool, clear water and today it is no longer cool and not clear. We cannot say definitively that it is polluted because there is no research and no proof. Certainly Kosinggolan's [one of the dams] water is polluted." Several respondents indicated that there was no environmental change when questioned directly, but they mentioned such changes in reference to other subjects. For example, one respondent said that there was no environmental change when asked directly, but then went on to describe changes in land use and decreased water quality.

Although there was consensus among respondents that there has been a drastic reduction in water discharge from the dams, there was disagreement as to the cause. Occasionally, a respondent would relate decreases in water to human activities such as mining, forest exploitation, or climate change. One Balinese villager mentioned that, despite lower availability of water collected by dams higher in the watershed, flooding in the valley, particularly in villages at lower elevations, had worsened. He said that as trees in the forest had been cut, villages below were being drowned. The environmental activist in Ikhwan said, “With the opening of the mining area, there was first an impact on water discharge. The discharge from the Kosinggolan River decreased drastically." On the other hand, one Village Secretary attributed lack of water to the climate saying, “It is because it is hot [dry]. Usually it [the river] flows. It is only because there have been so many hot [dry] months.”

When asked about environmental concerns, most respondents spoke of *penghijauan,* which literally translates as “greening”. *Penghijauan* focuses on cleaning trash and waste and planting government-provided trees in the village. I observed a graduate of a forestry program at a local university tossing trash into a river outside village boundaries. He explained that it was not acceptable to throw trash in areas where people would see it, but out in the countryside, trash was not a problem.

Explicit environmental concerns for many respondents were related to locally observable sanitary conditions. Several people expressed concern about contamination from open latrines. Others remarked that construction of community latrines had helped improve sanitary conditions. However, awareness of contamination is relatively new in the area, and residents do not have access to information about this topic. In an interview, a retired healthcare worker discussed changes in water quality. When asked how water quality was assessed, she indicated that water that is “fresh” is clean and does not smell bad. Despite her education and experience in healthcare, she was not aware of other potential dangers in water such as contaminants that can only be discerned through scientific testing.

3.3.3 Demographic change

One early settler indicated that in early days, people were not interested in sending their kids to school. He referred to education as a "secondary thing". However, he acknowledged that had changed. He explained that some families had educated their children and the families had been successful in securing reliable income and a better standard of living. Many households, particularly Balinese households, recognized the role of education in providing children with opportunities, and it has become increasingly important to send children to school.

Interviews indicated that schooling opportunities continued to be extremely limited in villages within the Dumoga Valley. Although there were a few primary schools, teachers were not always available. Schools built by international aid programs sat idle, as there were no qualified teachers to hold class. Teachers are all government employees and receive a salary. If they are unable to work, they still draw salary, but their classes are cancelled. To receive an education beyond middle school, children must relocate to one of the cities. Many children who attend high school live hours away by motorbike from their families in the city of Kotamobagu. Parents often sold land and became wage laborers to pay for tuition and housing expenses for their children.

Educated children often did not return to the villages, but rather obtain employment away from home and support their families through remittances when possible. This sets up conditions for "brain drain" and loss of human capital in Dumoga. A respondent noted that after obtaining a degree, young adults from Dumoga had to seek employment elsewhere. He explained that after paying for children's education, parents were often left with no land or savings. Therefore, these families become highly dependent on remittances from children working outside of the area.

Short-term out-migration is another important source of income to the Dumoga Valley. A respondent explained, "Now there are many people who seek a living outside [of the Dumoga Valley] because it is the dry season." Many families indicated that family members participated in mining in other regions of Sulawesi, or even on different islands in Indonesia. There were frequent mentions of remittances from children or other relatives who work in larger cities and send money to support their families.

3.3.4 Government Interventions

The government supports agricultural development through provision of fertilizers, pesticides, and seeds/seedlings. However, one farmer noted, "Farmers don't listen to the government. Government extension provides support in the form of seedlings, but they are not the varieties that farmers want." The system for distribution of aid also creates conditions for potential corruption and coercion. Farmers must be members of a farmer organization to receive government support, and the administrators of these organizations are often closely tied to local governments, making aid distribution subject to political bias.

There are also significant concerns about government misuse of funds and corruption related to national parks. One respondent explained,

> We are very happy that there is research here, but there is one thing that we don't like and that is if there are people who enter the forest [national park], it is usually with backing or back up of government officials, secretly. Like mining, it now has [unofficial] government support so that they are safe inside [the forest]… And we are very sorry because the government doesn't think about how farmers can get agricultural land, but they only think about how the mines can function. The government doesn't think about how the water can flow into the rice paddies. The government never comes to see directly what happened so that it can be remedied. Before, many people picnicked at the Toraut dam but now there are not. There were even people from outside the area that came to visit the national park.

The park had value to local people as well as to scientists studying the park's endemic species. However, as land became scarce, agricultural need began to outweigh the perceived value of the park. The respondent continued, “But now, because there isn’t land anymore, the people near the park break through to the interior of the forest because the boundary is in their back yard.” Areas with perceived value, such as the area adjacent to a small, rarely occupied research station, did continue to enjoy a level of protection. At the time of the research, this area was still intact forest, though the areas nearby were converted to agriculture.

Many people discussed this lax enforcement of the protected area. A Village Secretary described conflicting information from the government:

> There is an advisory from the Ministry of Forestry that we cannot destroy the forest. Of course, there are park boundaries, but after seeing the crops inside [the park] are good, well, they [the government] give us freedom [to cultivate], but only at the bottom [of the mountains].

Although the government established the park boundaries and occasionally expelled people from within the park, the villagers felt that they had permission to plant crops inside the park. No such permission was granted officially, but government officers rarely visit the valley to enforce boundaries. Another villager associated lack of irrigation water to lack of enforcement, saying, “One of the primary causes [of water shortage] is pilfering of the forest buffer due to lack of enforcement [of the national park boundaries].”

When asked if representatives from the Ministry of Forestry or the National Park Service visited or monitored the park, one Village Secretary explained, “No, because the reports that get to them say that everything is going fine. Therefore, they don’t come see things here even though the park is beginning to break down.” The National Park office is in Kotamobagu, approximately 50km from the nearest border to the park. The head of the park did not live in Sulawesi and never visited the area. The villagers indicated that reports about the status of the park were completely fabricated and that no monitoring was carried out by government agencies.

Interviews with government agencies demonstrated a confusing lack of authority when issues of illegal mining and health were discussed. A representative of the provincial environmental body, BLH (*Bidan Lingkungan Hidup*), indicated that they are aware that illegal mining occurs on a large scale and that this mining is unregulated. However, although BLH was responsible for water quality monitoring, they did not test for heavy metal contamination, which is commonly associated with illegal mining. They indicated that they did not have to complete those tests because they have not received reports from the provincial health department (*Dinas Kesehatan*) on potential health threats. However, the health department officials indicated that they could not begin to explore potential health threats associated with mining until they had testing that demonstrated the presence of heavy metals.

Local and regional governments play a key role in infrastructure development, and numerous interviewees noted changing infrastructure as a positive development. Several village heads indicated that they had recently obtained funding from the regional government to pave roads to their villages. Villagers pointed to improvements in sanitation, roads, and electricity as signs of how life had improved for them. New and better roads allow for better marketing of products and access to schools and health care that would have been burdensome in the past.

3.3.5 Livelihood Choices

Livelihood choices differed by ethnicity as well. In Chapter 2, I discussed differences in the number of income sources on which Many respondents expressed concerns that livelihood strategies are highly constrained by lack of land, infrastructure, and capital. One respondent estimated that only about 2% of the people in his village had employment outside of agriculture. These jobs included civil service (which, in Indonesia, includes teaching) and small businesses, such as independent taxi services or informal roadside stands selling drinks, snacks, noodles, or fruit. Other informal income sources were difficult to assess. Most households had gardens or planted subsistence crops along with their production crops. No respondents offered any evidence of barter systems or other informal markets other than the *mapalus* system discussed below.

When asked about the future of Dumoga, one of the early settlers (also a former village head) indicated that he thought the future would be difficult. He suggested that people would need to find other sources of income, such as animal husbandry, but that increasing prices of animal feed also makes that industry difficult. Opportunities to develop improved agricultural practices or invest in high value crops were constrained by lack of market infrastructure. Households with sufficient labor available to produce and market goods could sell agricultural products at the local market. Other households had to sell to aggregators. Some villages had locally owned mills where they could sell rice or corn. Farmers would sell other products, such as spices or coconuts, to someone who could transport their harvest to larger processing facilities or markets in the region. Mill owners and aggregators were well-positioned to set low prices for products because farmers did not have sufficient market access. However, lack of infrastructure, challenging environmental conditions, lack of education, unequal access to credit and other factors constrain current opportunities for individual households to engage in new livelihood strategies.

Between 70% and 99% of villagers identify as farmers. When asked about income sources, one Village Secretary responded, "Yeah, ninety-nine percent of the people here are farmers. There are even some civil servants who go straight to work their plot when they come home from work. There are some tradespeople, but only a few, but they all come back to farming." In another village, the village secretary shared, "In this village, people only expect income from farming, there is no other income. There are only four civil servants including me."

Respondents who predated the arrival of the transmigrants described how agriculture has changed over the decades. Changes in infrastructure (e.g., irrigation) and the environment have affected agriculture. Respondents from government extension agencies indicated that many farmers were conservative and slow in adopting new rice varieties or cultivation practices despite increasingly unreliable agricultural incomes. Respondents indicated that they noticed decreased yields, which they associated with longer dry seasons, less water, and increased pest outbreaks.

The environmental activist in the village of Ikhwan concluded,

> In terms of income per hectare, it does not go up with each harvest, it goes down. We follow the advised farming system, but the harvests decrease. Maybe the farmers conclude that the water is polluted or whatever, but they are not sure why the harvests are down. Farmers have not been able to conclude whether the water is contaminated, but they feel it. We can't make any conclusions because there is no proof and there needs to be concrete research.

Such concrete research into any of the potential causes for decreased agricultural yield is difficult to implement. The head of a farmers' cooperative in Imandi explained, "Here, we do not yet have tools to test pH, NPK [nitrogen, phosphorous, and potassium]. I only saw it when I went to a training in Palembang [the capital of South Sulawesi Province]. There is only one [test kit] here and it belongs to the government."

Government support for improvements in wet rice agriculture have resulted in benefits for farmers with sufficient reserves to bear the risk of experimenting with agricultural production. One Village Head insisted that agricultural outputs have increased because of technology, saying,

> Agricultural harvests are increasing now because people are using technology. There is a lot of extension from the agricultural service. Before, they worked their paddies [wet rice fields] manually and used cows to plow the paddies.

> They harvested only using manual labor. It is not like that now because they use machines [for planting and harvesting]. Therefore, the work is easier and faster. One hectare can be harvested in one day whereas before, it could be one week to ten days. It is different now. And before, the yield from one hectare was one ton, but now it can be as much as 2.5 tons because of fertilizer…

However, very few farmers have sufficient capital to benefit from this improved technology. In contrast to the statement by the Village Head touting mechanical advancements, farmers often complained about the cost of new production techniques. For example, few farmers owned tractors, and those who did rented out their services. Therefore, a farmer without a tractor to plow the paddy would have to pay for the service and wait until the tractor operator had time to plow his field.

Farmers also complained about the cost of fertilizers and the need to apply increasing amounts year after year to produce sufficient crops. In addition to water issues, farmers noticed loss of soil fertility, which forces them to be reliant on artificial, expensive fertilizer. As summarized by one respondent, “Ten years ago there wasn’t much fertilizer, but harvests were good. Now, many pests and less fertile soil means smaller harvests. If a lot of fertilizer is used and pesticide is sprayed, then there is a good harvest.”

Crop losses to pests, particularly mice, were also frequently mentioned. Even if a farmer can obtain sufficient water to plant a rice crop, the profitability of that crop can be destroyed by losses to pests. One respondent described how rats can decrease the yield of a one-hectare plot from 100 sacks of rice to four or five sacks of rice. This production would be sufficient to possibly serve as seed for a subsequent planting or feed the family for a few months but would not provide any additional cash income.

Farmers who were unable to meet their needs from agriculture were often forced to engage in illegal mining. One man explained the dangerous role the illegal gold mining plays in the local economy.

> In the mine there is big income, but there is big risk as well. If the mine collapses or there is a landslide, of course there are deaths because the mines are still traditional, and all the work is still manual. If there is someone that uses cyanide, people in the village are very afraid [of being exposed to cyanide]. Many people are at risk [in the mines], but they do not realize [mining] is dangerous.

In addition, a former mine owner explained, "If they enter the mine and production is good, they do not think about the risk anymore, but they only think about how production can bring big money. I, myself, am afraid when I enter the mine, but they are not."

Most respondents were hesitant to discuss the physical danger associated with mining. One respondent recounted the death of a friend: "I had a friend that mined as a hobby. He made a tank to process ore. He used chemicals and his lungs were destroyed by the exposure and he died. He processed by himself using cyanide." A couple that had previously owned a mine indicated that they were not unfamiliar with deaths in the mines: "If they worked for us, we arranged everything from bringing the corpse [from the mine], the funeral to the [religious] offering."

In addition to rise of physical harm or death, respondents spoke of fear of being arrested or losing the product of their labor because mining is illegal. Many former miners recalled periods when the government sought to shut down illegal mining in the national park and expressed fear of the government raids to remove illegal miners from the park. They recalled that, in the 1990s, the government expelled all the miners from the national park. This kicked off a period of violence, as frustrated miners with no income began to clash with one another. Many miners and mine owners reported that there had not been government raids in the mining area for some time and that they felt that the government now ignored illegal mining. This was supported in interviews with several government officials who indicated that they recognized the need for people to earn a living, and if they took away mining, many people would resort to other sorts of crime to meet their needs.

However, income from mining was described as uncertain and highly variable. Miners or their family members indicated that a miner could work for several weeks and not find gold. Others showed the products, such as motor bikes and televisions, that they had been able to purchase after highly successful mining ventures. Several respondents indicated that often, after a miner pays for food, lodging, and gold processing, there is not much income at all.

3.3.6 Land availability

As the valley was settled, farmers carved their plots from the forest. If a family needed land, they could simply clear the land and begin to farm. However, as the government has supported immigration and more farmers have entered the valley, land shortage has hit a crisis level. “Before, often people thought it is easy to get land, but now it is very difficult to get land. Now people think it is very difficult to get land,” said one village official. Another respondent pointed out, “…rarely is there available land”. Land ownership has also been consolidated by absentee landlords who do not work the land themselves, but instead hire local people as wage laborers. In Ponompiaan, one of the villages nearest the city of Kotamobagu, a village official and his family explained that all the land along the paved highway belonged to the regional governor or people from China.

In the past, when land was easily opened, the decision to sell or trade land was easily made. Said one respondent, “[In the 1970s], they would exchange [10 hectares] for a lamp.” Minahasa and Mongondow settlers would clear land, farm for a short time and then sell their land to the relatively wealthy Balinese farmers. They repeated this process until changes in the population and restrictions on land use made the decision to sell or trade land more difficult. In interviews, when speaking about the sale of lands, Minahasa and Mongondow respondents frequently spoke of being forced to sell land. Farmers were increasingly hesitant to sell land because they knew that obtaining land again, by clearing forest or purchase, would be more difficult. Therefore, there has been a shift away from practices of clearing and selling land as a livelihood strategy. Now land sales are executed only to meet needs for large expenditures. One long-time resident explained, “And people or farmers are forced to sell land because of the need to send children to school. It is not possible to sell land just to be able to eat.”

A village head described several reasons for land sales:

> People here often sell their land out of necessity. They are forced to in order to send children to school, or because there is a sick family member who has a big expense and their only way out is to sell their farm. There are other reasons too. When they need money, including if their child gets married, they sell land... Many people spend so much money [on weddings] that they sell their land or farm without realizing that it is their main income. So former landowners now have become laborers on their own land.

Balinese also sold land for household needs, but Balinese tended to have larger plots, and were able to retain some land for farming. Respondents indicated that although there are some Balinese who sell land, there are also many who buy. While Minahasa and Mongondow respondents indicated that there was a shortage of land, the Balinese can often purchase land from those who are forced to sell. One respondent from the village of Konarom explained,

> Balinese and Javanese people, if they already have one hectare, they think about how to get more land. However, Mongondow think that they already have the important things and if they have a need, they will sell land for whatever reason. The *transmigrasi* think that one piece of land has meaning.

Balinese and Javanese transmigrants, who came from places of land scarcity, value each hectare of land. In contrast, Mongondow and Minahasa people hail from areas with abundant available land and therefore do not prize land as much as the transmigrants.

3.3.7 Economics

In Dumoga, savings rates are very low (Chapter 2). One respondent summarized the situation saying, “But how do you save when there isn’t enough to buy food?” Some miners were able to save money and buy land, but others were not. A Minahasa couple in Imandi who once owned a mine indicated that they had saved funds sufficient to educate their children and invest in equipment for construction and agricultural marketing. In contrast, the wife of a miner who travelled to Irian Jaya for long periods to earn money in mines stated that she spent money as soon as it was remitted from the husband. However, she indicated their motor bikes, a karaoke machine, and other electronics that they had purchased with the last windfall profit.

It was not uncommon for Balinese to have debt. Balinese respondents often indicated that they borrowed from the mill to plant rice, then paid the mill back with income from harvest. In other villages, people indicated that their lack of collateral prevented them from borrowing from anyone other than loan sharks. None of the respondents in the villages referred to money owed to pay for medical care as a type of debt, but nurses at healthcare centers often showed me large ledgers that contained the amounts owed by patients. Although healthcare is ostensibly free, medications are not. Nurses that I interviewed often purchase medication with their own funds and are willing to let patients pay what they can when they can.

3.3.8 Social Capital

Gotong-royong, or in the Minahasa language, *mapalus*, is the Indonesian philosophy of mutual cooperation or mutual help. *Gotong-royong* manifests in several forms. Often families come together to contribute food and decorations for festivals, funerals, weddings, and other celebrations. Community members will also band together to contribute support to less fortunate community members through activities such as house construction or land clearing for the needy family. There is also a strong tradition of community service through projects conducted by groups, such as school groups or church groups. These projects often result in facilities or programs that benefit all community members and are a great source of pride for those who contribute.

Some respondents referred to this as “social” *gotong-royong* as opposed to “economic” *gotong-royong*. This latter form of gotong-royong consisted of mutual help in income-generating activities, particularly in planting and harvesting crops. During planting and harvesting, farmers used to help neighbors with the expectation that when they required additional labor on their farm, those who they had assisted would assist them. A government official in Imandi described mutual cooperation in farming: “Planting rice or corn, all you had to do was call from house to house. This week plant rice on a certain day and everyone who was called showed up”.

Respondents recognized a decline in this form of economic cooperation in the villages of the Dumoga Valley. As land ownership declined and wage labor increased, landless neighbors required payment to assist in farming activities. The same government official from Imandi continued, “Due to the need and timing for gotong royong, the culture of gotong royong gradually began to erode.” When asked about on-farm cooperation, a civil servant in Konarom explained, “There isn’t cooperation anymore because people are looking to eat.” His response indicated that investment in social bonding of cooperation was eroding as households turned their focus to meeting their own needs. One of the earliest residents of Ponompiaan recalled, “I used to be the head of a *mapalus* group. There used to be more than 30 [groups], but now there are none.”

In addition to causing a drastic change in the economics of agriculture of the area, loss of gotong-royong resulted in loss of social ties. As cooperation in the field has decreased, so has participation in social events. Working and celebrating together is a form of social capital that can be drawn on in times of need but is rapidly decreasing in prevalence.

Farmer cooperatives are another important social organization that bring members of different households together. The government only provides agricultural extension through farmer cooperatives; therefore, any farmer who seeks help from the government must join a cooperative. The cooperatives serve as farmer unions and require a degree of organization amongst members. Although they are not completely social organizations and are related to government, farmer cooperatives provide opportunities for communication about the distribution of resources (most importantly irrigation water) and information about farming practices. They are an additional center for development of social and economic ties. They also are potentially coercive, as described above.

Most respondents emphasize how well the different ethnicities get along, but there are suggestions of past, negative interactions: “Well, now, the difference isn’t like it was before because now we all live in [Bolaang] Mongondow. There is no difference anymore between the Minahasa, Mongondow, Javanese, Balinese tribes. They have all become one.” Despite this sentiment, most villages remained ethnically or religiously homogenous (see Chapter 2). Fighting between villages is not uncommon. During data collection, there were several deaths resulting from clashes between groups of young men from different villages. Local officials attributed this violence to lack of employment opportunities and the availability of alcohol. This suggests that social capital between villages was low.

3.4 Discussion

The preceding sections give insight to some conditions and dynamics that comprise the vulnerability context of the Dumoga system. The system currently includes a number of threats that increase vulnerability and dynamics that decrease sources of resilience and adaptive capacity. In this section, I return to the conceptual model (Figure 1) to discuss the state of livelihoods, health, and the environment in the Dumoga Valley (i.e., sensitivities), the stresses that drive change in those sectors (i.e., exposures) and factors that contribute to the SES's ability to respond to those stressors (i.e., resilience). Taken together, these attributes of the SES provide an assessment of the vulnerability of livelihoods, health, and the environment in the Dumoga Valley.

Respondents in the Dumoga Valley clearly stated that they feel that they have limited livelihood strategy choices. Culturally, they view themselves as farmers. That is their desired identity as evidenced by miners' desire returning to agriculture, and businesspeople who still engage in hobby farming. However, lack of infrastructure, population growth, and shifting land tenure patterns threaten the sustainability of this preferred livelihood strategy.

Developing livelihood alternatives requires investment, infrastructure, and agency, which are (or are perceived to be) scarce in the Dumoga Valley. Savings rates were low, and debt was high in some populations, and credit availability was limited because most households lack capital to secure loans. In these conditions, respondents were able to identify few alternative livelihood strategies.

A long history of natural resource exploitation coupled with lengthening dry seasons has decreased agricultural yields and increased water shortages. Creation of sufficient land for agriculture can only be realized through deforestation, which results in additional environmental change. At the same time, environmental change/landlessness cause economic pressure by simultaneously decreasing crop yield and arable land. Available alternate livelihood strategies also have potential for system-wide consequences that could further drive environmental change.

For example, illegal mining, the most widely mentioned off-farm livelihood strategy, destroys the forest and watershed, while also posing physical risk to miners and ore processors.

Effects of wide-spread, long-term stress of drought on a household can be exacerbated by household-level, sudden stresses like illness. Households in Dumoga commonly experience health shocks, including death. Diabetes and stroke are very common due to a diet that is heavy in sugar and simple carbohydrates (Sutanegara, Darmono, & Budhiarta, 2000). Respiratory illness, possibly related to poor air quality resulting from ash and dust, are also very common. However, it is difficult to assess illness and disease because of limitations in medical training and testing. Although most villages have access to government-supported health care, the central government determines which illnesses are tracked. It is not uncommon for deaths to occur without a clear diagnosis ever being made.

Households in Dumoga experience multiple stressors that occur at different spatial and temporal scales. There are stressors such as environmental change that impact all households and other stressors, such as crop failure, that impact individual households. Stressors also occur at different temporal scales. Press events are disturbances that may start suddenly but continue for a long period of time (relative to the system in which the disturbance occurs). Pulse events are disturbances that happen over a short period of time followed by a return to pre-disturbance levels (Bender, Case, & Gilpin, 1984; Lake, 2000). In SES terms, environmental change would be categorized as a press event and health shocks, which tend to be more acute and occur more quickly, would be referred to as pulse events. Pulse and press stressors interact to either dampen or enhance combined effects (Lake, 2000).

A feedback cycle of economic need and resource degradation perpetuate stressors that drive deterioration of environmental conditions and human well-being. Ability of households in the system to break free of this cycle is determined by the resources available to develop new response pathways. In this study system, sources of resilience and restructuring were limited and displayed dynamics that threatened their long-term viability.

Education is one area in which respondents choose to invest. Education opens new livelihood strategy options and increases potential income. However, interviews demonstrate a clear problem with emigration of human capital, as those with higher levels of education seek employment outside of the valley. Remittances from educated children are an important source of income for some households, and external financial support could add to the resilience of the system. However, it also creates a cycle of dependence that removes incentives for developing self-sustaining, stable livelihood strategies (Kofinas & Chapin, 2009). Adaptability of SESs is highly influenced by human actors whose actions influence the resilience of the system (Walker et al., 2004). In the long-term, loss of human capital (described in Chapter 1), reduces the resilience of the SES and increases its vulnerability.

One important source of resilience in the Dumoga Valley has been communal work (*gotong royong*). However, social resilience supported by this Indonesian emphasis on unity and communal work is declining. As households depend less and less on one another for meeting livelihood needs on farms, the social fabric that binds the community begins to fray. Loss of social connections weakens the social network through which information and support are transmitted (Granovetter, 1977). Loss of social cohesion and corrosion of the communication flow associated with social cohesion can result in marginalization of people who fall outside of the social network, failure to recognize that stresses are affecting multiple households, and delay in dissemination of strategies to cope with stressors. This fracturing of the social system has both social and ecological consequences. On the social-economic front, the loss of this fabric may increase the vulnerability of the poorest members of the community. In the past, a poor farmer could call upon neighbors to assist in planting and harvesting and repay that help in kind. Now, however, on-farm help expects payment either in wages or in a share of the harvest. This could radically change the viability of small-scale farming and limit yields based on availability of labor.

Human agency, defined as the ability to make choices and take actions that affect the system, is an important component of adaptive capacity (Brown & Westaway, 2011). Path dependencies, or constraints that past decisions or processes place on future outcomes, occur in many systems and result in part from human agency. In this study, pursuit of agricultural livelihoods has resulted in a system where agricultural livelihoods are the default future choice. Patterns of land exploitation and degradation also follow a dependent path. As environmental conditions have changed, these path dependencies have generated maladaptive responses that erode human and environmental well-being. Awareness of signals from the environmental system and cognizance of how these signals interact with the human system can help to divert path dependencies that drive vulnerability of the SES (Scholz, 2011).

Respondents in this study did note a relationship between some income activities-- particularly mining-- and health conditions, but they did not have confidence that their observations were reliable. Several people mentioned lack of research or testing to confirm their observation of environmental and health changes. For example, although miners may often be exposed to mercury and cyanide due to gold processing practices, testing and tracking are not available. Cause of illness or even death was often undetermined, so any possible connection to environment or to livelihood pursuits remained obscured.

Few respondents demonstrated access to detailed information about environmental and health conditions. Although many people offered that their forest is “the lungs of the world,” few had information about what that meant and how their actions influenced this important resource. Interviews also revealed increasing concern about the environment, but these issues of concern were highly localized. There was significant concern over trash and sewage in the villages, but little concern for environmental conditions in the larger region. Fracturing of social ties may impede information exchange that could support changes in environmental awareness, and a lack of environmental awareness decreases the society’s adaptive capacity by preventing timely actions. This presents the possibility of a path-dependency leading to ecological degradation, increased negative health issues and loss of livelihoods.

Recent changes in livelihood strategy, particularly the rapid adoption of artisanal mining, suggest that the system retains significant adaptive capacity. The Dumoga Valley does not have a long history of cultivation, and that history is strongly influenced by government support. The first permanent homesteads in the valley were established in the 1950s. The population has rapidly grown due to local immigration (Minahasa, Mongondow and Jaton) as well as *transmigrasi* (Balinese). Each of these groups adapted to new conditions. Local migrants adapted cultivation techniques to take advantage of government supported infrastructure by adopting wet rice agriculture. Transmigrants adapted their traditional wet-rice agriculture to a radically different biophysical and social environment.

However, households have limited livelihood options and some, such as mining, could be considered maladaptive. There is an absence of skills, education, and investment for development of socially, ecologically, and economically sustainable activities. As a result, even when residents are aware of environmental and social consequences of their livelihood strategies, they make choices that have negative outcomes.

The vulnerability of households in the Dumoga Valley is governed by multiple exposures and eroding adaptive capacity. Resource-dependent households are sensitive to environmental change when their options for livelihoods are limited. In the Dumoga Valley, loss of natural resource and social-economic cooperation are eroding the resilience and adaptive capacity of their SES. Policies aimed at increasing economic development, such as support for wet rice agriculture, also threaten to destabilize the system by differentially benefiting some and driving maladaptive behaviors of others.

Furthermore, feedbacks that signal the need for adaptation are muted or absent in this system. Indications of environmental change such as decreasing water levels are not interpreted as something over which humans have agency. While water availability may be a cross-scale process that is influenced both by global climate change and local activities, the system does not have the capacity to identify strategies to adapt to this stressor.

Chapter 4 Health-Livelihood Relationships in the Dumoga Valley

The purpose of this chapter is to explore the relationship between respondents' health condition, socio-demographic factors, and engagement in mining activity. Literature suggests that the role of natural resources in livelihood strategy may be governed by household socio-demographic factors (Ellis, 2008; Peng et al., 2017). The dominant socio-demographic factors that influence livelihood decision-making vary from location to location. In a study in China, Peng et al (2017) conclude that geographic location, access to land (natural capital), household age and size, level of human capital and enabling ecological policies are the primary explanatory variables for livelihood strategy. However, de Sherbinin et al. (2008) undertook a survey of various studies and found that, generally, human and social capital loss drive dependence on natural capital, but that effects of exact components of those capitals (e.g. education, morbidity, cooperation) are influenced by context.

Descriptive data presented in Chapter 2 as well as qualitative data presented in chapter 3 give rise to the hypothesis that there is a cultural component to use of mining as part of a livelihood strategy. I start by quantitatively testing the relationship between ethnicity and engagement in mining. Then I test socio-demographic factors between ethnic groups to identify other factors that may explain why some groups engage in mining while others do not.

4.1 Methodology and Site Description

I developed a structured survey by modifying an existing survey that had been implemented by the Center for International Forest Research (CiFOR). The original survey had included specific questions about well-being, but not health. I added health questions for the specific purposes of this research, though these questions were not validated.

I collected surveys in twelve randomly selected villages in the Dumoga Valley. I made this selection from a list of forty-nine of the fifty-four villages in the five regions of Dumoga, as five villages were eliminated from consideration due to safety concerns or because permission was denied by local officials. After data collection began, officials from one region revoked permission, further reducing the sample size by three villages. Villages in this study were randomly selected from all but North Dumoga, which declined to participate. Unfortunately, all of the Javanese villages and several of the Balinese villages in the valley are located in that district. Alternate Balinese villages were included in the sample, but Javanese villages were not.

Prior to initiating the survey, a team visited officials in each village to select households for participation in the survey. Each village provided a roster of residents by household, and I used a random number generator to select individual households from that roster. I selected more households than required to reach sampling targets in each village to buffer against households that could not be located or declined to participate.

Pairs of trained local enumerators implemented the surveys. Enumerators attempted to contact each household a maximum three times during each survey period. Due to safety concerns, surveys were only collected during daylight hours. Enumerators collected data at two points in time four months apart in 2015 and 2016 to assess impact of changing health conditions on household livelihood. These two rounds of interviewing also captured differences in seasons. The first round (referred to as the 2015 survey) captured income during the rainy, harvest season. The second round of data collection (referred to as the 2016 survey) occurred toward the end of the dry season that had resulted an extended drought.

I drafted the survey in English and translated it into Indonesian with the assistance of a native speaker. The survey was pre-tested with approximately one dozen local university students and revised to adjust to local language differences before implementation. Before both rounds of survey implementation, I adjusted survey questions based on feedback from enumerators to make questions easier for respondents to understand and answer.

During each time period, I collected data on household demographics, income sources, household assets, and health and well-being. Household demographics included age, gender, level of education, profession, tribe, religion, and length of time the household has been in the village. During the first survey, enumerators asked respondents to recall income from the previous three months. During the second, they asked respondents to recall income generated since the previous survey was conducted.

I measured household income by asking specific questions about all sources of revenue. The survey included one indirect and one direct measure of illness. The indirect measure asked respondents generally if the household had experienced any sort of financial crisis and provided illness as one of the possible responses. The second measure captured specific details of illness, including the type of illness and associated loss of household productivity. I combined data into a dichotomous (0 or 1) dummy variable for each time period. This variable was calculated from the difference in value for the illness indicator between 2015 and 2016 data collection. A negative value indicates a household that had not experienced illness in 2015 experienced illness in 2016. A positive value indicates the opposite.

I used a similar process for engagement in mining. Mining engagement is central to the primary question of this research, so the survey was made more sensitive to capture mining behaviors. Mining was included among the income sources that were quantified, and an additional question was asked specifically about mining. We collapsed all measures of mining to a dummy variable and assessed change in the same manner as change in health status.

I entered data into a database that I developed for data management as soon as possible after collection, then spot checked data to ensure accuracy of enumerators. For most of the analysis, groups that represented less than 5% of the sample (i.e., Bugis, Gorontalo, Jawa, Manado, Sunda) were removed. Data analysis was carried out in SPSS (IBM Corp, 2017). All data were categorical and group differences were analyzed using a chi-square test with a p-value of .05.

4.2 Results

4.2.1 Demographics

A total of 341 households participated in the survey in 2015 and 294 (86.2%) of those same households followed up with a second survey in 2016. Respondents were from 12 villages. Most villages are comprised of households of a single ethnicity. The heads of participating households identified as belonging to nine different ethnic groups: Bali, Bugis, Gorontalo, Jaton, Jawa, Manado, Minahasa, Mongondow and Sunda. The sample sizes of Javanese and other ethnic groups were too small for inclusion. Therefore, the main ethnic groups represented in the study are Mongondow, Minahasa and Balinese (Figure 3). Two villages, Imandi and Dumoga I are roughly equally divided between the dominant ethnicities of the area, Minahasa and Mongondow (Table 2 and Table 3).

Table 2. Respondents by village and ethnicity 2015

	Ethnicity								
Village	Bali	Bugis	Gorontalo	Jaton	Jawa	Manado	Minahasa	Mongondow	Sunda	**Total**
DumogaI	0	0	0	0	0	0	19	11	0	**30**
Ibolian I	0	0	1	0	0	0	26	1	0	**28**
Ikhwan	0	0	1	21	2	0	2	1	1	**28**
Ikuna	1	3	0	0	0	0	0	18	0	**22**
Imandi	0	0	1	0	1	0	15	11	1	**29**
Konarom	0	3	2	0	2	0	1	26	0	34
Mekaruo	3	0	3	0	1	0	23	0	0	31
Mogoyunggung	0	0	0	0	0	0	26	0	0	26
Ponompiaan	0	0	0	0	0	0	26	1	0	27
Tapadaka 1	0	0	0	0	5	0	0	28	0	33
Toruakat	1	0	1	0	0	1	3	17	0	23
Werdhi Agung Timur	28	0	0	0	0	0	0	0	0	28
Total	**33**	**6**	**9**	**21**	**11**	**1**	**142**	**115**	**2**	**341**

Table 3. Respondents by village and ethnicity 2016

	Ethnicity									
	Bali	Bugis	Gorontalo	Jaton	Jawa	Manado	Minahasa	Mongondow	Sunda	**Total**
DumogaI	0	0	0	0	0	0	19	9	0	**28**
Ibolian I	0	0	1	0	0	0	26	1	0	**28**
Ikhwan	0	0	0	18	2	0	2	1	0	**23**
Ikuna	1	3	0	0	0	0	0	18	0	**22**
Imandi	0	0	1	0	1	0	8	9	1	**20**
Konarom	0	2	2	0	0	0	0	22	0	**26**
Mekaruo	3	0	3	0	1	0	21	0	0	**28**
Mogoyunggung	0	0	0	0	0	0	24	0	0	**24**
Ponompiaan	0	0	0	0	0	0	25	1	0	**26**
Tapadaka 1	0	0	0	0	5	0	0	23	0	**28**
Toruakat	1	0	1	0	0	1	3	13	0	**19**
Werdhi Agung Timur	22	0	0	0	0	0	0	0	0	**22**
Total	**27**	**5**	**8**	**18**	**9**	**1**	**128**	**97**	**1**	**294**

4.3 Health Change

A total of 55 households (16% of the sample) that were not sick in 2015 experienced illness in 2016. Eighty households (23% of the sample) that had an illness in 2015 did not have illness in 2016. There was no relationship between ethnic groups and health change (Table 4). For the rest of these analyses, I focus on the predominant ethnic groups in the study.

Table 4. Health changes by tribe between 2015 and 2016

Tribe	Illness increase (-1)	No Change (0)	Illness decrease (1)
Bali	3	16	14
Jaton	4	13	4
Minahasa	28	87	27
Mongondow	16	72	27
Total	51	188	72

χ^2 (6, n = 311) = 9.948, p = 0.127

Health changes were different between villages, but the sample sizes from each village were very small (Table 5). Some villages had several times more households indicating a decrease in illness than those indicating an increase (Dumoga I, Konarom, Tapadaka I, Werdhi Agung Timur). Others had the opposite response (Imandi, Toruakat) and many remained roughly equal.

Table 5. Health changes by village between 2015 and 2016

Tribe	Illness increase (-1)	No Change (0)	Illness decrease (1)
DumogaI	3	17	10
Ibolian I	7	18	3
Ikhwan	5	18	5
Ikuna	2	15	5
Imandi	9	19	1
Konarom	3	20	11
Mekaruo	4	21	6
Mogoyunggung	6	13	7
Ponompiaan	6	16	5
Tapadaka I	4	17	12
Toruakat	3	19	1
Werdhi Agung Timur	3	13	12
Total	**55**	**206**	**78**

χ^2 (22, n = 339) = 36.007, p = .030

4.4 Mining Activity

Mining activity, indicated by any portion of household income being attributed to mining, was also assessed in 2015 and 2016. Changes in mining activity are displayed in Table 6. Balinese households were not included because no Balinese household indicated mining as a source of household income in 2015 or 2016. There was no significant change in mining behavior between ethnic groups.

Table 6. Changes in mining activity between 2015 and 2016 surveys

Tribe	Started mining (-1)	No Change (0)	Stopped mining (1)
Jaton	2	17	2
Minahasa	9	124	9
Mongondow	4	103	8

χ^2 (4, n = 278) = 2.113, p = 0.715

Few households (n=15) changed status in both health and mining (Table 7). Again, Balinese households were eliminated from this analysis, as no Balinese households engaged in mining in either timeframe. Among the households that started mining, equal numbers experienced a decrease in illness and an increase in illness. Among the households that stopped mining, 89% experienced an increase in illness and 11% experienced a decrease.

Table 7. Households that changed health status and engagement in mining

Tribe	Health change	Started mining (-1)	Stopped mining (1)
Jaton	Illness increase	1	1
	Illness decrease	0	0
Minahasa	Illness increase	1	5
	Illness decrease	1	0
Mongondow	Illness increase	1	2
	Illness decrease	2	1
Total	Illness increase	3	8
	Illness decrease	3	1

Mining engagement varies significantly by village. Table 8 shows respondents from each village that have ever engaged in mining. No residents of Werdhi Agung Timur have ever mined. The highest percentage of respondents that indicated that they have engaged in mining was found in Mekaruo, where nearly 20% of households had engaged in mining at some point.

Table 8. Mining activity by village

	Has ever engaged in mining		
Village	No	Yes	**Total**
Werdhi Agung Timur	22	0	**22**
DumogaI	24	4	**28**
Ibolian I	23	5	**28**
Ikuna	16	6	**22**
Toruakat	12	8	**20**
Tapadaka 1	18	9	**27**
Mogoyunggung	13	11	**24**
Konarom	15	12	**27**
Ponompiaan	15	12	**27**
Imandi	9	13	**22**
Ikhwan	9	15	**24**
Mekaruo	10	19	**29**
Total	**186**	**114**	**300**

χ^2 (11, n = 300) = 47.513, p < 0.000

There are also significant differences in mining engagement between ethnicities (Table 9). The Minahasa ethnicity had the highest percentage of households that have participated in mining, and Balinese in this sample do not derive income from mining.

Table 9. Mining activity by ethnicity

	Has ever engaged in mining		
Ethnicity	No	Yes	**Total**
Bali	27	0	**27**
Jaton	9	10	**19**
Minahasa	74	57	**131**
Mongondow	61	36	**97**
Other	15	11	**26**
Total	**186**	**114**	**300**

χ^2 (4, n = 300) = 20.201, $p < 0.000$

4.4.1 Landownership and Mining

A significantly higher percentage of landless household indicated that they had mined (p <0 .001) than households that owned land. Households with insecure forms of land access, such as renters or sharecroppers, were included as landless.

Table 10. Mining activity and landownership

	Land Ownership		
Mining activity	Do not own	Own	Total
No	89	97	186
Yes	68	39	107
Total	157	136	293

χ^2 (1, n = 293) = 6.733, $p = 0.009$

However, there was not a significant difference between the mining activity by land ownership when comparing among ethnic groups. There was a significant difference in landownership between the ethnic groups in 2015 (Table 11), but there was not a significant difference in landownership patterns in 2016 (Table 12).

Table 11. Landownership among ethnic groups 2015

	Own Land			Percent Own Land	
	No	Yes	Total	No	Yes
Bali	11	22	33	33%	67%
Jaton	13	8	21	62%	38%
Minahasa	95	47	142	67%	33%
Mongondow	56	59	115	49%	51%
Other	18	12	30	60%	40%
Total	193	148	341	57%	43%

χ^2 (4, n = 341) = 16.713, p = 0.002

Table 12. Landownership among ethnic groups 2016

	Own Land			Percent Own Land	
	No	Yes	**Total**	No	Yes
Bali	11	16	**27**	41%	59%
Jaton	10	8	**18**	56%	44%
Minahasa	78	49	**127**	61%	39%
Mongondow	45	51	**96**	47%	53%
Other	13	12	**25**	52%	48%
Total	157	136	**293**	54%	46%

χ^2 (4, n = 293) = 6.715, p = 0.154

4.4.2 Demographics and Mining

Demographic factors have been associated with choice of livelihood strategy (Ellis, 2008). For this analysis, the highest level of education obtained by any current member of the household was used as the education level of the household. There was no significant difference in education between ethnicities (Table 13). There was also no discernable relationship between education level and mining activity (Table 13).

Table 13. Highest level of education of household by ethnic group

	Grade School	Middle School	High School	College	**Total**
Bali	10	7	13	3	**33**
Jaton	0	7	12	2	**21**
Minahasa	18	42	66	11	**137**
Mongondow	23	43	43	6	**115**
Other	3	9	14	4	**30**
Total	**54**	**108**	**148**	**26**	**336**

χ^2 (12, n = 336) = 17.469, p = 0.133

Table 14. Highest level of education and mining activity

Ever engaged in mining	Grade School	Middle School	High School	College	**Total**
No	32	58	80	16	**186**
Yes	12	39	55	7	**113**
Total	**44**	**97**	**135**	**23**	**299**

χ^2 (3, n = 299) = 3.340, p = 0.342

Household size also does not affect mining activity. There was no difference in average household size between ethnic groups. Age of the head of household, used as a proxy for the length of time since the establishment of the household, was related to engagement in mining (Table 14). Households with a head of household between the ages of 30 and 50 are more likely to engage in mining than younger or older households.

Table 15. Age of head of household and mining activity

	Ever engage in mining		
Age of head of household	No	Yes	**Total**
Below 29	7	12	**19**
30-49	123	98	**221**
50 and above	53	4	**57**
Total	**183**	**114**	**297**

χ^2 (2, n = 297) = 31.961, p < 0.000

4.5 Discussion

The purpose of this chapter is to explore the relationship between respondents' health condition and engagement in mining activity. In Indonesia, each individual has an official profession, which may or may not be related to actual sources of income. Because there is no formal manufacturing, transportation, retail or tourism in the valley, livelihood choices are limited. We expected that the role of natural resources in livelihood strategy (i.e., engagement in mining) may be governed by household health and demographic factors (Ellis, 2008; Peng et al., 2017)

Among the houses that started mining from 2015 to 2016, equal numbers experienced a decrease and an increase in illness. Among the households that stopped mining between 2015 and 2016, more households experienced an increase in illness than experienced a decrease in illness. This suggests that if working age adults were struck with illness, they were unable to engage in physically demanding mining activities. However, only about 5% of the sample of households reported changes in both mining activity and illness.

The data collected for this study is not sufficient to discern whether health status is related to mining activity. As mentioned in Chapter 2, health conditions are not clearly diagnosed, so responses to health questions on the survey were unreliable. Many people responded that they did not know exactly what their illness was, and others offered a guess. Although there are other factors, such as indoor air pollution, water quality, local biomass burning, that could affect health, there is no reliable data on the extent to which these factors exist in Dumoga. However, we uncovered other factors that were associated with willingness to engage in mining. Most households that engage in mining belong to Minahasa and Mongondow ethnic groups. These groups have a stronger mining tradition. In these groups, it is common for all adult members of the household to stay home and care for a sick family member. Therefore, illness in these households results in fewer workdays for healthy household members. Household illness would also prevent healthy household members from mining, as mining requires a substantial absence from home.

Existing literature demonstrates that demographic factors such as age, size, and education level of a household can govern the extent to which a household includes exploitation of natural resources as part of its livelihood strategy (de Sherbinin et al., 2008). This literature also indicates related demographic factors vary by location. In this study, there are no clear trends that suggest differences in demographic factors are associated with mining. Relationships between household size and education are not significant. The relationship between broad age groups and head of household and mining is significant, but it is intuitive that there would be more mining among the age group that contains more working adults.

Geographic location, specifically proximity to available natural resources, is also suggested as a factor influencing exploitation of natural resources (de Sherbinin et al., 2008; Ellis, 2008). Again, in the Dumoga Valley, there is no clear relationship between proximity to the national park and engagement in mining. Mekaruo, Ikhwan and Imandi are three villages with the highest percentage of households indicating that they have ever earned income from mining (65%, 62% and 59%, respectively). Mekaruo and Ikhwan are located at the western end of the valley, furthest away from a large population center and close to the park boundary. However, Imandi is located in the middle of the valley (Figure 2).

Secure land tenure is strongly related to engagement in mining. Among the households that had engaged in mining, 65% did not own land. There is also a significant difference in mining activity between ethnic groups and a significant difference in landownership between ethnicities. However, there is no significance between landlessness and mining activity when compared by ethnic group. In 2015, 67% percent of Balinese households owned land while only 33% of Minahasa households owned land. These percentages changed in 2016, when there was no longer a significant difference in landownership between ethnic groups. However, many of the households that did not participate in 2016 were landless; this likely skewed the 2016 sample toward households with land.

These data do not demonstrate a relationship between change in health status and change in mining activity, nor do they show a significant difference in health or in mining activity between 2015 and 2016. However, ethnicity is significantly related to mining activity, with no Balinese households participating in mining. There is also a significant relationship between land ownership and mining. Most households in the Dumoga Valley rely on agriculture, so households with no access to land have limited alternatives and engagement in mining is an option that is exercised.

Chapter 5 Dynamics of Health-Livelihood-Environment Interactions: An Agent-Based Modeling Approach

5.1 Introduction

This chapter examines health-livelihood-environment interactions in a dynamic system by developing an agent-based model (ABM) as an experiment. Computer simulation models are a powerful tool in allowing scientists to embrace the complexity inherent in SES. While models allow manipulations that would not be feasible in the physical environment, they also require simplification of complex systems. The decisions about excluded factors are conscious, cautious, and open to critique. Cilliers et al. (2013) state, "All models are abstractions and reductions in the sense that the modeler chooses to encode a finite subset of possible observables." (p. 4).

The role of natural resources in livelihoods of rural people has been a topic of interest in development and conservation literature for several decades. Angelsen et al. (2014, p. S13) summarize three functions of natural resources in rural livelihoods from this literature: (i) supporting current consumption; (ii) providing safety-nets in response to shocks and gap-filling of seasonal shortfalls; and (iii) providing means to accumulate assets and a pathway out of poverty

Numerous studies have focused on natural resources as a safety net, and they generally have suggested that a specific type of shock plays a key role in determining whether natural resources are extracted as a coping mechanism. Although crop failures and illness are the two most common household shocks identified in studies of crises-driven resource extraction (Wunder, Börner, et al., 2014), there is little data on the role of health in livelihood choice and its concomitant ecological impact.

Of the studies that have explored effects of health on household production, two theoretical hypotheses have arisen. The first posits that ill-health results in lower availability of labor that can engage in physically demanding natural resource extraction. The second suggests that sudden and unexpected expenses associated with a health crises lead to an increase in exploitation of free and immediately-available natural resources (Wunder, Börner, et al., 2014).

In this chapter, I use an ABM to test the relationship between health and livelihood choice and associated natural resource extraction in the Dumoga Valley of Indonesia. The focus of analysis is on system dynamics and trends over time rather than outputs at a single point. The rules that govern agent decision-making and the parameters of the context in which agents interact are derived from the qualitative and quantitative data presented in the previous chapters. This ABM represents households that interact with natural resources and other households to develop and implement an approach to meeting livelihood needs (livelihood strategy). Several variables can be manipulated to explore how they each influence outcomes for the entire system. The model begins with land allocation established when the valley was initially settled by local Mongondow and Minahasa migrants as well as Balinese transmigrants re-settled by the government. Households earn income, grow, split, buy, and sell land and make livelihood choices. Model runs stepped through levels of each input variable in all possible combinations of those input variables, providing outputs of variables of interest at each step. We then graphed outputs from these runs to assess emergent trends and identify variables that most affected dynamic responses.

Model results suggest that household health does influence engagement in mining. However, the model suggests that mining also serves an important coping function for Minahasa and Mongondow households. In all permutations of the model, mining increases initially, but eventually diminishes. Initial increases in mining are higher when overall health levels are lower.

5.2 Methods

I developed the ABM using NetLogo (Wilensky, 1999). A detailed description of the model using the Overview, Design Concepts, and Details protocol (Grimm et al., 2010) is provided as Appendix A. The model represents a simplified set of villages from the dominant ethnic groups of interest in this study: Minahasa, Mongondow, and Balinese (Figure 21) Jaton households are not included in the model because of their similarity to Minahasa.

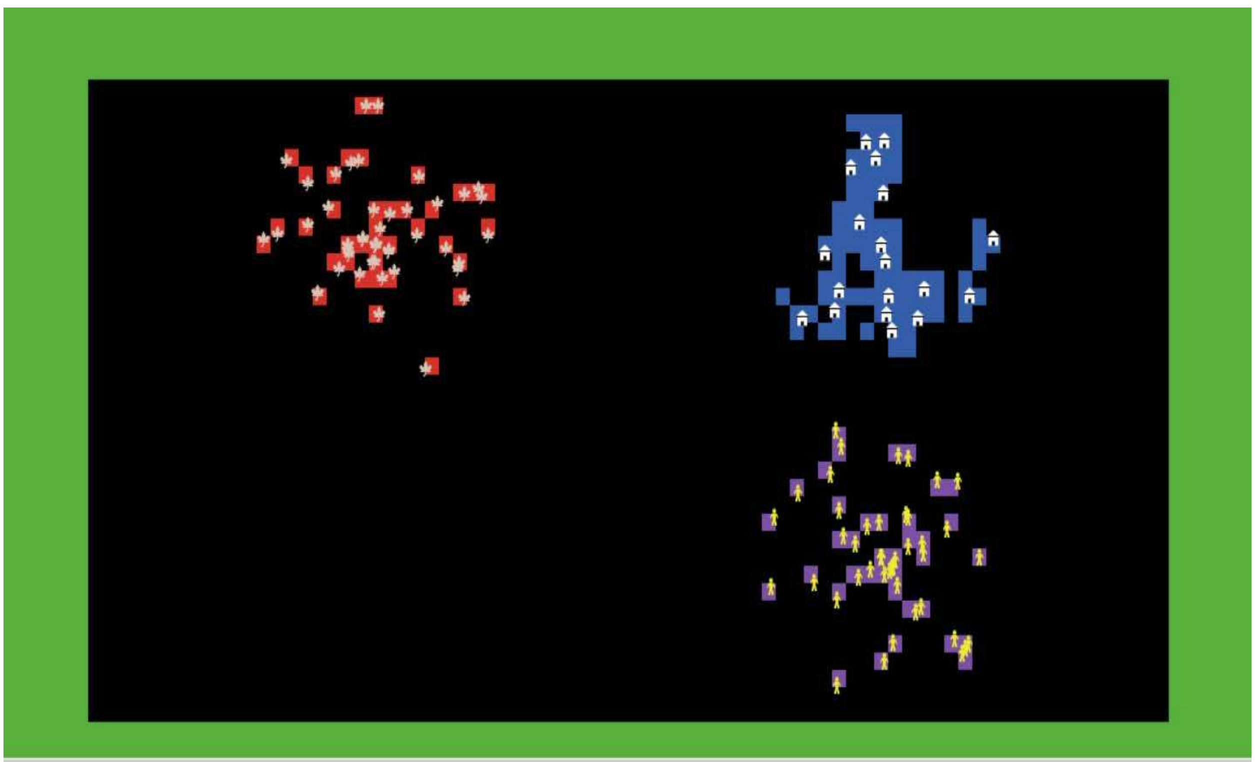


Figure 21. Initial model setup. Agents of different shapes belong to different ethnic groups (Bali – house, Mongondow = person, Minahasa = leaf). Black patches are cleared agricultural land and green patches are forest.

The agents are households that grow, age, split and die over time. Each time step, or 'tick', represents a process by which a household chooses and implements a livelihood strategy, earns income, and makes other decisions regarding income expenditures such as education and land purchase. Agents interact with a landscape that consists of cleared land that is suitable for agriculture and forested land where mining can take place.

Each household makes a livelihood choice based on their household status. If a household has access to land and sufficient capital to buy seeds to cultivate land and hire required labor to manage their land, the household will choose agriculture. When a household has sufficient wealth and land is available, they may buy land. If a household does not have land or sufficient capital, they may sell land and seek labor on another farm. If there is not sufficient employment available, the household will begin mining. Household engagement in mining reduces parcels coded as forest.

Health status of an individual household is determined at the beginning of each production period by assigning a random level of health based on a user-defined level of community health. Users can set a level of health that serves as mean value around which individual household health levels are determined. Higher community health results in fewer households with illness. Fieldwork determined that when a household member is sick in a Minahasa or Mongondow household, the entire family will stay home to care for the ill. Therefore, households assigned these ethnicities will not earn income when a household member is ill. Balinese households do not have this tradition and do not forego work when struck with an illness, so the model allows these ethnicities to continue earning income in the case of illness.

Households add members periodically. They will also split only if they have sufficient members, wealth, and land.

The model allows the user to set values for the following variables:

- Health-comm: This is the level of general health that affects all households. When health-comm increases, a higher number of households will suffer from ill health. Household health is a function of health-comm that is assigned at each step. Illness affects households when their health level drops below a pre-determined threshold.

- Production: Sets a level of productivity for all parcels in the model. Each parcel of land had a productivity that is a function of production and determines income derived from agriculture.
- Sell land: The amount of wealth earned by selling land. When a household's wealth falls below the 'sell land' value, the household may sell land and earn that amount of money.
- Buy land: The cost of land. If a household has a level of wealth higher than the 'buy land' value, they may purchase land.
- Work-per-plot: The number of households that can be supported by work on a plot that is owned by another household. This determines the entire available employment pool for landless households.

I repeated sensitivity analyses for combinations of variables to determine reasonable values for parameters that could be used in the final analyses. Reasonable values were those that resulted in persistent populations (i.e., did not result in the population dying out), resulted in dynamics that reflected observations from qualitative and quantitative data, and were far enough apart that differences could be observed. For example, initial model runs set global agricultural production at 50% and 100%, corresponding to a 50% yield and a 100% yield. However, at 50% yield, most households failed to reach income requirements. This did not reflect dynamics that I observed in quantitative data and qualitative estimates of production failure. Therefore, model runs used for this analysis ultimately used 80%, 90% and 100% of the productivity global variable. Because household productivity is a function of global productivity, some households would still experience production failures at these global production levels.

Once I established reasonable parameters, I used Behavior Space in Netlogo to run the model for the equivalent of 50 ticks using each of the parameters. Health-comm was set at 25, 50, 75 or 100. Productivity was set at either 0.8, 0.9 or 1 and work-per-plot at 5 or 10. Sell land and buy land were set at either 100 or 150. Each scenario was initially repeated five times. When results did not yield conclusive results, I repeated those scenarios to add more data points and confirm output patterns. There were twenty-four combinations for each level of health-comm, resulting in ninety-six total combinations. Table 16 demonstrates possible combinations for a single health-comm setting.

Outputs of primary interest were the number of miners and amount of forest remaining at the end of the model run. Total population was different for each model run, so mining engagement was measured as a percentage of the total population coded as a miner at each step. Number of forest units was constant for all model runs, so I report forest as number of units.

Table 16. Combinations of variables for Health-comm set at 25.

Health Comm	Work-per-plot	Production	Sell Land	Buy Land
25	5	0.8	100	100
				150
			150	100
				150
		0.9	100	100
				150
			150	100
				150
		1.0	100	100
				150
			150	100
				150
	10	0.8	100	100
				150
			150	100
				150
		0.9	100	100
				150
			150	100
				150
		1.0	100	100
				150
			150	100
				150

5.3 Model results

Household health could be considered a co-variate of agricultural production (i.e., lower health results in lower production), so model runs were analyzed by production level to isolate effects of production at 80%, 90% and 100% production. Eight combinations of variables were run for each level of health-comm at each production level (Table 17).

Table 17. Definitions of non-health variable combinations obtained for each health-comm level at each production level.

	Summary Scenarios		
	sell-land	work-per-plot	buy-land
Run1	100	5	100
Run2	100	5	150
Run3	100	10	100
Run4	100	10	150
Run5	150	5	100
Run6	150	5	150
Run7	150	10	100
Run8	150	10	150

Total number of miners (i.e., households categorized as miners across all 50 steps of the run) generally decrease as health increases. Nearly all combinations of variables result in a decreasing trend in number of miners as health increases (Figure 20 and Figure 21). The relationship appears to be stronger at higher production levels, as slopes of trendlines in lower production levels are less steep. There is one scenario (Run 4) associated with 80% productivity that does not follow that trend (Figure 22).

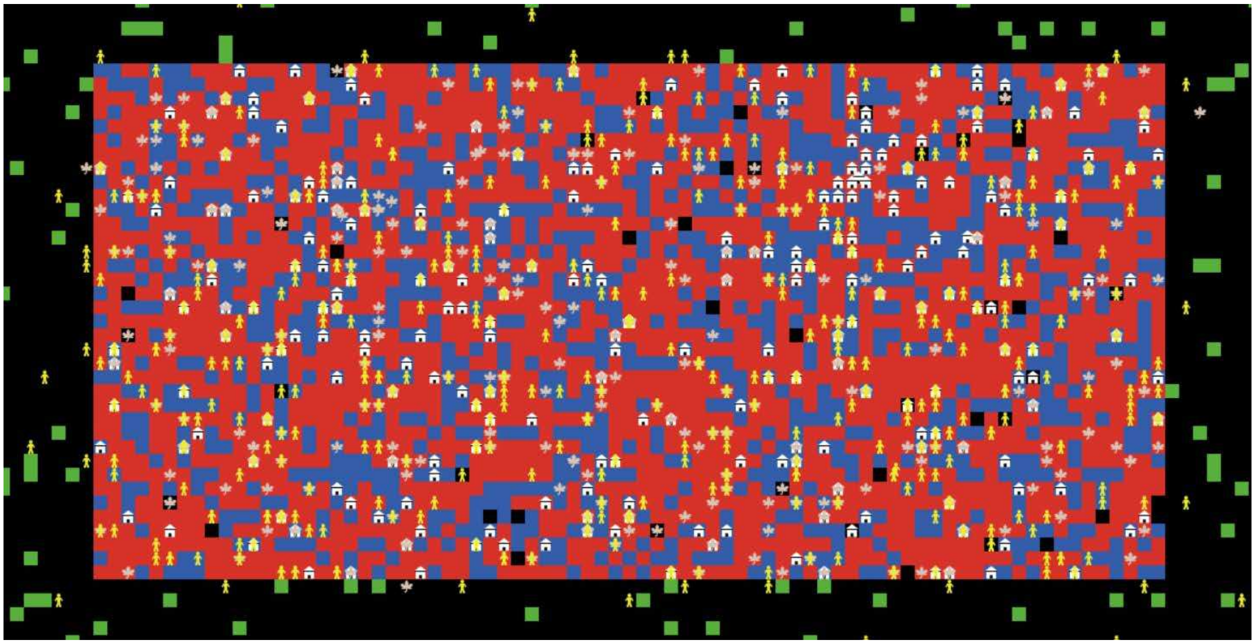


Figure 22. Screenshot of model at the end of a model run. Green patches are remnant forest, blue and red patches are occupied farmland and black patches are converted forest.

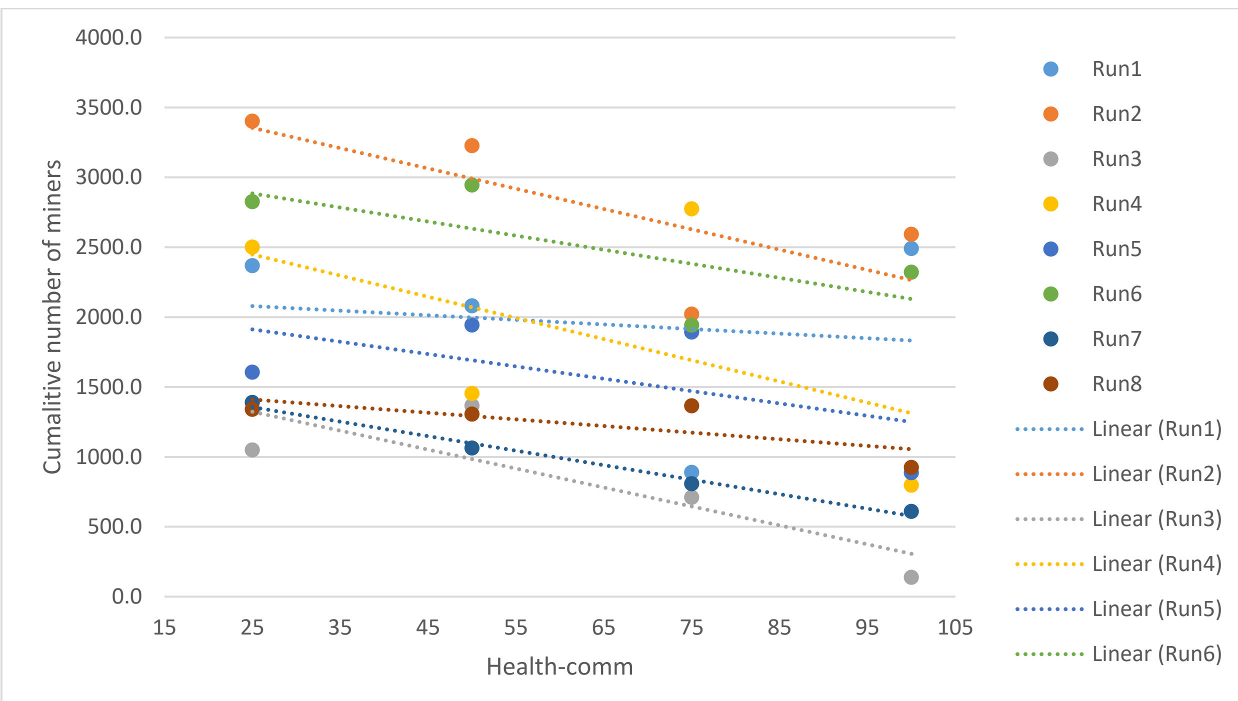


Figure 23. Cumulative miner count and trendlines for model runs for 100% production scenarios

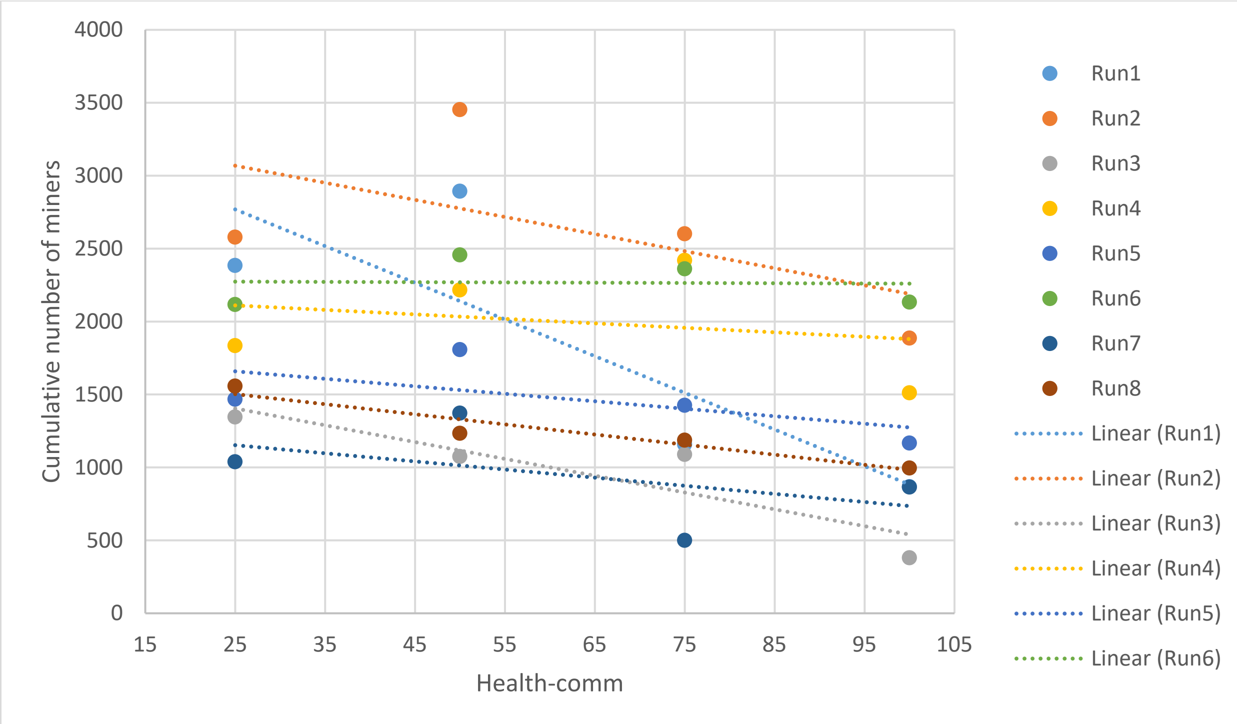


Figure 24. Cumulative miner count and trendlines for model runs for 90% production scenarios

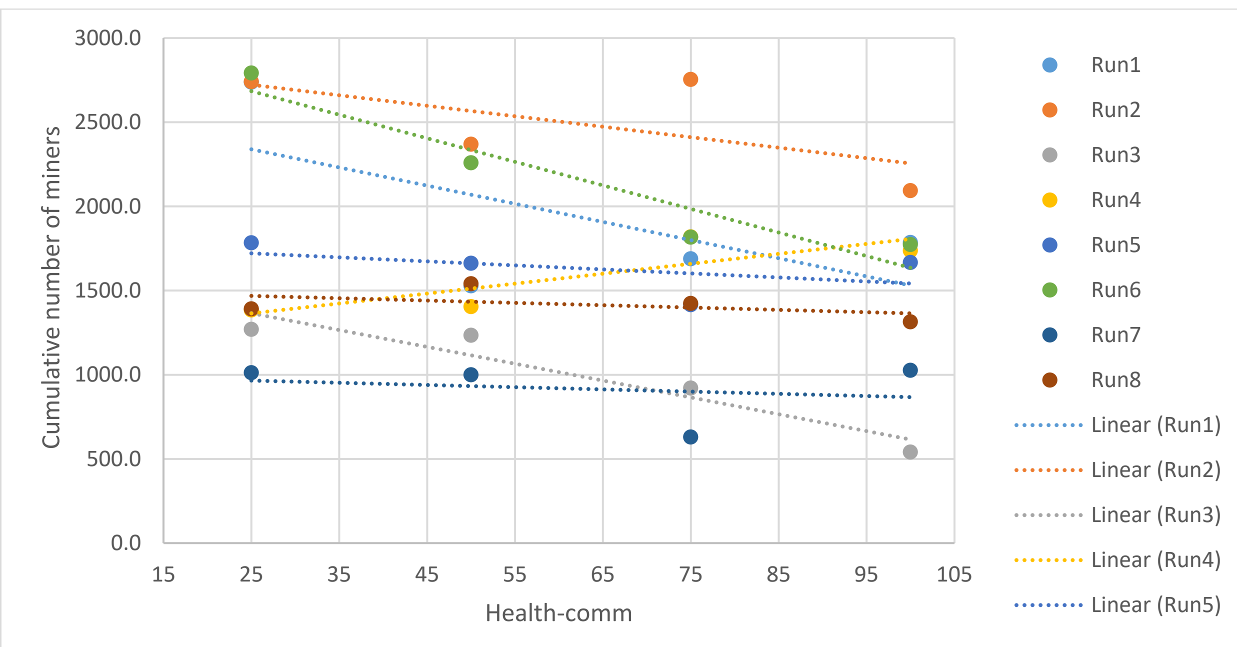


Figure 25. Cumulative miner count and trendlines for model runs for 80% production scenarios

The number of forest parcels converted to mining also decreases as health-comm increases (Figure 23, Figure 24 and Figure 25). Engagement in mining does not directly correlate with forest damage because each forest unit that converts to mining can employ up to ten households. In several scenarios, the final number of remaining forest units are similar for multiple combinations of variables and do not necessarily reflect total forest loss through time. Therefore, the figures below present the total loss of forest parcels for three production levels using the same eight scenarios as the mining scenarios (Figure 23, Figure 24 and Figure 25).

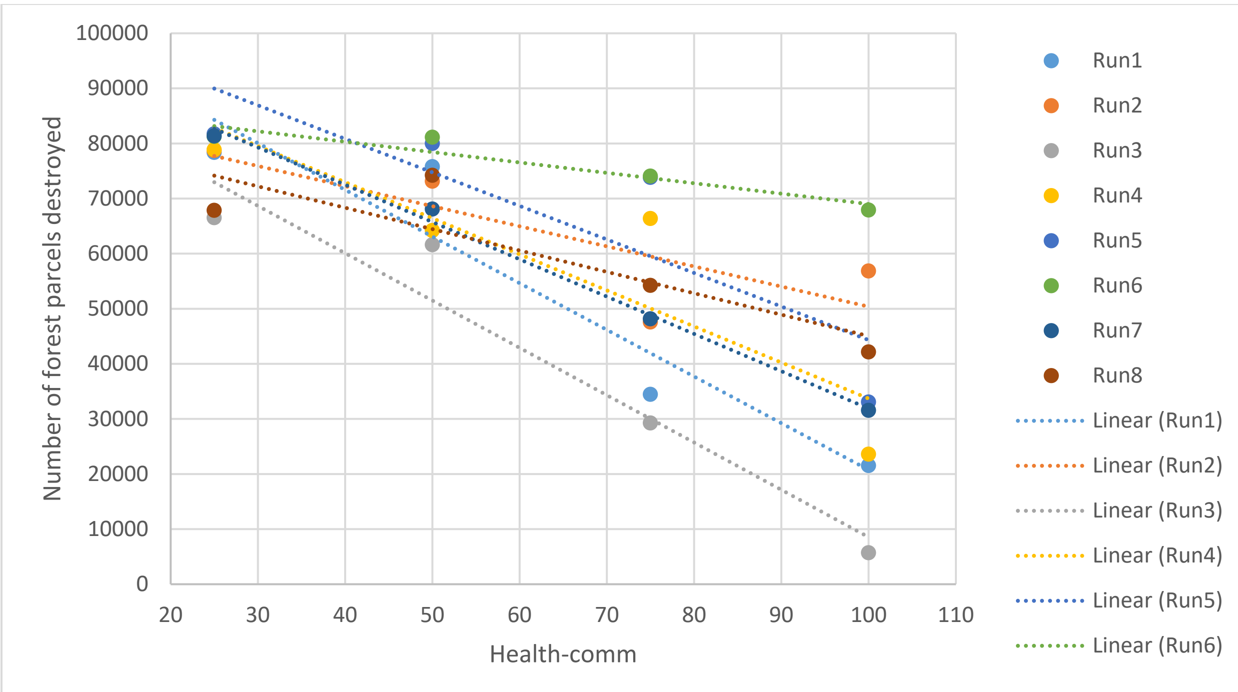


Figure 26. Total loss of forest parcels at 100% production.

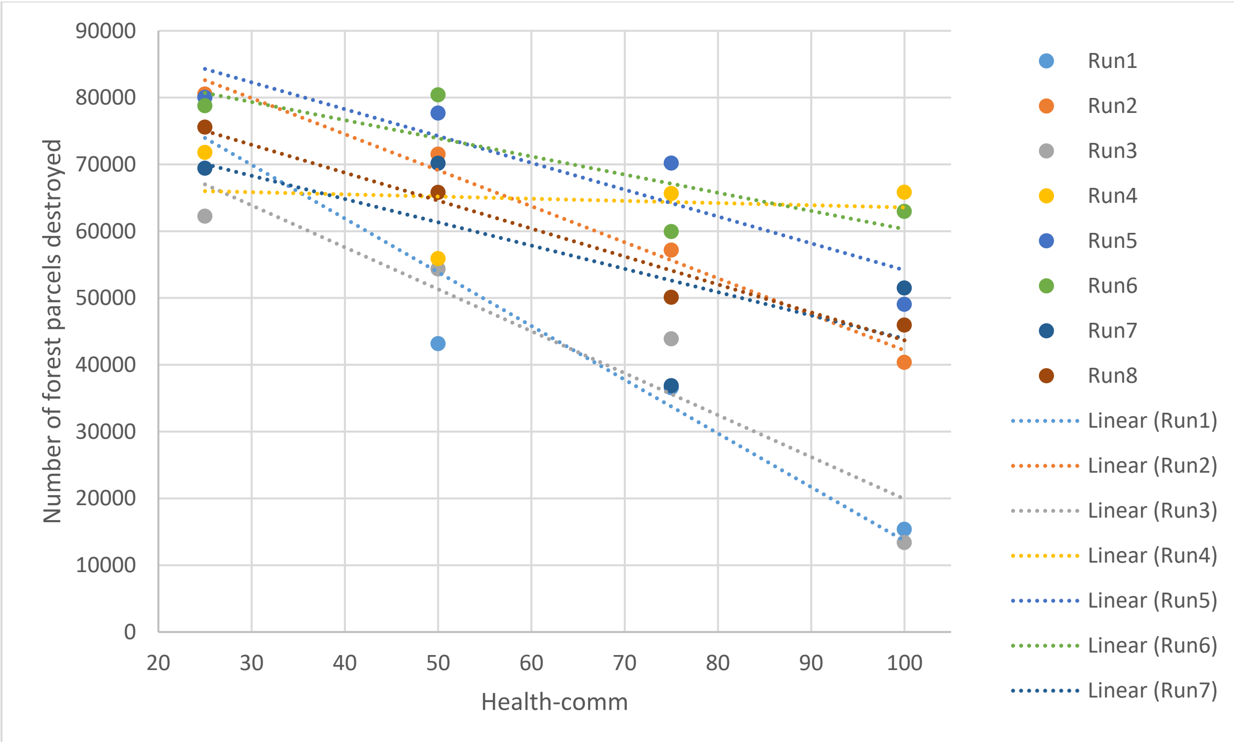


Figure 27. Total loss of forest parcels at 90% production.

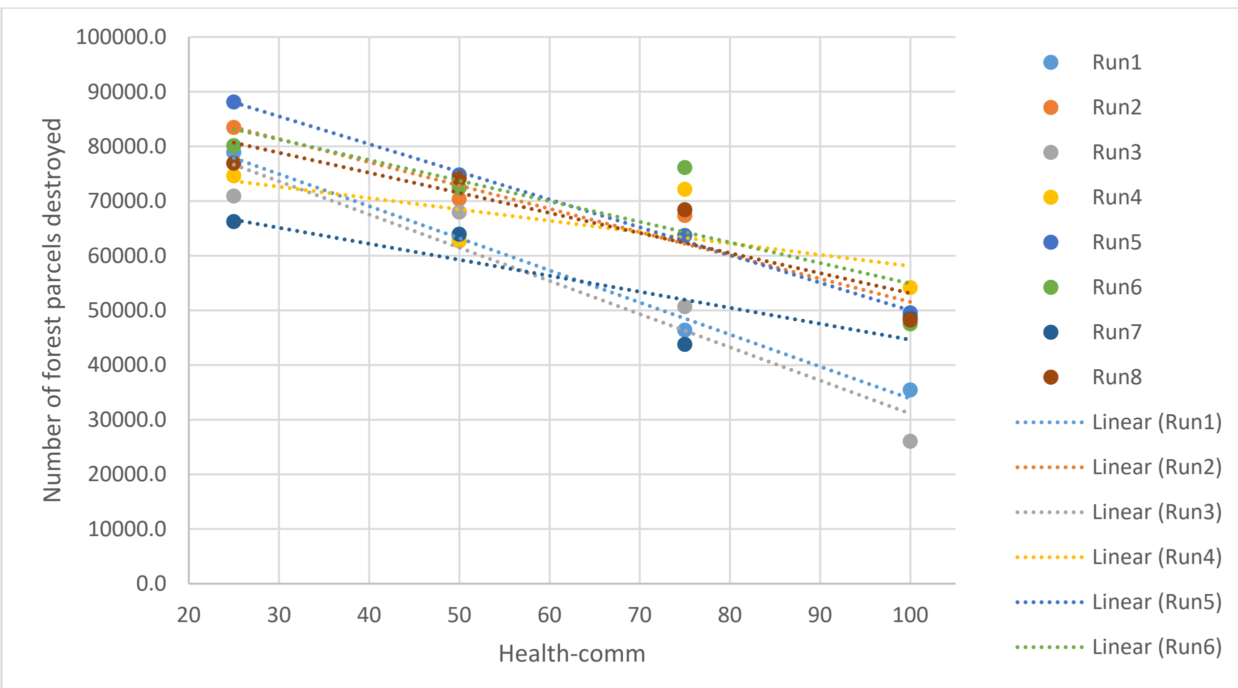


Figure 28. Total loss of forest parcels at 80% production.

The primary focus of this analysis is understanding the dynamics that emerge over time under various conditions. Consequently, analysis of mining engagement and forest loss at each step provides more detailed information than summary measures. In all scenarios, there is an initial increase in engagement in mining, followed by decreases to an equilibrium. This dynamic is observed in Figure 26, Figure 27 and Figure 28 below. Each figure presents model output for a single scenario described in Table 17. Each line within the figure depicts the outcome from the indicated health-comm setting.

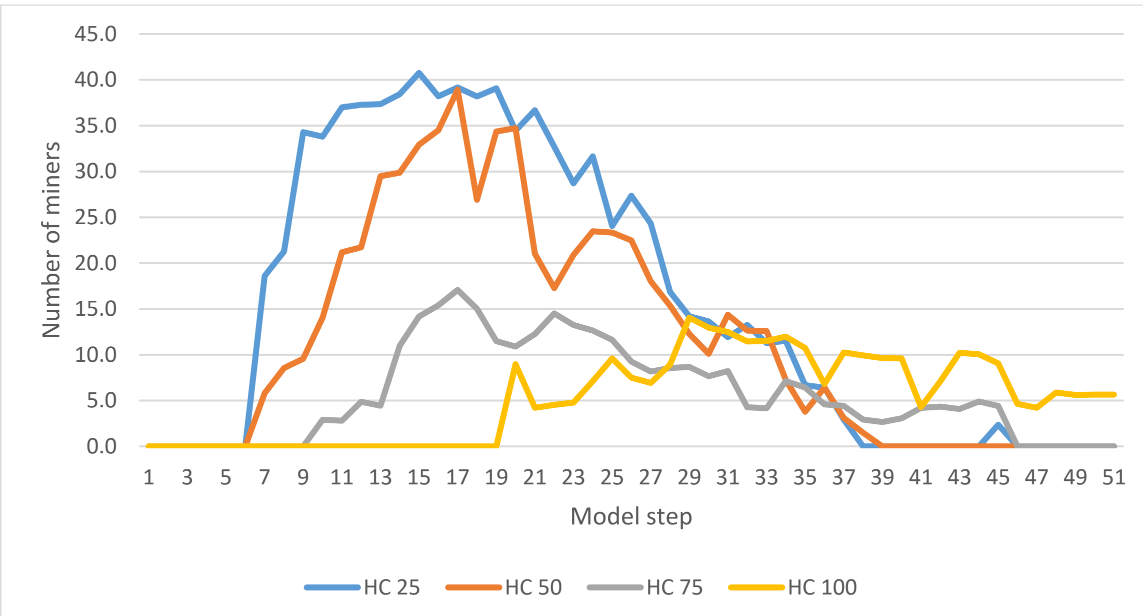


Figure 29. Percent of total population categorized as miners at 100% productivity for the Run 1 scenario using four measures of health comm (HC).

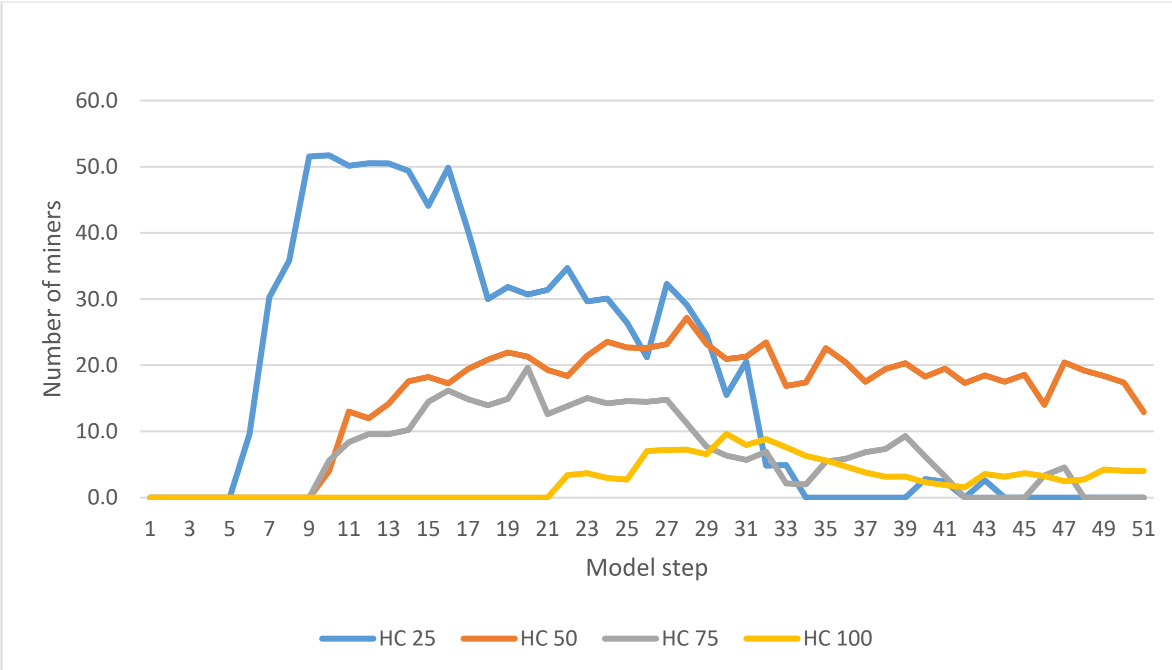


Figure 30. Percent of total population categorized as miners at 90% productivity for the Run 1 scenario using four measures of health comm (HC).

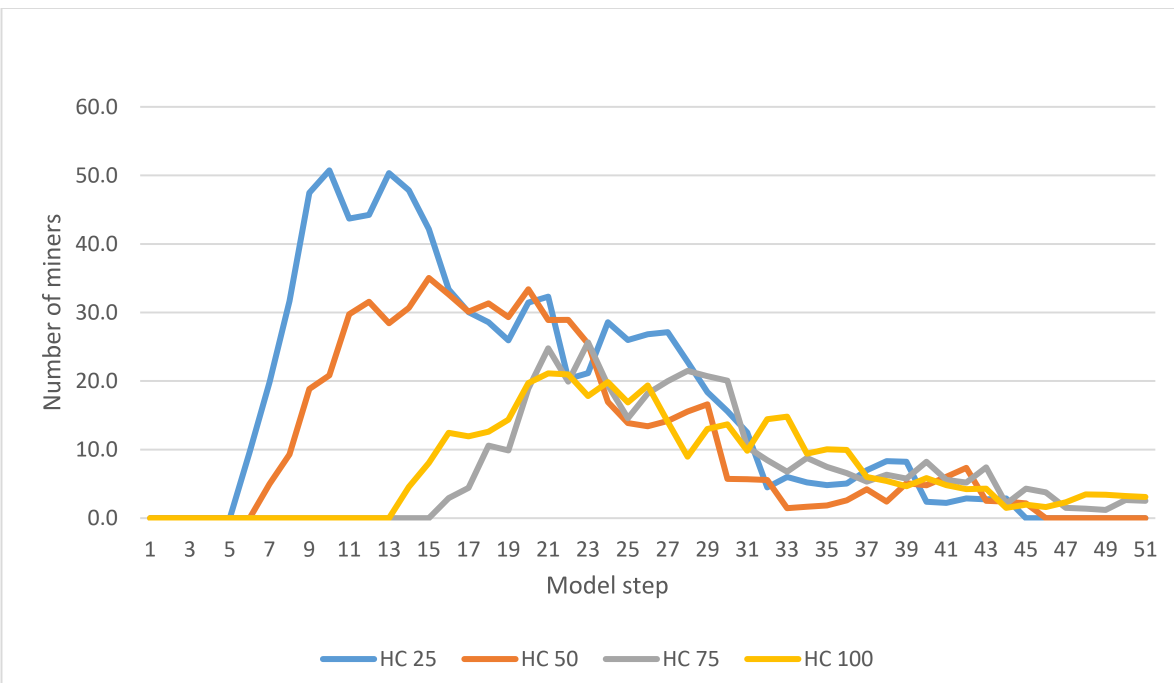


Figure 31. Percent of total population categorized as miners at 80% productivity for the Run 1 scenario using four measures of health comm (HC).

Initial increases in percent of population engaged in mining are not only higher for lower health-comm settings, but also begin earlier in the run. For example, in Figure 27, the HC 25 line exceeds 50% of the population in the fifth step of the model. The lines representing the other health-comm settings do not start to increase until the ninth step or later.

Final equilibria of percent of the modeled population engaging in mining do not follow a consistent pattern. For example, higher health-comm does not always result in lower final equilibrium levels. In Figure 26, health-comm 100 levels off at about five percent, staying above the equilibria for lower health-comm settings that drop to zero. Conversely, Figure 27 indicates that health-comm 50 reaches an equilibrium of between ten and twenty percent, which is higher than health-comm 100, which equalizes around four percent. In that scenario, health-comm 25 and health-comm 50 equalize below health-comm 100. Additional model runs that extended beyond the fifty-step limit were examined to determine if these equilibria are stable. In all cases there was little or no change past the fifty-step limit.

Forest loss associated with these scenarios displays a similar trend of rapid increase followed by equilibria (Figure 29, Figure 30 and Figure 31). The model does not account for forest regrowth, so there is no decrease in forest loss, only a decrease in additional forest loss.

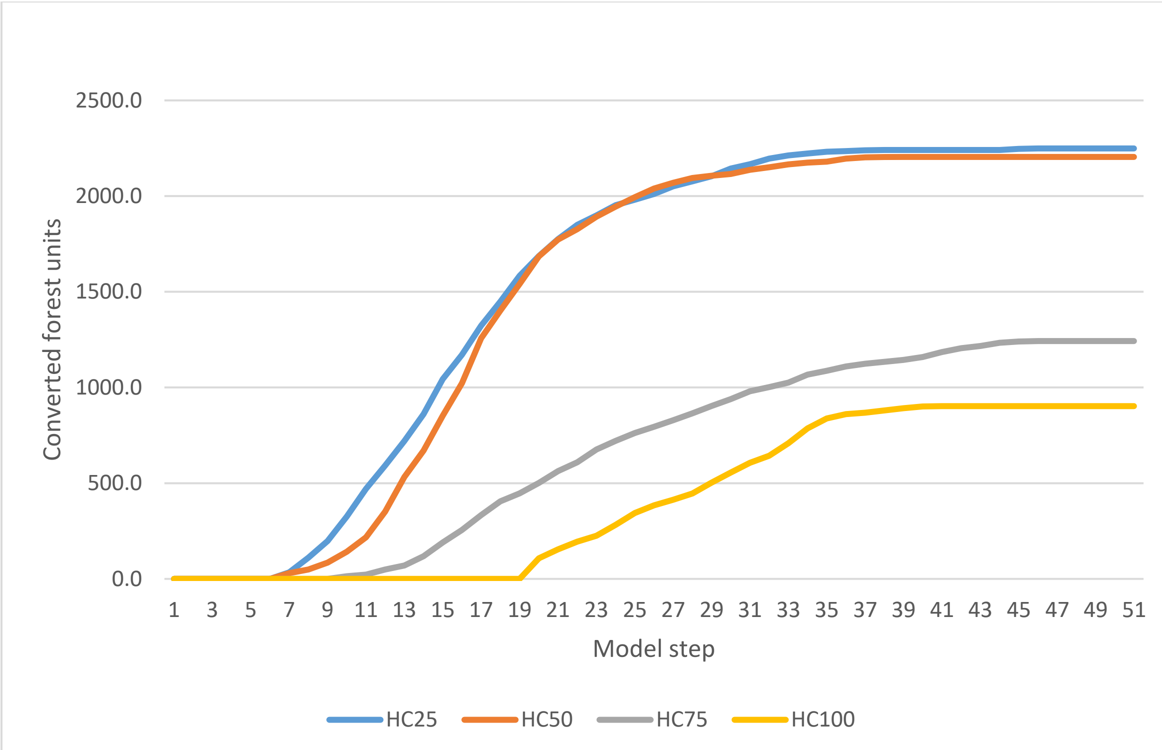


Figure 32. Forest loss at 100% productivity for the Run 1 scenario.

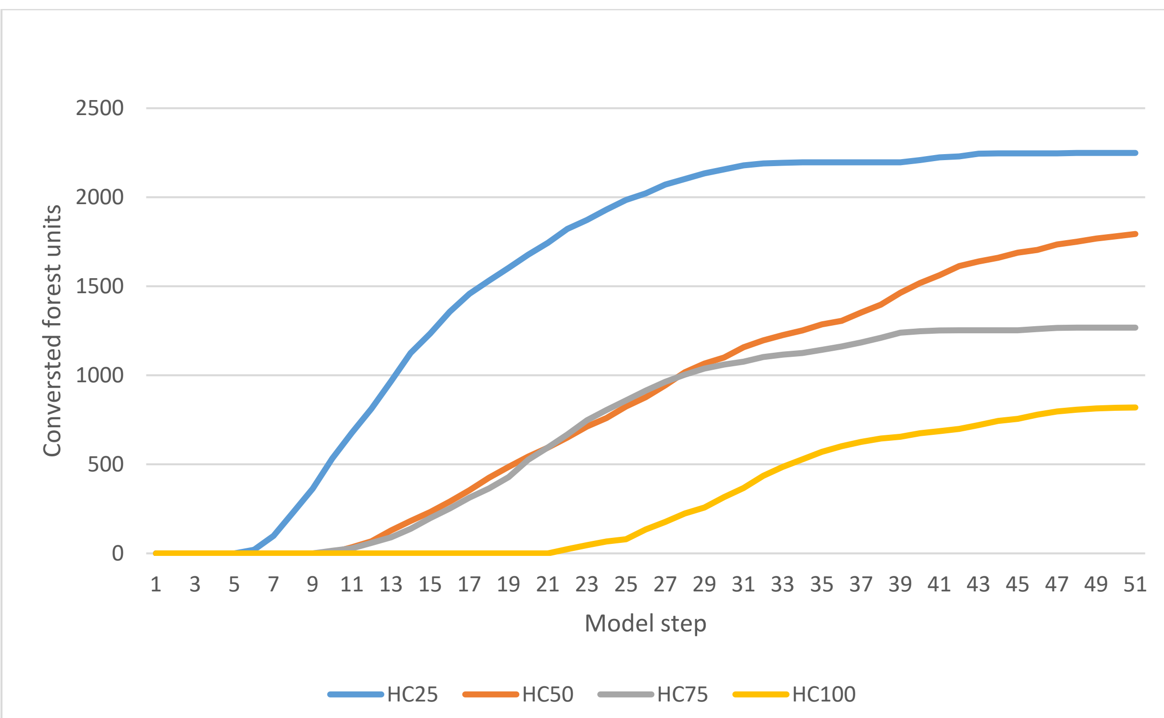


Figure 33. Forest loss at 90% productivity for the Run 1 scenario.

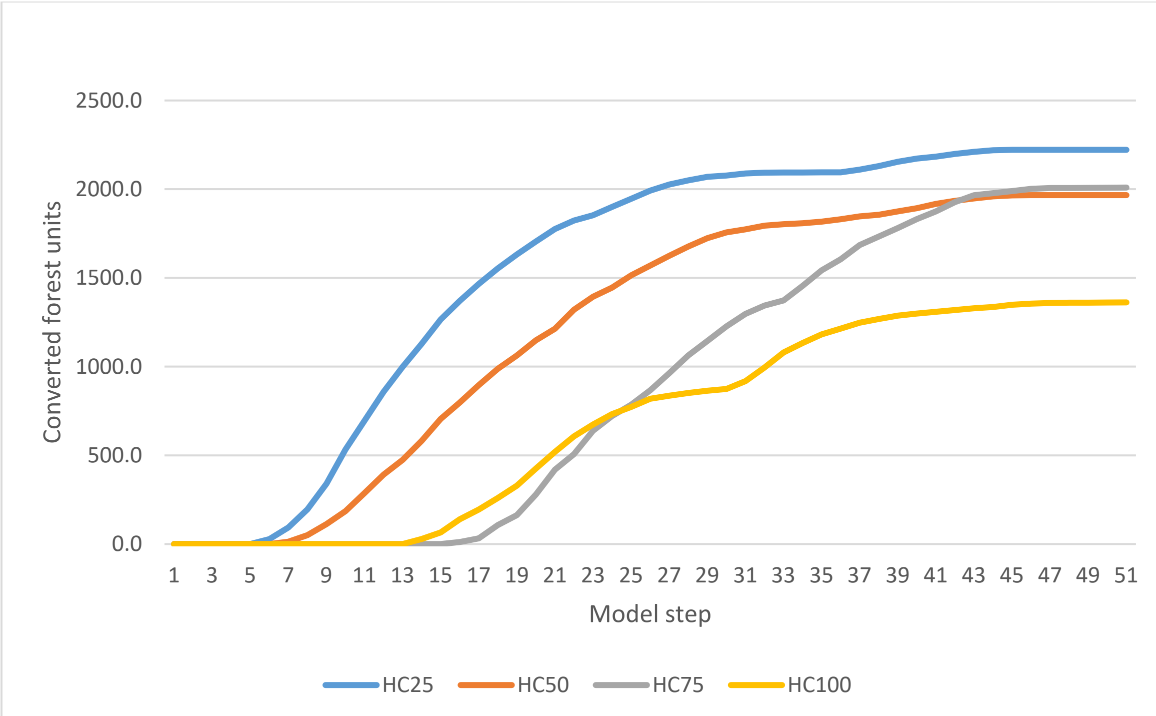


Figure 34. Forest loss at 80% productivity for the Run 1 scenario.

There are some scenarios in which the health-comm settings converge at equilibria that are very close to one another, though the shapes of the curves are different in earlier steps (Figure 32, Figure 33 and Figure 34). These convergences occur when the buy-land value is higher.

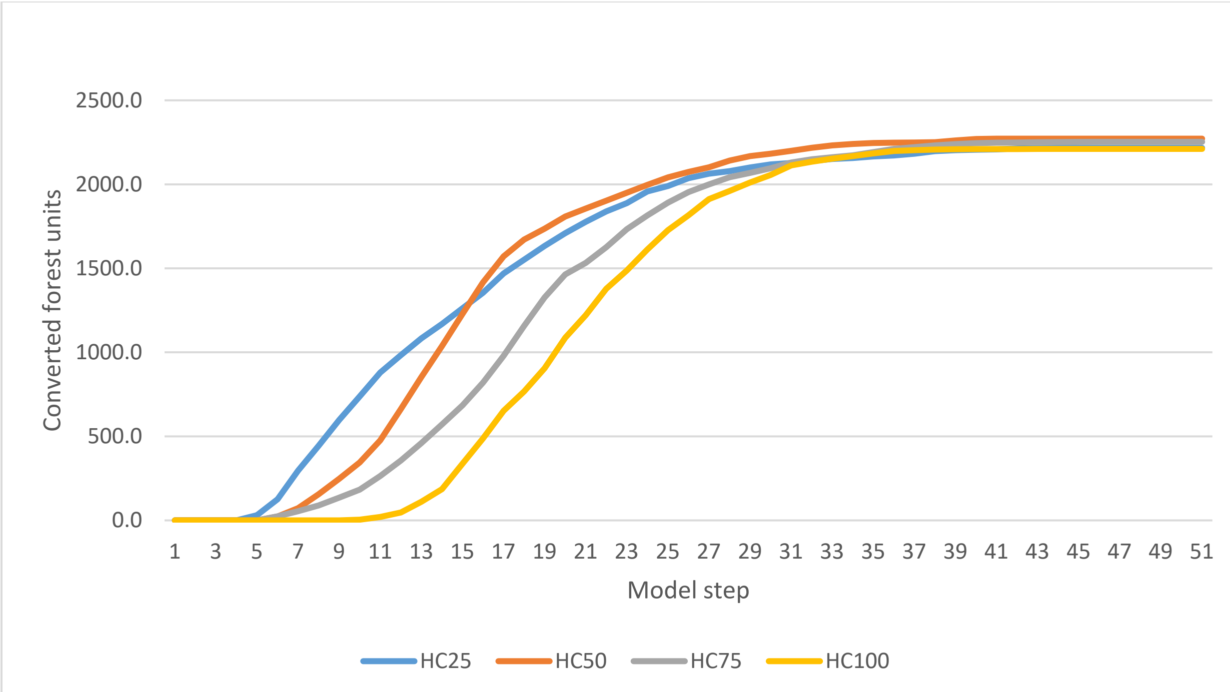


Figure 35. Forest loss at 100% productivity for the Run 6 Scenario.

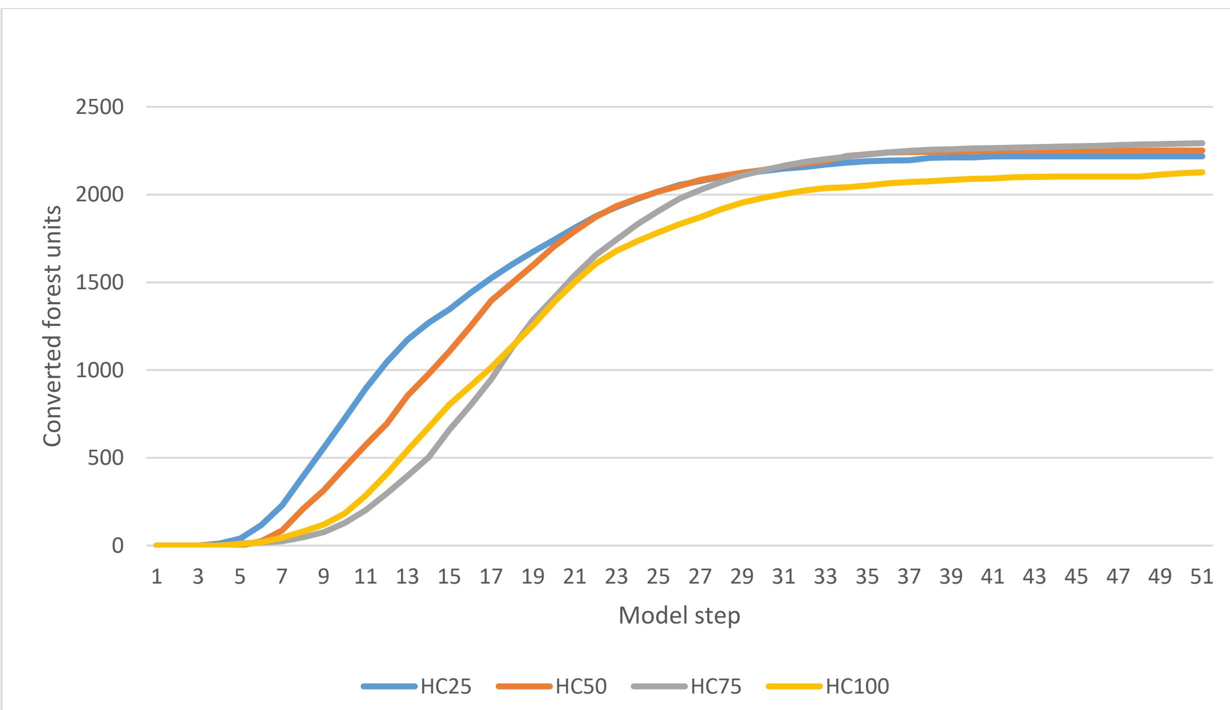


Figure 36. Forest loss at 90% productivity for the Run 6 scenario.

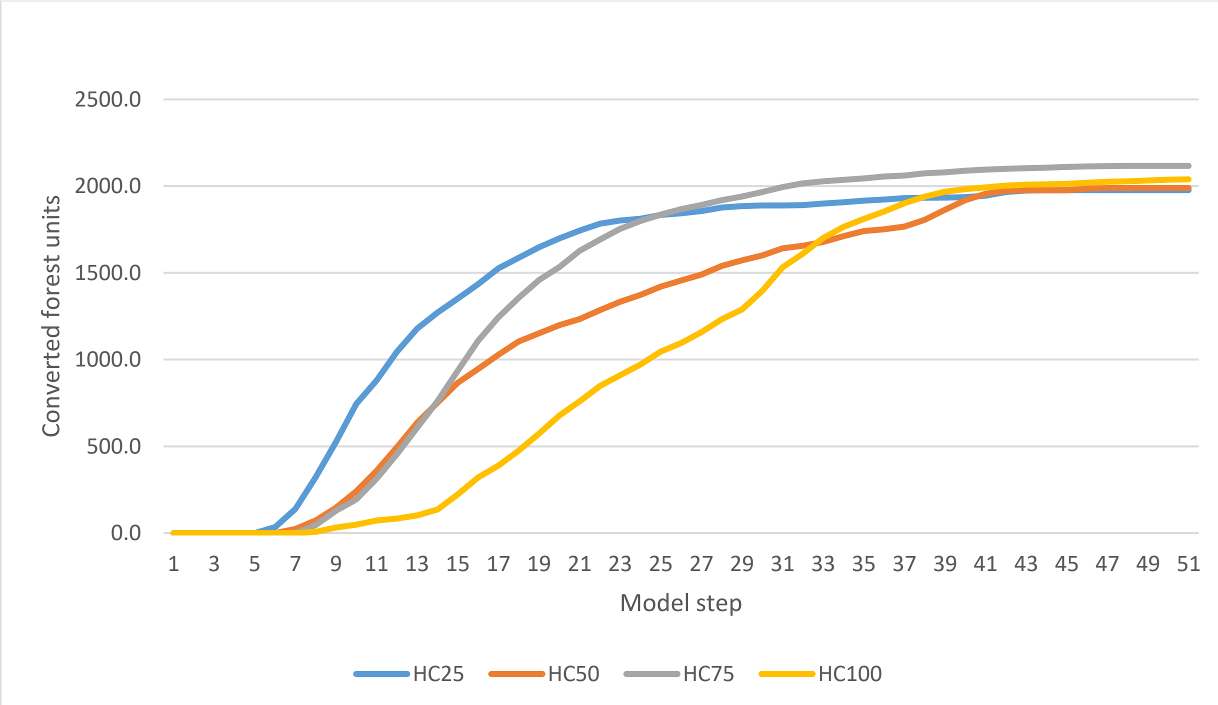


Figure 37. Forest loss at 80% productivity for the Run 4 scenario.

Changes in other variables adjust the amplitude of initial increases and/or the vertical distance between health-comm scenarios, but they do not alter the general pattern of initial increase followed by reduction to a lower-level equilibrium. For example, when work-per-plot is increased, the maximum percentage of miners reached in the initial increase is lower. Table 18 displays maximum percentage of miners for Run 1 (five workers per plot) and Run 3 (ten workers per plot) for four health-comm levels. In all cases, the maximum percentage of miners in Run 1 are higher than Run 3. However, the dynamic of a high number of miners followed by a decrease to an equilibrium is still present (Figure 35, Figure 36 and Figure 37).

Table 18. Comparison of maximum percentage of miners from Run 1, which allows five workers per cultivated plot, and Run 3, which allows ten workers per cultivated plot.

Production	100%		90%		80%	
HC	Run 1	Run 3	Run 1	Run 3	Run 1	Run 3
25	40.8	33.4	51.7	40.5	50.7	45.8
50	38.9	31.3	27.2	29.2	35.0	33.2
75	17.1	22.8	19.6	15.3	25.6	28.2
100	14.1	1.9	9.6	11.7	21.1	15.3

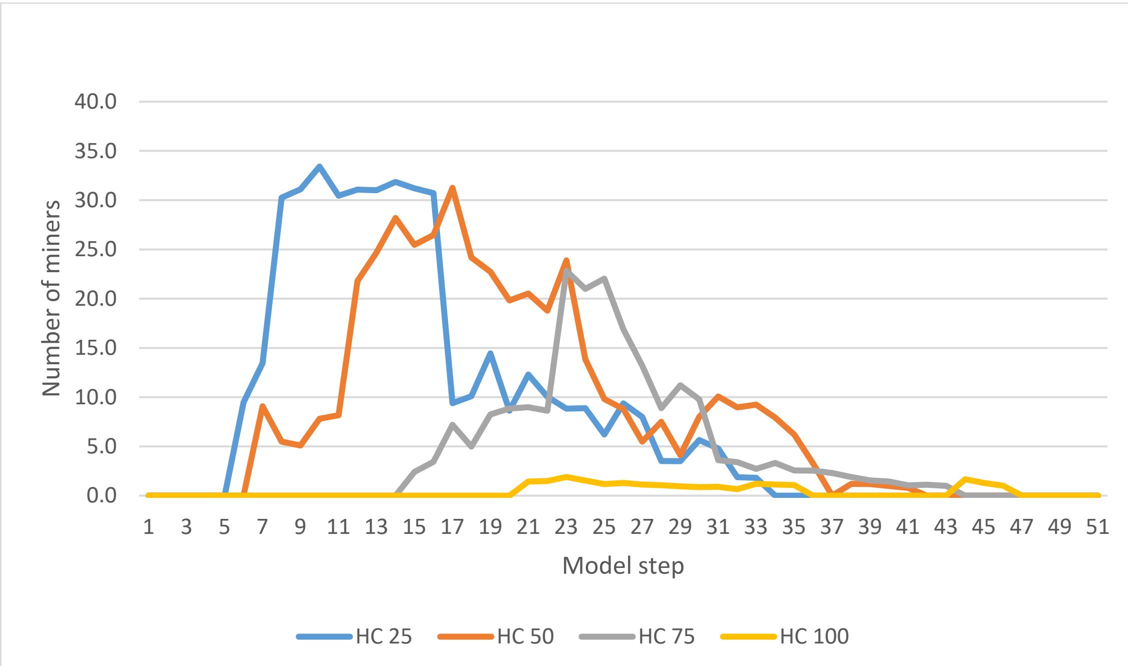


Figure 38. Percent of total population categorized as miners at 100% productivity for the Run 3 scenario.

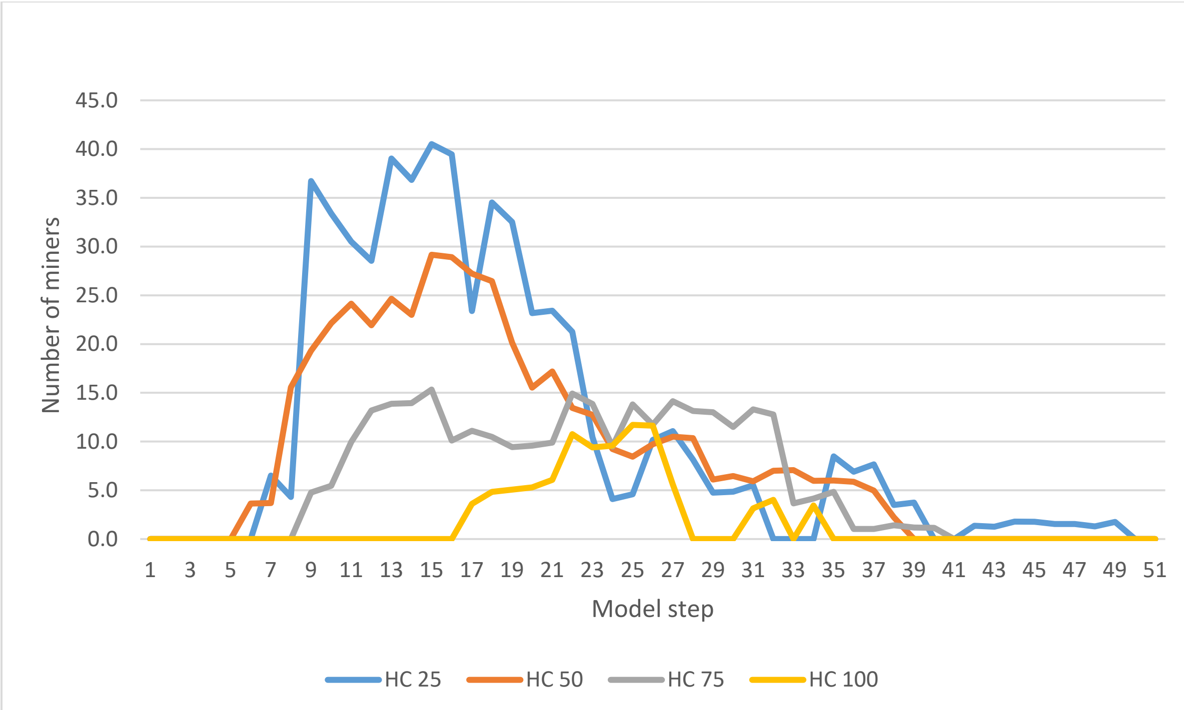


Figure 39. Percent of total population categorized as miners at 90% productivity for the Run 3 scenario.

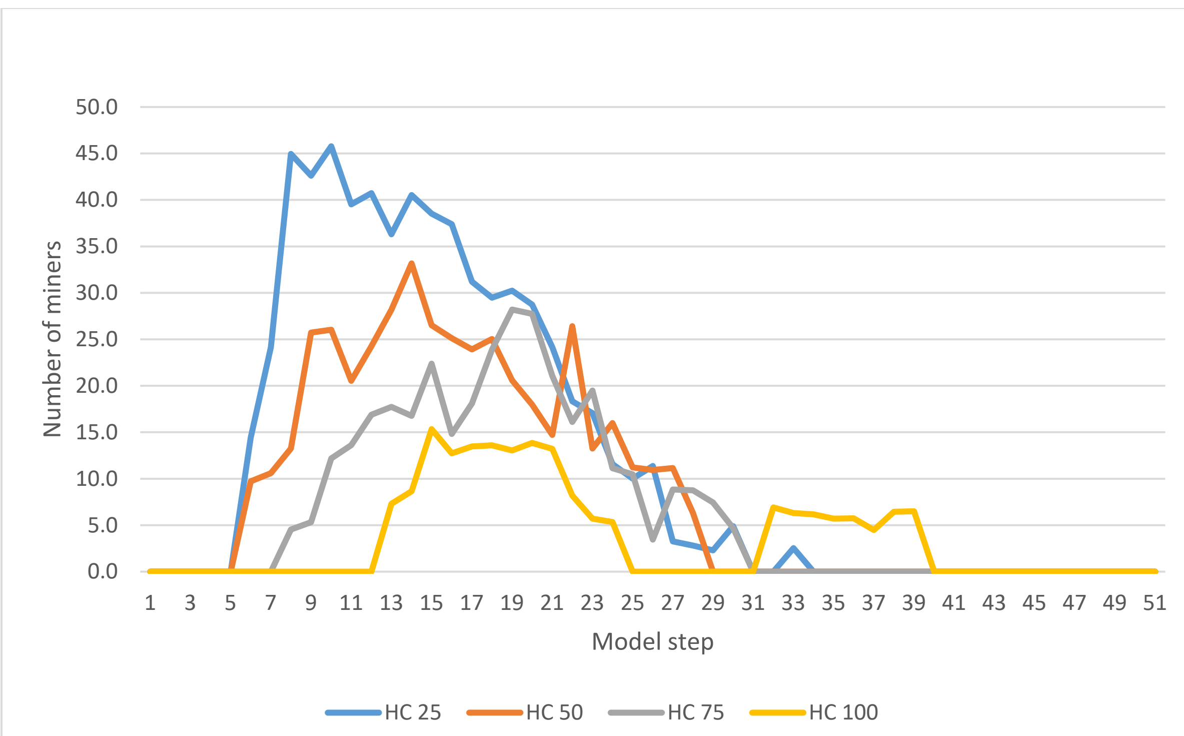


Figure 40. Percent of total population categorized as miners at 80% productivity for the Run 3 scenario.

Changes in sell-land threshold and buy-land change the shape of the curves, but the dynamic of increase and return to equilibrium remains. When the sell-land threshold increases, initial increases in mining happen more quickly than scenarios that use a lower threshold. This holds for all productivity levels and most scenarios.

Table 19. Step at which maximum mining engagement is reached demonstrated using Run 2 and Run 6 for all productivity levels. Anomalies are highlighted.

	100%		90%		80%	
HC	Run 2	Run 6	Run 2	Run 6	Run 2	Run 6
25	25	17	20	18	20	23
50	23	23	26	20	24	29
75	31	30	34	27	32	23
100	28	30	40	37	30	28

Figure 38 and Figure 39 depict the outputs from two model runs at 100 percent that differ only by the sell-land threshold. In Figure 38, the health-comm 25 scenario reaches its peak at step 25, but the peak of that line in Figure 39 is reached in only 17 steps.

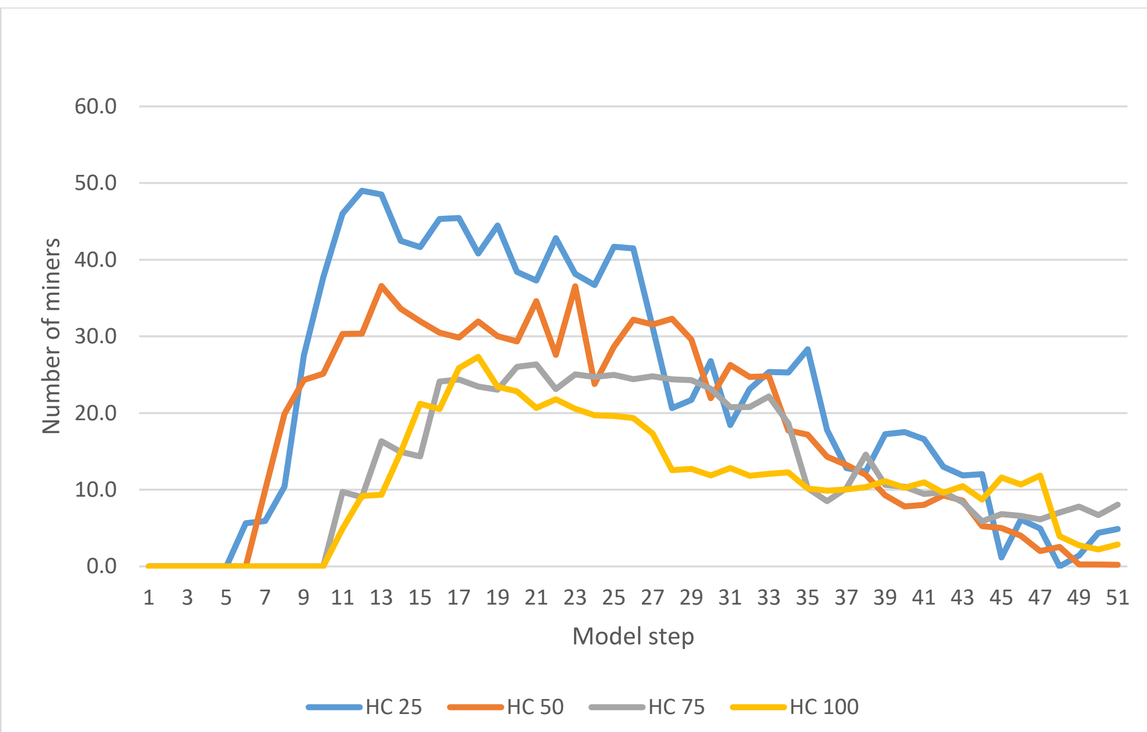


Figure 41. Percent of total population categorized as miners at 100% productivity for the Run 2 scenario.

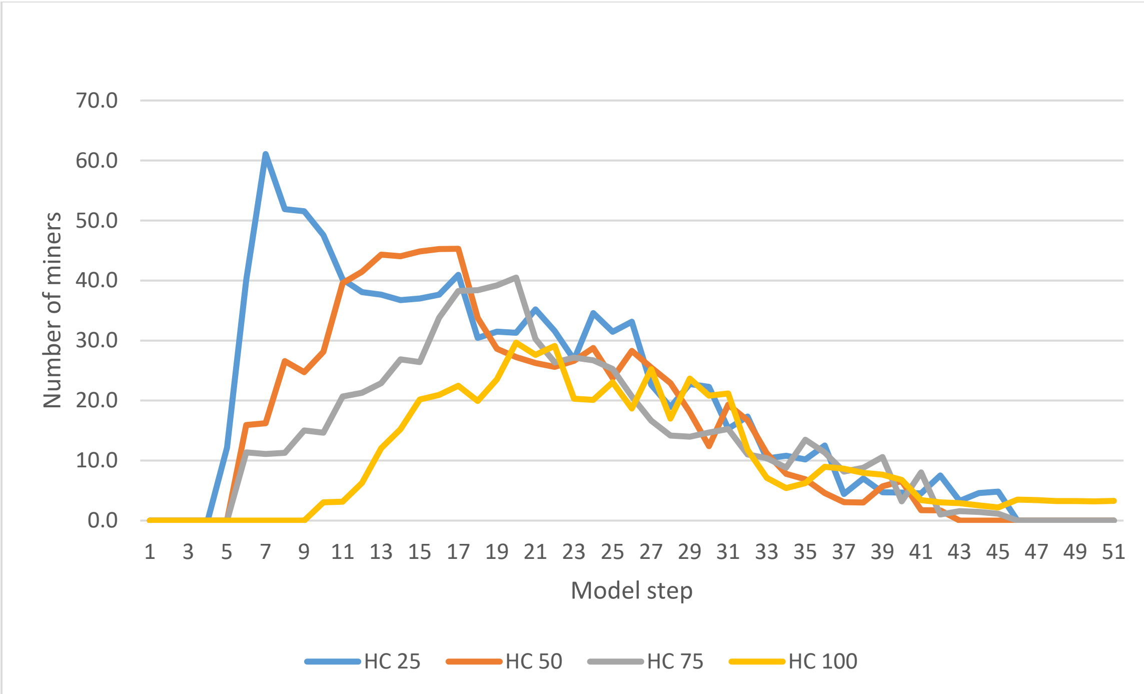


Figure 42. Percent of total population categorized as miners at 100% productivity for the Run 6 scenario.

When the buy-land variable is increased, the curves tend to descend to equilibrium more slowly. Figure 40 and Figure 41 depict comparable scenarios that differ by buy-land value.

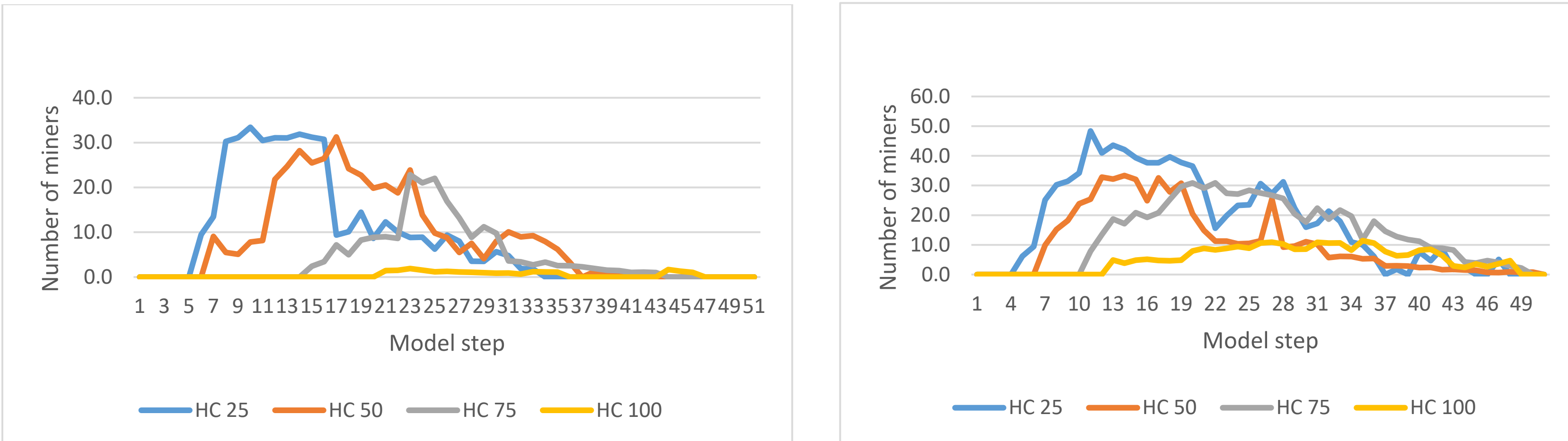


Figure 43. Comparison of Run 3 (left, buy-land value of 100) and Run 4 (right, buy-land value of 150) at 100% productivity.

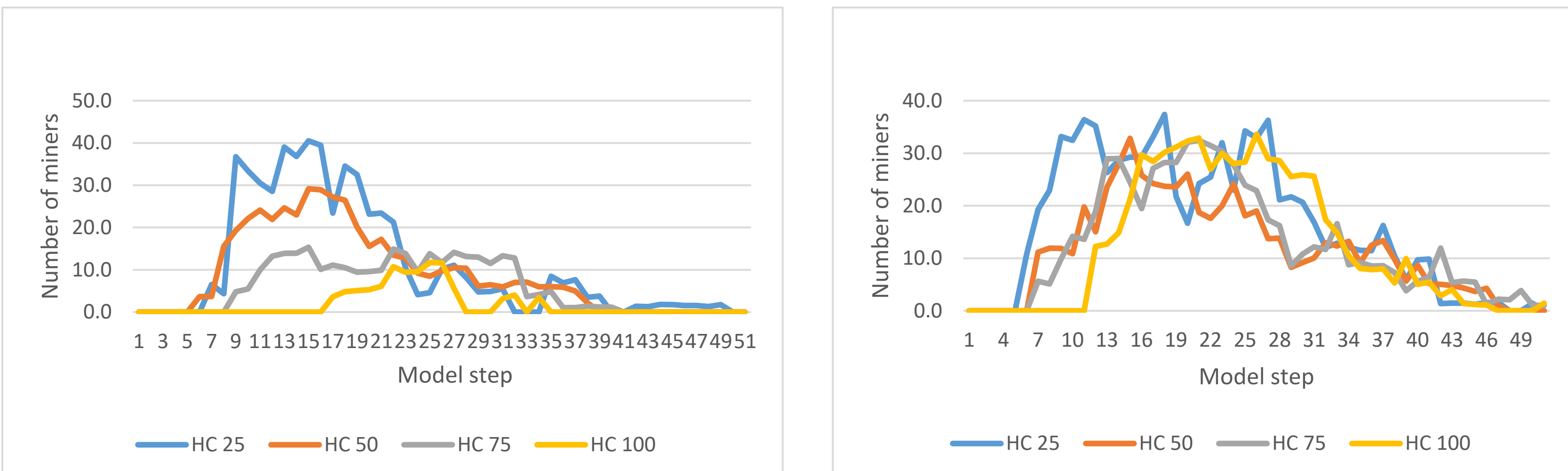
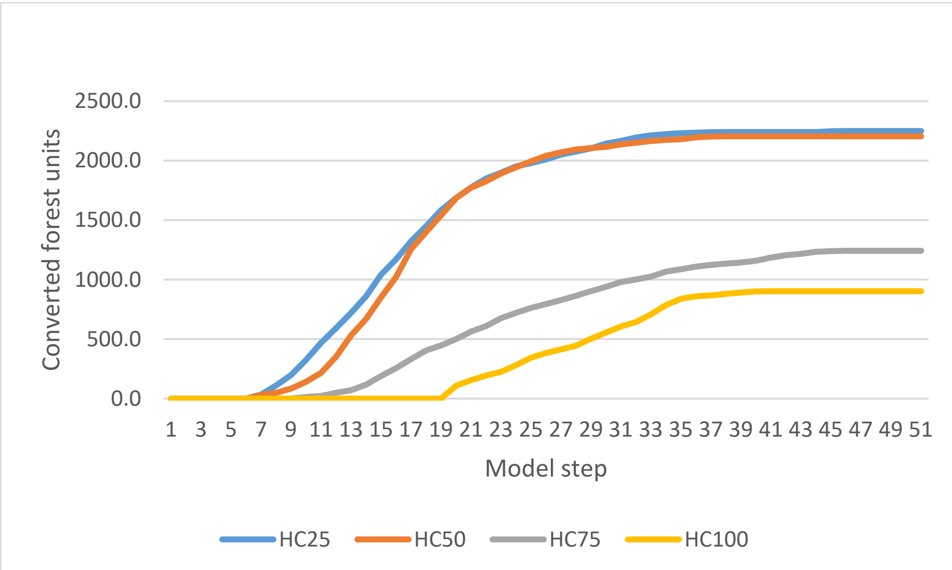


Figure 44. Comparison of Run 3 (left, buy-land value of 100) and Run 4 (right, buy-land value of 150) at 90% productivity.

Forest destruction is also altered by land costs. Changes in sell-land do not have a uniform effect on the output curves. However, when buy-land is increased, forest loss increases for scenarios with higher health-comm settings. This reduces the difference between the outputs of lower health-comm scenarios and higher health-com scenarios (e.g. Figure 42).



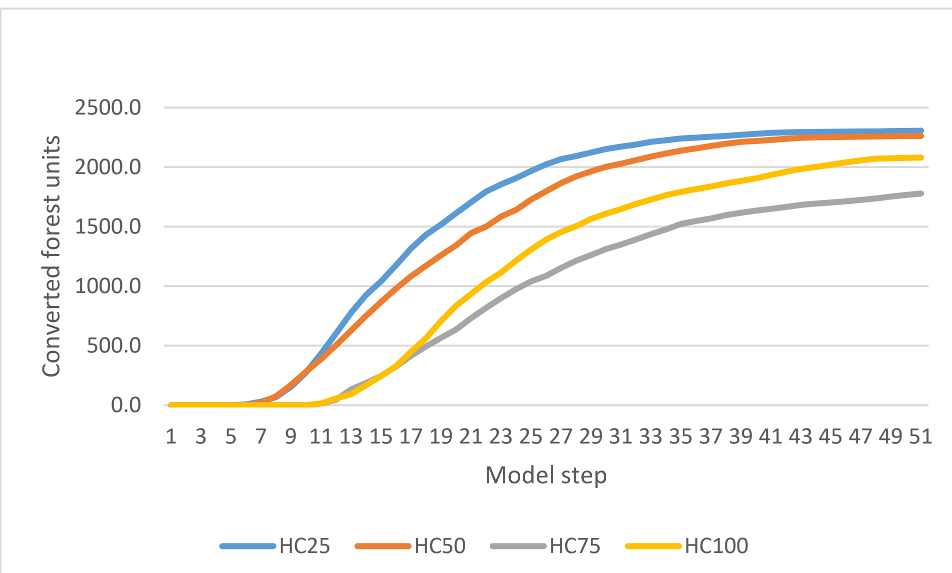


Figure 45. Comparison of forest destruction output at 100% productivity for Run 1 (upper) and Run 2 (lower), at buy-land values of 100 and 150, respectively.

5.4 Discussion

5.4.1 Health and Mining

Patterns that emerge from model runs indicate that there is a relationship between health and livelihood choice, and that these livelihood choices affect natural resources to varying degrees. In all scenarios, there is in increase in mining engagement followed by a decrease to a somewhat stable equilibrium. Increases in mining at lower health-comm levels are greater than those of higher health-comm levels, suggesting that health is a driver of mining and concomitant forest loss.

When health-comm is lower, more households fail to meet the model's requirement for engaging in production or labor and therefore earn income. This results in additional poor households that may not generate sufficient income to cultivate their land. Consequently, they may have to sell their land. Landless households have limited options for alternative income generation.

Livelihood options for households that are unable to produce their own marketable agricultural goods are limited in the model, as they are in the Dumoga Valley. In the model, households can only find on-farm employment in parcels that are cultivated by members of their own ethnicity. This model constraint reflects the use of social networks to identify work opportunities as well as respondents' preference for working within their ethnic group, as documented by qualitative data (see Chapter 3).

Shape and amplitude of response curves are changed by other model variables, but the variables do not change the pattern of the relationship between health and mining. Model results are presented using three production levels to demonstrate effects of variations in ecological conditions that influence harvest success of all farmers. This could approximate drought, pest outbreak or market failures. Figure 23 through Figure 25 suggest an interaction between health and production. In all productivity scenarios, low health comm scenarios result in higher number of miners than high health comm scenarios. At lower production (e.g., Figure 28), the difference between the number of miners at low health comm and high health comm is smaller. If health condition were simply a factor that reduced productivity, then the variance between the health comm scenarios would stay constant as production decreases. However, there is a non-linear relationship between health and production, which would indicate that health condition is not simply an additional factor influencing production.

At higher sell-land thresholds, more households are subject to selling land at each time step, causing a steeper rise in mining. Although households are coded to prefer on-farm labor to mining, increases in land sales results in fewer available on-farm jobs and drives poorer households to mining.

The response curves for higher buy-land values are wider, as the descent from peak mining engagement to the equilibrium level is slower. Higher buy-land thresholds require additional wealth before households can purchase land. This appears in the model as a barrier to reengaging in agriculture because more steps are needed to acquire sufficient wealth to purchase land.

The final variable that influences response curves is work-per-plot. When work-per-plot is adjusted up, more households can earn income on each cultivated plot. This reduces the need to engage in mining, reflected by lower peaks in mining engagement for all scenarios.

5.4.2 Mining and Natural Resources

Although engagement in mining is not directly correlated to specific levels of forest loss or ecosystem destruction, this model demonstrates several factors that suggest a complex relationship between mining and forest loss. When health increases, engagement in mining decreases, but does not always result in less forest destruction.

A key assumption relating health condition with forest loss is that households have a member that is physically capable of engaging in mining after household production is reduced either by illness or another stochastic event. Although this is supported by literature (Mcsweeney, 2005; Nguyen, Nguyen, & Grote, 2020), some literature suggests that sick people are less likely to engage in resource extractive behaviors because of the physical requirements of most of these behaviors (e.g., Völker & Waibel, 2010).

The model does not directly capture indirect effects of mining on the ecosystem that could affect health and agricultural production. However, qualitative data in Chapter 3 suggests that farmers in the valley are experiencing decreasing production because of ecological conditions. This model demonstrates change in the system's dynamics as productivity decreases. Therefore, the real situation may be moving from one production level to a lower production level as natural resources are degraded, and the system suffers effects from loss of ecosystem integrity.

5.4.3 Weaknesses of the model

This model is intended to be an initial step toward analysis of complex interaction of health, livelihood, and environment. There are several assumptions in the model that could use additional analysis. To keep the model simple, households were only given a single livelihood source. Livelihood diversification is well-documented in the literature (Ellis, 1998, 2008; Scoones, 2009; Zimmerer & Vanek, 2016) and in the quantitative data in Chapter 2 that supports this research.

In the model, land is not sold to other agents in the model, therefore sellers do not need to identify buyers with sufficient wealth to obtain land. This would serve to make land sales easier to complete. The algorithm that results in land sales includes multiple conditions and a random variable that controls when land is sold. This serves to slow the rate of land sales and approximate time needed to identify land buyers. When a household decides to sell land, that land is no longer cultivated, and all potential labor associated with the parcel is eliminated.

Finally, health is not associated with wealth in the model and each household has the same probability of being struck by illness. In contrast, literature has documented that poorer people tend to be sicker and sicker people tend to be poorer (Niessen et al., 2018; Nugent et al., 2018; Wagstaff, 2002). A more realistic scenario might include a weighted health-wealth variable, but there was no data in this study to parameterize such a variable.

5.5 Conclusions

Over time, health condition influences engagement in mining as well as loss of forest. Almost all scenarios demonstrate an initial increase in mining and forest exploitation followed by a decrease to an equilibrium. This initial increase suggests that mining provides an important coping strategy when on-farm income (through either production or labor) is not available. This is consistent with a body of literature on the role of forest resources as a safety-net for household consumption when experiencing an economic shock (Wunder, Börner, et al., 2014).

However, this model is predicated on the condition that health shocks can be severe and cause loss of land. All miners in this model are landless and unable to find work. This reflects conditions that lead to engagement in mining captured in survey data collected for this project. This dynamic also supports theory that natural resources can be an important route to gather wealth as a route out of poverty (Angelsen et al., 2014; Wunder, Börner, et al., 2014).

Additional permutations and repetitions of model variables may reveal more subtleties of the relationship between health and livelihood strategy. This model presents an experimental context that allows observation of possible effects of changes in health on livelihood strategy and the success of strategies. However, the surprising element of this model is that if health is improved, it may be possible for a reversal of livelihood strategy from illegal mining that is damaging to human and ecosystem health to more sustainable farm-based livelihood strategies. Therefore, mining may present an important coping strategy to support households in times of decreased income generation.

Chapter 6 Chapter Six: System-wide Analysis of Health-Livelihood-Environment Interaction

In this chapter, I return to the conceptual model described in Chapter 1 (Figure 1 duplicated below). Chapters 2 through Chapter 5 have provided insight into components of the model, and in this chapter, I draw on information from those chapters to address the system as a whole.

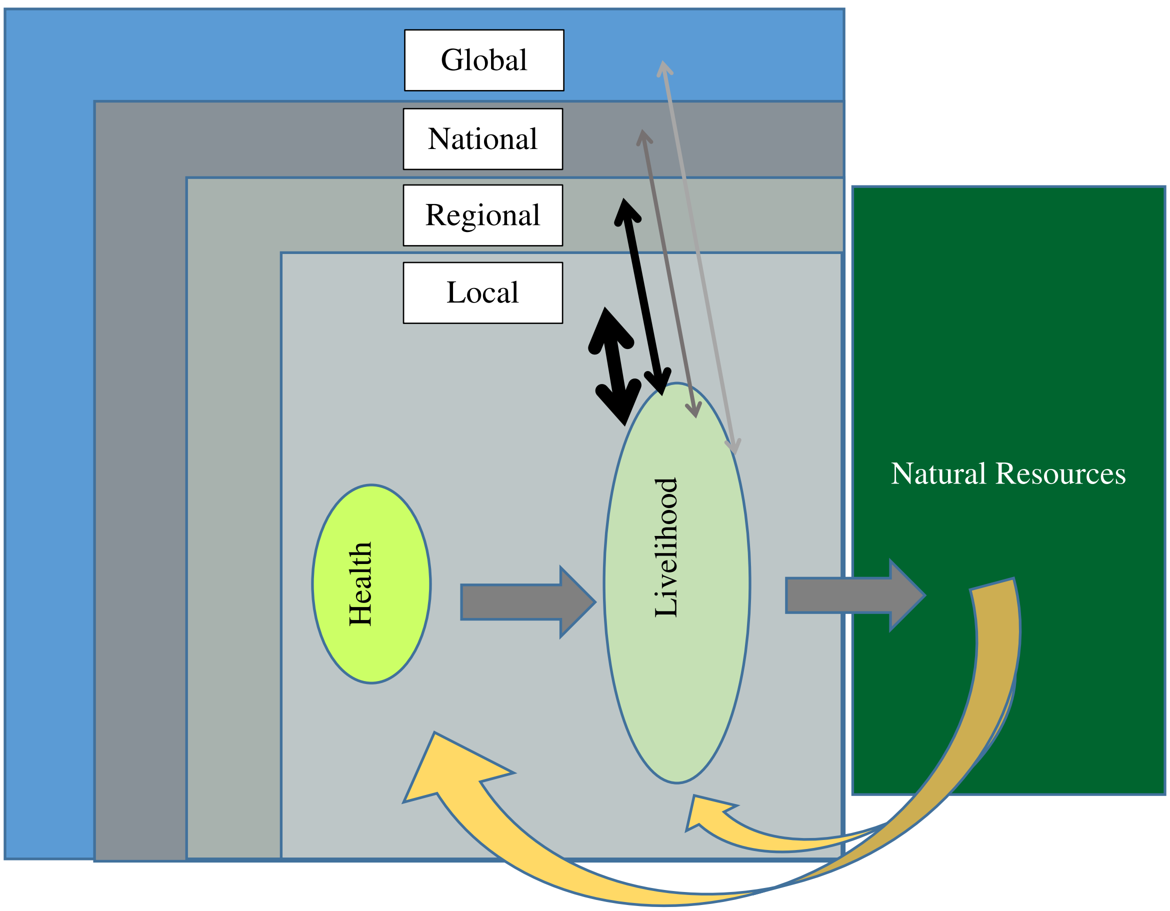


Figure 46. Conceptual model repeated from Figure 1.

6.1 Reviewing the conceptual model

This study began with a focus on how health status relates to use of natural resources in livelihood strategies. Literature indicates that socio-demographic variables can influence the role of natural resources in livelihoods in times of good health and in response to health shocks. This research demonstrates that there are also cultural components associated with the role that natural resources play in long and short-term livelihood strategies. Balinese households demonstrate a different behavioral response to health crises than their Minahasa and Mongondow neighbors. The different behavioral responses to illness can result in different livelihood choices. In addition, there is a component of Balinese culture that, for a reason not captured by this research, makes illegal mining an invalid livelihood choice.

Previous studies on health, livelihood choice and natural resources (Reid & Vogel, 2006; S. E. Shackleton & Shackleton, 2012; Völker & Waibel, 2010; Wagstaff & Lindelow, 2014) have examined economic and socio-demographic factors that have influenced these interactions. However, studies have not focused on households of different ethnicities that share a common environment. In the case of Dumoga, households are situated in ethnically homogenous villages, but have apparently similar access to land, irrigation resources, education, government support and other factors that have been correlated with use of natural resources in response to health shocks. This study suggests that there is a strong cultural component to how livelihoods are adjusted in times of ill health. Policy responses that intend to address negative environmental and social impacts of illegal gold mining in Dumoga would be strengthened by understanding that cultural plays a role in the decision to engage in gold mining.

Independent of issues of cultural norms associated with livelihood choice, the central question of this research asks if changes to health result in changes to natural resource-related livelihood strategies. I tested this relationship using both a quantitative survey and an ABM. Two different assessments emerge from the different analyses. In quantitative survey results, I do not find a significant relationship between changes to health condition and participation in mining.

However, the ABM indicates that lower levels of community health result in increased numbers of miners and increased forest destruction. SES analysis emphasizes that emergent dynamics observed at one spatial or temporal scale do not necessarily hold at other scales. Quantitative survey results depict health-livelihood interaction over a short time, while the ABM covers several decades during which different patterns of results emerge.

The pattern observed in the ABM suggests that mining serves as a coping function when there are health shocks. In all model outputs, there is an initial increase in mining followed by a decline to an equilibrium. Mining increases occur earlier in the model run and are generally higher when health conditions are low. However, miners do not stay miners when they have an opportunity to buy land and return to agriculture. This supports literature that suggests natural resources can form a “safety net” in times of economic need (Mcsweeney, 2005; Wunder, Börner, et al., 2014).

Descriptions in interviews and responses to surveys show different pictures of health in the villages. Few people indicated health as problematic in qualitative interviews, however, illness was frequently captured in quantitative surveys and in personal observations. It may be that respondents were hesitant to discuss topics that could cast a negative light on their community with an outsider in face-to-face interviews.

In interviews, respondents focused on the ability to obtain food and material wealth as primary outcomes of livelihood activities. They did not mention health and well-being as part of their livelihood strategy development. In fact, several respondents indicated that miners are aware of the physical and psychological dangers of mining but indicated the need to mine outweighed potential dangers.

Limitations of livelihood choices are confirmed by both interviews and surveys. Nearly all livelihood options in the valley are associated with land, and there are limitations on land availability. Development of new livelihood options that do not rely on land would require additional infrastructure and support to build human and financial capital.

Qualitative interviews provide insight into the vulnerability context in which livelihood decisions are made. There is a historic imbalance in access to land that is perpetuated by policies that support some livelihoods at the expense of others. For example, the government has supported wet rice agriculture through development of irrigation systems and provision of improved rice varieties. This differentially benefits Balinese farmers who have experience with this type of production and ignores the needs of the traditional practices of the other ethnic groups in the valley. Cultural isolation also drives imbalances by making different livelihood strategies available to different ethnicities. In particular, cultural isolation reduces on-farm wage labor opportunities because farmers are more likely to network and identify people to hire from their own village and ethnic group. The Minahasa and Mongondow people rely more on wage labor but increasing landlessness in those communities reduces the availability of on-farm wage labor opportunities. Because of cultural isolation, it is difficult for these groups to find on-farm work on Balinese farms.

Government decision-making is highly centralized and draws on regional or national trends to determine what aid is provided to communities. Interviews with national park staff and regional environmental and health officers indicate a disconnect between the experience of the people in the Dumoga Valley and the activities planned at the regional and national level. For example, farmers noted that the varieties of seed that the government provides do not meet their needs. Furthermore, government health officials provide medicine based on national and regional trends, and do not let local conditions determine the care that people receive. Therefore, the medicines and care that are available are not useful. Needs that are identified at the national level are abstracted to a degree that the needs of the people in this study are not met. Disconnects caused by this abstraction between scales of the system appear to increase vulnerability at the lowest scale.

There are indications of environmental change (e.g., water reduction and pest increases), but there is a lack of data that can be used to motivate change or conservation. Qualitative interviews indicate that many people have a sense that conditions are changing and that these conditions result in decreased agricultural yields. Their primary concerns are decreasing water availability and increases in agricultural pests, but there was no indication that there was anything that they could do to address these concerns. Although the people rely directly on ecosystem services for livelihoods, their focus is on survival to such an extent that they are, willfully or not, unaware of the link between their actions and the environmental conditions with which they struggle.

Taken as a whole, the system appears to have several dynamics that increase vulnerability. These dynamics include limited livelihood options, declining ecosystem services, limited environmental perception, and lack of information on health consequences of livelihood choices. The ABM suggests that, when health declines occur in this vulnerability context, natural resources are an important source of coping. The dynamic, longer-term assessment made possible through the ABM leads to a different conclusion than quantitative surveys that have explored this link in the past (Angelsen et al., 2014; Wunder, Angelsen, et al., 2014).

6.2 Limitations and Implications for Future Research

Most questions about dynamics within SESs are complex, and health-livelihood-environment interactions fit this description. Research on daunting, complex topics can suffer when research seeks to find a deterministic solution to a problem. Deterministic approaches seek to find causal relationships between component factors of a system and fail to incorporate the role of human agency into system dynamics. Complex problems also defy management when the specificity of a qualitative case study narrows applicability of lessons learned. However, when approaching complex problems, multiple lines of inquiry can be useful. The research presented here provides a framework that can be expanded upon and benefit from additional research.

The strong role of culture or ethnic group in constructing livelihood strategies as well as in responding to illness is a key insight gained from this study. Previous studies of have noted contextual differences that influence health-livelihood-environment interactions (or component interactions). The coexistence of homogenous, relatively isolated groups sharing a common political, physical, and economic environment allows this study to evaluate the role of culture without confounding environmental effects. In other words, because environmental factors are held constant in this site, the role of culture can more easily be observed. Future research should focus on a more nuanced view of the role of culture in livelihood decision making and response to illness. A better understanding of the role of cultural differences could support targeted economic development, public health, and biodiversity conservation policies.

Data presented here were collected with the assistance of local stakeholders, but the primary researcher was not a member of the communities being asked to participate. This likely introduced bias. In addition, the analysis was conducted by the researcher and was not validated by community members. Their perspectives on the conclusions reached would be a valuable addition to this work.

More precise parameters developed with the help of disciplinary specialists would help strengthen the ABM. Furthermore, more accurate economic data and research on behavioral economics could help develop more precise decision-making algorithms in the model. Better details on the environmental consequences of mining and distribution of mining and agricultural contaminants would allow future modelers to add additional environmental parameters to the model. Finally, data on actual health consequences of livelihoods could be a meaningful contribution.

6.3 Conclusion

Balinese households exhibit different livelihood strategies and responses to illness than Minahasa, Mongondow or Jaton households, highlighting a cultural component associated with these behaviors. None of the other measured socio-demographic variables differentiate Balinese households from the other groups in the valley and therefore cannot explain the difference. This key insight warrants further research and emphasizes the need for sustainability policies to incorporate cultural models.

This research indicates that analysis from different temporal scales results in different conclusions about health-livelihoods-environment interactions. A dynamic view at a longer timescale shows that natural resources serve an important coping mechanism when health status worsens. This dynamic is not observed in shorter-term statistical data.

Although data to fully elaborate all primary dynamics captured in the model were not available for this analysis, the methodology presented here is robust enough to be expanded to incorporate additional data. The ABM provides an experimental context that is open for additional revision. It suggests a way to conceptualize system factors and places some factors in the framework as a starting point for discourse.

As mentioned in the introductory chapter, wicked problems in SESs require perpetual management and communication. Their complex nature defies deterministic resolution. The approach presented here can facilitate management of wicked problems by providing simulations that can support dialogue, test assumptions, and create a platform for stakeholder input. This model draws on both quantitative and qualitative data but can also be strengthened by incorporation of diverse perspectives and epistemologies.

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Appendix I: ODD Protocol

Purpose

This model can be used to explore factors that contribute to the rise of illegal mining in a predominantly agricultural system. It is based on data collected in the Dumoga Valley, North Sulawesi, Indonesia. The model allows users to manipulate probability of health crisis, threshold prices at which agents buy and sell land, plot productivity, number of harvests per year and on-farm work availability. These factors were identified through primary data collection to be potential drivers of expanding illegal mining in the area.

Entities

There are two types of interacting entities. Patches represent the landscape present in Dumoga. The world consists of a 91 x 57 grid in which each cell represents a plot of land of approximately one-half hectare. Patches have productivity and work values. They also take the ethnicity of the associated agent when owned. Agents represent households that belong to the three primary ethnic groups in the area. These ethnicities are represented in the model as different breeds, which have different decision rules. All households have the same state variables: wealth, number of members, age, health and parcels.

Scales

The model represents a constrained spatial area divided into parcels that represent approximately one-half hectare of land. This specificity of the spatial extent is mostly important in the initialization of the distribution of land. Interactions are programmed between individual agents and patches that they own or utilize. As a result, the scale of interaction between agents and patches can be one-to-one or one-to-many.

Ticks represent a portion of the year that is determined by the selection of the number of harvests. When the harvest slider is set to 1, a tick represents one year. When harvests are set to three, a tick represents a four-month period.

Table 20. Description of model entities

Entity	Variable	Description
Patches	own-id	Indicates the identification number of the agent who owns the patch. If a patch is open to mining, this variable is set to 9999 and if it is not owned, it is set to -1.
	Productivity	Random number up to 100 that determines how much wealth a patch provides to its associated turtle
	Work?	Amount of landless households the patch can support. Applies only to patches that are already associated with an active agent.
	Mine-work?	Number of landless workers that can be employed on that patch when on-farm employment is unavailable.
	Bown	Name of the breed of the patch's owner
Turtles	h-id	Allows connection between agent and multiple patches simultaneously.
	Age	Number of years household has been in existence
	Members	Number of members in household
	Health	Assigned random value for the household's health status
	Wealth	Amount earned through mining, work or selling land
	Parcels	Number of patches associated with the turtle
Globals	Mine-count	Counts each time a turtle executes the "mine" procedure
Inputs	Health-comm	Applies global health condition. Household health is a function of health-comm and health
	Production	Global modifier of production that represents events, such as droughts, that impact all parcels
	Harvests	Number of harvests per year
	Sell-land	Wealth threshold at which households sell land and the amount that they earn for selling it.
	Buy-land	Wealth threshold above which households can opt to buy land
	Work-per-plot	Number of households that an owned plot can employ per tick

Process overview and scheduling

When the model runs, patches are assigned a random productivity score. Then the following procedures are run in order.

<u>Plant</u>

Turtles must invest in production before they earn profits from their plots.

Earn

Turtles earn money from the parcels that they own. Each parcel has a productivity score that is derived from a randomly assigned productivity score multiplied by a global production level set with a slider. The higher the production slider, the higher productivity scores are in general. Wealth earned is a function of patch productivity.

Health also affects earning. In Minahasa and Mongondow houses, where there is a member of the household that is sick, all members of the household will stay at home. In a Balinese household, only the sick member is excused from working, even in the case of severe illness. Therefore, an illness in the household has a greater impact on earnings in Mongondow and Minahasa households than in Balinese households. In the model, if the health score (community health divided by randomly assigned household health) is lower than two, Mongondow and Minahasa household earnings are reduced by half and Balinese household earnings are reduced by one-tenth. These reductions are were selected based on a qualitative estimate of difference for demonstration purposes and could be further refined with an analysis of empirical data.

This procedure also includes a decrease in wealth associated with household operations. Households lose10 wealth units to support each member of the household in each time-step

Seek-work

If a household does not have a plot from which to earn income, the household seeks work. Each patch can employ a number of households. A landless household identifies a patch with available work. The patch's work is reduced by one and the household earns 50 wealth. Households may only work in patches is owned by their breed. In field observations, farm employment is obtained through social connections and is primarily limited to working within the same ethnic group.

If no work is available in a patch that is owned by a household of the same breed, Mongondow and Minahasa households will turn to mining. To mine, the households identify an unowned patch and turn that patch green. Mining will increase their wealth by a random amount in each tick.

Buy

Following earning, households can buy land. Households will buy land if their wealth exceeds the threshold value set with the buy-land and a random probability threshold. Households are allowed to buy any available land and patches can only be owned by one household.

Sell

If wealth falls below the threshold indicated using the sell-land slider, the household will sell one plot of land. Their wealth increases by the amount indicated in the sell-land slider.

Grow and Split

Households add a member every time a random growth probability is less than 20%. If a household has more than 3 members and more than one parcel, the household will split. A new household forms and takes one of the patches from the parent household. The new household takes half of the parent's wealth.

Design Concepts

A core principle of this model is the use of individual decision rules to allow for emergence of land use and land ownership patterns. Agents are provided a limited set of decision rules that are based on livelihood strategies and preferences observed in the Dumoga Valley. All other dynamics can be considered emergent.

The model also embraces stochasticity in establishing several conditions. Health is presented as a combination of both individual health variables that are randomly assigned at the beginning of each procedure as well as a global health variable that serves to attenuate or exacerbate randomly assigned health conditions. Illness striking a household is a stochastic event, but the probability of an individual household suffering from a health shock is affected by health conditions of the whole community. The less-health the community, the more likely an individual household is to suffer from poor health.

Productivity (a representation of crop yields) of an individual plots also has a stochastic element that draws from both local and global conditions. Individual patch productivity is randomly assigned at the beginning of each procedure. This is a simplified representation of spatial variation in land quality, access to fertilizer, disease occurrence and other factors that influence productivity of individual plots of land. At the same time, there are also events that strike global productivity, such as drought, which, again, enhance or limit crop yields.

Details

Initialization

The model is initialized with fifty Mongondow households, fifty Minahasa households and twenty Balinese households. This roughly represents the proportions of the division of ethnicities observed in the valley. Mongondow and Minahasa households own one patch (or parcel) and Balinese households own four patches. This represents the household land allocations provided by the government when the valley was initially settled. Health, wealth, number of household members, and age of the household are randomly assigned at setup. Turtles are arranged in quadrants of the interface to represent the ethnically homogenous villages that are currently observed. Patches are assigned randomly a productivity score.