The Livelihood-Energy-Conservation Nexus: Intervention strategies to promote conservation in rural villages located near wildlife sanctuaries

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ABSTRACT: For poverty-stricken communities located near the Kumbhalgarh Wildlife Sanctuary, harvesting natural resources from forests within designated sanctuaries constitute a critical source of livelihood. Kumbhalgarh sanctuary meets household and market demand for fuelwood, timber, grassy fodder, and non-timber forest produce. Approximately 160 villages depend on this sanctuary for a variety of products and the sanctuary is being denuded at an unmistakable rate. This study utilizes marginalized community-based group model building and expert testament to trace and scrutinize local livelihood behavior patterns in order to identify routes of intervention. The resulting System Dynamics Model of village livelihood and extraction from sanctuary highlights employment, buffer zone management, and household energy efficiency as three potential routes that could directly reinforce conservation efforts and reduce sanctuary degradation without disrupting the livelihoods of the implicated communities. Strategies of intervention are developed and justified in this paper

Keywords: *Livelihoods, household economics, poverty, conservation, ecological modeling, natural resources, energy, fuelwood, cook stoves, field modeling, group model building, and participatory rural appraisal*

Introduction

Forest and wildlife conservation goals of a state are often difficult to meet without the support of people who are dependent on the natural resources being conserved. Billions of people around the globe depend both directly and indirectly on forests for a wide variety of resources; forests contain natural resources that are fundamental to sustaining diversified land-based activities. In addition to preserving ecosystems, serving as carbon sinks, and providing several other crucial ecosystem services, forests are of vital importance to securing livelihoods of poor and marginalized communities. Widespread dependence on forests paired with society's accelerating demand for land area is unmistakably affecting the condition of forests around the globe. From the once-vast rainforests of the Amazon basin to the flayed, charred tracts that remain in South Asia, human intervention in forests is evident. For example, an estimated 1.2 billion people worldwide still depend on fuelwood for heating and cooking purposes, and extract resources at a rate limited by what they can carry. India, exemplifies the constraints and difficulties of managing protected areas that are also populated by people.

Models of household and collective behavior under conditions of critical depletion of timber and other resources offer insight into potential areas of intervention to reverse resource decline. In this study, rural village resource usage and extraction practices are scrutinized for behavioral structures and feedback threads that directly affect household decisions that in turn impact forest resources inside and outside the boundaries of a wildlife sanctuary. Multi-disciplinary field teams of development practitioners, social scientists, and engineers embedded in Rajasthan, India undertook firsthand observation of these behavioral patterns, and gathered data to build dynamic models of people and sanctuary interaction.

This paper is structured in the following way: background details on the area under study; a description of behavioral patterns highlighting the livelihood-energy-conservation nexus; methods adopted for the study, including field modeling, participatory rural appraisal, group model building, interview and survey method, and expert interaction; results attained through the application of the field methods and critical issues driving the behavior of forest dependent communities and the present condition of the Kumbhalgarh Wildlife Sanctuary. Finally, the paper describes the System Dynamics Model and various simulations indicating sensitivity of energy, livelihood, and conservation variables and a discussion and recommendations for future work.

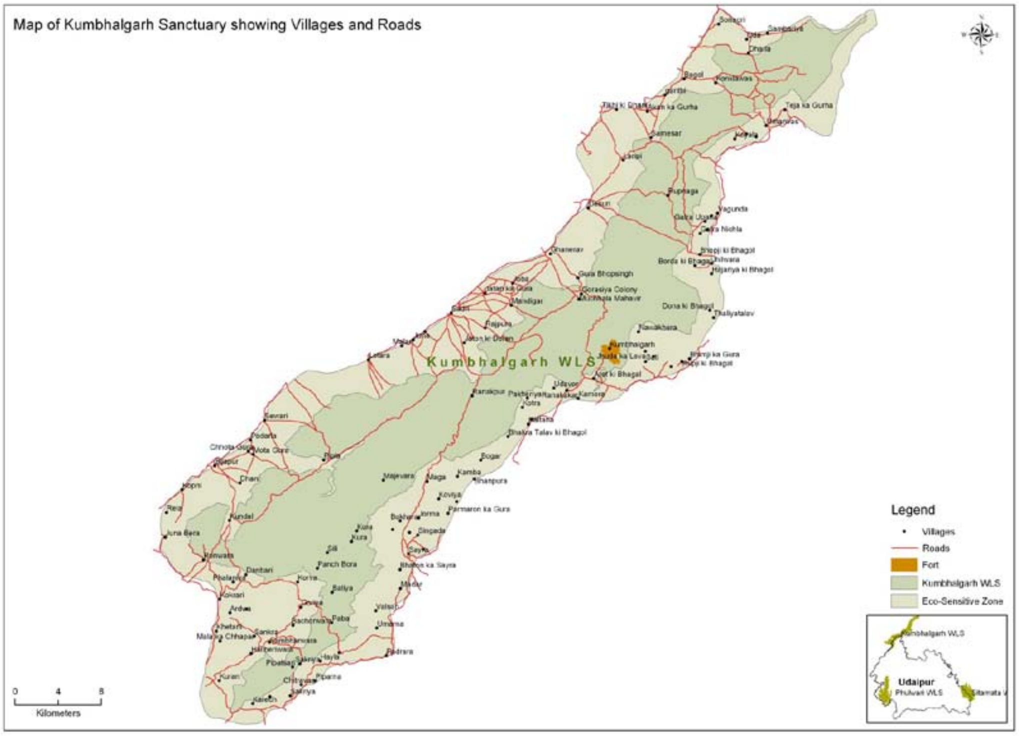
Background

This study was conducted in the Kumbhalgarh Wildlife Sanctuary (KWLS) and its peripheral villages of Padrada, Kyarakhet, Haila, and Pipalsari. Located between 25° – $25^{\circ}40'$ N latitude and $73^{\circ}2'$— $73^{\circ}30'$ E longitude, KWLS is situated north of Udaipur and covers 610.53km^2 (231.7mi^2) in the Udaipur, Pali, and Rajsamand districts (see Figure 1). Its federal delineations are comprised of 600.18km^2 of reserved forest and 10.35km^2 of protected forest (231.7mi^2 and 4.0mi^2, respectively).

This wildlife sanctuary is an ecotone between the forests of Aravallis and the Thar Desert, serving as a barrier between forest and desert biomes. As a result, many rare flora and fauna are under constant threat of impinging habitat based on climate conditions. Additionally, the hills of this Protected Area (PA) serve as catchments for many rivers and nullahs, providing water for the human and livestock populations and irrigating the agricultural land in the Pali, Jalore, and Jodhpur districts.

The PA is comprised of rugged topography, with particularly steep hills in the Rajsamand and Udaipur districts. The forest tract consists of hill ranges between 300 and 4000 ft above sea level, including the highest elevation point in the Ranakpur region. Formed in the Archean eon, the Aravalli hill range is one of the oldest formations in the world. The underlying rocks consist primarily of gneisses, biotite, schists, and limestone. The soil is predominately sand and sandy loam; vegetation coverage in these hills serves to bolster the low moisture retention consistent with this soil stratum. Rocky outcrops strewn with boulders are common throughout the region, as rain erodes much of the area not covered with significant vegetation.

Figure 1: Map of Kumbhalgarh Sanctuary, Rajasthan, India



Flora

The floral components of the PA are chiefly edapho-climate climax type; the forests of this area fall into the Category II Tropical Dry Deciduous forest classification (see Figure 2). Specific classifications identify the PA as 5B – Northern tropical dry deciduous forest and C2 – Northern tropical dry mixed deciduous forest. Other sub-types within the sanctuary include DS1- Dry deciduous scrubs, E2- Boswellia forests, E5- Butea forests, E8- Saline Alkaline scrub savannah, and E9- Dry bamboo brakes (Champion and Seth 1968).

The subtropical climate of the region yields extremely hot summers and relatively moderate winters. The PA experiences three seasons: summer, monsoon, and winter. Summer typically lasts from March until June, during which temperatures can reach up to 44°C. Monsoon season generally starts in the last week of June and continues intermittently through September, contributing the majority of the average annual rainfall (~725 mm) within an average of 20 to 25 days of rain per year. Winter lasts from November to February; January is typically the coldest month. Moderate winds prevail from the south-west to the north-east during summer, and are reversed in the winter months. The region is subject to periodic and frequent droughts; adequate rains are typically received once in three years. Furthermore, in recent years the frequency of drought has increased and the amount of annual rainfall has decreased; rains have become more erratic and less predictable.

Figure 2: Land Cover and Forest Types in Kumbhalgarh Wildlife Sanctuary

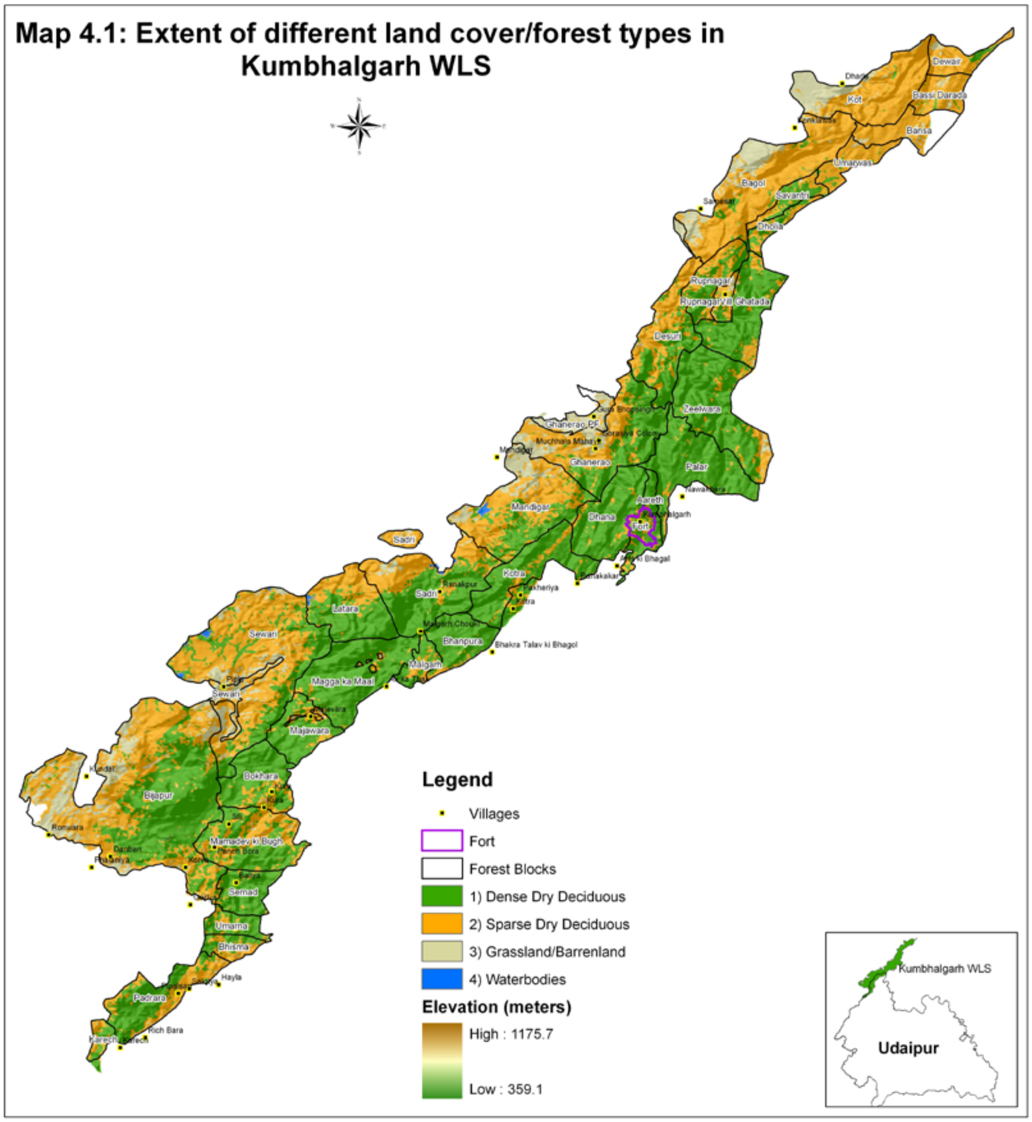


Figure 3: Average Seasonal Rainfall

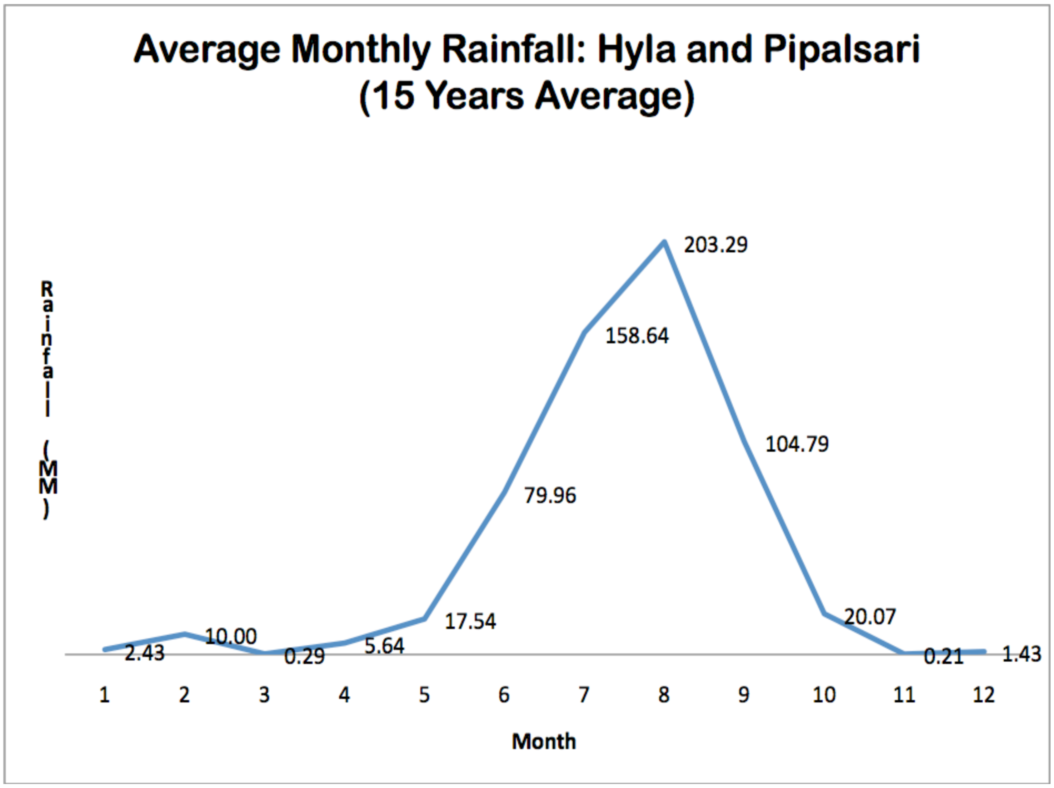
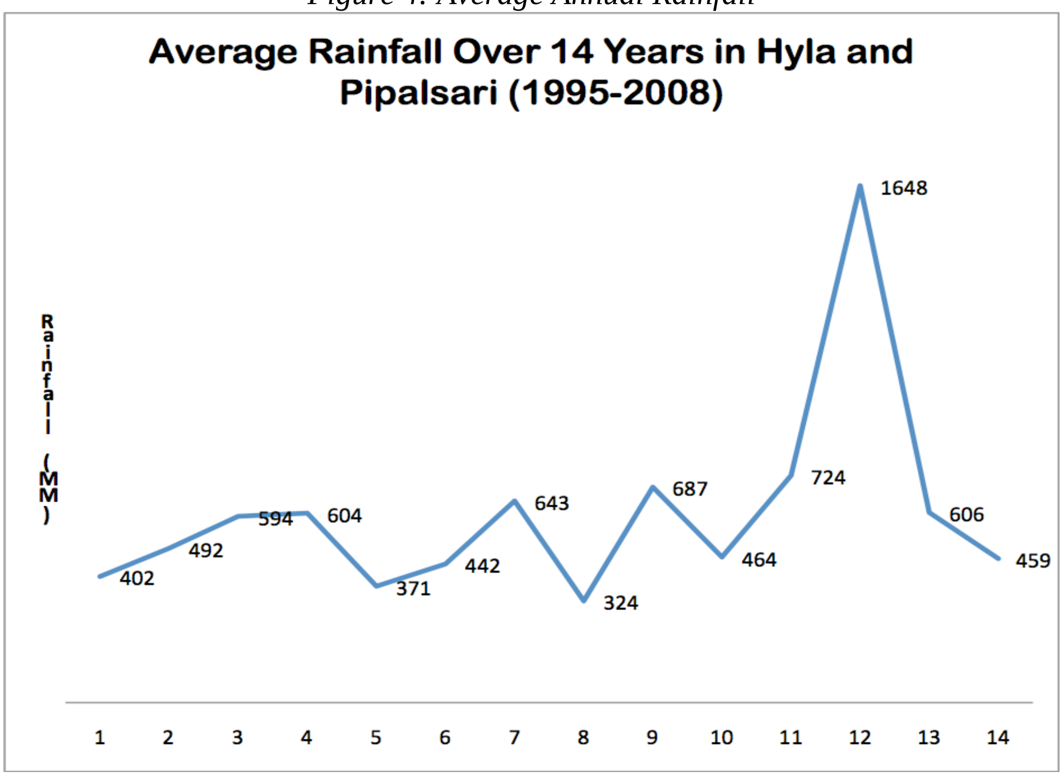
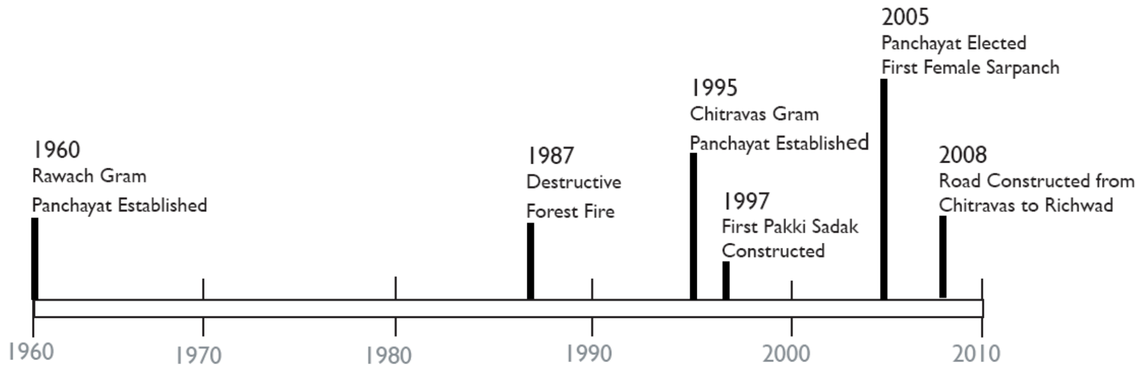


Figure 4: Average Annual Rainfall



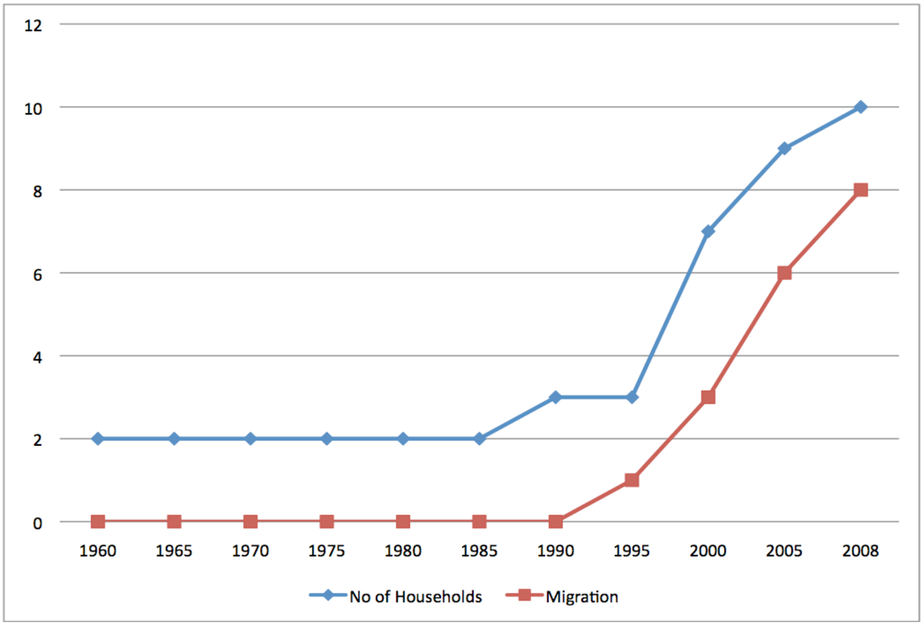
Population and Demographics

The richness of natural resources in this landscape has enabled the communities to settle in this environment and secure a sustainable livelihood; over several centuries, many indigenous, pastoralist, and migrating communities have settled the area. For centuries, this population has been living symbiotically with the land, coexisting with the forests and diverse wildlife without significant effect or detriment. The society flourished due to set rules and systems based on the principles of subsistence and minimum interference driven by traditionally evolved management with socio-ecological-economic boundaries.



Currently there are 22 villages situated inside the Kumbhalgarh sanctuary and 138 villages located along the periphery. The population of these villages has increased gradually from 1960 due to migration resulting from diminishing natural resources in surrounding areas. However, this population growth rate has slowed since 2000 (See Figure 2).

Figure 5: Relative Change in Number of Pipalsari Households and Migration
(With Respect to 1960 level as perceived by village residents, formal data unavailable)



Families from communities within and bordering KWLS, traditionally cohabitate in multi-generational homes. Polygamy is also accepted practice, thus it is not uncommon for the family of one patriarch to occupy several households. This filial structure has significant implication for increases in the rate of natural resource consumption, because population increases have translated to disproportionate increases in the number of households in the area, and resources are typically consumed on a per-household basis.

Sanctuary Extraction

The households in this area depend on the forests of KWLS and the surrounding areas for a variety of natural resources that sustain their nutritional needs and economic livelihoods. These products include fuelwood, timber for construction of houses, agriculture implements and other tools, non-timber forest products (NTFP), fodder grass, livestock grazing and foraging grounds, agricultural land area, and habitation land area. The area surrounding KWLS is not a designated buffer zone. A large area around the park boundaries is also forestland mainly designated as Reserve Forests by the government. The management of these lands is not strictly in the role of a 'buffer' to the park though local communities through Joint Forest Management are involved in the protection of some of the Reserve Forest areas outside of the park boundary.

Issue Description and Reference Mode

Historically, there has been a critical dependence of communities on forest resources in India's arid and semi-arid regions. Unrelenting needs for timber, fuelwood, NTFP, and livestock foraging grounds have led to increasingly scarce forest resources. Consistent with this pattern, excessive extraction of forest products from KWLS has meant an increased rate of degradation of the sanctuary.

As observed by the communities in close proximity to the forest, forest cover in the region during 1960-80 was significantly dense but has since decreased. Research corroborates this trend; about 10% of initial forest cover remains today. Reasons for this degradation include increasingly infrequent rainfall, road construction, extraction of timber by the forest department a few decades ago, and increased deforestation due to local population growth.

Detailed biodiversity assessments by the Foundation for Ecological Security (FES) over the past three years across KWLS indicate sluggish forest regeneration. Decrease in rainfall in the area as well as extraction of tree reproductive assets has contributed to slower regeneration and recruitment rates. There have been attempts to mitigate this dependence on the sanctuary, but forest conservation efforts and rules governing sanctuaries ultimately interfere with the ability to increase availability of natural resources on which sanctuary inhabitants depend. Thus, these efforts have had little effect on the general deforestation trend.

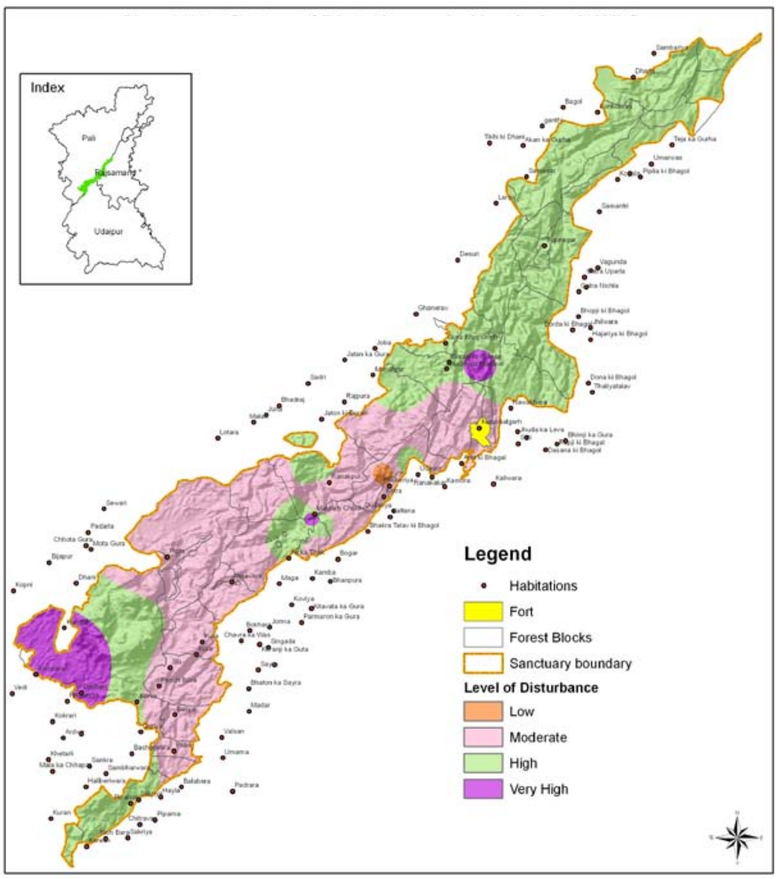
At the core of protection and conservation are a set of interrelated factors that concern peoples livelihoods inside and outside the sanctuary. Energy insecurity and animal husbandry of households outside and inside the sanctuary is a significant aspect of pressure on the resources of the sanctuary. In a large way, household and other rural energy needs are significant drivers of extraction patterns in KWLS that over time have reduced the availability of fuelwood and timber, grass for fodder, and other non-timber forest products.

Livelihood – Energy Interaction

Multiple communities depend on KWLS to meet their energy and livelihood needs in the form of fuelwood, fodder for livestock, NTFP, and many other resources listed previously. These forest products are primarily used to meet household subsistence needs, however, a proportion is typically sold for cash or bartered in nearby villages. Furthermore, net fuelwood demand and frequency of forest product collection varies between villages, depending on levels of poverty, distance from the forest resources and other climatic influences. There is also an active trade of fuelwood (some of it bartered for buttermilk and the remaining for cash) between villages inside and on the periphery of the sanctuary and villages in some distance from the sanctuary. For instance, a large fraction of fuelwood collected from the sanctuary is sold in a nearby town, Sayara, where fuelwood resources have been exhausted due to excessive extraction from local forest areas.

Energy – Conservation Interaction

Figure 6: Disturbance in Kumbhalgarh Wildlife Sanctuary



Growing demand for fuelwood due to increasing population numbers unmistakably affects forest resources, and the communities residing in close proximity to KWLS are aware of sanctuary degradation. However, these communities are un-equipped and/or unwilling to act to conserve this resource. For example, food is cooked on traditional, low-efficiency stoves; fuel-efficient or more complete combusting stoves are absent in the study area. Furthermore, certain villages have exhausted their natural surroundings and are nonetheless increasingly dependent on forest products from KWLS. Additionally, fuelwood sales continue to be driven by demand regardless of perceived deforestation in the purchaser community or collection area.

It follows logically that external conservation efforts directly influence the ability of the affected communities to gather fuelwood to meet energy demands. Hence, increases in timber availability could supplement this fuelwood demand.

Livelihood – Conservation Interaction

Households within this community supplement their economic needs by gathering and selling products from within KWLS. Additionally, declining agricultural productivity and increasing population drive the need for more farmland to provide for higher economic and sustenance demands; since these farmlands are often forested areas that are cleared and converted to agricultural fields, encroachment within KWLS borders is increasing (the forest areas adjacent to the KWLS are being steadily reduced and park boundaries are also being contested by adjacent communities). At odds with these behavioral patterns, regulatory conservation efforts potentially undermine the economic interests of the KWLS community.

This situation has led to various efforts to design policy to support forest conservation without significant effect on the community economic and energy needs. One such policy design is through the formation of Village Forest Protection and Management Committees (VFPMC) by the JFM Program for management of Reserved Forest areas within village Panchayat boundaries. VFPMCs protect specific areas of land designated for meeting livestock fodder requirements and requirements for other forest produce through a set of bylaws that govern the user regime of the village-protected forestland. This policy has been enacted with some success, although the protected land area is not sufficient to support the community herd in its entirety.

Methods

To understand the energy dependence of rural households on local renewable natural resources and the subsequent impact on forest resources of the sanctuary, we will use system dynamics computer modeling (e.g., Ford, 1999; Sterman, 2000) with FES staff, rural villagers and households using group model building participatory techniques (Andersen & Richardsen, 1997; Vennix, 1996, 1999). System dynamics is a method for understanding the dynamics of complex social and natural systems in terms of the underlying reinforcing and balancing feedback mechanisms and their influence on the stocks and flows of a natural-human system. What distinguishes system dynamics is the combination of being able to involve multiple stakeholders in the development and testing of computer simulation models using group model building (GMB) participatory techniques (ibid).

This section gives an overview of the methods utilized in gathering data on the foundations and impacts of KWLS behavioral patterns and developing a system dynamics model mapping the Livelihood – Energy – Conservation Nexus.

Field Modeling Approach

Participatory Rural Appraisal and Group Model Building

The Participatory Rural Appraisal (PRA) method was utilized to develop awareness of the dynamic problem through firsthand descriptions of the system. In this method, information was collected directly from the involved community with various PRA tools specified below. The goal of this data collection method is to incorporate the knowledge and opinions of rural people in the planning and management of development projects and programs; PRA tools facilitate collection and analysis of information by or for the community. Because this is a collaborative process, PRA actively empowers marginalized communities and helps to identify resource needs and sustainable use patterns.

- Social Mapping: Utilized to understand social dimensions and demographics, including settlement patterns, institutions, and social structures of the surveyed villages.
- Resource Mapping: Employed in investigating the various resources available, as well as their importance, specific locations, and usages at the village level. Resource mapping served useful in understanding the interconnections between different variables such as forests, agriculture, and water.
- Seasonality: Gathering and analyzing data on seasonal variations in terms of extraction of fuelwood, fodder, and NTFP.
- Focused Group Discussions and Timelines: Focused group discussions were conducted in the surveyed village to understand the trends spread over a period from 1960 to 2009. The major components covered under these discussions included population, livelihood, family size, rainfall, crops and agricultural productivity, livestock, water availability, migration, and forest degradation. These discussions helped to identify the root causes of trends.

In this investigation, the PRA method was employed to examine livelihood, energy, and conservation relationships within the surveyed villages in order to gain insight and accurately define the dynamic system. System dynamics software was then utilized to visually map behaviors and effects in order to simulate patterns in the system and test dynamic hypotheses.

One of the strengths of this field modeling approach is its highly iterative nature; hypotheses are created, tested, and re-engineered as long as community input and expert feedback are available. Field visits were spent evaluating community-specific hypothesis priorities, honed with subsequent visits, in order to better model behaviors and variable relationships. The results of these visits were utilized in group model building sessions involving domain experts and stakeholder representatives. As a result, the model structure remained fluid through the scoping and consensus building processes until the final moments of its synthesis, and was agile to discover influence and factors revealed with sequential iterations of PRA and SD group modeling (Costanza and Ruth 1998). As a result, final hypotheses accurately reflect the habits, preferences, and faculties at employ in the dynamic system, gleaned directly from the involved community.

Data Sources

Household Surveys

The interview and survey method was used to collect data at the household level in the surveyed village. Major focuses were energy sources and demands, livelihood dependence, land description, details of livestock and fodder demand, income sources and expenditures, and coping mechanisms, all of which are directly or indirectly linked with the forest. A stratified sampling approach was selected for the household survey— relatively well off and very poor households were selected to represent the diversity of the village.

Community Group Discussions

Throughout the course of this study, meetings were held with groups of village residents in order to address particular sub-domains of behavioral patterns as a supplement and/or confirmation of survey data. Households were invited to send a representative to gender-separated meetings. The data gathered from this method provided insight into household behaviors and feedback structures that are valuable to building model confidence; discussions were seeded through an impartial translator to ascertain model substructure priorities such as usage of available resources, product collection patterns, perception of reference modes conservation feedback loops, future lack-of-resource awareness and behavioral change outlooks.

Expert Key Informants

Local knowledge resources were tapped in order to gain accurate insight to crucial behaviors in the Livelihood – Energy – Conservation system.

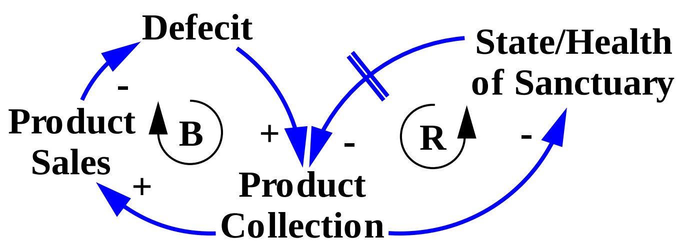
- Village Household Economics: Kesulal Meghwal (Field Associate, Foundation for Ecological Security). Served as KWLS community liaison throughout the project timeline, providing commentary on livelihood substructures and household decision processes.
- Forestry: Dr. Nihal Chandra Jain (Chief Conserver of Forest- Wild Life Wing – Udaipur division): Meeting was held to discuss the interlinking components of the livelihood and energy demands of the forest dependent people with consideration of forest conservation efforts.

- Dr. Justus Joshua (Wildlife expert and Manager – Ecology working with Foundation for Ecological Security): has conducted detailed biodiversity assessments in the KWLS over the last three years, and we engaged his expertise and understanding of ecological factors to triangulate findings from the field.

Livelihood-Energy-Conservation Model

The system dynamics model (VENSIM®) created from the mental and numerical data collected effectively maps the relationships between juxtaposed -household livelihoods and degradation of the Kumbhalgarh Sanctuary (Forrester 1980). This model, comprised of eleven different views focusing on key themes, is a research-stage model intended to aid in analyzing policy-centric effects in order to adapt to eventual management tooling (Costanza and Ruth 1998). The overall relationship discovered is depicted in the following causal loop diagram, and is described herein.

Figure 7: Overall Causal Loop Diagram



Deficit is the difference between expenditures and income, influencing household decisions on which- and to what extent potential income sources are pursued (Causal Loop B). Additionally, consequences of increased forest product collection are reflected in the State/Health of the Sanctuary. As this variable diminishes, less forest products are available for collection (Causal Loop R). However, whereas the balancing, deficit-decision loop operates on a human-decision dependent time scale, forest degradation is much slower; moreover, behavioral patterns indicate that Product Collection is affected only by diminishing supply and not perceptions of sanctuary degradation. Thus, a feedback delay in sanctuary health and product collection is observed, and deforestation is sustained. Because of the largely mental basis of the economic decision making, and the highly interlinked variability biological systems, evaluation and mapping of these causal loops involves Ecological and Economic Modeling, the results of which are characterized in the following section (Forrester 1980; Folke 2006).

Model Assumptions

While constructing the model, assumptions were made for simplification and estimation purposes. These assumptions are utilized to create generalizations for the activities occurring in and around the sanctuary without sacrificing the accuracy of the structure of the model.

- The sanctuary would be in stable ecological condition if all human impacts were removed.
- Villagers do not have preference for collecting different species of timber for fuelwood.
- Aggregate amounts of timber, NTFP, and fodder masses dictate the state of the sanctuary.
- A household is of average size and collects average amounts of products from the sanctuary, disregarding seasonal collection rates.
- The maximum number of livestock in each household is three cattle and three buffalo.
- Rainfall is based on a yearly average and does not account for seasonality.
- Wage labor is available when needed.
- The same motivations lie behind participating in seasonal and permanent migration.

Model Data

The modeling process consisted of alternating data collection and model building activities. Survey results on livelihood and energy are depicted in the following table:

Sr. No.	Parameter	Average	Range
1.	Number of adults per household	6.7	3 to 13
2.	Landholding (Hectare/household)	1	0.08 to 4.8
3.	Number of large cattle per household	4.4	1 to 10
4.	Number of small cattle per household	7.3	1 to 20
5.	Amount of fodder collected per year (kg/yr)	4600	1300 to 17000

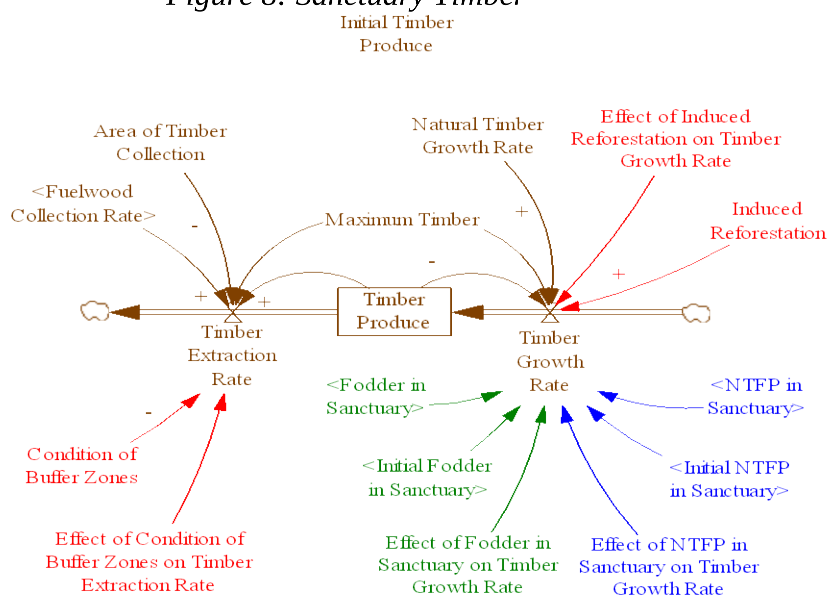
6.	Amount of fuelwood collected per household (kg/yr)	5400	1800 to 19000
7.	Per capita collection of fuelwood (kg/year)	900	200 to 2000
8.	Kerosene consumption per household (lit./year)	34	0 to 36
9.	Amount of Jatropha collected per household (kg/yr)	81	0 to 650

Ecological Modeling

Sanctuary Timber

The variable Timber Produce represents how many kilograms of timber are in the Kumbhalgarh Wildlife Sanctuary at a given time. This amount is affected by its growth rate and the rate at which it is extracted from the forest. Timber growth rate is affected by multiple factors, both internal sanctuary states and external effects. The amounts of NTFP and fodder in the forest affect the growth rate of timber at different levels, indicated by Effect of Fodder in Sanctuary on Timber Growth Rate and Effect of NTFP in Sanctuary on Timber Growth Rate. Induced reforestation efforts, in both forms of planted seeds and saplings, increase the amount of kg of timber produce in the sanctuary. Maximum Timber represents an upper limit on forest growth, the most timber that can be in the forest given the size of forest and amount of resources available. Maximum Timber affects both timber growth and timber extraction. The timber extraction rate is affected by external factors from the sanctuary. The Fuelwood Collection Rate has the greatest impact on timber extraction. Each village household consumes about 10 kg of fuelwood each day to use for cooking and heating. As the population grows, the need for fuelwood also increases, which increases the timber extraction rate. Timber extraction rate is also affected by the condition of the forests and other common lands surrounding the sanctuary. These lands moderate extraction of sanctuary timber by providing fuelwood resources. They provide alternative sources of fuelwood, thus decreasing the amounts of fuelwood extracted from the sanctuary.

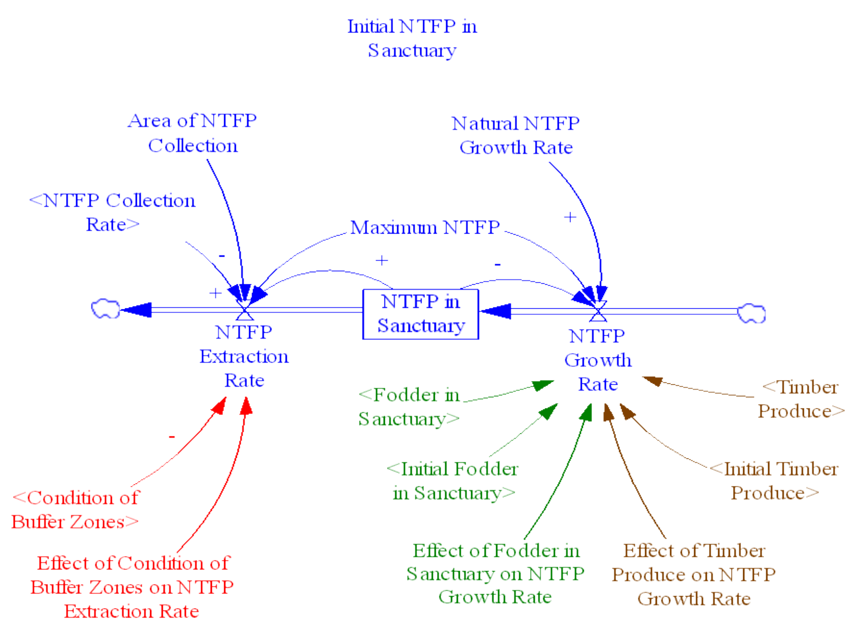
Figure 8: Sanctuary Timber



Sanctuary Non-Timber Forest Products

The stock of NTFP in Sanctuary depends on the NTFP Growth rate and the NTFP Extraction Rate. Besides the Natural NTFP Growth Rate, the overall growth rate factor depends on amounts of other products present in the forest, including timber and fodder. The maximum NTFP represents a boundary that implies NTFP growth is not limitless, given fixed land area and amounts of resources. This variable affects both the growth rate and extraction rates of NTFP. The NTFP Extraction Rate is mainly influenced by the NTFP Collection Rate, which is a measurement of the total NTFP weight being gathered from the forest per year; this total weight is currently increasing each year. The adjacent forest areas provide a buffer that alleviate the amount of NTFP taken from the sanctuary by providing other fruitful areas for villagers to gather NTFP.

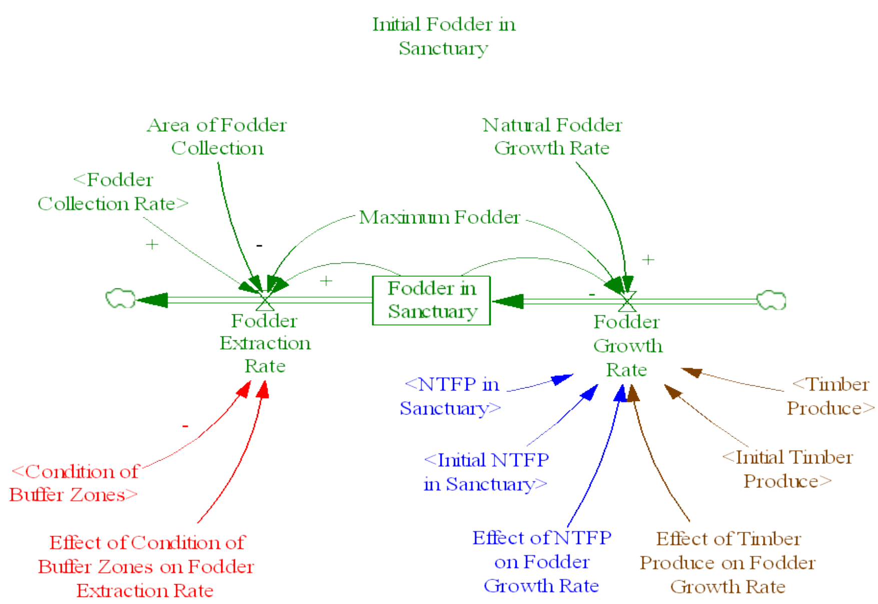
Figure 9: Sanctuary NTFP



Sanctuary Fodder

This view of the model shows the process causing the fodder from the sanctuary to deplete. In this model, both grassy and leafy fodder are combined to evaluate an overall fodder measurement. The fodder in the sanctuary is increased by the Fodder Growth Rate. This growth factor is influenced by multiple factors, including effects from other types of growth in the forest, most notable timber and NTFP. The natural growth rate of fodder also contributes to this overall growth, which is limited by Maximum Fodder, an upper limit on how much grassy and leafy fodder can be grown, given the fixed land and resources of the sanctuary. The fodder in the sanctuary decreases as fodder is extracted by grazing animals and villagers cutting trees for stall feeding. The forest lands outside the sanctuary play a role in determining the overall fodder extraction rate and serve as intermediaries between the people and the protected land.

Figure 10: Sanctuary Fodder



The resulting ecological model substructure is a combination of these considerations of interconnected growth rates and produce states, represented in a series of table-lookup functions. This structure affords indications of Sanctuary Health as well as model-based analysis of conservation efforts and elicited effects. A conceptual representation of this model structure is shown here.

Economic Modeling

Kumbhalgarh village households typically generate monthly income from four main sources: selling Timber/Fuelwood, Non-Timber Forest Produce, and Livestock Products, and seeking Wage Labor opportunities. A household's expenditures decrease the in-pocket money, which is typically spent on fertilizer or farming accouterments. Household Expenditures account for food that a household may need to purchase in a season with low-yielding crops that are not sufficient enough to supply the food demand of the household members, as well as small purchases such as medicine, dry goods, and other one-time purchases. The resulting Causal Loop Diagram serves as a conceptual map of household decisions in times of debt, when expenditures exceed income.

Figure 11: State/Health of Sanctuary System structural representation

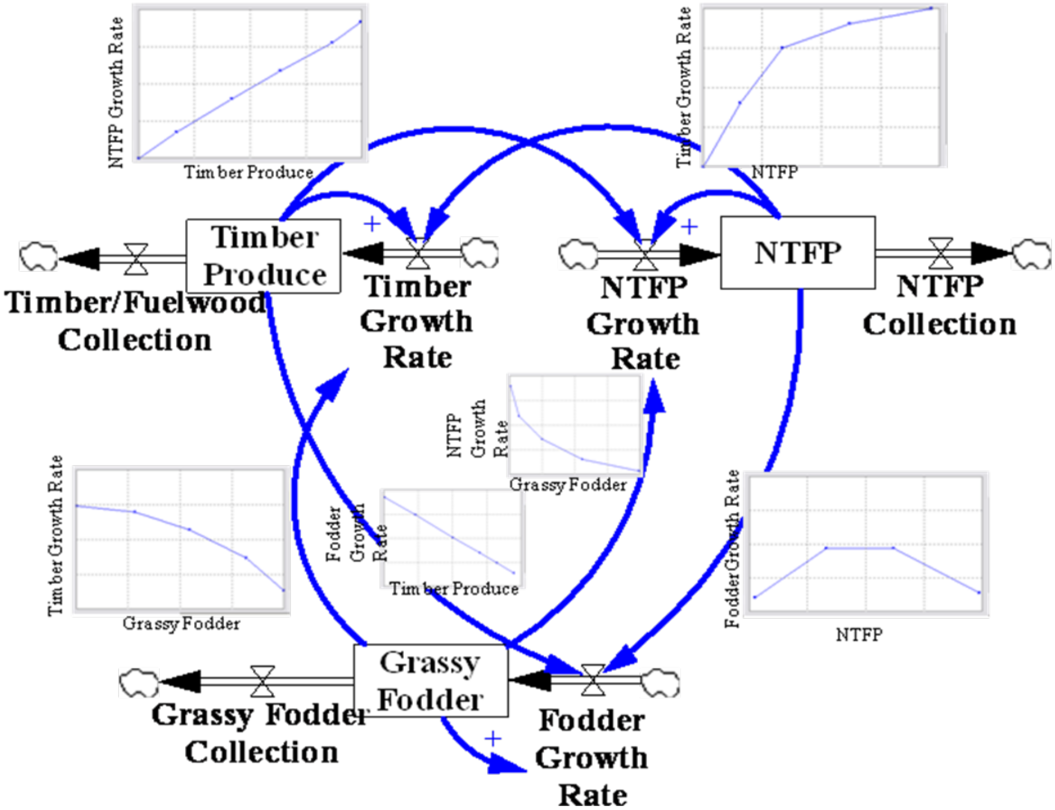
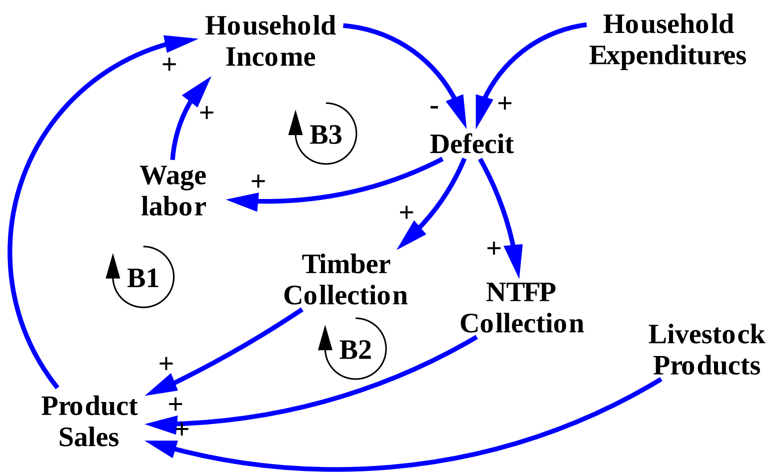
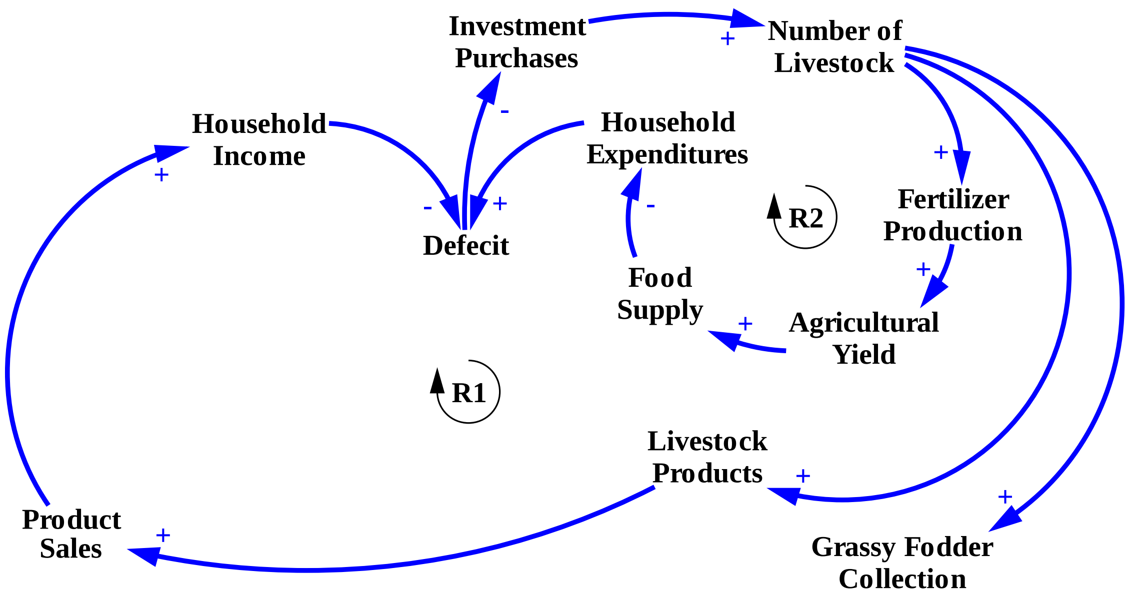


Figure 12: Causal Loop Diagram depicting household decisions in times of debt



In times of surplus, village households may be able to save sufficient amounts to buy additional livestock. This Investment Purchasing behavior is depicted in the following Causal Loop Diagram, mapping the decision to spend saved funds on either cattle or buffalo, the preferred purchases in the Kumbhalgarh villages.

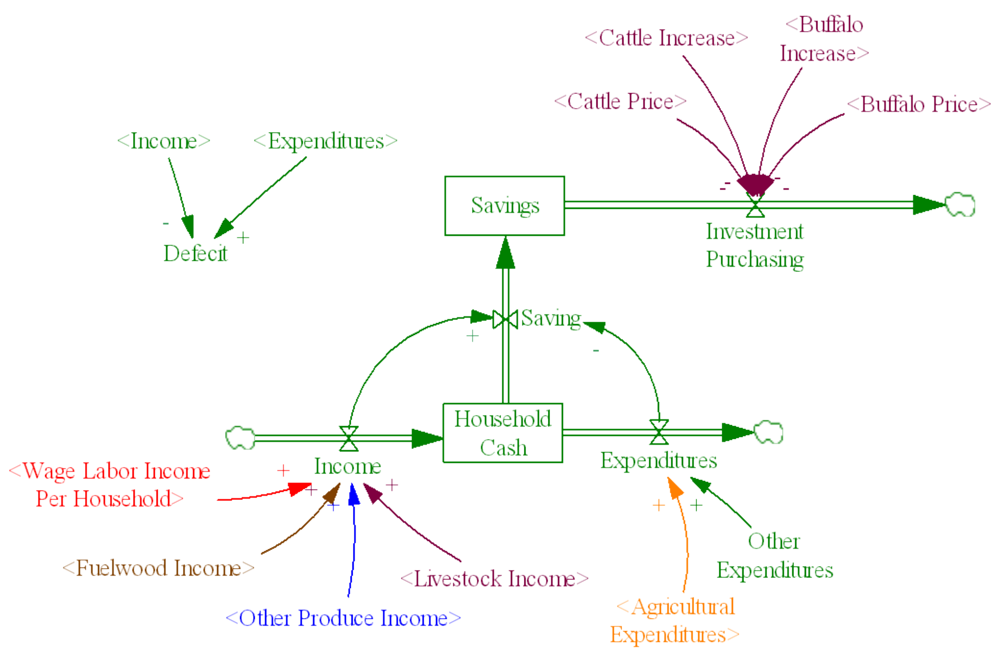
Figure 13: Causal Loop Diagram depicting household Decisions in times of surplus



Livelihood Structure

The resulting model substructure mapping Kumbhalgarh village household economic decisions and behaviors is shown here. The four sources of income: Fuelwood sales, NTFP sales, livestock product sales, and Wage Labor are detailed in the following sections.

Figure 14: Livelihood

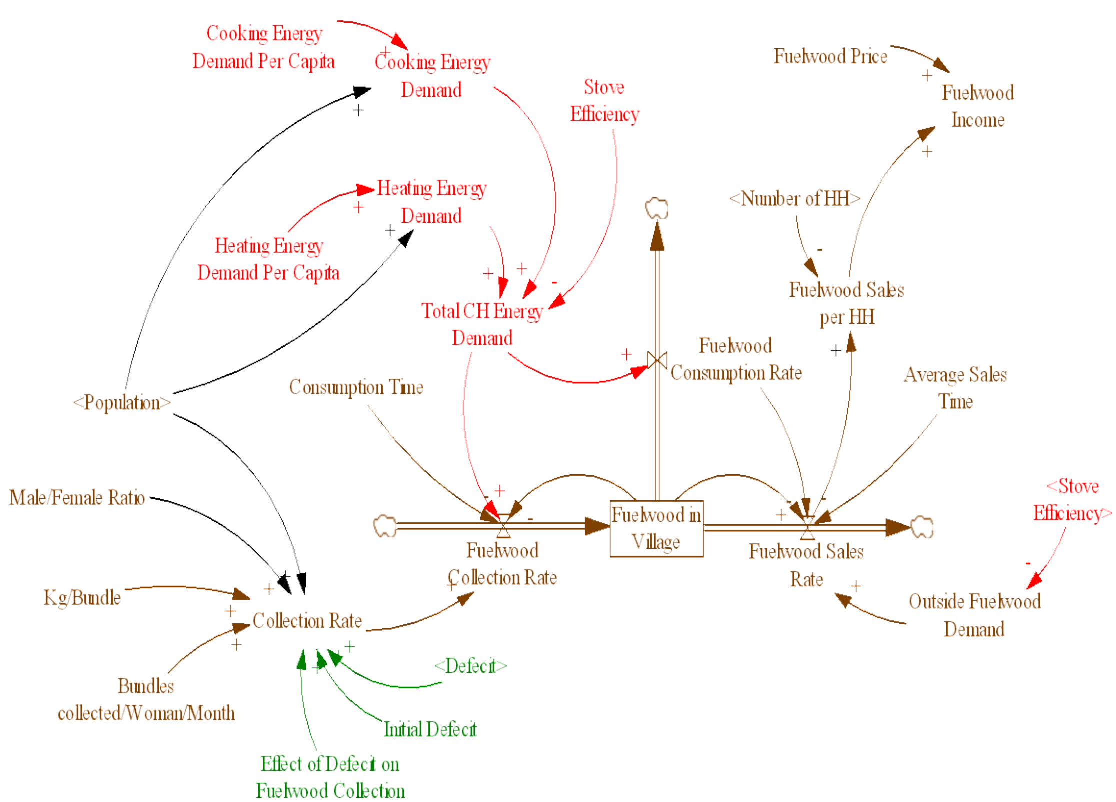


Fuelwood

Fuelwood, the major energy source of the village, is collected according to the household demand, approximately 10 kg dry wood mass per day. The amount of fuelwood present in the village depends on the timber collection rate and decreases according to fuelwood consumption and sales rates. Various types of cooking stoves consume different amounts of wood for a specified output, and more efficient stoves consume significantly less wood. Women, the main collectors, collect 20 kg of wood every other day in order to meet this energy demand, which is used for cooking and heating. The remainder is sold to neighboring villages, supplementing Household Income. Naturally, as the population increases, so do the heating and energy demands. It has also been shown that when households have higher monetary deficit, more fuelwood will be collected to sell in nearby villages. Fuelwood sales depend solely on the outside fuelwood demand; this product is a major source of income for many village households because many of the neighboring villages have completely exhausted their timber resources.

Timber extraction rates are also affected by the condition of the forest and common lands surrounding the sanctuary; high timber yield in these is observed to moderate extraction of sanctuary timber. Because fuelwood is collected from an area including these zones, they serve as an alternative source of fuelwood, thus decreasing sanctuary extraction.

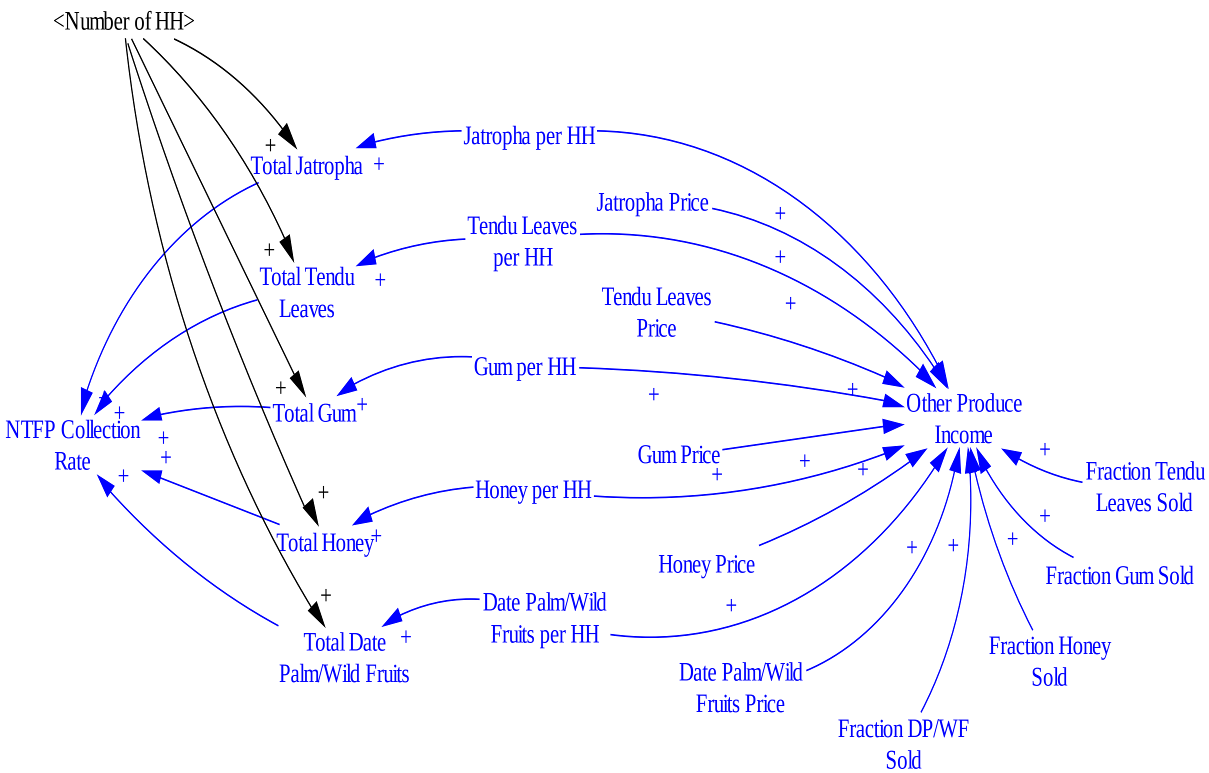
Figure 15: Fuelwood



Non-Timber Forest Product Income

Most households in the village collect NTFP both to use at the household level and to sell as a supplemental income source. In the past many of these resources were much more abundantly present in the forest, but over the years, hyper-extraction has caused these resources to become scarce and some, non-existent. Historically, tendu leaves were also collected when in season and sold to nearby villages as a source of income, but have since vanished. Lacking income from tendu leave sales, the households needed to find ways to compensate to make up for this lack of income they once regularly had by extracting even more goods from the forest, both timber and other types of NTFP. Gum and wild fruits, including date palm, are collected from the sanctuary and consumed by the household. Honey and jatropha are collected specifically for sales in nearby villages. As the number of households increases, more of these NTFP goods are collected from the sanctuary, increasing the pressure on the forest.

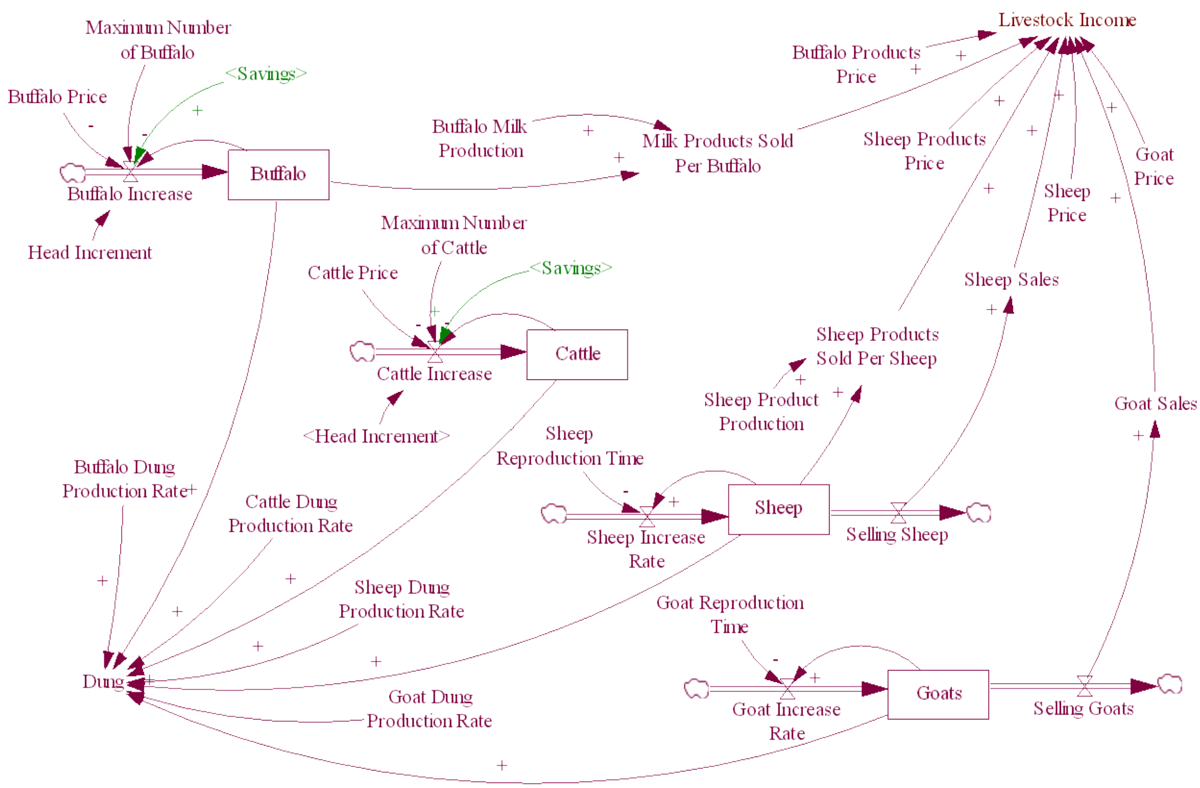
Figure 16: NTFP Collection



Livestock

This view captures Livestock Income, Investment Purchasing, and Dung Production. The four types of livestock contributing to livelihood and income are buffalo, cattle sheep, and goats. Livestock income consists of animal sales as well as sales of buffalo and sheep products. The number of livestock also contributes to the amount of available dung, which is utilized to increase crop yield.

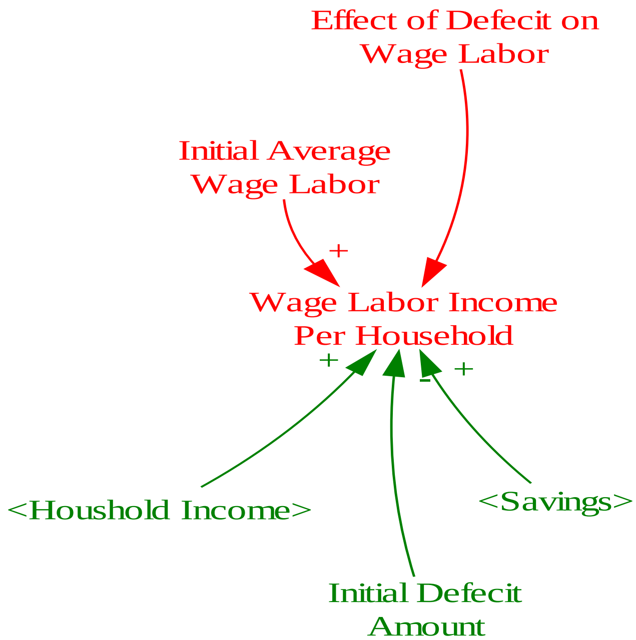
Figure 17: Livestock Income



Wage Labor

The wage labor model substructure to left illustrates the household's decisions to participate in wage labor. The amount of household income from wage labor is determined by multiple factors, which often vary seasonally. Households with expenditures greater than income will opt to participate in wage labor activity, which in this model collectively evaluate permanent migration and seasonal work. Initial Deficit Amount indicates the decision basis as to whether the household chooses to participate in this type of work. As a household's deficit increases, additional household members will begin to participate in wage labor to compensate for surmounting debt.

Figure 18: Wage Labor



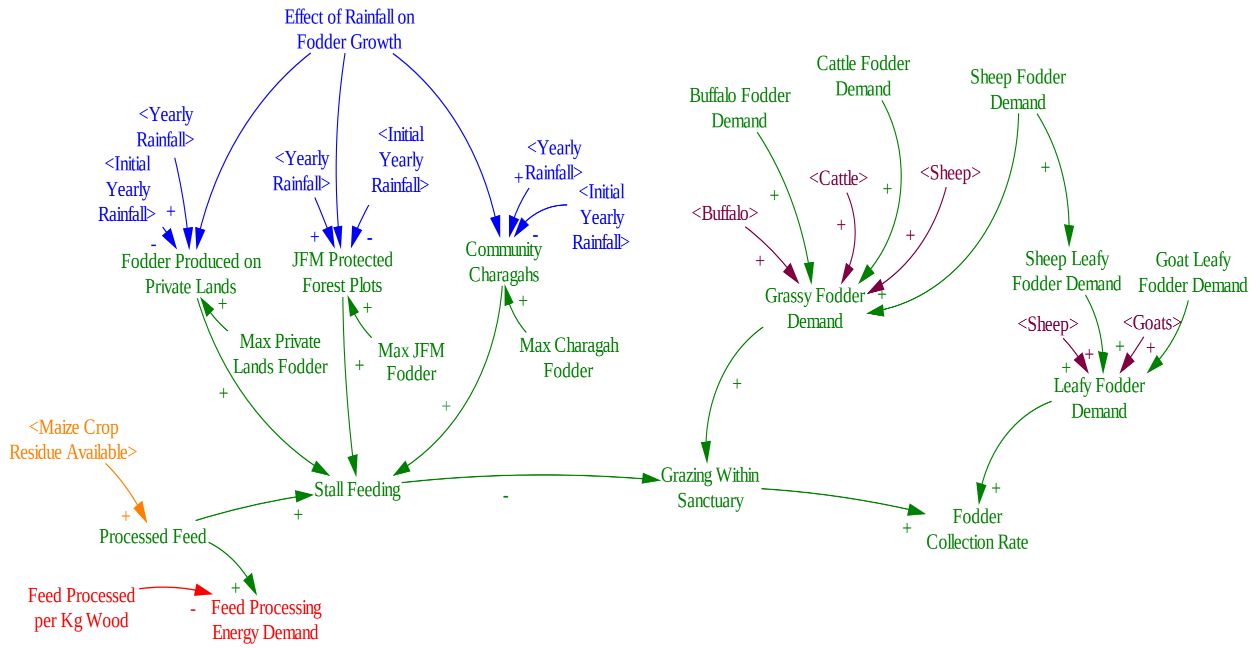
Fodder Demand

Products from sheep and buffalo, such as ghee or buttermilk, are sold at neighboring villages and contribute to a household's income. Production of livestock products greatly depends on animal health, which is greatly impacted by fodder availability.

Fodder demand from the sanctuary depends on two main factors, the number of livestock in the village and fodder availability from alternate sources. Buffalo and cattle require grassy fodder, goats require leafy fodder, and sheep feed off of both types. Grassy fodder from the sanctuary is consumed as the livestock freely graze the forest. The leafy fodder requirement is met by branches pruned from trees and fed to the livestock.

Alternative fodder sources include Fodder Produced on Private Lands, JFM Protected Forest Plots, and Community Charagahs. However, the amounts of fodder grown in these domains greatly depend on rainfall. In years of low rainfall, more fodder is extracted from the sanctuary because of lower quantities of stall feeding fodder.

Figure 19: Fodder Demand



Population

As the village population grows, there is a higher demand for natural resources, most of which are extracted from the sanctuary. Although the population has been increasing, the average number of people per household has steadily stayed at eight family members for the past 50 years, indicating that the number of households in the village has increased.

Figure 20: Population

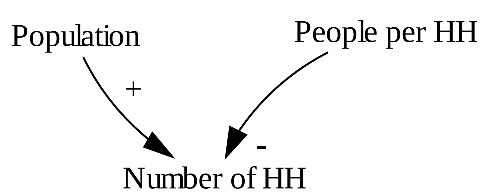
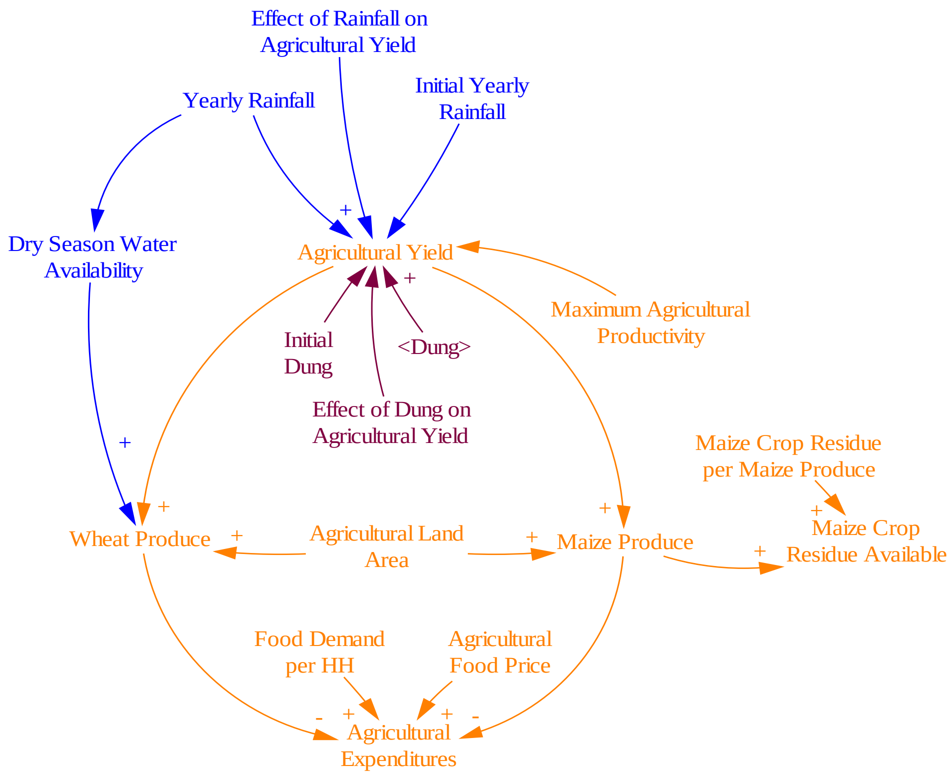


Figure 21: Agriculture



Agriculture

This view of the model illustrates effects on agricultural yield, which plays a key role in the livelihood of the village because of the high-dependence on agricultural produce for food and livestock fodder. Maize is the most common annual crop, and in years of prosperous water availability and climate conditions for the year, wheat and chickpea will also be grown as a second crop. Other determiners of the amount of agricultural produce supply are land area and availability of dung fertilizer from livestock. Moreover, maize crop residue is an important source of fodder and villagers must resort to other fodder sources such as the sanctuary grounds after weak agricultural seasons. Agricultural Expenditures rise when crop yields fail to meet household demand, and food must be purchased.

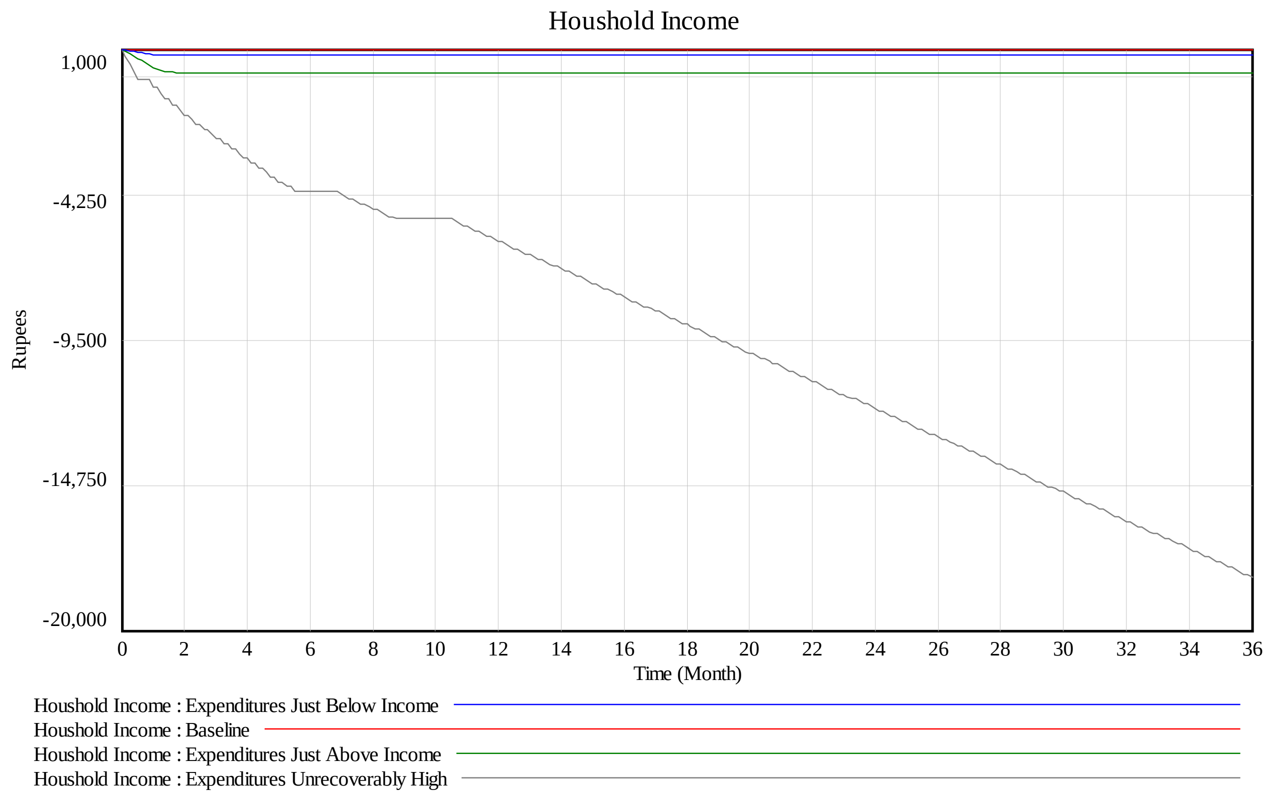
Simulation Runs of Scenarios

A plurality of simulations was conducted with varied inputs in order to characterize system sensitivity to variable changes. The results of this analysis indicated two crucial influences on the rate of degradation of the sanctuary: expenditures and condition of buffer zones.

Expenditures

In this analysis, Other Expenditures (Rs) was varied to below and above the critical value at which total household expenditures (Agricultural Expenditures and Other Expenditures in aggregate) is equal to household income. These simulations simulate the KWLS household decisions that are made in order to supplement monetary supply in situations when expenditures rise. Situations as such could include seasons of failed subsistence crops during which food must be purchased, or strict sanctuary regulation in which fees must be paid in order to gather forest products from within KWLS. These scenarios and the effects therein are depicted in the following figures.

Figure 22: Household Income Impacts

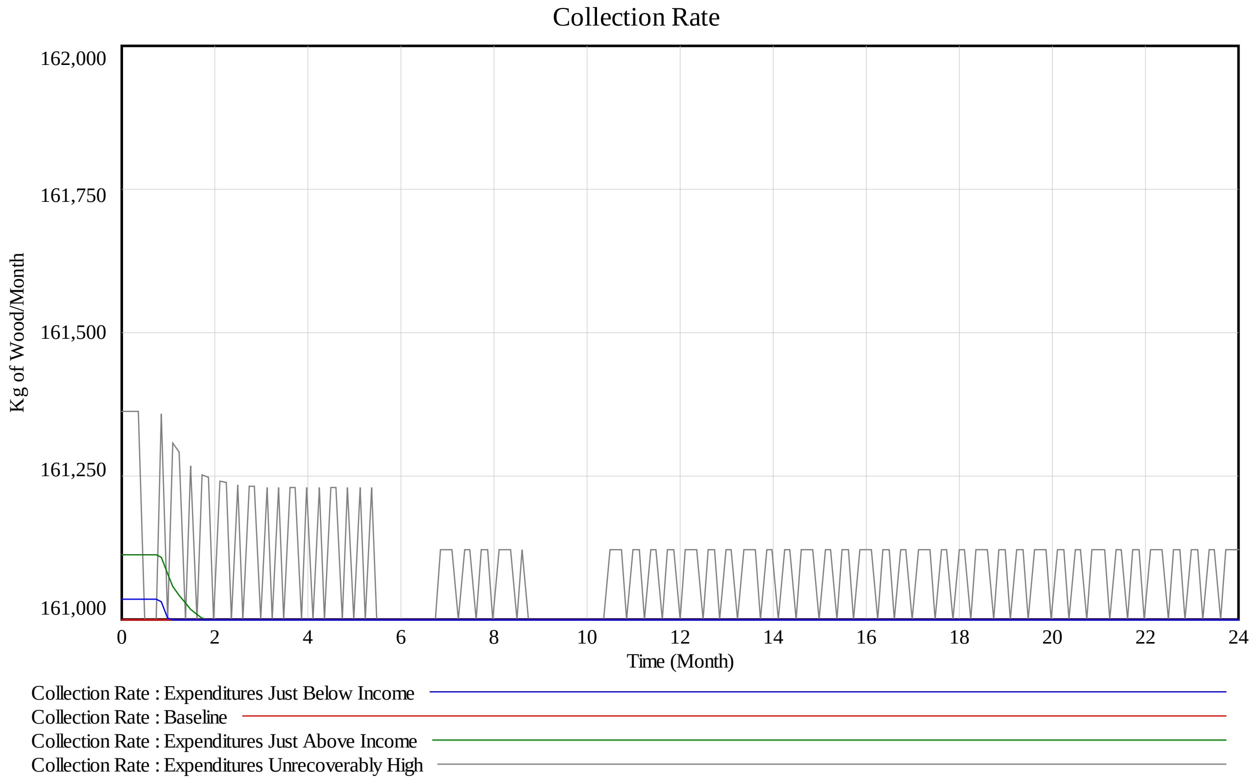


- In times of low expenditures (Expenditures Just Below Income), Household Income is sustained without alteration of behavior or collection rates.

- In times of high expenditures (Expenditures Just Above Income), Household Income must be supplemented by gathering additional forest products to sell.

- In times of expenditures above a level recoverable through additional forest product sales (Expenditures Unrecoverably High), Household Income is in steady decline.

Figure 23: Timber Collection Rate Impacts

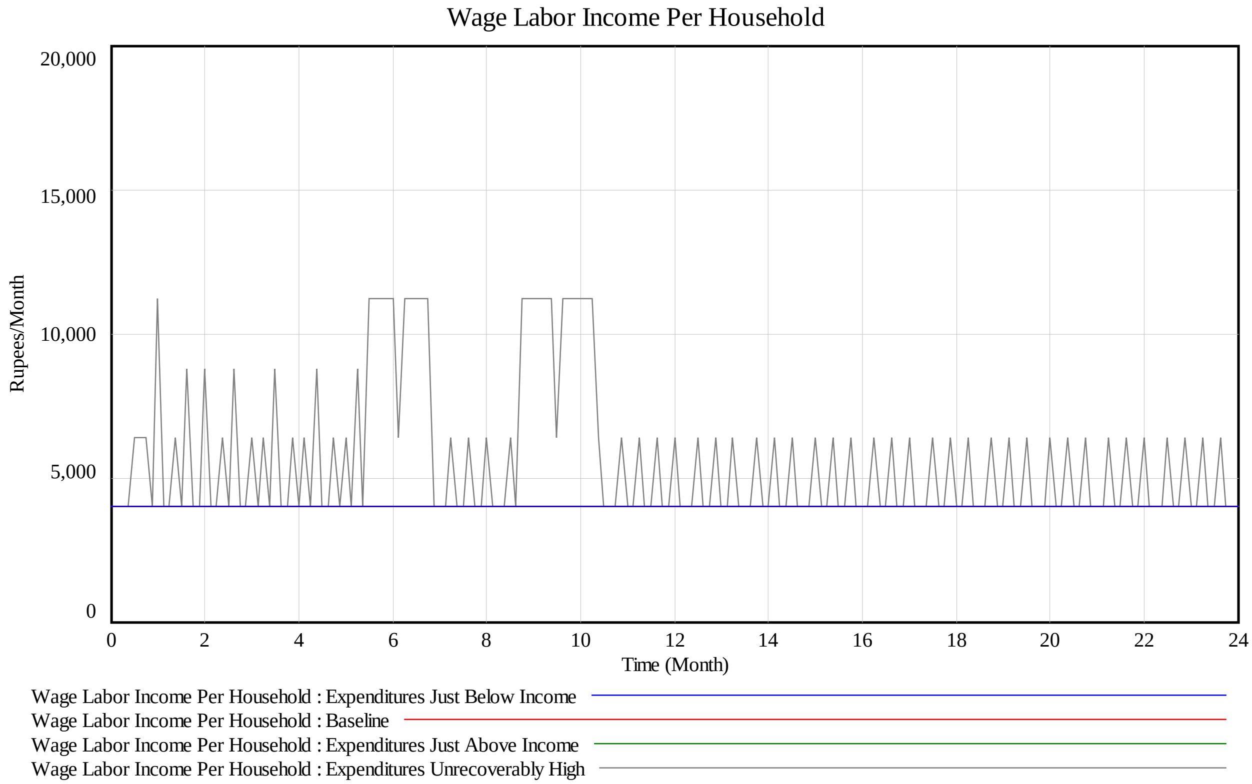


- Expenditures Just Below Income: Fuelwood collection rates are sustained until household supplies are effectively saturated, and sales rate is lower than outside fuelwood demand.

- Expenditures Just Above Income: Fuelwood collection is increased to meet outside demand in order to supplement Household Income with sales. This soon diminishes as other products sales are similarly increased and sustained.

- Expenditures Unrecoverably High: Migration for Wage Labor is increased on a temporary basis, decreasing the number of product-collecting members per household. Thus, fuelwood collection is initially high, and erratic thereafter.

Figure 24: Wage Labor Impacts

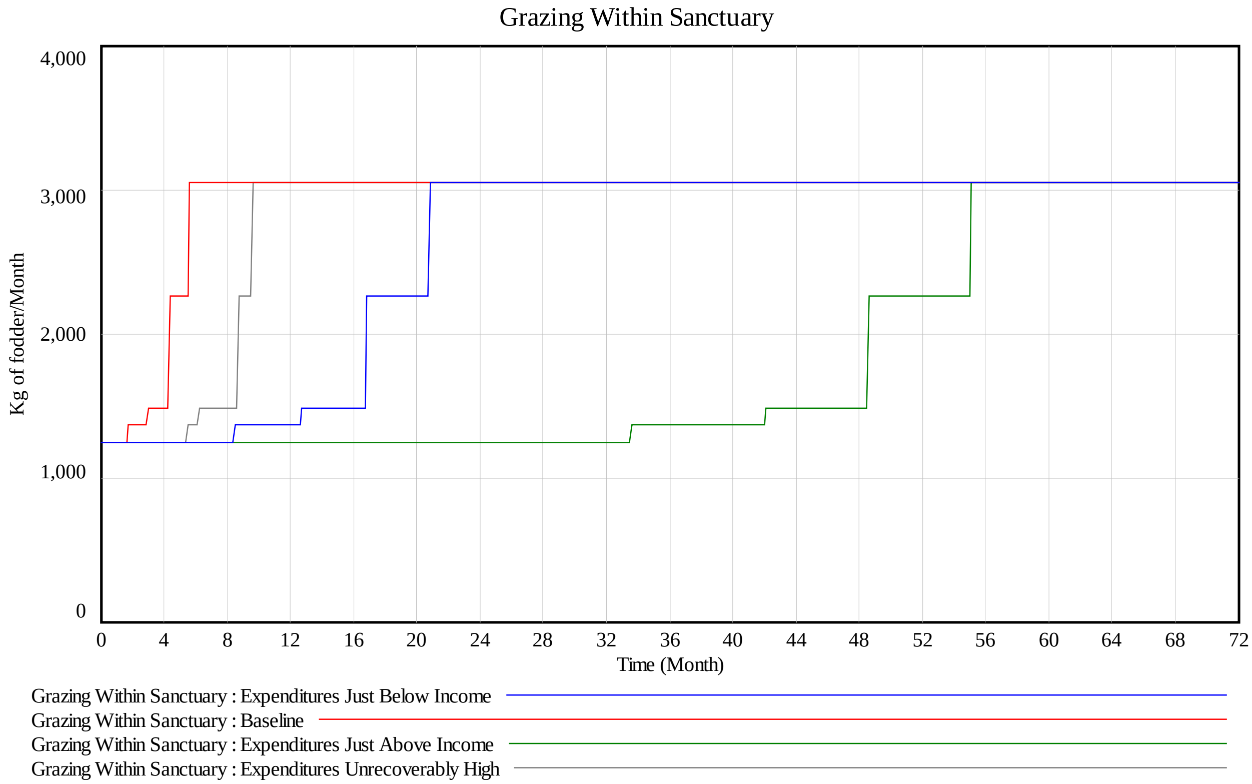


- Expenditures Just Below Income: Wage Labor efforts are sustained at a level allotted by outside factors such as National Rural Employment Guarantee Act.

- Expenditures Just Above Income: Wage Labor efforts are sustained at a level allotted by outside factors such as National Rural Employment Guarantee Act. Forest product based sources of income only are increased in order to supplement income.

- Expenditures Unrecoverably High: Migration for Wage Labor is increased on a temporary basis (per month) in order to inject Household Income with sufficient monetary resources with which expenditures can be paid. Livestock investment purchases are made when small, incremental saving efforts amount to afford livestock prices, in order to further supplement income. Debt is rampant in this scenario, and often three or more members of a household must travel to find work.

Figure 25: Fodder Grazing Impacts



- Expenditures Just Below Income: Livestock Investment Purchases are made early, due to availability of savings. Grazing within sanctuary is increased incrementally with each purchase, contributing to the degradation of the sanctuary.

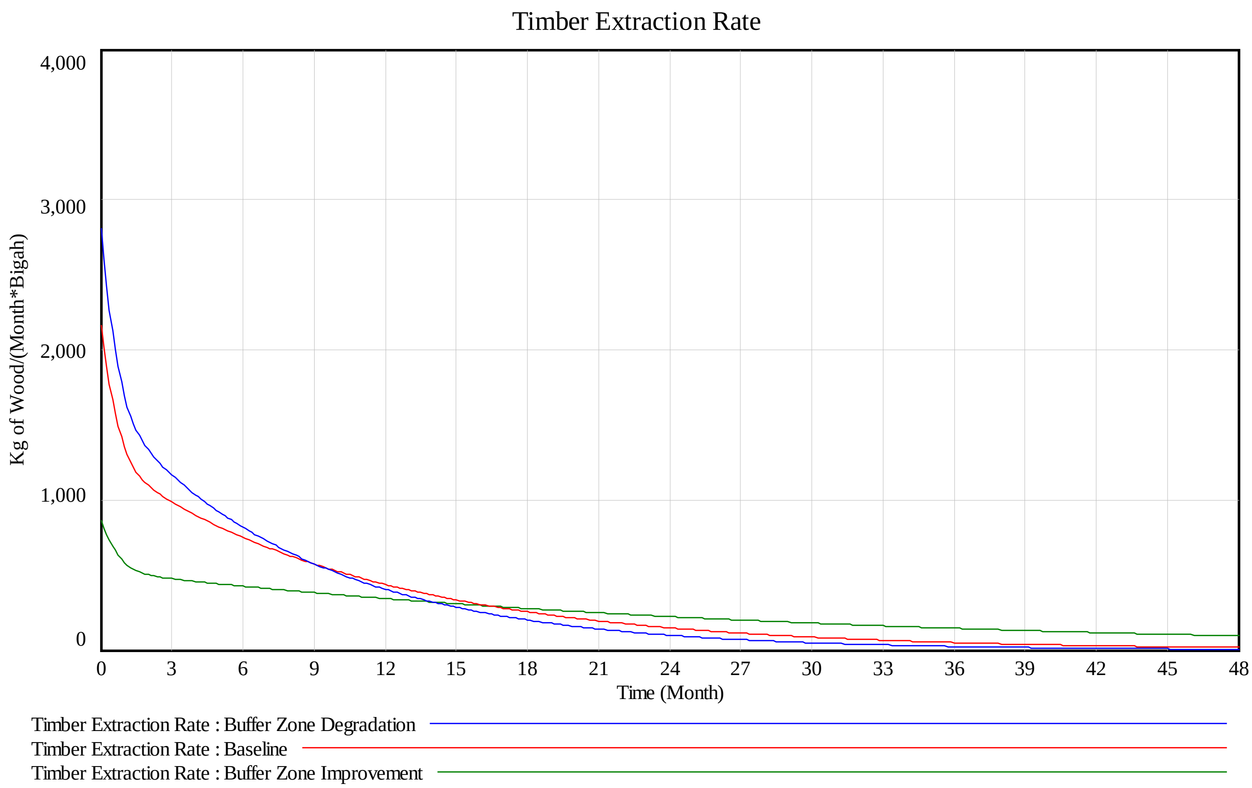
- Expenditures Just Above Income: Livestock Investment Purchases are made when savings allow. Grazing within sanctuary is increased incrementally with each purchase, contributing to sanctuary degradation equally, albeit after a time delay.

- Expenditures Unrecoverably High: Migration for Wage Labor is increased on a temporary basis, and Livestock Investment Purchases are made desperately, as any potential source of income is exploited in order to supplement Household Income. Sanctuary degradation is highest in this case, because all forest product extraction rates are increased as much as possible.

Condition of Buffer Zones

Among the simulations in which conservation efforts and regulatory policy strategies were varied to maximum and minimum levels, Condition of Buffer Zones elicited the most impact on sanctuary degradation. Reforestation efforts did not indicate long-sustained influence on sanctuary degradation, nor did fodder policy enactments such as JFMs or Community Charagahs. Scenarios in which current Buffer Zone condition is improved and degraded are depicted in the following figures.

Figure 26: Timber Extraction Rate Impacts

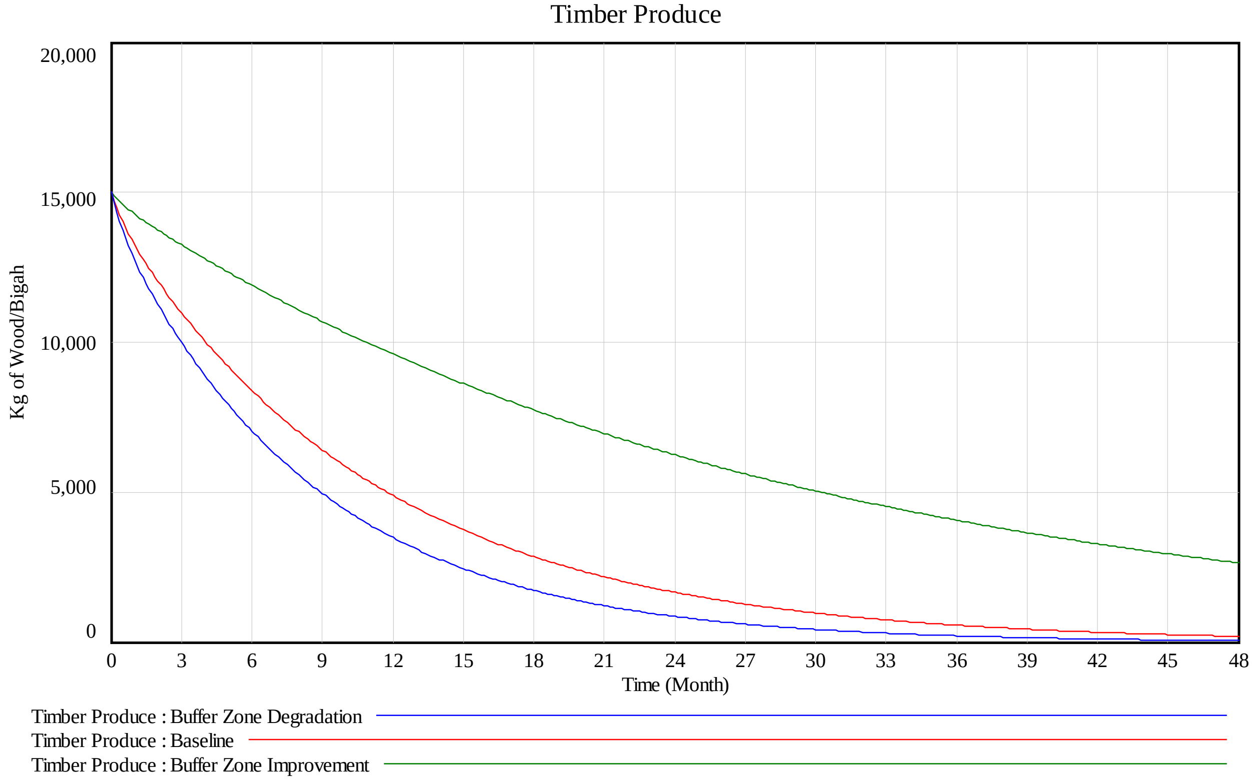


- Current Buffer Zone Condition (Baseline): Timber extraction rate from within the sanctuary is outpacing natural growth rates. Deforestation is unmistakable and resources are being diminished to eventual zero availability.

- Buffer Zone Degradation: Timber extraction rate significantly outpaces natural growth rates. Deforestation is rampant and catastrophic.

- Buffer Zone Improvement: Timber extraction rates are more sustainable, as forest products collected are supplemented by availability outside KWLS boundaries. Deforestation is slowed, but remains an issue because total Buffer Zone land area cannot support forest product demand entirely.

Figure 27: Timber Produce Available Impacts



- Current Buffer Zone Condition (Baseline): Timber available in sanctuary is diminishing, as extraction rates are outpacing natural growth rates. Deforestation is unmistakable.
- Buffer Zone Degradation: Timber available in sanctuary is diminishing rapidly, as extraction rates far outpace natural growth rates. Deforestation is rampant and catastrophic.
- Buffer Zone Improvement: Timber available in the forest is more sustained, as forest products collected are supplemented by availability outside KWLS boundaries. Deforestation is slowed, but remains an issue because total Buffer Zone land area cannot support forest product demand entirely.

Discussion

Model Based Insight

This study reveals that, to a noticeable extent, KWLS village populations consider household economics to be of utmost importance. In times of debt, these households consider conservation efforts as subordinate to securing sources of income, and forest product collection rates reflect this behavioral diagnosis. In light of current climatic drought having reduced agricultural productivity, it is fairly certain that poverty conditions will be sustained or will worsen in the foreseeable future; thus, sanctuary degradation is projected to continue.

This admission may seem debilitating to external conservation efforts, but taking economic consideration into account in policy design can potentially focus strategy on the most effective routes of intervention. Hence, it is an encouragement that KWLS product extraction rates will respond to village-based economic stimulus.

Study Limitations

- Time constraint: The study had to be conducted within a stipulated, compressed time frame.
- Human error: Substantial reliance on the verbal responses of the inhabitants is potentially inconsistent with actual behaviors.
- Approximations: Some data procured are based on approximations and appraisals made by experts. For example, absence of GIS mapping lead to estimated areas of collection.
- Language: Local translators potentially could have manipulated communication in the course of interviews and/or surveys.
- Variable measurement and quantification: Unobservable concepts, such as the state of the sanctuary, must be quantified through multiple variables, in this case total mass of timber, total mass of NTFP, and total mass of fodder in the sanctuary. These concepts must be quantified with appropriate units to best represent the directly unobservable idea in the system dynamics model.

Strategies of Intervention

Wage Labor Availability and Buffer Zone Management

First and foremost, supplementing household incomes has been shown to directly affect the necessity of KWLS village populations to collect forest products for sales purposes. In support of this hypothesis, the National Rural Employment Guarantee Act (NREGA) has triggered unintended positive impacts on sanctuary health, as guaranteed employment for members of the majority of maligned households affords secure, more sustainable alternatives to gathering forest products.

Thus, it is proposed to work to shift the general economic foundation from gather-and-sell based to a more wage-labor based economy by increasing wage labor activity. Outside of improving NREGA performance and implementation, this can be addressed by creating work opportunities through which household income streams can be fortified.

Since sanctuary regulation efforts are currently being undermined heavily, perhaps resources could be re-applied toward such work opportunities. If the intended behavioral response takes effect, these resources would be better utilized by indirectly eliciting conservation results.

Furthermore, promoting quality land resource management outside the KWLS boundaries is shown to be a panacea for deforestation. Plantation to meet timber, fodder, and NTFP requirements could effectively forestall sanctuary degradation; many indigenous, multi-purpose trees can be introduced for meeting demands of the forest-dependent households.

In combination, these strategies present a compelling potential design that directly addresses conservation necessity by utilizing behavioral patterns: employing village residents to manage and maintain buffer zones. If local people are employed to cultivate carefully-chosen species with agricultural practices consistent with sustainability concepts, buffer zones would be transformed to product –and income- yielding farmland. Sustainable extraction from this land area would be an indirect conservation effort, and local management and maintenance would help to ensure the economic security of the area.

Fuel Efficient Stoves and Alternative Energy Technologies

Combustion percentages and wood fuel efficiency hold direct influence on rate of deforestation. Improvements to conventional chulha stove efficiency are simulated to immediately reduce timber extraction rates, translating to increased growth rates and general sanctuary health.

Additionally, alternative energy technologies have the potential to transform the traditional energy usage paradigm in effect in KWLS. For instance, solar panels were found to be installed in some of the households, powering light fixtures through a simple battery assembly. This a reflection of such implementation potential; solar radiation in the area is available for 10-11 months per year, and is already being used to sustain some energy needs on a small scale.

As a result of these considerations, it is proposed to distribute or to sell cheaply fuel-efficient stoves and/or renewable energy technologies as a direct alternative to excessive timber extraction. At the household level, scope for alternate energy devices such as solar photovoltaics, solar water heaters, solar stoves, and biogas heating/cook stoves can be widened significantly. For instance, these technologies could be utilized to irrigate agricultural fields and buffer zone cultivations, provide household lighting, and improve the health effects involved with incomplete-combusting stoves. They would also immediately affect fuel consumption and forest degradation.

Future Work

To move from the research and learning model stage to a more robust management tool will involve significant model analysis and testing. Fortunately, with the significant support from the Foundation for Ecological Security, a local natural resource management stakeholder, current policy and subsequent effects can be analyzed for behavior verification and model confidence building. Only after extensive model based analysis of current policy can the model be utilized to make better-informed policy decisions based on adaptive resource management strategies. (Costanza and Ruth 1998; Grumbine 1994)

Using the current research model and the results of this study as an outline, a second study of these energy-livelihood-conservation connections is anticipated to take place in the summer of 2010. The goal of this additional field work is to further refine the current system dynamics model and gain a better understanding of the trends behind these complex relationships. Acquisition of additional data will also aid in testing the model to ensure that it accurately represents the activities taking place in the village and the state of the sanctuary.

Given the project scope, the results of this study offer an accurate depiction of the Livelihood – Energy – Conservation Nexus, however, we posit that additional data would be beneficial to the model accuracy. This entails widening the project scope to include the following:

- Labor migration preferences
- NREGA Performance Data
- GIS-Vensim Complexity
- Forest fire frequency and effects
- Biological species-specific interrelationships
- Climate change effects

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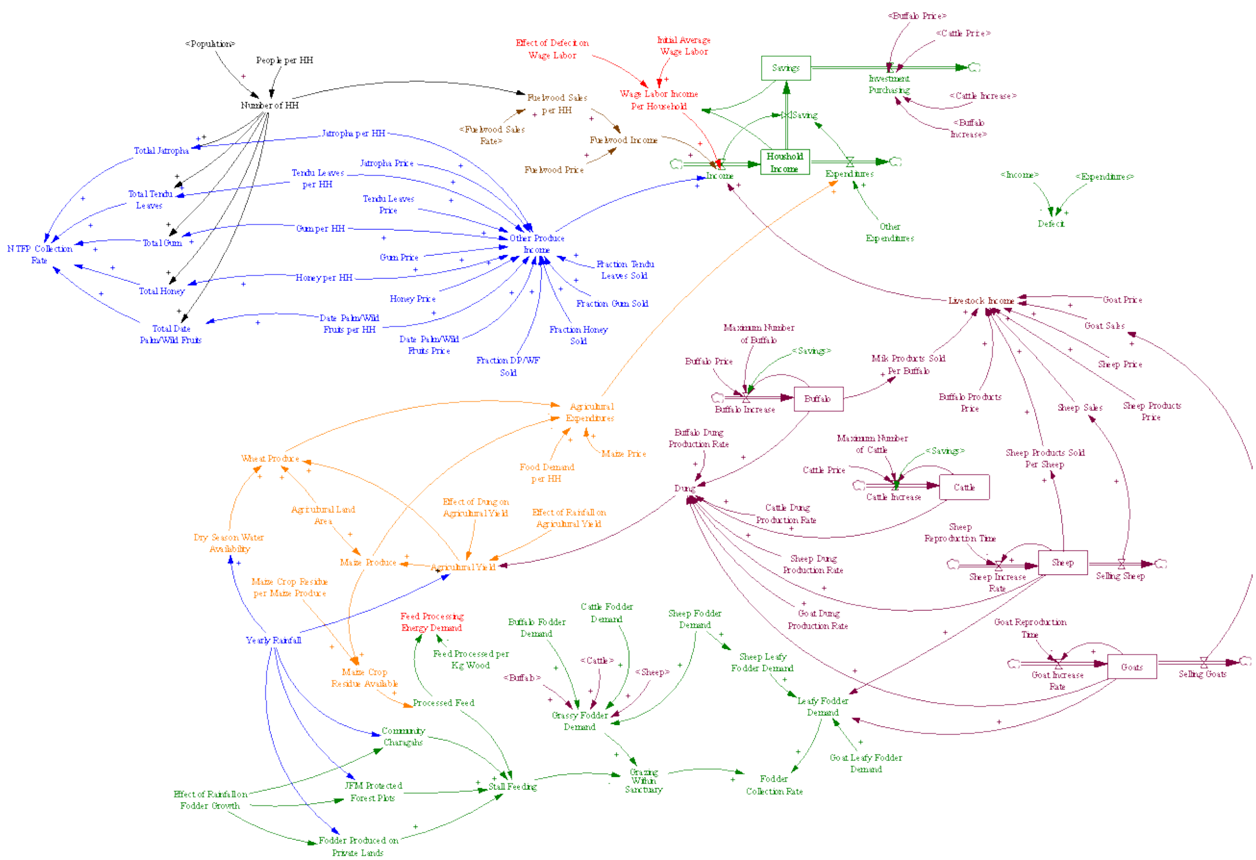
Appendix: Equation List

Livelihoods

Due to unreliable resource availability, KWLS households are forced to alter their behaviors in order to meet their economic and sustenance needs. Livelihood needs are met through many different resources, many of which come from the Kumbhalgarh sanctuary. In seasons of poor resource supply, these households may increase resource collection rates, diversify collected products, or sell previously obtained goods such as livestock.

Figure 28: Livelihood Sources



(030) Defecit=IF THEN ELSE((Income-Expenditures)<0, Expenditures-Income, 0)
Units: Rupees/Month

(048) Expenditures=Agricultural Expenditures+Other Expenditures
Units: Rupees/Month

(086) Income=Fuelwood Income+Livestock Income+Other Produce Income+Wage Labor Income Per Household
Units: Rupees/Month

(085) Houshold Cash= INTEG (Income-Saving-Expenditures,1000)
Units: Rupees

(133) Saving=IF THEN ELSE(Income>Expenditures, Income-Expenditures, 0)
Units: Rupees/Month

(134) Savings= INTEG (Saving-Investment Purchasing,0)
Units: Rupees

(097) Investment Purchasing=Cattle Increase*Cattle Price+Buffalo Increase*Buffalo Price
Units: Rupees/Month

(126) Other Expenditures=2500
Units: Rupees/Month

Fuelwood Collection

There is an increase in need for fuelwood by the resident communities as well as the communities further from the conserved areas. The population of sanctuary villages continues to increase, driving up the demand of timber, used as fuelwood for cooking and heating. Most of the timber resources outside the sanctuary have been depleted; currently nearly all of the fuelwood extraction is from sanctuary forest. Nearby communities not located in or along the periphery of the sanctuary continue to demand timber from sanctuary communities. Monetization of resources has led the local communities living in the vicinity of the protected forests to cut, transport, and sell fuelwood in the outlying villages, where communities are affluent and willing to pay for the resources. Brick kilns, hotels, and other businesses also meet their energy needs by purchasing sanctuary resources. The advent of road networks and transport facilities has accelerated the sales of forest product, making it easier to transport large quantities of materials further distances in less time. Approximate calculations reflect that 10% of the total fuelwood currently collected is sold in the local market, thus, both sanctuary villages and more distant villages are becoming increasingly dependent on resources from conserved and protected areas.

(008) Average Sales Time=1
Units: Month

(036) Effect of Defecit on Fuelwood Collection([(0,0)-(4.83e+007,400000)],(0,161000),(483000,241500),(4.83e+006,241500),(4.83e+007,241500))
Units: Kg of Wood/Month

(016) "Bundles collected/Woman/Month"=20
Units: bundle/(Month*person)

(025) Consumption Time=20/15
Units: Month

(022) Collection Rate=IF THEN ELSE(Defecit>0, Effect of Defecit on Fuelwood Collection(Defecit/Initial Defecit), (Population*"Male/Female Ratio"*"Kg/Bundle"*"Bundles collected/Woman/Month"))
Units: Kg of Wood/Month

(026) Cooking Energy Demand=Cooking Energy Demand Per Capita*Population
Units: Kg of Wood/Month

(027) Cooking Energy Demand Per Capita=120
Units: Kg of Wood/person/Month

(027) Stove Efficiency=1
Units: Kg of Wood/Kg of Wood

(062) Fuelwood Collection Rate=Collection Rate+Total CH Energy Demand-Fuelwood in Village/Consumption Time
Units: Kg of Wood/Month

(063) Fuelwood Consumption Rate=Total CH Energy Demand
Units: Kg of Wood/Month

(064) Fuelwood in Village= INTEG (Fuelwood Collection Rate-Fuelwood Consumption Rate-Fuelwood Sales Rate,30000)
Units: Kg of Wood

(065) Fuelwood Income=Fuelwood Price*Fuelwood Sales per HH
Units: Rupees/Month

(066) Fuelwood Price=2
Units: Rupees/Kg of Wood

(067) Fuelwood Sales per HH=Fuelwood Sales Rate/Number of HH
Units: Kg of Wood/Month

(068) Fuelwood Sales Rate=MIN(Outside Fuelwood Demand, IF THEN ELSE(((Fuelwood in Village/Average Sales Time)-Fuelwood Consumption Rate)<0, 0, (Fuelwood in Village/Average Sales Time)-Fuelwood Consumption Rate))
Units: Kg of Wood/Month

(081) Heating Energy Demand=Heating Energy Demand Per Capita*Population
Units: Kg of Wood/Month

(082) Heating Energy Demand Per Capita=30
Units: Kg of Wood/person/Month

(089) Initial Defecit=1
Units: Rupees/Month

(128) Outside Fuelwood Demand=250000
Units: Kg of Wood/Month

(107) "Male/Female Ratio"=0.5
Units: person/person

(101) "Kg/Bundle"=20
Units: Kg of Wood/bundle

(155) Total CH Energy Demand=Heating Energy Demand+Cooking Energy Demand
Units: Kg of Wood/Month

Wage Labor Income

Many of the people living in villages in and around the sanctuary participate in wage labor to supplement the household income. Wage labor consists of both seasonal labor and permanent migration. Permanent migration occurs when a family member relocates to another region to work and send this earned money back to the family. Seasonal migration involves sporadic wage labor participation for short periods of time when additional income is necessary and work is available. This commonly involves payment for farming work in other villages, both distant and nearby.

(037) Effect of Defecit on Wage Labor([(-300,0)-(0,20000)],(-300,11200),(-200,11200),(-200,8800),(-100,8800),(-100,6400),(-0.001,6400),(0,4000))
Units: Rupees/Month

(088) Initial Average Wage Labor=4000
Units: Rupees/Month

(090) Initial Defecit Amount=1
Units: Rupees

(161) Wage Labor Income Per Household=IF THEN ELSE((Houshold Income+Savings)<0, Effect of Defecit on Wage Labor((Houshold Income+Savings)/Initial Defecit Amount), Initial Average Wage Labor)
Units: Rupees/Month
Total wage labor earnings per household

Other Produce Income

Collection of NTFP from the sanctuary contributes to the livelihood of the people. When present in the forest, small amounts of date palm and other fruits are collected strictly for household consumption. Honey is seasonally collected and exclusively sold at markets in nearby villages. This resource provides direct monetary income; none of the honey collected is consumed by the households. In past years, gum has been collected for household use, but is no longer available. Forest degradation has caused this resource to become scarce and even nonexistent in most areas. Likewise, tendu leaves, also commonly known as bidi leaves, were at one time collected and sold in neighboring villages. Large amounts of these leaves would be collected during their short two week season, significantly contributing to household earnings, but have since disappeared with forest depletion. The NTFP most widely collected today is jatropha, a drought resistant plant commonly used for bio-diesel production. Although resilient, this plant has extremely negative effects on soil quality.

(121) NTFP Collection Rate="Total Date Palm/Wild Fruits"+Total Gum+Total Honey+Total Tendu Leaves+Total Jatropha
Units: Kg of NTFP/Month

(156) "Total Date Palm/Wild Fruits"="Date Palm/Wild Fruits per HH"*Number of HH
Units: Kg of NTFP/Month

(157) Total Gum=Gum per HH*Number of HH
Units: Kg of NTFP/Month

(158) Total Honey=Honey per HH*Number of HH
Units: Kg of NTFP/Month

(159) Total Jatropha=Jatropha per HH*Number of HH
Units: Kg of NTFP/Month

(160) Total Tendu Leaves=Number of HH*Tendu Leaves per HH
Units: Kg of NTFP/Month

(028) "Date Palm/Wild Fruits per HH"=5.416
Units: Kg of NTFP/Month

(029) "Date Palm/Wild Fruits Price"=0
Units: Rupees/Kg of NTFP

(078) Gum per HH=0
Units: Kg of NTFP/Month

(079) Gum Price=40
Units: Rupees/Kg of NTFP

(083) Honey per HH=0.025
Units: Kg of NTFP/Month

(084) Honey Price=85
Units: Rupees/Kg of NTFP

(098) Jatropha per HH=40/12
Units: Kg of NTFP/Month

(099) Jatropha Price=10
Units: Rupees/Kg of NTFP

(149) Tendu Leaves per HH=0
Units: Kg of NTFP/Month

(150) Tendu Leaves Price=1.99
Units: Rupees/Kg of NTFP

(058) "Fraction DP/WF Sold"=0
Units: Kg/Kg

(059) Fraction Gum Sold=0
Units: Kg/Kg

(060) Fraction Honey Sold=1
Units: Kg/Kg

(061) Fraction Tendu Leaves Sold=1
Units: Kg/Kg

(127) Other Produce Income=(Tendu Leaves per HH*Tendu Leaves Price*Fraction Tendu Leaves Sold)+(Gum per HH*Gum Price*Fraction Gum Sold)+(Honey per HH*Honey Price*Fraction Honey Sold)+("Date Palm/Wild Fruits per HH"*"Date Palm/Wild Fruits Price"*"Fraction DP/WF Sold")+(Jatropha per HH*Jatropha Price)
Units: Rupees/Month

Livestock Income

The total livestock population in the villages has decreased substantially due to deforestation. At one time, a typical household maintained 30-40 cattle. However, lack of fodder and water has led to a significant decrease in livestock population per household. Products from sheep and buffalo, such as ghee, are sold at neighboring villages and contribute to a household's income. Production of livestock products greatly depends on animal health, which is greatly impacted by fodder availability. Households also use livestock dung as fertilizer for crops. Fewer animals results in less dung, making it more difficult to have high yielding agriculture seasons.

(009) Buffalo= INTEG (Buffalo Increase,1)

Units: Head

(010) Buffalo Dung Production Rate=360
Units: Kg of Dung/(Head*Month)

(012) Buffalo Increase=IF THEN ELSE(Maximum Number of Buffalo>Buffalo, IF THEN ELSE(Savings>(Buffalo Price*Head Increment), STEP(8, 1), 0), 0)
Units: Head/Month

(013) Buffalo Milk Production=1
Units: Kg/Month/Head

(014) Buffalo Price=4000
Units: Rupees/Head

(015) Buffalo Products Price=300
Units: Rupees/Kg

(017) Cattle= INTEG (Cattle Increase,1.5)
Units: Head

(018) Cattle Dung Production Rate=210
Units: Kg of Dung/(Month*Head)

(020) Cattle Increase=IF THEN ELSE(Maximum Number of Cattle>Cattle, IF THEN ELSE(Savings>(Cattle Price*Head Increment), STEP(8, 1), 0), 0)
Units: Head/Month

(021) Cattle Price=5000
Units: Rupees/Head

(069) Goat Dung Production Rate=1
Units: Kg of Dung/(Month*Head)

(070) Goat Increase Rate=Goats/Goat Reproduction Time
Units: Head/Month

(072) Goat Price=2500
Units: Rupees/Head

(073) Goat Reproduction Time=24
Units: Months

(074) Goat Sales=Selling Goats
Units: Head/Month

(075) Goats= INTEG (Goat Increase Rate-Selling Goats,7)
Units: Head

(135) Selling Goats=7/24
Units: Head/Month

(136) Selling Sheep=1/24
Units: Head/Month

(137) Sheep= INTEG (Sheep Increase Rate-Selling Sheep,1)
Units: Head

(138) Sheep Dung Production Rate=30
Units: Kg of Dung/(Month*Head)

(140) Sheep Increase Rate=Sheep/Sheep Reproduction Time
Units: Head/Month

(142) Sheep Price=1650
Units: Rupees/Head

(143) Sheep Product Production=1/12
Units: Kg/Month/Head

(144) Sheep Products Price=60
Units: Rupees/Kg

(145) Sheep Products Sold Per Sheep=Sheep*Sheep Product Production
Units: Kg/Month

(146) Sheep Reproduction Time=24
Units: Months

(147) Sheep Sales=Selling Sheep
Units: Head/Month

(103) Livestock Income=(Milk Products Sold Per Buffalo*Buffalo Products Price)+(Sheep

Products Sold Per Sheep*Sheep Products Price)+(Sheep Sales*Sheep Price)+(Goat Sales*Goat Price)
Units: Rupees/Month

(117) Milk Products Sold Per Buffalo=Buffalo Milk Production*Buffalo
Units: Kg/Month

(080) Head Increment=1
Units: Head

(114) Maximum Number of Buffalo=3
Units: Head

(115) Maximum Number of Cattle=3
Units: Head

(032) Dung=(Buffalo*Buffalo Dung Production Rate)+(Cattle*Cattle Dung Production Rate)+(Goat Dung Production Rate*Goats)+(Sheep*Sheep Dung Production Rate)
Units: Kg of Dung/Month

Fodder Demand

Conservation Efforts: Community Charagahs

Charagahs are common pasturelands and forests that provide natural resources to community members. These charagahs are a principal source of fodder for livestock; animals freely graze these pasturelands year-round. However, nearly 40% of these communal resources are barren and ineffective due to over-extraction and poor environmental conditions. Managed by village panchayats, community members frequently use these areas that are critical to their livelihoods, but often neglect and deny responsibility for the condition of these lands. This view results in abuse and overuse of charagahs. Excessive grazing inhibits fodder regeneration, and overcutting trees and shrubs causes soil erosion. The condition of these mismanaged community lands significantly affects amounts of fodder extraction from the sanctuary. It has been observed that the more fertile charagah lands available, the less the village members will have to resort to extracting natural resources, most notably fodder, from the sanctuary.

Conservation Efforts: Joint Forest Management Protected Plots

Joint Forest Management (JFM) protected plots were created to alleviate pressure on the sanctuary as well as meet livelihood requirements of local people. These areas are governed by combined efforts from local communities and state forest departments. Agreements between the people and the government allow the local people to become involved in conservation efforts and become aware of conservation concepts. JFMs also provide additional labor opportunities and as well as fodder and NTFP resources, helping contribute to villagers' livelihoods.

(011) Buffalo Fodder Demand=120
Units: Kg of fodder/(Month*Head)

(019) Cattle Fodder Demand=780
Units: Kg of fodder/(Month*Head)

(071) Goat Leafy Fodder Demand=300
Units: Kg of fodder/(Month*Head)

(139) Sheep Fodder Demand=30
Units: Kg of fodder/(Month*Head)

(141) Sheep Leafy Fodder Demand=60-Sheep Fodder Demand
Units: Kg of fodder/(Head*Month)

(049) Feed Processed per Kg Wood=1
Units: Kg of fodder/Kg of Wood

(050) Feed Processing Energy Demand=Processed Feed/Feed Processed per Kg Wood
Units: Kg of Wood/Month

(052) Fodder Collection Rate=Grazing Within Sanctuary+Leafy Fodder Demand
Units: Kg of fodder/Month

(056) Fodder Produced on Private Lands=Effect of Rainfall on Fodder Growth(Yearly Rainfall/Initial Yearly Rainfall)*Max Private Lands Fodder
Units: Kg of fodder/Month

(023) Community Charagahs=Effect of Rainfall on Fodder Growth(Yearly Rainfall/Initial Yearly Rainfall)*Max Charagah Fodder
Units: Kg of fodder/Month

(076) Grassy Fodder Demand=Buffalo*Buffalo Fodder Demand+Cattle*Cattle Fodder Demand+Sheep*Sheep Fodder Demand
Units: Kg of fodder/Month

(077) Grazing Within Sanctuary=IF THEN ELSE(Stall Feeding<Grassy Fodder Demand, Grassy Fodder Demand-Stall Feeding, 0)
Units: Kg of fodder/Month

(102) Leafy Fodder Demand=(Goats*Goat Leafy Fodder Demand)+(Sheep*Sheep Leafy Fodder Demand)
Units: Kg of fodder/Month

(131) Processed Feed=Maize Crop Residue Available
Units: Kg of fodder/Month

(045) Effect of Rainfall on Fodder Growth([(0,0)-(3000,1)],(0,0),(500,0.3333),(1000,0.6666),(1500,1),(1752.29,0.942982),(1908.26,0.820175),(2073.39,0.425439),(2348.62,0.166667),(3000,0))
Units: mm/mm

(108) Max Charagah Fodder=0.6*1700/12
Units: Kg of fodder/Month

(109) Max JFM Fodder=0.4*1700/12
Units: Kg of fodder/Month

(110) Max Private Lands Fodder=300/12
Units: Kg of fodder/Month

(100) JFM Protected Forest Plots=Effect of Rainfall on Fodder Growth(Yearly Rainfall/Initial Yearly Rainfall)*Max JFM Fodder
Units: Kg of fodder/Month

(148) Stall Feeding=Community Charagahs+Fodder Produced on Private Lands+JFM Protected Forest Plots+Processed Feed
Units: Kg of fodder/Month

Agriculture

The combination of agricultural productivity decline and human population increase has amplified the need for farmlands, which are often created by clearing of conserved areas. Maize is most commonly grown, with wheat and chickpea as a second rotational crop in years with ample water resources. Maize crop serves as a staple food source, and crop residue is used and processed for animal fodder. In years where agricultural yield fails to meet food demand, a household must resort to purchasing food, which increases expenditures. In order to prevent deficit, households turn to other income sources, many of which involve extraction of sanctuary products. Agricultural yield is a sensitive variable changing from year to year that has the potential to cause cascading effects on a household's income and livelihood state.

(001) Agricultural Expenditures=(Food Demand per HH-(Maize Produce+Wheat Produce))*Agricultural Food Price
Units: Rupees/Month

(002) Agricultural Food Price=8
Units: Rupees/Kg of Ag

(105) Maize Crop Residue per Maize Produce=0.0625
Units: Kg of fodder/Kg of Ag

(057) Food Demand per HH=90
Units: Kg of Ag/Month

(003) Agricultural Land Area=1.5
Units: Bigah

(004) Agricultural Yield=Effect of Dung on Agricultural Yield(Dung/Initial Dung)*Effect of Rainfall on Agricultural Yield(Yearly Rainfall/Initial Yearly Rainfall)*Maximum Agricultural Productivity
Units: Kg of Ag/Bigah/Month

(044) Effect of Rainfall on Agricultural Yield([(0,0)-(1200,1)],(0,0),(300,0),(365.138,0.486842),(425.688,0.776316),(484.404,0.929825),(528.44,0.964912),(600,1),(675.229,0.991228),(704.587,0.938596),(748.624,0.833333),(807.339,0.688596),(855.046,0.583333),(900,0.5),(1060.55,0.210526),(1200,0))
Units: mm/mm

(096) Initial Yearly Rainfall=1
Units: mm/Month

(104) Maize Crop Residue Available=Maize Produce*Maize Crop Residue per Maize Produce
Units: Kg of fodder/Month

(091) Initial Dung=1
Units: Kg of Dung/Month

(031) Dry Season Water Availability=IF THEN ELSE(Yearly Rainfall>600, 1, 0)
Units: Yesno

(038) Effect of Dung on Agricultural Yield([(0,0)-(5400,1)],(0,0.5),(450,0.75),(900,1),(1350,1),(1800,1),(2250,1),(3600,1),(4050,1),(4500,1),(4950,1),(5400,1))
Units: Kg/Kg

(106) Maize Produce=Agricultural Land Area*Agricultural Yield
Units: Kg of Ag/Month

(111) Maximum Agricultural Productivity=32
Units: Kg of Ag/(Month*Bigah)

(163) Yearly Rainfall=650
Units: mm/Month

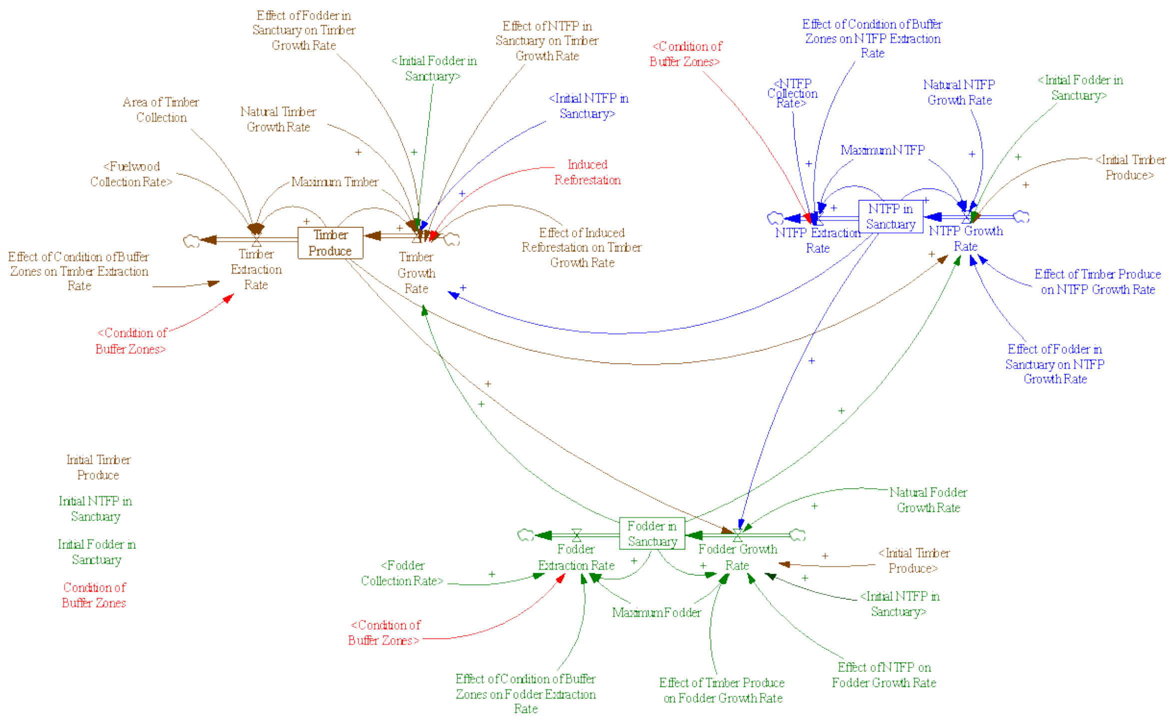
(162) Wheat Produce=IF THEN ELSE(Dry Season Water Availability=1, Agricultural Land Area*0.2*Agricultural Yield, 0)
Units: Kg of Ag/Month

State of the Sanctuary

Evaluation of the overall health of the sanctuary requires observation of multiple factors. Forest density data alone is not an accurate sole indicator of the state of the sanctuary because other crucial factors such as regeneration rate cannot be construed. A few common indicators of sanctuary health include regeneration rate, seed germination, grass cover, forest density, species type, stage of species, seed viability, and food chain balance, which all interlinked and affect one another. Gathered field data affords a selection of these indicators, which affect the interconnected states of timber produce, NTFP, and fodder in the sanctuary.

The complex relationships between mass of Timber Produce, NTFP, and Fodder in the sanctuary all impact one another, as illustrated in the model below.

Figure 29: Sanctuary State



Sanctuary Timber

The raw amount of mass of timber produce in the sanctuary is affected by many variables, including presence of other forest products such as NTFP and fodder. Types of plants in the forest affect the growth rates of each other, as they compete for ground space, sunlight, nutrients, and other essential resources. Multiple species also reinforce the growth of each other, providing nutrients and attracting wildlife to help complete a flourishing ecosystem cycle. Increased amounts of fodder in the sanctuary slow the timber growth rate. However, higher amounts of NTFP in the sanctuary stimulate timber growth rates. As NTFP is extracted from the forest, timber growth rates will accordingly suffer. Although timber can be classified as a single product type and net timber mass typically serves as an accurate measurement of forest health, the presence of favorable and unfavorable trees, as well as observation of diverse classes of species also serve as effective indicators.

Figure 30: Effect of Fodder in Sanctuary on Timber Growth Rate

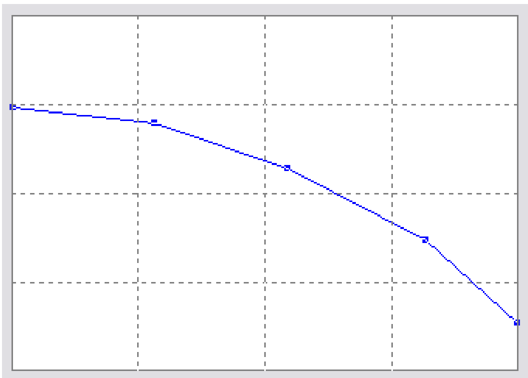
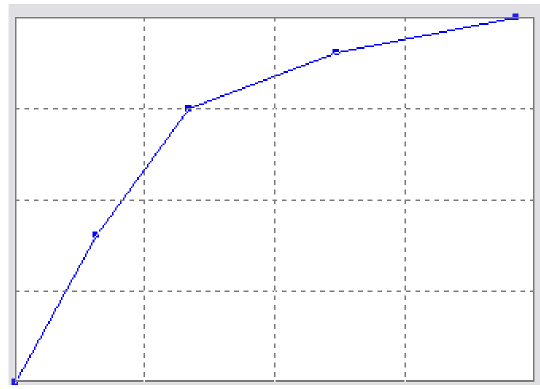


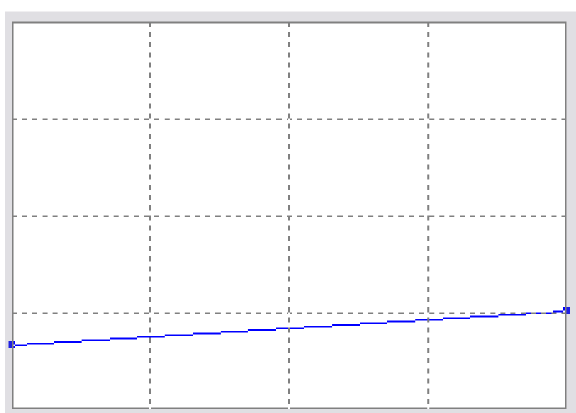
Figure 31: Effect of NTFP in Sanctuary on Timber Growth Rate



Conservation Efforts: Reforestation

The Foundation for Ecological Security (FES) has led a great reforestation effort to plant saplings and seeds of indigenous species in the surrounding forest and common lands with the involvement of local community institutions. Although these reforestation actions have contributed to forest sustainment, because the rate of biomass extraction exceeds reforestation rates, the current planting activities do not have the capability to counterweigh forest product withdrawal.

Figure 32: Effect of Induced Reforestation on Timber Growth Rate



Surrounding Forest and Common Lands

Designated protected areas surrounding the border of the sanctuary alleviate pressure on the sanctuary. The presence of these clearly marked buffer areas has significant impact on the degradation rate of the forest. Typically enclosed by short stone walls to designate boundaries and prevent encroachment, these areas serve as cushions to reduce the negative impacts that the increasing population has on the sanctuary. By providing distinct regions to separate the sanctuary and the village lands, the presence of buffer zones decreases extraction of sanctuary materials.

Figure 33: Effect of Condition of Surrounding forests and commons (Buffer Areas) on Fodder Extraction Rate

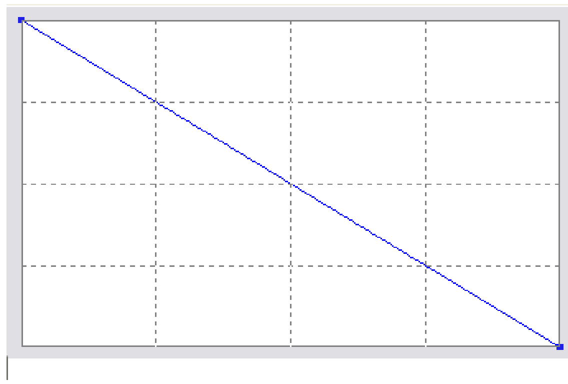


Figure 34: Effect of Condition of Buffer Areas on NTFP Extraction Rate

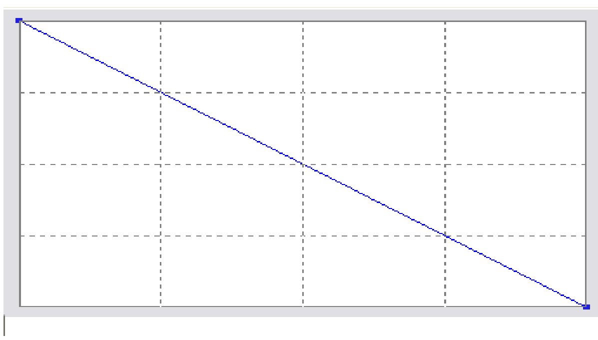
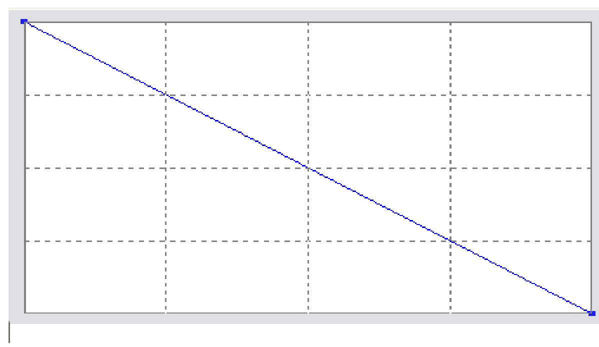


Figure 35: Effect of Condition of Buffer Areas on Timber Extraction Rate



(035) Effect of Condition of Buffer Zones on Timber Extraction Rate([(0,0)-(10,10)],(0,1),(1,0))
Units: Kg/Kg

(041) Effect of Induced Reforestation on Timber Growth Rate([(0,0)-(100,10)],(0,1),(1,1.1))
Units: Kg/Kg

(042) Effect of NTFP in Sanctuary on Timber Growth Rate([(0,0)-(10,10)],(0.0001,0),(1.59021,1.6),(3.36391,3),(6.20795,3.6),(9.63303,4))
Units: Kg/Kg

(040) Effect of Fodder in Sanctuary on Timber Growth Rate([(0,0)(10,10)],(0.030581,4.43),(2.53823,4.16),(4.92355,3.4),(7.37003,2.2),(8.99083,0.8))
Units: Kg/Kg

(024) Condition of Buffer Zones=0.5
Units: Kg/Kg

(007) Area of Timber Collection=60
Units: Bigah

(087) Induced Reforestation=0.5
Units: Kg/Kg

(094) Initial Timber Produce=15000
Units: Kg of Wood/Bigah

(116) Maximum Timber=15000
Units: Kg of Wood/Bigah

(120) Natural Timber Growth Rate=(1+(0.02/12))
Units: 1/Month

(151) Timber Extraction Rate=Effect of Condition of Buffer Zones on Timber Extraction Rate(Condition of Buffer Zones)*Fuelwood Collection Rate*Timber Produce/(Maximum Timber*Area of Timber Collection)
Units: Kg of Wood/(Month*Bigah)

(153) Timber Produce= INTEG (Timber Growth Rate-Timber Extraction Rate,Initial Timber Produce)
Units: Kg of Wood/Bigah

(152) Timber Growth Rate=Natural Timber Growth Rate*((Maximum Timber-Timber Produce)/Maximum Timber)*Effect of NTFP in Sanctuary on Timber Growth Rate(NTFP in Sanctuary/Initial NTFP in Sanctuary)*Effect of Fodder in Sanctuary on Timber Growth Rate(Fodder in Sanctuary/Initial Fodder in Sanctuary)*Effect of Induced Reforestation on Timber Growth Rate(Induced Reforestation)
Units: Kg of Wood/Bigah/Month

Sanctuary NTFP

NTFP is a crucial part of the forest ecosystem, supplying diverse products for wildlife and other plants alike. These forest commodities from the Kumbhalgarh sanctuary include date palm, wild fruits, honey, gum, tendu leaves, and jatropha, and when present, are collected by people in the nearby communities. These products directly contribute to the livelihoods of the people; some are directly used by households in the community and others are sold or traded at nearby markets. As the forest depletes, less NTFP is produced, directly affecting critical livelihood resources. The amounts of NTFP present in the sanctuary are affected by multiple factors, most notably the amounts of fodder and timber coexisting in the forest. Increased fodder in the sanctuary slows the NTFP growth rate. Fodder and NTFP compete for nutrients and ground space. Aggressive grasses and shrubs can suffocate and oust NTFP plants. The presence of timber produce positively affects NTFP growth rate; as the amount of timber produce increases, so does NTFP growth proportionally increases as well. As timber is extracted from the forest for fuelwood, NTFP forest product growth slows.

Figure 36: Effect of Fodder in Sanctuary on NTFP Growth Rate

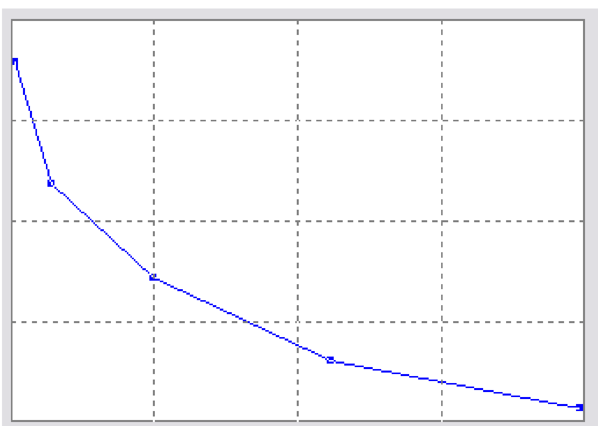
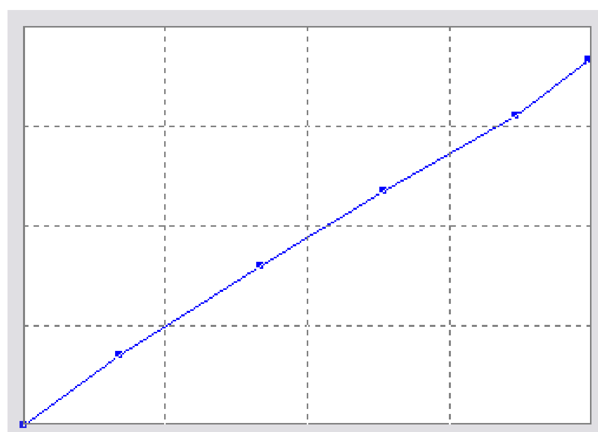


Figure 37: Effect of Timber Produce on NTFP Growth Rate



(006) Area of NTFP Collection=1
Units: Bigah

(034) Effect of Condition of Buffer Zones on NTFP Extraction Rate([(0,0)-(10,10)],(0,1),(1,0))
Units: Kg/Kg

(039) Effect of Fodder in Sanctuary on NTFP Growth Rate([(0,0)(10,10)],(0.0611621,8.90351),(0.642202, 5.92105),(2.23242,3.59649),(5.01529,1.49123),(8.92966,0.307018))
Units: Kg/Kg

(047) Effect of Timber Produce on NTFP Growth Rate([(0,0)-(10,10)],(0.0001,0),(1.52905,1.71053),(3.76147,3.94737),(5.71865,5.87719),(7.79817,7.7193),(8.96024,9.12281))
Units: Kg/Kg

(093) Initial NTFP in Sanctuary=1610
Units: Kg of NTFP/Bigah

(113) Maximum NTFP=1610
Units: Kg of NTFP/Bigah

(119) Natural NTFP Growth Rate=(1+(0.05/12))
Units: 1/Month

(122) NTFP Extraction Rate=Effect of Condition of Buffer Zones on NTFP Extraction Rate(Condition of Buffer Zones)*NTFP Collection Rate*NTFP in Sanctuary/(Maximum NTFP*Area of NTFP Collection)
Units: Kg of NTFP/(Month*Bigah)

(123) NTFP Growth Rate=Natural NTFP Growth Rate*((Maximum NTFP-NTFP in Sanctuary)/Maximum NTFP)*Effect of Timber Produce on NTFP Growth Rate(Timber Produce/Initial Timber Produce)*Effect of Fodder in Sanctuary on NTFP Growth Rate(Fodder in Sanctuary/Initial Fodder in Sanctuary)
Units: Kg of NTFP/(Month*Bigah)

(124) NTFP in Sanctuary= INTEG (NTFP Growth Rate-NTFP Extraction Rate,Initial NTFP in Sanctuary)
Units: Kg of NTFP/Bigah

Sanctuary Fodder

Fodder availability is critical for managing livestock, which is a key contributor to livelihood. Households obtain fodder from crop residue, JFM forested plots, community charagahs, and private lands, in addition to collecting fodder from the sanctuary. Local people collectively protect defined areas to meet their own fodder requirement during the summer seasons, but allow livestock to roam freely within the federal boundaries during the rest of the year. Households send livestock, mainly cows, goat, and sheep, to graze the sanctuary for grassy fodder. Sheep roam the forested lands for grassy and leafy fodder, and goats consume only leafy fodder. Typically, livestock roam the forests during the day hours and are stall fed each night. Excessive grazing of these sanctuary lands over time causes the forest resources to deplete, which hinders the forest's ability to recover and grow. Presence of NTFP has positive effects on fodder growth rate, but only up to a certain point. NTFP provides soil nutrients, attracts wildlife, and contributes to the overall state of the forest ecosystem, which in turn, affects fodder growth. At this stage, extraction of NTFP slows the fodder growth rate, directly providing NTFP, but reducing future fodder resources. If too much NTFP is present, fodder will not have room to grow and flourish in the limited grounds space in the forest. Similarly, as timber produce increases, fodder growth decreases. An increased presence of trees will limit the amount of sunlight on the forest floor, impeding grassy fodder growth.

Figure 38: Effect of NTFP on Fodder Growth Rate

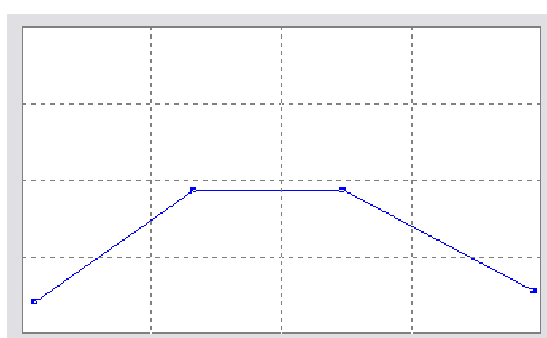


Figure 39: Effect of Timber Produce on Fodder Growth

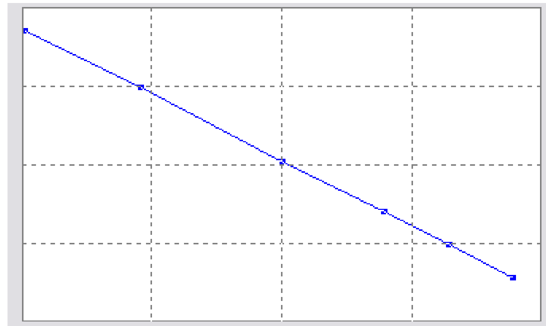
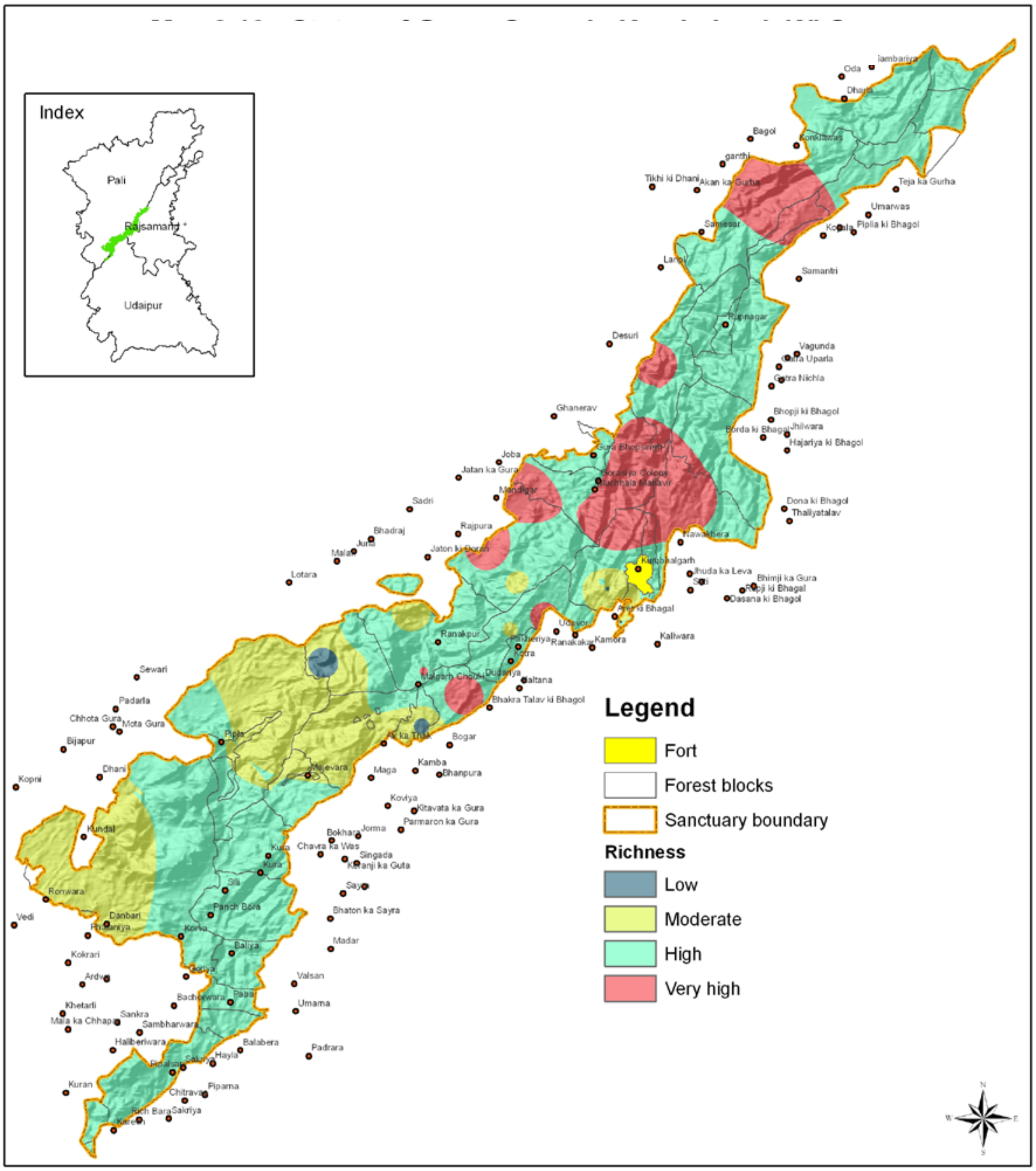


Figure 40: Grass Cover in Kumbhalgarh Wildlife Sanctuary



(005) Area of Fodder Collection=1
Units: Bigah

(033) Effect of Condition of Buffer Zones on Fodder Extraction Rate([(0,0)-(10,10)],(0,1),(1,0))
Units: Kg/Kg

(043) Effect of NTFP on Fodder Growth Rate([(0,0)-(10,10)],(0.58104,0.921053),(1.49847,1.35965),(2.35474,1.35965),(3.45566,0.964912))
Units: Kg/Kg

(046) Effect of Timber Produce on Fodder Growth Rate([(0,0)-(10,10)],(0.0611621,9.21053),(2.29358,7.45614),(5.04587,5.04386),(6.97248,3.50877),(8.25688,2.45614),(9.48012,1.35965))
Units: Kg/Kg

(053) Fodder Extraction Rate=Effect of Condition of Buffer Zones on Fodder Extraction Rate(Condition of Buffer Zones)*Fodder Collection Rate*Fodder in Sanctuary/(Maximum Fodder*Area of Fodder Collection)
Units: Kg of fodder/(Bigah*Month)

(054) Fodder Growth Rate=Natural Fodder Growth Rate*((Maximum Fodder-Fodder in Sanctuary)/Maximum Fodder)*Effect of NTFP on Fodder Growth Rate(NTFP in Sanctuary/Initial NTFP in Sanctuary)*Effect of Timber Produce on Fodder Growth Rate(Timber Produce/Initial Timber Produce)
Units: Kg of fodder/(Month*Bigah)

(055) Fodder in Sanctuary= INTEG (Fodder Growth Rate-Fodder Extraction Rate,Initial Fodder in Sanctuary)
Units: Kg of fodder/Bigah

(092) Initial Fodder in Sanctuary=200
Units: Kg of fodder/Bigah

(112) Maximum Fodder=200
Units: Kg of fodder/Bigah

(118) Natural Fodder Growth Rate=(1+(0.23/12))
Units: 1/Month

Population

(125) Number of HH=Population/People per HH
Units: person/person

(129) People per HH=8
Units: person

(130) Population=805
Units: person

Miscellaneous

(051) FINAL TIME = 100
Units: Month
The final time for the simulation.

(095) INITIAL TIME = 0
Units: Month
The initial time for the simulation.

(132) SAVEPER = TIME STEP
Units: Month [0,?]
The frequency with which output is stored.

(154) TIME STEP = 0.125
Units: Month [0,?]
The time step for the simulation.