# Modeling the Economics of Grassland Degradation in Banni, India, using System Dynamics

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## Abstract

*This is a study on the interactions between the grassland, livestock, the invasive species Prosopis juliflora and the economy of the Banni grasslands, located in the district of Kachchh, Gujarat, India. The study focuses on modeling grassland degradation of Banni from 1992-2015 and simulates future scenarios up to 2030 using system dynamics modeling. An economic valuation of Banni's economy is done by discounting the future earnings of the pastoral economy (milk, livestock sale, dung manure) and charcoal economy under two scenarios 1) Base case (Business as Usual), i.e. keeping things as they stand today and 2) Prosopis Removal Policy (PRP) i.e. where a decision is implemented to remove Prosopis from Banni. Under the BAU scenario, modeling results indicate that the Banni grassland is headed for severe fodder scarcity due to shrinking area under grassland. If PRP is implemented then Banni would be able to revive its grasslands and more than double the Present Value of future earnings, up to 2030. If the policy decision to remove Prosopis is delayed by 5 years then it results into a 30% reduction in earnings indicating the policy's time sensitivity. The model serves as a test bed to evaluate management policies of Banni grasslands.*

Key Words: Grasslands, Livestock, System Dynamics, Economics, Land Degradation

## Introduction

An area of approx. 2500 sq. km located in the district of Kachchh (Koladiya et al., 2016), Gujarat, the Banni grassland was once known as Asia's finest tropical grassland (Bharwada&Mahajan, 2012). However, the grassland has been degrading over the years. The grassland productivity has come down from 4000 kg/hectare in the 1960s to 620 kg/hectare in 1999 (Bharwada&Mahajan, 2012). The area under grassland has reduced from 142,000 hectares in 1989 to 63,000 hectares in 2009 while the area invaded by *Prosopis* juliflora has increased to 82,000 hectares (Koladiya et al., 2016). While many reasons are attributed to the degradation of the Banni grassland, the evidence is still inconclusive on whether the dominant cause is increasing salinity or spread of the invasive species *Prosopis juliflora*. However, the most cited reason by the pastoralists of Banni (Maldharis) is the spread of *Prosopis juliflora.* With livestock rearing being the primary occupation of the people of Banni, grassland degradation poses a serious problem for sustaining their pastoral economy.

This study is an investigation into the dynamics of Banni grasslands and an exploration into possible futures under different scenarios. It highlights the interdependencies existing between different sectors and between variables of each sector using system dynamics modeling. The model helps in developing a deeper understanding of the complexities of Banni and serves as a tool for policy testing and evaluation. The study highlights the need for further research on the ecological and economic parameters of Banni, and presents a case for the development of a decision support tool to manage the Banni grasslands.

## Banni Grasslands

The Banni grassland is located on the northern border of Bhuj taluka (23° 19’ 23° 52’ N latitude and 68° 56’ to 70° 32’ E longitude) of Kachchh district in Gujarat State (ref. fig 1) (Mehta et. al, 2014). The mainstay of Banni’s economy is livestock rearing.

The Banni grassland is divided into three areas, 1) Ugamani Banni - East Banni, 2) Vachali Banni - Central Banni, 3) Aathamani Banni or Jat Patti - West Banni (Bharwada&Mahajan, 2012). There exist 13 different estimates of its geographic area ranging from 1800 sq km to 3800 sq km (Bharwada&Mahajan, 2012). But the recent estimates have converged to the figure of 2500 sq km (Koladiya et al., 2016). For this study total Banni area is taken as 2500 sq km (250,000 hectares).

The livestock breeders of Banni are called Maldharis. There are many pastoral communities in Banni like Raysipotra, Halepotra, Pirpotra, Hingorja, Sumra, Mutva, Node etc. who migrated several generations ago from Sindh, Marwar and Baluchistan (Bharwada&Mahajan, 2012). The other community in Banni is the Meghwals. Their main occupation has been leather tanning and shoe making including making artifacts from leather (Bharwada&Mahajan, 2012).

## Brief History of Banni Grassland

The Banni grassland was once known as Asia’s finest tropical grassland. Before independence its geographic area spread beyond Indian borders into the geographic areas of Pakistan.

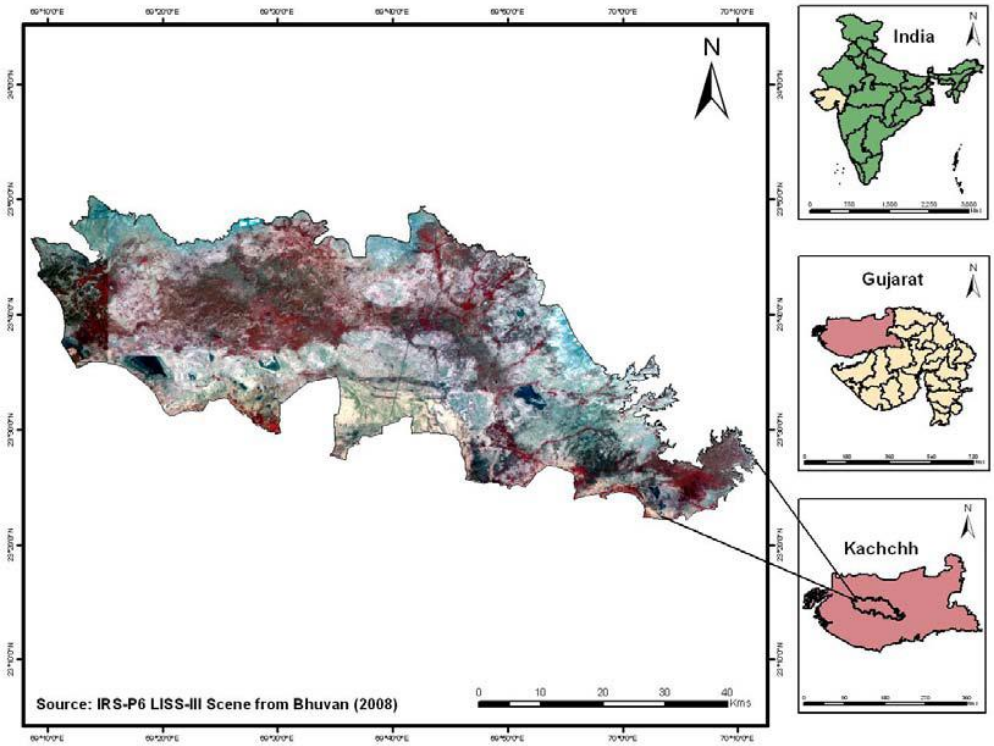



**Figure 1 Map of Banni Grassland. Source: (Mehta et. al, 2014)**

The entire Banni area is largely a flat land which often results in seasonal water flooding during the monsoon. Banni grassland is also sometimes referred to as a seasonal wetland (Mehta et. al, 2014). The Government forest department reports about 254 small and large wetlands in Banni (Bharwada&Mahajan, 2012). It was first declared as a protected forest in May 1955, under the Indian Forest Act, 1927 (Mehta et. al, 2014). The climatic condition falls under arid and semi-arid zone (Mehta et. al, 2014) with an average annual rainfall of around 300-353 mm (Bharwada&Mahajan, 2012) (Geevan, 2003). The grasses of Banni are a common pool resource. The Maldharis by and large consider the grasses of Banni to be a common pool resource, and so all the pastoralists have equal rights to use them as fodder for their livestock.

## Prosopis Juliflora

*Prosopis juliflora* is a species native to South America, the Caribbean and Mexico. It was first introduced along the Banni and Great Run of Kutch border in 1961 covering an area of 31,550 hectare by the Forest Department in order to control the Rann's ingression (Bharwada&Mahajan, 2012). In the last 55 years the spread of *Prosopis* has led to the loss of native vegetation in Banni, including the grasslands. It is today cited as one of the dominant causes for grassland degradation. Its spread is aided in the summer when grasses are in short supply and thus *Prosopis juliflora* pods become a ready feed for grazing animals. Seeds rejected with the fecal matter quickly germinate and take root as they get both manure and moisture. The open grazing system of Banni further accelerates its rapid spread (Bharwada&Mahajan, 2012). Due to *Prosopis*' allelopathic properties it has led to loss of indigenous plants and reduction in area under grasslands (Bharwada&Mahajan, 2012). The pastoralists of Banni cite the spread of *Prosopis* as the main reason for grassland degradation and opine that if *Prosopis* were to be removed the grasslands would recover. In Banni it is locally called *Gando Baval*, which means 'mad' *Ácacia*.

### Dairy

Banni buffalo and Kankrej cattle are the dominant livestock of Banni. Traditionally the Banni pastoralists were breeders of livestock and were involved in the trade of the Banni Buffalo and Kankrej cattle and bullocks, and Banni was not traditionally a dairy-farming economy. Only recently, after the introduction of dairy in 2009-2010 for milk collection, have the pastoralists of Banni started selling milk in large quantities. The introduction of dairy has led to a revival of buffalo breeding in Banni, and the population has been increasing over the last few years. Also registration of Banni buffalo as the $11^{th}$ buffalo breed in India in 2011 motivated the Maldharis, especially the young generation, to continue and strengthen their pastoral occupation (Bharwada&Mahajan, 2012). The population of the Kankrej cattle on the other hand has been reducing as consuming the pods of *Prosopis* leads to their death (Bharwada&Mahajan, 2012). Thus, the population of Kankrej cattle has been falling due to spread of *Prosopis*. This has had a negative impact on the bullock trade. However, in recent years it has been observed by the Maldharis that Kankrej has adapted to survive in dense *Prosopis* areas. The loss in grassland productivity also means that the Maldharis have to purchase more fodder from outside Banni, having a negative impact on the economy of Banni. Discussions with Maldharis revealed that this also spurred them to migrate out more, in order to save costs.

### Charcoal Making

Charcoal making is practiced by Maldharis to earn income in addition to the livestock income. *Prosopis* wood is harvested for making charcoal, without uprooting the tree. Since the Banni Grassland is classified as a Protected Reserve Forest, it is illegal to cut *Prosopis* and there has been a ban in place. However, in 2004 this ban was lifted, leading to a huge increase in charcoal production. It led to reduction in area under *Prosopis* as Maldharis resorted to removing *Prosopis* trees from the roots for making charcoal. Maldharis recollect that the grasslands had come back as a result of its removal, as uprooting the tree frees up the land allowing grasses to grow in that area. It is hard to estimate the exact amount by which the production went up but estimates of the increase in number of charcoal-laden vehicles leaving Banni suggest that it could have been as high as ten times (Bharwada&Mahajan, 2012). In 2008, this ban was again imposed. The reasons for this vary. Some suggest that the ban was again imposed because indigenous trees were also being harvested for charcoal. Others suggest that the charcoal trader's cartel influenced the re-imposition of the ban since they were unable to exercise control over production and supply of charcoal which resulted in a loss for them (Bharwada&Mahajan, 2012). The ban persists, but charcoal making still continues in Banni, though in limited quantities.

## Research Objective

Banni's ecological and economic system is highly dynamic. The research methodology relies on use of system dynamics modeling for developing a base case and policy scenarios on the future of Banni. This study focuses on the issue of grassland degradation of Banni, its key drivers, factors that could lead to collapse of livestock economy, what impact the removal of *Prosopis* would have as a solution for halting grassland degradation, etc. The model runs from 1992-2014 and simulates future scenarios up to 2030 under 1) Base Case, 2) Policy implementation of *Prosopis* Removal and 3) 5 year Delay in *Prosopis* removal policy implementation.

## Research Methodology: System Dynamics

Ecological-economic systems are complex and composed of various interconnected, interrelated, interdependent sectors that are closely related by multiple cause and effect relationships and feedback. Such complex systems are well understood using dynamic simulation techniques (Casti, 1997). System Dynamics (SD) is one such approach, suited to understand the non-linear behaviour of complex systems over time using stocks and flows, internal feedback loops, and time delays (MIT, 1997). Pioneered by Jay W. Forrester at MIT (Forrester, 1958), SD is able to unveil the counterintuitive nature of complex systems and uncover relationships between variables that are responsible for the behaviour of the system. Further, being transparent, it provides the reader with the opportunity to go through the model structure and study the linkages (Gallati, 2011).

This SD model of the Banni grassland is comprised of three sectors: livestock (Buffalo and Kankrej Cattle), grassland & *Prosopis* juliflora and the economy. Impacts of drivers of livestock growth and *Prosopis* growth, their impact on the local environment, and the consequent multiple feedback that could impact the future of these sectors, have been modelled. The model runs are from 1992 to 2030. The dynamic hypothesis, key assumptions, model description, simulation results, and insights generated from them are presented below. Equations and model structure are given in the supplementary material.

### Dynamic Hypothesis

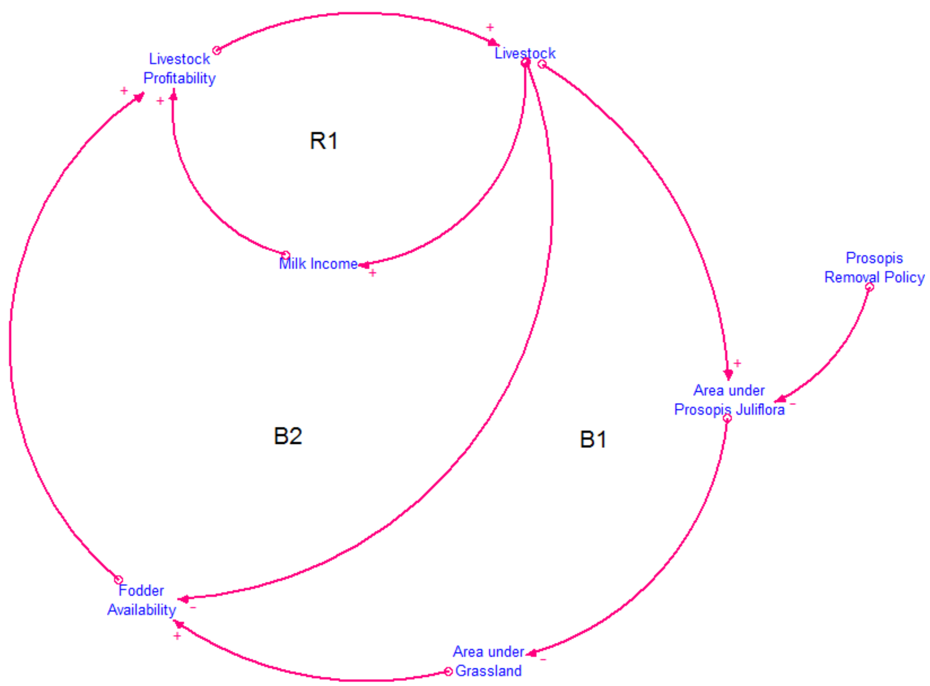


**Figure 2 Dynamic Hypothesis**

The above dynamic hypothesis shows higher order linkages of our system dynamics model. There are two Balancing Loops (Livestock-Fodder-Livestock, Livestock-Prosopis-Grassland-Livestock) and one Reinforcing Loop (Milk income-Livestock).

As the livestock increases it results into higher fodder requirement. With limited grassland, the fodder availability falls. As fodder availability falls it results into Maldharis purchasing feed and fodder from outside Banni. This results into higher input costs thereby reducing the profitability per livestock. As profitability falls below zero it leads to stress sale of livestock for recovering losses, balancing out the livestock numbers. Consequently, as the livestock numbers go down the fodder requirement comes down leading to an increase in the livestock profitability (Balancing Loop B2). This is a balancing process, however currently the reinforcing loop R1 is dominant as Maldharis are earning enough from milk sales to sustain their livestock, even with the grassland degradation and consequent fodder deficit. Dairy income is an economic incentive for Maldharis to retain and grow their livestock numbers. Higher livestock would yield higher milk thereby increasing their milk income. Higher milk prices for Banni buffalo milk is a key driver for growth of Banni buffalo.

The other balancing process concerns the spread of Prosopis dominated area. The growth in area under Prosopis is aided by presence of Livestock which carry the seeds and help it germinate fast and wide. As area under Prosopis goes up the area under grassland comes down, again leading to negative impact on livestock due to falling fodder availability. (Balancing Loop B1)

The policy testing is done for a case of Prosopis removal. If Prosopis is removed then it could potentially reverse the current trend of grassland degradation in Banni, increasing the grassland area and fodder availability, as shown in the above diagram.

## Key Assumptions

1. **Prices for milk, livestock, feed, charcoal, and dung manure are kept constant at 2015 levels.** Forecasting future prices, at local level, has lot of uncertainty which would add to the complexity of carrying out an economic valuation of Banni grasslands. Hence, here it is assumed to be constant at 2015 prices.
2. **No limit on external supply of feed, fodder and water.**
   Today, an external supply of feed and fodder is an integral part of Banni and is assumed to be available for purchase at a cost. Water is available in Banni through pipelines coming in from outside the Banni boundary, and is assumed to remain sufficient for the duration of model runs.
3. **Exclusion of small ruminants (eg. sheep, goat etc.)**
   Buffalo and cattle constitute most of the Banni livestock. In 2011 their share was around 92% of the total livestock (Bharwada&Mahajan, 2012). Hence, considering the small proportion of small ruminants they are excluded from the study.
4. **Rainfall for 2015-2030 is assumed to be same as 1999-2014**
   Rainfall is highly erratic and drought is a recurring phenomenon in Banni. However, rainfall follows a cyclical pattern, with sub-normal rainfall and heavy rainfall patterns repeating every five years (Bharwada&Mahajan, 2012). Hence this assumption is made to include the cyclical pattern of Banni rainfall variation.

## Model Sector Description

The model consists of three interconnected sectors[1]: Livestock Dynamics (Buffalo and Kankrej Cattle), Prosopis and Grassland Dynamics and the Economy (Pastoral - milk, livestock sale, dung manure and charcoal made from *Prosopis*) (Figure 3). These sectors are explained below. Important parameter values are provided in Table 1 in the next section.

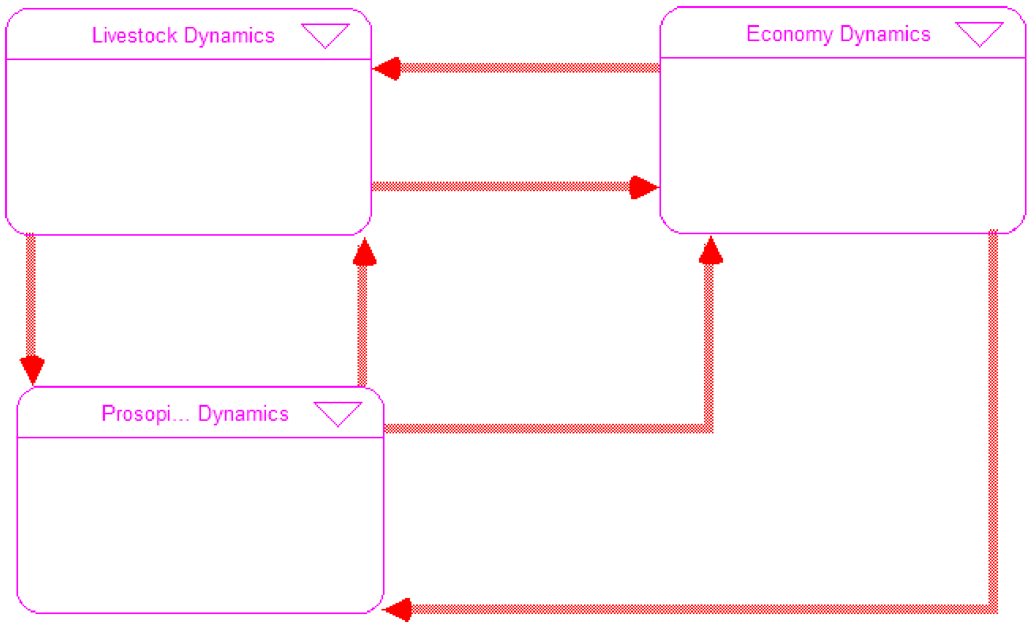



**Figure 3 Sectorial Linkages**

## Grassland and *Prosopis* juliflora

The total area of Banni is taken as 2500 sq. km i.e. 250,000 hectares(Koladiya et al., 2016). Of this, 90% is taken to be total possible productive land area (includes grassland, *Prosopis* dominated area and other vegetation) while 10% is taken to be waste land (wasteland includes saline land, water bodies). In 1992 (the base year), the area of land dominated by *Prosopis* is taken to be 41,180 ha (Koladiya et al., 2016) while grassland area equals total productive area less area under *Prosopis.*

The dynamics between grassland area and area under *Prosopis* are the key factors influencing most of the changes in Banni. *Prosopis juliflora* is the main driver of land use change. It is highly invasive and literature suggests that *Prosopis* cover has been increasing at an average rate of 26.73 sq. km. per year in Banni (Bharwada&Mahajan, 2012). As the area under *Prosopis* expands it invades the area under grassland. The normal spread rate of *Prosopis* is taken to be 8.5% per year of the total area under *Prosopis* (Vaibhav et al., 2012). However, this spread rate is enhanced by the presence of livestock, as the seeds are carried by livestock and the passage through the digestive tract facilitates quick germination. (Geevan et al., 2003) (Bharwada&Mahajan, 2012). This has been modelled as a multiplier through a graphical

[1] Model sector diagrams are provided in the supplementary material

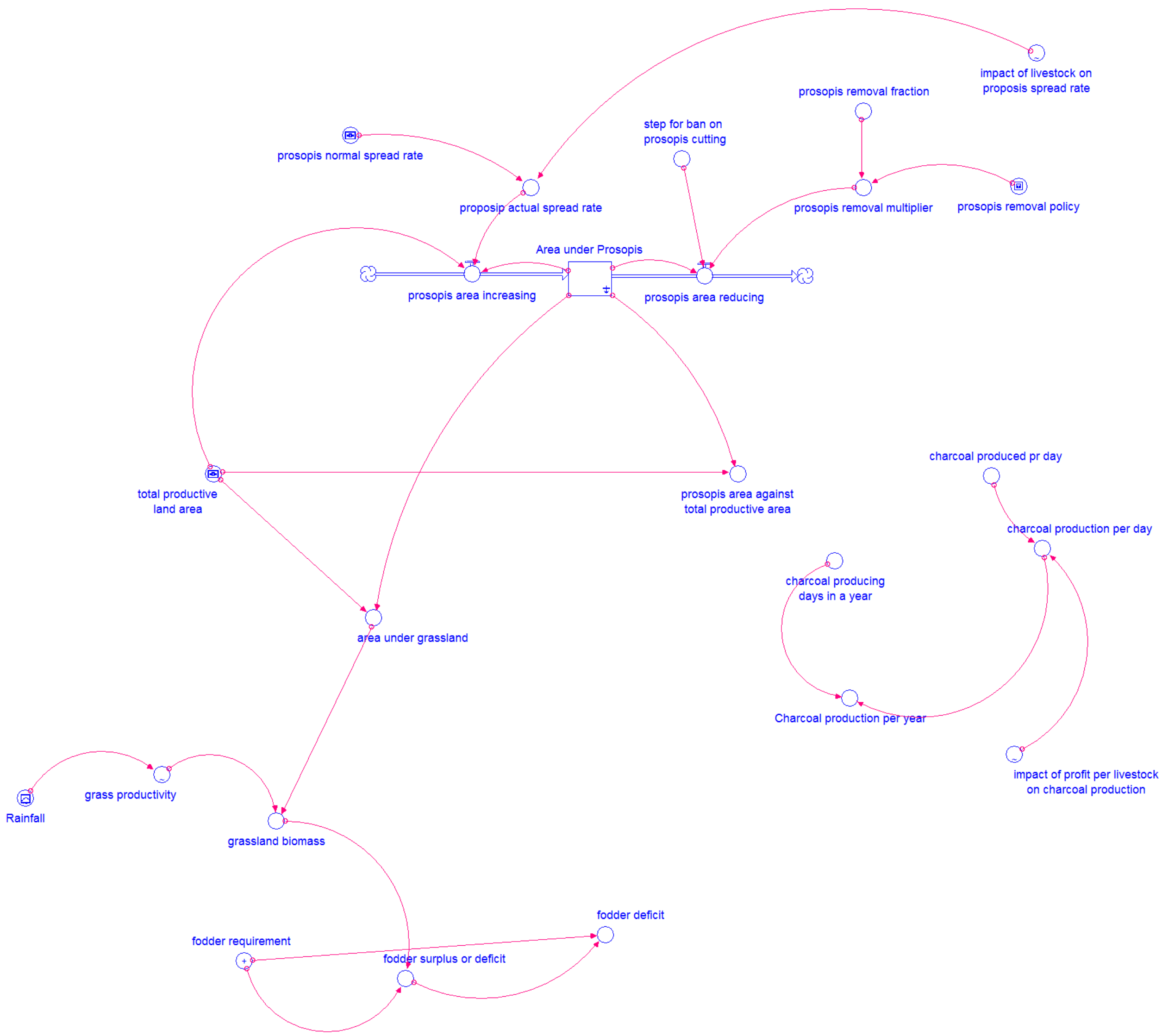
function in our model, the impact increases with increase in livestock population ultimately levelling off at a maxim. The graphical function is given under ‘Graphical functions and key feedback relationships’. The growth of *Prosopis* is limited by the total land area available. The equation for the *Prosopis juliflora* growth is:

Increase in *Prosopis juliflora* area = Normal *Prosopis* spread rate*Enhanced spread rate due to livestock presence*Area under *Prosopis**(1-(Area under *Prosopis*/Total productive land area))

Since Maldharis only use above-ground wood of *Prosopis* for charcoal making it does not reduce the area under *Prosopis* under normal conditions. Historically, *Prosopis* area came down only when the ban on making charcoal from *Prosopis* was lifted. This happened between 2004 and 2008, which has been modelled using time based “if” function. The grassland biomass is calculated using grassland area (total productive land less area occupied by *Prosopis*) multiplied by the grassland productivity. The latter is a function of the rainfall in a particular year. Personal interviews revealed that the grassland productivity of Banni is high in a specific bandwidth of rainfall, and lower on both extremes (low and very high rainfall). This bandwidth of ‘good rainfall’ has been kept as between 250 and 700 mm of rainfall. Rainfall from 2015-2030 is assumed to be the same as from 1999-2014. Rainfall data for 1992-2010 is taken from (Bharwada&Mahajan, 2012), for year 2011-12 it is taken from (Gavalli, 2015) and for 2013-14 Kachchh district data is used for Banni from Indian Meteorological Department website (IMD, 2016).

A parameter ‘fodder deficit’ is defined as the ratio between the fodder available in Banni in a particular year less the fodder requirement in that year divided by the fodder requirement. This ratio is important as it determines the input cost (feed and fodder purchased from outside Banni) for milk-producing Banni buffalo. As the deficit increases, the buffalo input cost increases. Further, this ratio also determines the migration of livestock from Banni in fodder deficit years.

Figure 4 Model Diagram of Prosopis and Grassland Sector



### Livestock Dynamics

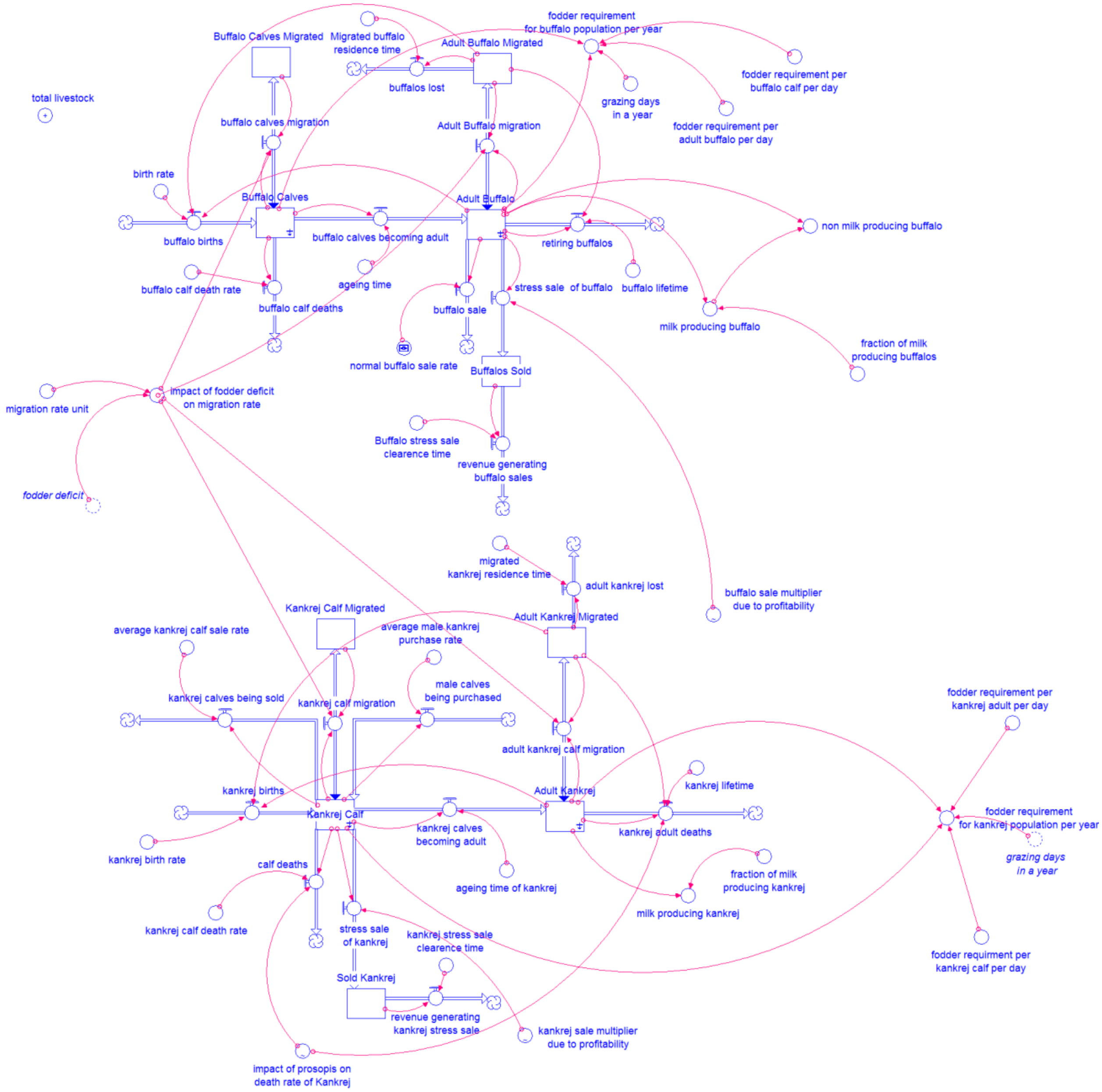
This sector consists of populations of the two large ruminants: the Banni buffalo and Kankrej cattle. Small ruminants such as sheep and goats, though present in Banni are excluded due to their relatively smaller share of the total livestock (less than 10%). For both the livestock (buffalo and cattle), modelling has been done by making ageing chains i.e. breaking down the populations into calves and adults, considering a maturation time and taking different death rates/retiring times for both stocks. Calves are born to a certain fraction of the adults every year. Some calves die before they transit into adults according to a calf death rate. There is also a retiring time for the adults after which they stop producing milk and calves. To manage the frequent droughts in Banni, the Maldharis have adopted two dominant coping mechanisms. One is migrating out of Banni with their livestock for the dry period and the second is by increasing the sale of livestock in dry years.

It is assumed that if the fodder deficit crosses 30% in a certain year, 30% of the livestock leaves Banni, and if it crosses 50%, 50% of livestock leaves Banni. Also, the buffaloes that migrate outside accumulate in a stock of migrated buffaloes which come back when the deficit falls below 10% (See figure 5). A maximum residing time is given to the migrated stock of adult livestock after which the migrated stock permanently migrates out of the Banni periphery. This residing time is kept at 2 years.

The Banni buffalo ageing chain is composed of two main stocks: Calves and Adults (Figure 5). The stock of buffalo calves has one inflow (births), two outflows (calf deaths, maturation to adult buffaloes) and one bi-flow (calf migration).The births are governed by a certain fraction of the adult buffaloes which give birth to a calf every year (approx. 50% of the total adult stock). 50% of the births are female and 50% male. The model considers only females, as males are generally not reared.  The fraction of buffalo calf death every year is taken as 20% (after discussions with Maldharis). Maturation time from calf to adult is taken as 3 years. The lifetime is taken as 23 years and sale rate of buffaloes is assumed at 1% per year (based on interviews). A buffalo sale multiplier is build using graphical function which depicts the impact of falling profitability on the flow of buffalo (stress) sales. This sale multiplier depends on the profit per livestock. As the profit per livestock in a year becomes negative, the stress sale multiplier increases and later levels off.

The Kankrej ageing chain is very similar to the buffalo, having birth fraction, lifetime, maturation time, fodder requirement etc. (Table 1). Further, there exists a practice in Banni of purchasing Kankrej calves every year and as the Kankrej calves are very valuable, the stress sale function due to profitability (a function of livestock profitability, similar to buffaloes above) is of Kankrej calves and not adults. Another distinguishing feature is that the Kankrej cattle population is negatively affected by Prosopis, as the cattle are unable to digest the pods and die on consuming them. This relationship is shown through a graphical function where the death multiplier increases due to increase in Prosopis density.

Figure 5 Model Diagram of Livestock Sector

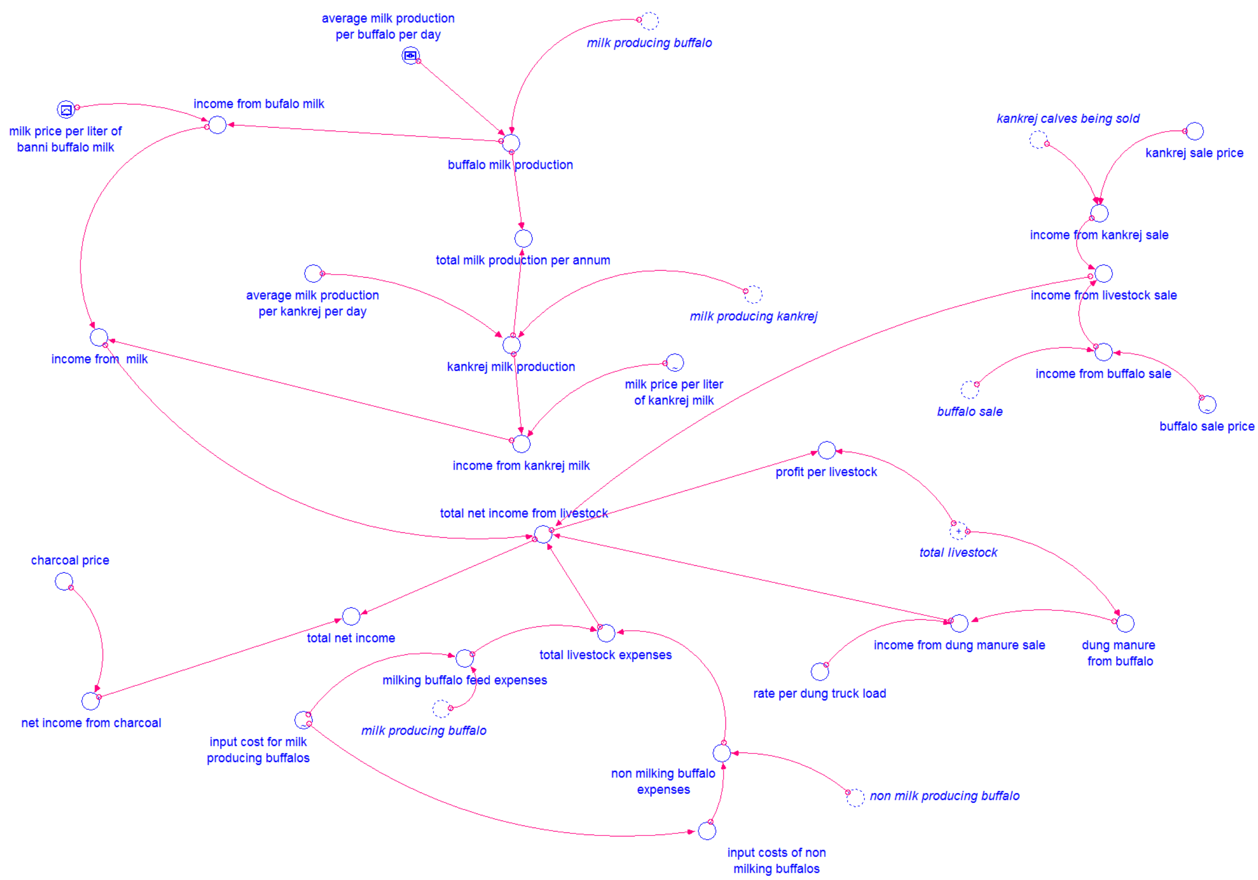



## The pastoral and charcoal economy

This sector consists of livestock based income (milk, dung and livestock sale) and charcoal income (Figure 6). Summing the income from livestock and dividing it be the total livestock population, a number for profit per livestock is calculated. This number creates a feedback and governs the stress sales of adult buffaloes and Kankrej calves. As the profit per livestock in a year goes negative, the stress sale multiplier increases.

Charcoal making is the second biggest source of income for Maldharis after livestock. The charcoal production in a year has been differentiated according to history. 1) Before the ban on charcoal production was lifted (i.e. before 2004)- the charcoal production is taken as 2400 sacks of 40 kg each per day for 240 days in a year (based on discussions with Sahjeevan and personal interviews with Maldharis). 2) During the time when the ban was lifted (between 2004 and 2008)- the charcoal production is increased by 10 times as compared to before the ban (Bharwada&Mahajan, 2012). 3) After the ban was again imposed (i.e. after 2008)- the charcoal production is taken as 4800 sacks of 40 kg each produced per day for 240 days in a year, the same as before the ban period. A feedback function is created to increase the rate of production in event of fall in profits from livestock.

**Figure 6 Model Diagram of Economy Sector**



## Graphical functions and key feedback relationships

There are 6 cross-sectorial feedback loops which govern the dynamics of the model. The numbers for these graphical functions can be found in the model equations in Supplementary Material.

1) **Impact of fodder deficit on livestock input cost**. As the fodder deficit increases so does the livestock input cost, reflecting the need to purchase fodder from outside.

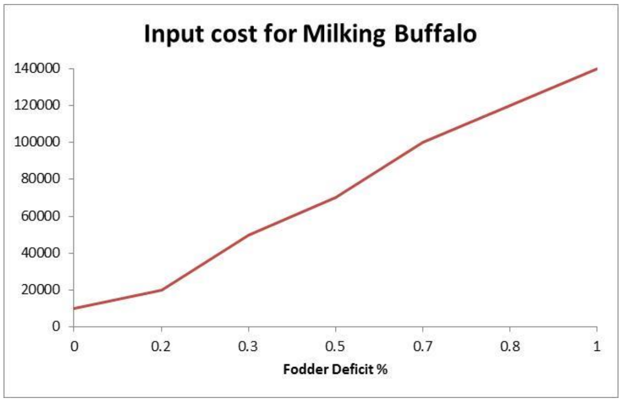



Figure 7 Impact of Fodder Deficit on Livestock input cost

2) **Impact of profit per livestock on livestock stress sale rate**. As the profit per livestock becomes negative, the stress sale of livestock goes up, reflected in an increase in stress sale fraction.

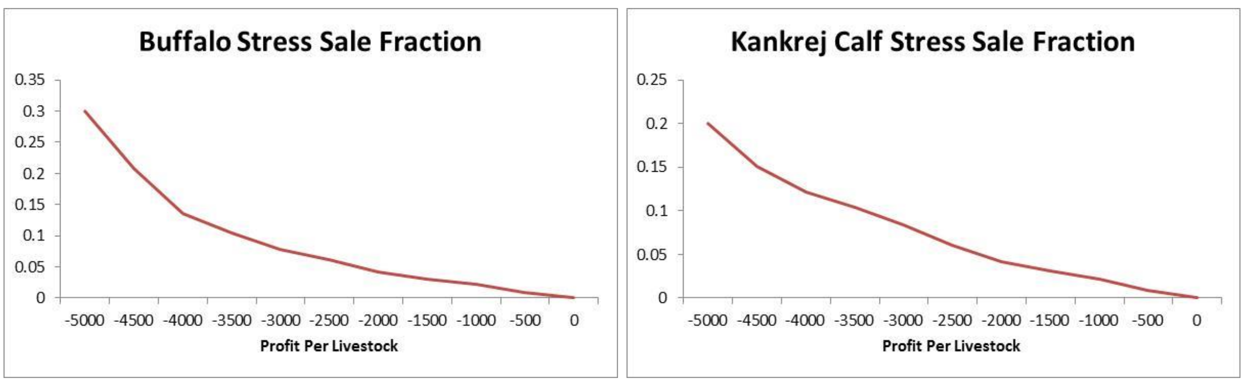



Figure 8 Impact of Livestock Profitability on Buffalo and Kankrej Sale

3) **Impact of fodder deficit on temporary livestock migration**. If the fodder deficit lies between 30% and 50% in a certain year, 30% of the livestock leave Banni, and if it crosses 50%, 50% of livestock leave Banni. If fodder deficit is 10% or lower, the livestock migrate back to Banni.

4) **Impact of livestock on *Prosopis* spread rate**. As the livestock population increases it leads to increase in the spread rate of area under *Prosopis*.

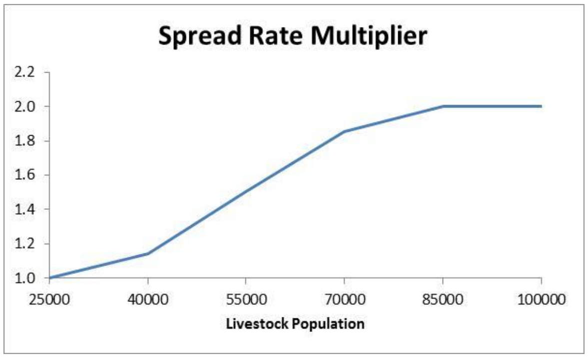



Figure 9 Impact of Livestock on Prosopis Spread Rate

5) **Impact of *Prosopis* density on Kankrej death rate**. As the *Prosopis* density (area under *Prosopis* ÷ total productive area) increases it leads to an increase in Kankrej death rate. However, it has been observed by the Maldharis that Kankrej has adapted to survive in *Prosopis* dense areas. Thus the death multiplier evens out at high levels of *Prosopis*.

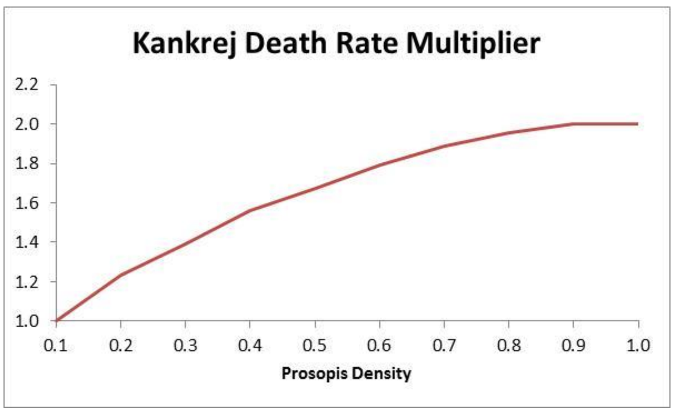



Figure 10 Impact of Prosopis Density on Kankrej Death Rate

6) **Impact of profit per livestock on charcoal production**. As the profit per livestock becomes negative, charcoal production starts increasing to compensate for the losses.

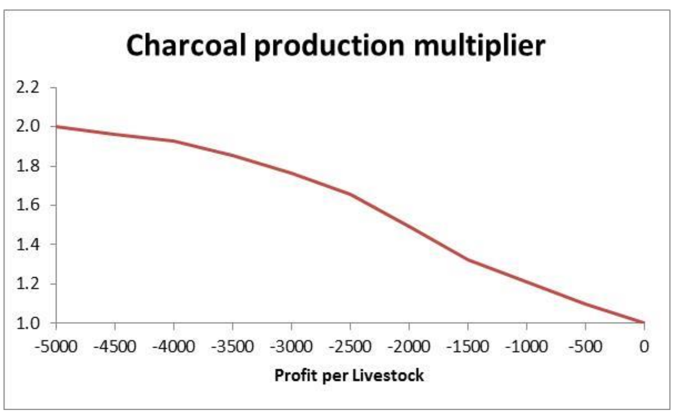


Figure 11 Impact of Livestock Profitability on Charcoal Production

The behavior of the system is governed by these feedback variables and whether the system grows, declines or oscillates depends on which of these feedbacks are dominant at a particular time of the simulation.

# Results

## Base Run: Business as usual scenario

The business as usual scenario i.e. base run simulation, indicates that the total livestock in Banni will fall from 2015 to 2030 (Figure 9) reaching around 26,000. The primary reason for this is stress sales due to reducing area under grassland (consequently fodder availability) and the migration that is practiced by Maldharis in years of poor rainfall. Two consecutive years of poor rainfall (2019-2020) are the reasons for the steep fall in livestock numbers in year 2020 similar to what was observed in year 2004.. Thus, livestock variability could be higher in periods of fodder scarcity. However, rainfall is impossible to predict accurately, and our simulation assumes that the rainfall pattern observed between 1999 and 2014 would reoccur in 2015 to 2030, to account for the cyclical rainfall pattern.


Figure 12 Base Case Livestock Population: 1992-2030

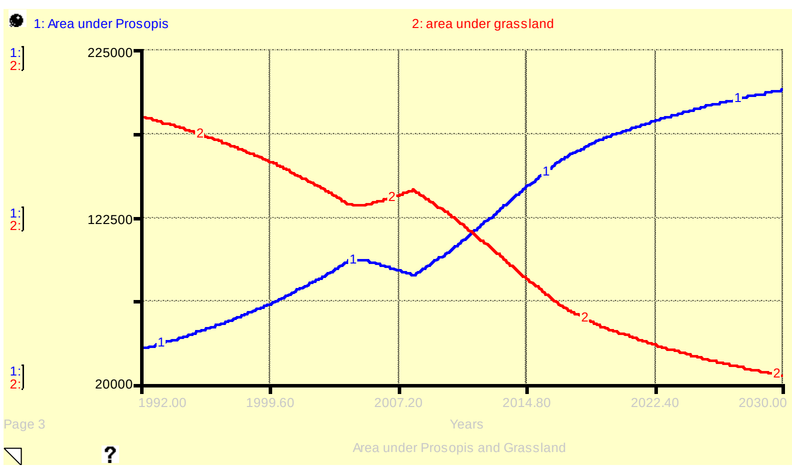



Figure 13 Base Case Land Use Change. All figures in hectares: 1992-2030

The shrinking area under grassland, due to *Prosopis* spread, is a cause of concern for Banni (Figure 10). If current conditions persist then by year 2030 the area under grassland will reduce to 23,000 hectares from 83,000 hectares in 2015, a reduction of around 70%. The primary reason for reduction in grasslands is the increase in spread of area under *Prosopis* juliflora. The model runs suggest that the area under *Prosopis* juliflora will reach 200,000 hectares by year 2030.

The period 2004-2008 shows a dip in area under *Prosopis* and an increase in area under grassland. This is due to the lifting of the ban on charcoal-making which caused an escalation in removal of *Prosopis* from the roots. Because of this, the grasses recovered, increasing the area under grassland. After the ban was again imposed, it led to growth in area under *Prosopis* while the grasslands continued to shrink.

Our base case simulation runs indicate that the net livestock income is projected to fall in future years and become negative for year 2020 due to two continuous low rainfall years, 2019-20 (Figure 11). The decline in net livestock income is mainly due to falling livestock population and increase in livestock input costs, mainly feed and fodder (due to an increased fodder deficit). These input costs spike due to fodder deficit which increases in the later years due to reducing area under grassland. The input costs are projected to go up mainly because of increase in external inputs of feed to compensate for the fodder deficit.

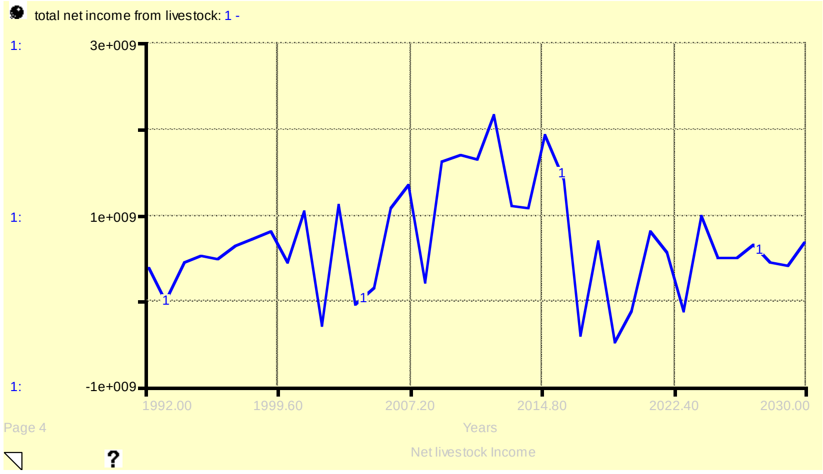



**Figure 14 Base Case Net Livestock Income: 1992-2030**

Grassland biomass depends on the extent of rainfall and grassland productivity. The variation in rainfall greatly influences the extent of grassland productivity and ultimately how much grass grows in that particular year. As can be seen in figure 12 the fodder deficit is expected to spike and rise in future years. This is mainly due to reducing grassland area coupled with some low rainfall years which lead to low grass production. The future trend indicates increase in fodder deficit. It is worth noting that in the future years the fodder deficit is never able to fall back to zero as seen in past years. This is a cause of concern because it puts continuous pressure on Maldharis to buy feed and fodder from outside Banni thereby steadily increasing the input costs for livestock maintenance. This also implies that some fraction of Banni livestock would remain migrated in comparison to the current temporary livestock mobility.

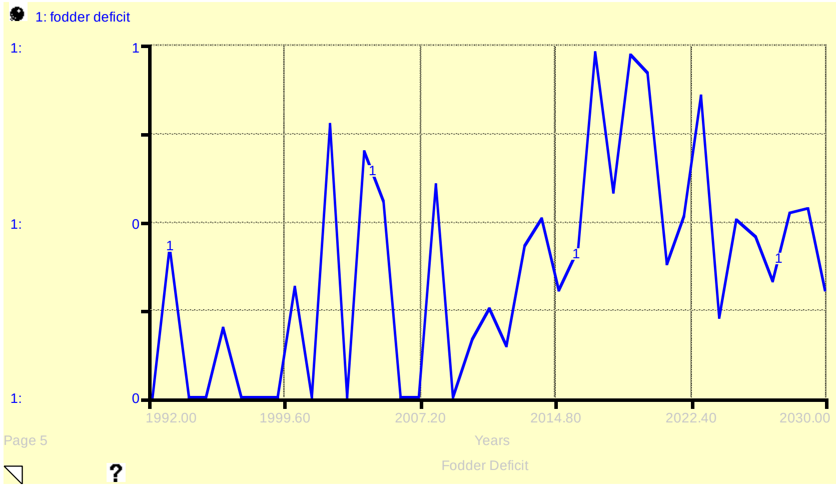


**Figure 15 Fodder Deficit – Base Case**

The base case future runs present a sorry picture for the livestock economy of Banni. If the current spread of *Prosopis* continues then the area under grassland could reduce to the point that livestock rearing becomes uneconomical for the Maldharis of Banni. This could be detrimental since livestock forms more than 95% of the income of Banni. Moreover, the loss of these fragile grasslands would have numerous other impacts-for biodiversity, for biodiversity-based ecotourism and possibly for bird migration as well. Also, since it is a low rainfall region, finding alternative land based livelihoods which can compensate for livestock income loss could be very difficult, if not impossible.

## Policy testing: *Prosopis* removal

Against this backdrop, we have modeled the impacts of a hypothetical *Prosopis* removal policy (PRP) either decided by the community or by government order. The *Prosopis* area removal rate is kept at 20% per annum and the policy becomes active from year 2016 and takes full effect after a delay of 3 years (a step function is used). In this scenario the livestock population is estimated to increase and reach close to 1.3 lacs by 2030 (Figure 13). The dominant cause for the rise in livestock population is the increased fodder availability due to increase in area under grassland due to removal of *Prosopis* juliflora. Also removal of *Prosopis* reduces the death multiplier on Kankrej, allowing the Kankrej cattle to grow more.

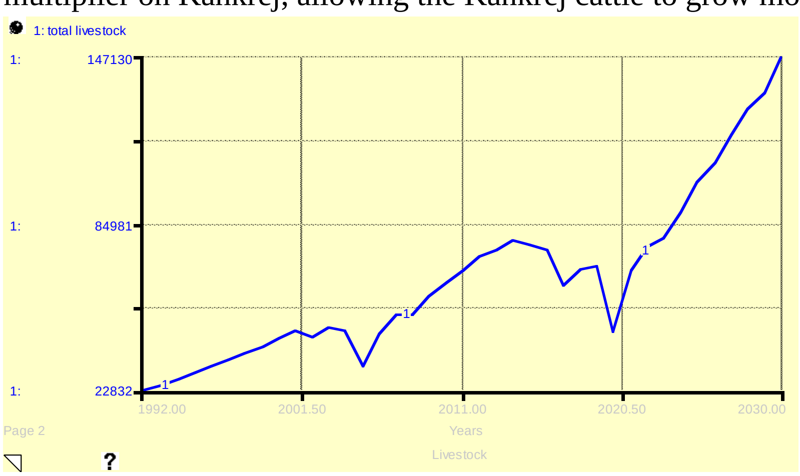


**Figure 16 Total Livestock under a hypothetical *Prosopis* removal policy**

It is projected that the area under grassland would go up to 169,000 hectares by 2030 while the area under *Prosopis* would reduce to 55,000 hectares and continue to fall. This would increase the grass availability leading to an increase in Banni's livestock carrying capacity (Figure 13).

A key assumption is that grassland area currently occupied by *Prosopis* still has grass seeds and that in event of complete removal of *Prosopis* the grasses would start growing almost immediately. This was observed to happen in 2004-2008, and nearly all the Maldharis we interviewed believe that this is indeed the case.

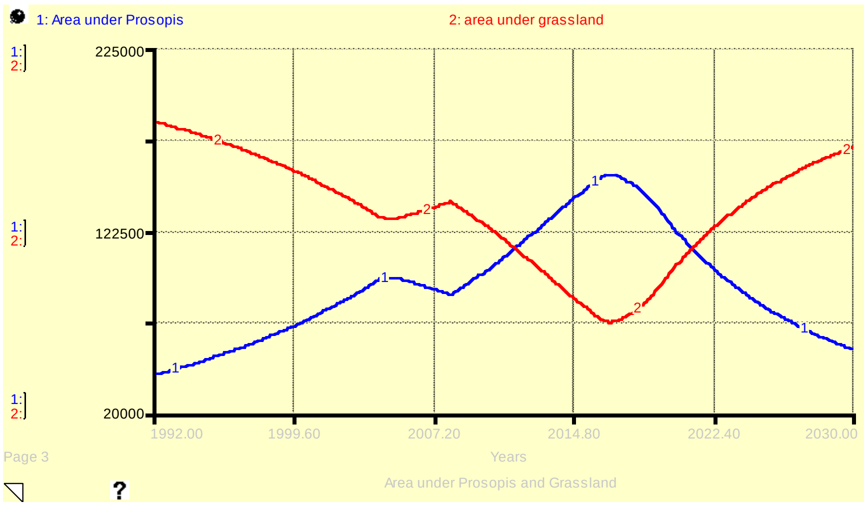



**Figure 17 Land Use Change under *Prosopis* Removal Policy**

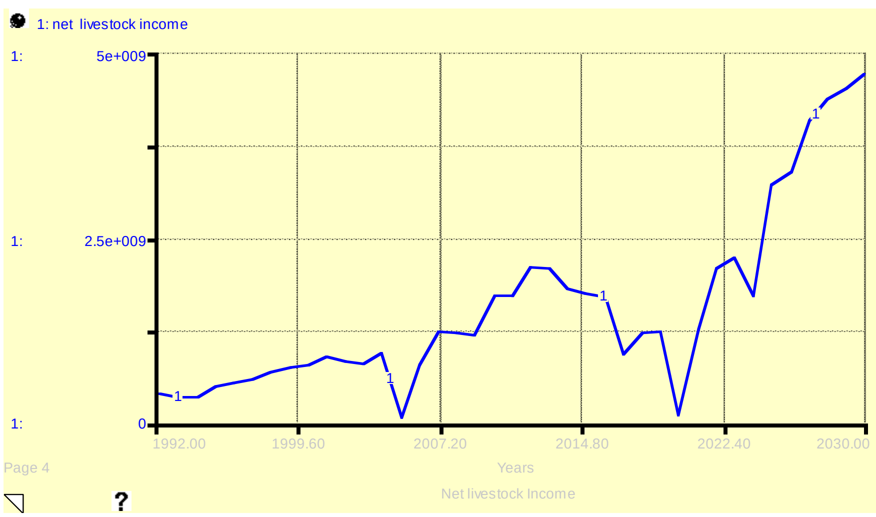



**Figure 18 Net Livestock Income under *Prosopis* Removal Policy**

Under the PRP scenario the net livestock income is projected to increase after a steep dip in year 2020. This increase is mainly attributable to increase in area under grassland and subsequent rise in availability of fodder. This leads to rise in livestock population due to increased livestock carrying capacity while the input costs remain low due to abundant fodder availability. Increased livestock leads to increase in milk output, dung income and income from livestock sale, all leading to increases in net livestock income (Figure 15).

## Comparing the Scenarios

The previous two scenarios are superimposed on each other to give a comparative picture below.

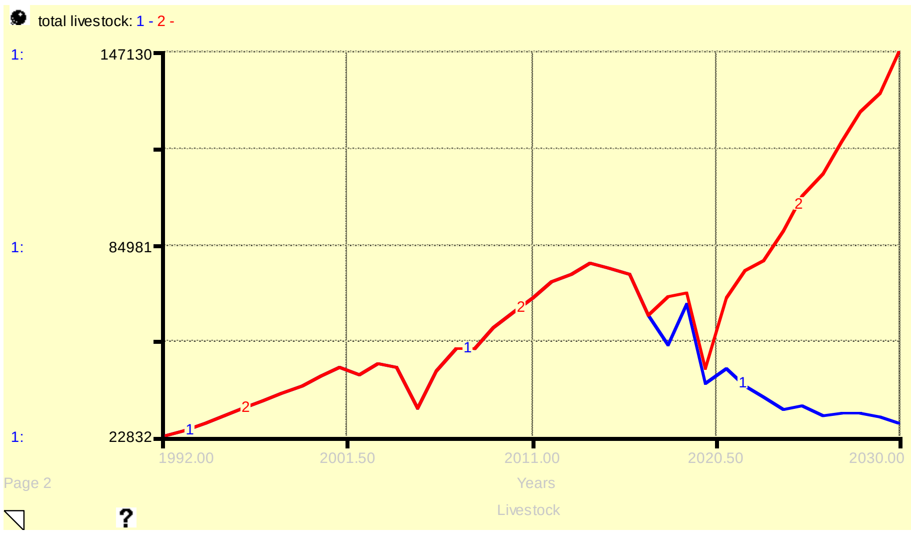



Figure 19 Total Livestock Population Projections

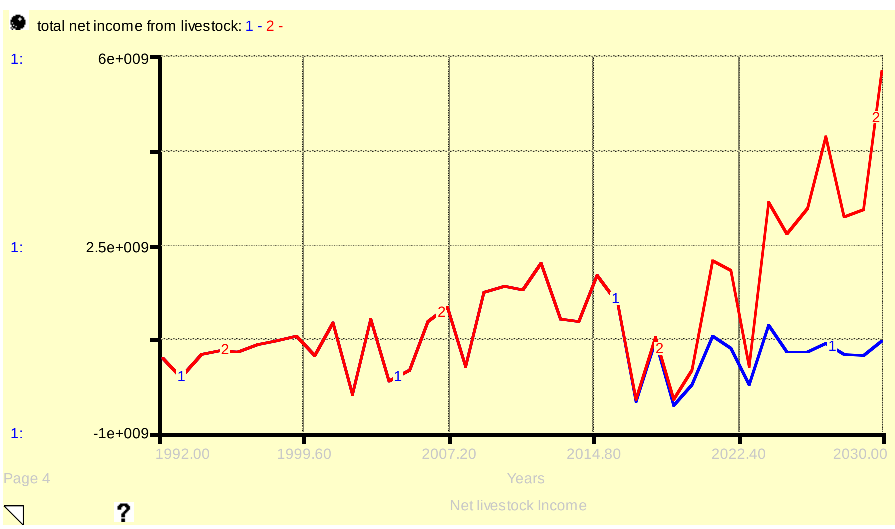



Figure 20 Net Livestock Income Projections (INR)

As can be seen in figures 16 & 17, *Prosopis* removal has a positive impact on the livestock population of Banni, mainly due to grassland area regeneration. The net livestock income levels also increase.

In the following section we perform a discounted valuation of future livestock earnings under Base case and PRP scenario from year 2015-2030 using a discount rate of 10%. The difference between the two can be assumed to be the partial costs of grassland degradation induced by *Prosopis* spread in the Banni[2].

## Economic Valuation of Income Flows from 2015 to 2030

As per the base run model results the total net annual income of Banni in 2015 is around INR 190 crores i.e. USD 28,787,879. Milk income contributes more than 95% of the total pastoral income of Banni and more than 85% to the total income of Banni. Charcoal income contributes around 14% of the total income of Banni.

The total net income includes net income from 1) milk, 2) dung, 3) livestock sale, 4) charcoal production. The net livestock income, under the base case, is projected to continuously decline. The sum of present value of livestock and total net income from 2015-2030 comes to INR 500 crores and INR 750 crores respectively. If PRP is in place then the PV (Present Value) increases to INR 1,385 crores and INR 1,618 crores. This indicates that *Prosopis* removal has a big positive multiplier impact on the economy of Banni. Although, there would be a loss of charcoal-based income due to removal of *Prosopis* (it is assumed that the *Prosopis* removed is not used for charcoal making) the net impact remains positive.

| Sr. No. | Present Values (10% Discount Rate) | Net Livestock income | Net Total Income |
|---|---|---|---|
| 1) | Base Case | INR 4,963,208,007<br>USD 75,200,121 | INR 7,502,200,836<br>USD 113,669,709 |
| 2) | *Prosopis* Removal Policy (PRP) @ 20% p.a. | INR 13,850,200,977<br>USD 209,851,530 | INR 16,180,821,218<br>USD 245,163,958 |
| 3) | Policy Multiplier (PRP÷Base Case) | 2.8 | 2.2 |
| 4) | Difference i.e. costs of grassland degradation (No. 2 minus No. 1) | INR 8,886,992,969<br>USD 134,651,409 | INR 8,678,620,382<br>USD 131,494,248 |
| 5) | Per ha costs of grassland degradation (No. 4÷2,50,000 ha) | INR 35,548<br>USD 539 | INR 34,714<br>USD 526 |

**Table 1 Economic Analysis of Base Case and Policy Runs**

One more policy run is done to test the impact of a five year delay in the decision to remove *Prosopis* and the impact this would have on the PVs.

[2] We assume that these are the partial costs, because we do not include other costs such as of loss of biodiversity, loss in tourism incomes and other ecosystem services provided by the grasslands.

| Sr. No. | Present Values (10% Discount Rate) | Net Livestock income | Net Total Income |
|---|---|---|---|
| 1) | PRP with 5 year delay | INR 8,737,446,329<br>USD 132,385,550 | INR 11,283,188,536<br>USD 170,957,402 |
| 2) | Loss due to delay | 37% | 30% |

**Table 2 Economic costs of Policy Delay**

The costs of delaying the implementation of *Prosopis* removal policy are substantial. The PV for net livestock income comes down by 37% while the total net income comes down by 30% due to the delay in policy implementation. This indicates that PRP is a time sensitive policy decision and any delays would result in economic losses for Banni.

# Discussions

The general perceptions of the people of Banni, on the reason for grassland degradation in Banni, point to the growth of area under *Prosopis*. It is also widely believed that if the *Prosopis juliflora* is completely removed then the grasses would come back. Maldharis have repeatedly indicated their preference to remain as livestock breeders and pastoralists because they consider it to be their traditional, profitable and sustainable occupation. Our model results are consistent with their perceptions and claims. The economic valuation indicates that *Prosopis* removal is a favorable policy option for sustaining their livestock economy and halting grassland degradation. The results indicate that livestock profitability goes up in event of *Prosopis* removal and that in order to sustain livestock as the main occupation of Maldharis the land area under *Prosopis* needs to be cleared, preferably without any delay. However, our results cannot verify their claims because the model presents a simplified representation of Banni.

The model provides a glimpse into the future possibilities that exist for Maldharis and the landscape of Banni based on the use of plausible assumptions and parameters. Rainfall is a key variable that determines grass productivity, so variation in rainfall could also change the income dynamics. This is particularly important for Banni since the livestock sensitivity to grass availability is very high and *Prosopis* density greatly influences the grass availability.

## Limitations and further scope of research

This study needs to be further supported with more data and information about the micro-dynamics of Banni. There are information gaps with respect to the grass productivity, fodder availability in different seasons, extent of seasonal livestock migration due to fodder deficit, the role of salinity, future price estimates etc. In order to strengthen the results of such a modeling exercise, these gaps need to be addressed through empirical field research which can then serve as inputs to a further disaggregated system dynamics model. There is also an unresolved issue of entitlement of land ownership. This makes studying the political ecology of Banni pertinent, since these factors would also have a bearing on the decision-making processes.

The current ecological situation of Banni and presence of uncertainty over land rights calls for development of decision-support tools which can be used for performing multi-stakeholder exercises to enable consensual decision making. Thus, this study serves as a motivation for further research into the dynamics of the Banni grassland and development of decision support tools for policy planning and consensus development for management of Banni grasslands.

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**List of Organizations**:

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**List of People**:

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# Annexure

## Parameter values and sources

Table 3 Key parameter values and sources

| S No. | Factor | Value taken | Sources &Explanations where necessary |
|---|---|---|---|
| 1. | Fraction of adult buffaloes giving birth every year | 0.5 | Discussions with local NGO Sahjeevan and Maldharis |
| 2. | Buffalo calf death rate | 20% p.a. | Data from personal interview with experts and pastoralists. |
| 3. | Buffalo calf maturation time | 3 years | Discussions with local NGO Sahjeevan and Maldharis |
| 4. | Normal Buffalo sale rate | 1% p.a. | Discussions with local NGO Sahjeevan and Maldharis |
| 5. | Buffalo lifetime | 23 years (3 yrs. as calf and 20 as adult) | Discussions with local NGO Sahjeevan and Maldharis |
| 6. | Fodder requirement per adult buffalo per day | 30 kg | Discussions with local NGO Sahjeevan and Maldharis |
| 7. | Fodder requirement per buffalo calf per day | 7.5 kg | Discussions with local NGO Sahjeevan and Maldharis |
| 8. | Fraction of milk producing buffalos | 50% | Discussions with local NGO Sahjeevan and Maldharis |
| 9. | Kankrej birth rate | 50% of adult Kankrej cattle give birth every year | Discussions with local NGO Sahjeevan and Maldharis |
| 10. | Kankrej calf death rate | 20% p.a. | Discussions with local NGO Sahjeevan and Maldharis |
| 11. | Average Kankrej calf sale rate | 60% p.a. | Discussions with local NGO Sahjeevan and Maldharis |
| 12. | Average male Kankrej purchase rate | 25% p.a. | Discussions with local NGO Sahjeevan and Maldharis |
| 13. | Kankrej calf maturation time | 3 years | Discussions with local NGO Sahjeevan and Maldharis |

| | | | |
|---|---|---|---|
| 14. | Kankrej lifetime | 12 years as adult and 3 years as calf | Discussions with local NGO Sahjeevan and Maldharis |
| 15. | Fraction of milk producing Kankrej | 50% p.a. | Discussions with local NGO Sahjeevan and Maldharis |
| 16. | Fodder requirement per Kankrej adult per day | 15 kg | Discussions with local NGO Sahjeevan and Maldharis |
| 17. | Fodder requirement per Kankrej calf per day | 5 kg | Discussions with local NGO Sahjeevan and Maldharis |
| 18. | Buffalo sale multiplier due to profitability | Increases from 0 to 30% with profit per livestock falling from INR 0 to INR -5000. | Parameterized using sensitivity runs |
| 19. | Kankrej sale multiplier due to profitability | Increases from 0 to 20% with profit per livestock falling from INR 0 to INR -5000. | Parameterized using sensitivity runs |
| 20. | Impact of *Prosopis* on death rate of Kankrej | Increases from 0 to 20% and tapers off as *Prosopis* density doubles | Parameterized using sensitivity runs |
| 21. | Rainfall | Rainfall from 2015-2030 assumed to be the same as from 1999-2014. | Rainfall data for 1992-2010 taken from (Bharwada&Mahajan, 2012 pg 143), for year 2011-12 taken from, (Gavali, 2015 pg 5) and for 2013-14 taken from IMD website for Kachchh district from http://hydro.imd.gov.in/hydrometweb/(S(lmae0jvse31sb045m2gxd5i1))/DistrictRaifall.aspx |
| 22. | The total productive area of Banni | 225000 hectares | (Koladiya et al., 2016pg 20) |

| | | | |
|---|---|---|---|
| 23. | Normal spread rate of *Prosopis* | 8.5% | (Vaibhav et. al, 2012) |
| 24. | Impact of livestock on *Prosopis* spread | Increasing from 1 to 2 when livestock population increases from 25000 to 100000 | Parameterized using sensitivity runs |
| 25. | Charcoal production | 4800 sacks of 40 kg each produced per day | Discussions with local NGO Sahjeevan and Maldharis |
| 26. | Impact of profit per livestock on charcoal production | As profit per livestock falls below 0, this function begins to increase from 1 and goes up till 2 at a loss of INR -5000 per livestock | Parameterized using sensitivity runs |
| 27. | Average milk production per buffalo per day | 12 litres | Discussions with local NGO Sahjeevan and Maldharis Milk production per buffalo ranges from 8 liters to 20 liters a day. Average taken as 12 litres a day. |
| 28. | Milk price per litre of Banni buffalo milk | Graphical function varying from Rs.19 per litre in 1992 to Rs. 40 per litre in 2015. Kept at 2015 prices in future. | Historical milk prices taken at 2015 constant values.<br><br>2015 milk price taken from personal interviews with dairy industry.<br><br>2010 milk price taken from Bharwada&Mahajan, 2012pg 71)<br><br>2000 milk price taken from (Geevan et al., 2012pg 56) table 6.9<br><br>1992 milk prices are assumed. |
| 29. | Average milk production per | 9 liters | Discussions with local NGO Sahjeevan and Maldharis |

| | | | |
|---|---|---|---|
| | Kankrej per day | | Milk production per Kankrej cattle ranges from 6 to 14 litres a day. Average taken as 9 litres a day. |
| 30. | Milk price per litre of Kankrej cattle milk | Graphical function varying from Rs.10 per litre in 1992 to Rs. 18 per litre in 2015. Kept constant at 2015 prices in future. | Historical milk prices taken at 2015 constant values. Current prices for 2015 taken from personal interview, while earlier prices are re-calculated to reflect 2015 constant values. |
| 31. | Charcoal Price | Rs. 5/kg taken constant | Discussions with local NGO, Sahjeevan, Personal interviews with Maldharis |
| 32. | Price of Dung | Rs 1500 per truck load | (Bharwada&Mahajan, 2012pg 74) |
| 33. | Quantity of Dung sold | One truck load every 15 days- one truck load from 100 livestock | (Bharwada&Mahajan, 2012pg 74) |
| 34. | Kankrej sale price | Rs 10000 | Average price varies from Rs 12000 to Rs 30000 for a pair of bullock. Taken as average Rs. 10000 per Kankrej. (Bharwada&Mahajan, 2012pg 65) |
| 35. | Buffalo sale price | Varying from Rs 38000 in 1992 to Rs75000 in 2015 (post breed registration). Constant at Rs 75000 in future. | Current Buffalo price for year 2015 range from INR 50,000 to INR 3,00,000. Mode value of sale price taken as INR 75,000 and then normalized for the past years taking into consideration the rise in price due to Buffalo registration in year 2011. |
| 36. | Input cost for milk producing buffaloes | Graphical function of fodder deficit. Varies from 10000 at 0 fodder deficit to | At 50% fodder deficit the cost of feed for milk producing buffalo is estimated to be Rs. 70,000/- per annum. The numbers are adjusted to reflect fall and increase in |

| | | | |
|---|---|---|---|
| | | 140000 at 100% fodder deficit | fodder deficit and its corresponding impact on feed cost due to increase in supply. |
| **37.** | Feed cost for non-milk producing buffaloes | One-third of No. 36. | Discussions with local NGO Sahjeevan and Maldharis |

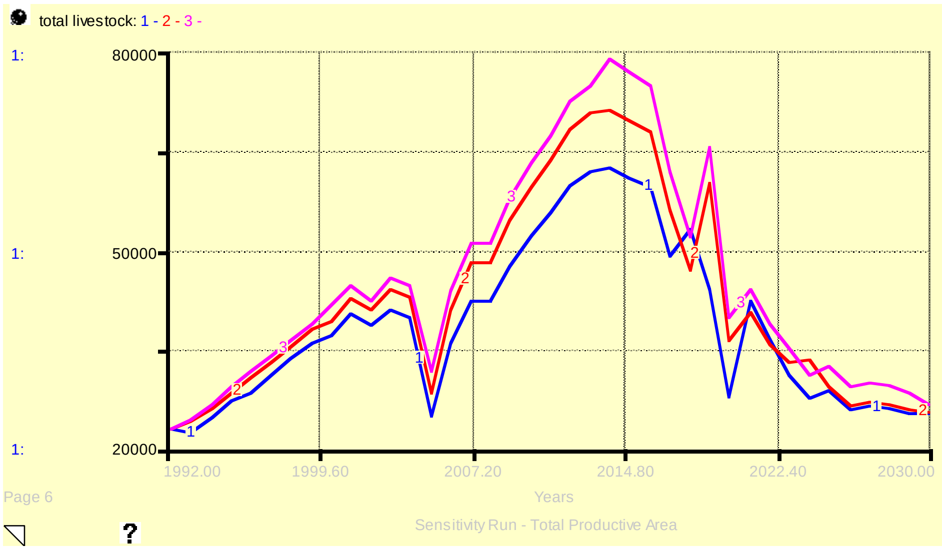
## Sensitivity Runs

The results of sensitivity runs are presented below. All the graphs show that the shape of change of variables remain the same with changes in parameter values. This consistency under changes of parameter values demonstrates the model's robustness.

A. Impact of changing DT from 1 to 1/10

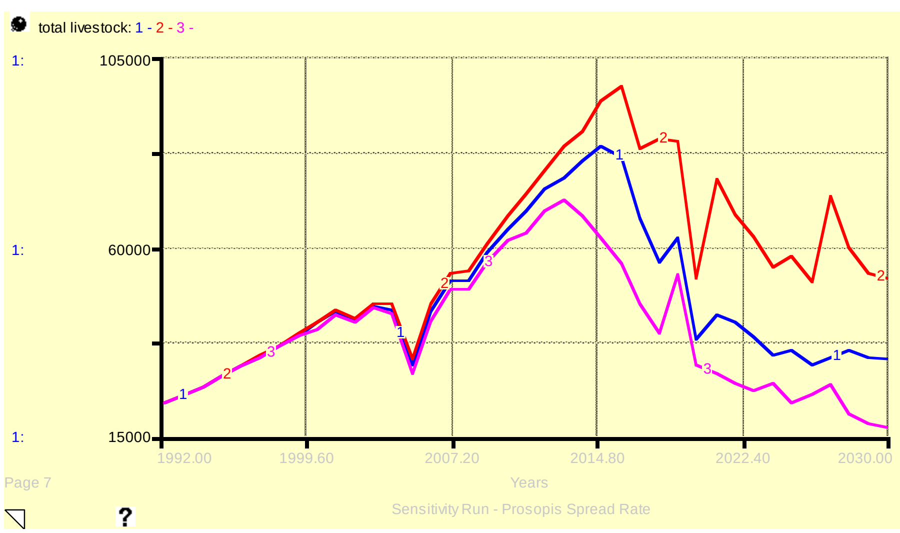

B. Parameter Changed: Total Productive Area

1. 1.75 lac hectare
2. 2.00 lac hectare
3. 2.25 lac hectare



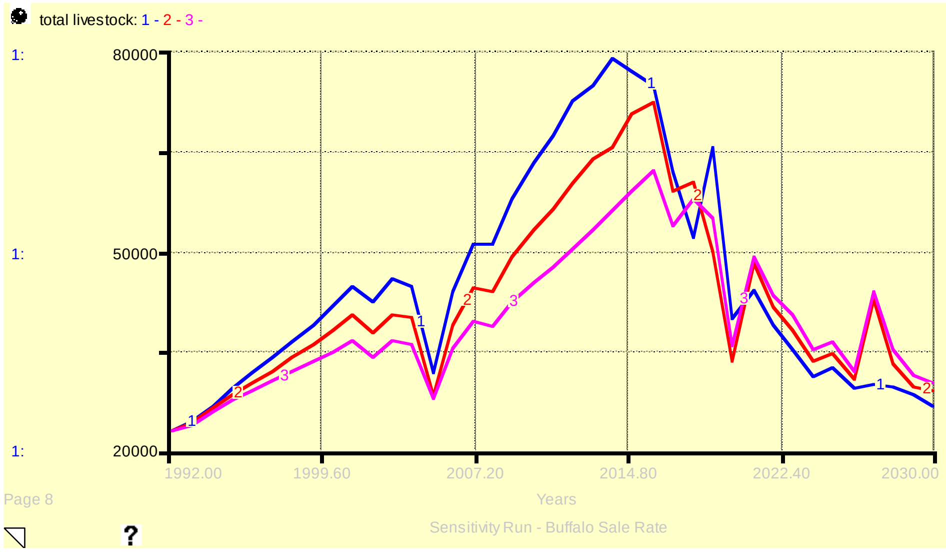

C. Parameter Changed: Prosopis Spread Rate

1. 0.08
2. 0.06
3. 0.10



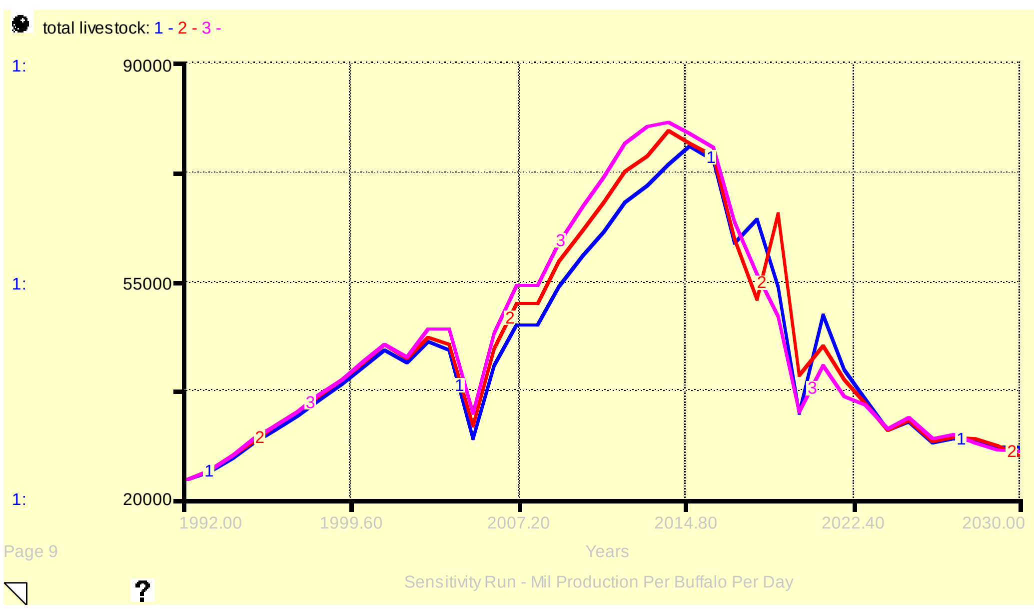
D. Parameter Changed: Buffalo Sale Rate

1. 0.01
2. 0.03
3. 0.05




E. Parameter Changed: Milk Production Per Buffalo Per Day

1. 10
2. 12
3. 15



## Extreme Conditions Test

1. Total Productive Land Area = Reduced from 2,50,000 ha to 10,000 ha
2. Prosopis Spread Rate = Reduced from 8.5% to 0%
3. Buffalo Milk Price from 2015-2030 = Reduced from Rs. 40 per liter to Rs. 1 per liter
4. Rainfall from year 2016-2030 = Reduced and kept minimum 100 mm