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RESEARCH PAPER

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

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Abstract: This is a study of the interactions between the ecology and economy of the Banni grassland, located in the district of Kutch, Gujarat, India. The study focuses on modelling the economic impact of grassland degradation in the Banni from 1992–2015 and simulates future scenarios up to 2030 using system dynamics. The specific sectors being modelled are the area spread of the invasive species *Prosopis juliflora*, palatable grass, the populations of livestock as well as the livestock and charcoal incomes of Banni. An economic valuation is done by discounting the future earnings of the pastoral (milk, livestock sale, dung manure) and charcoal economy under two scenarios 1) Base case (Business as Usual), i.e. keeping current policies constant and 2) *P. juliflora* removal policy (PRP) i.e. where a decision is implemented to remove *P. juliflora* from Banni. Under the BAU scenario, modelling results indicate that the Banni grassland is headed for severe fodder scarcity due to the shrinking area under grassland. Under the PRP scenario, Banni is able to revive its grasslands and increase the present value of future earnings (up till 2030) by 62 per cent. A delay of five years in the decision to remove *P. juliflora* results in a 28 per cent reduction in earnings indicating the policy's time sensitivity. The model serves as a test bed for generating what-if scenarios of the Banni grassland.

Keywords: Grasslands; livestock; system dynamics; economics; land degradation

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1. INTRODUCTION

Changes in ecosystems, climate, and peoples' livelihoods are all interdependent. The way in which biological resources are converted into goods and services, as inputs and outputs of the economy, contributes to shifts in local livelihoods and to climate change (Perrings 2010, 3). The loss of biotic species, reduced biomass, and, thereby, reduced carbon sequestration contributes to climate change and impacts the livelihoods of people dependent on such resources, especially grasslands and forests. Interventions designed at the policy or community level to induce changes in ecosystems often generate economic and social feedback by changing the livelihoods and lifestyles of resource-dependent communities after a long time delay. This is more so in the case of large-scale changes made to convert forests to croplands or grasslands to forests.

One such example of this coupling between humans, the economy, and ecosystems is seen in tropical semi-arid grasslands, wherein the livelihoods of dwelling communities are deeply interlinked with ecological dynamics (Reid *et al.* 2005, 56). In India, in recent times, there has been the tendency of policymakers to misconceive grasslands for degraded forests or wastelands; planting up grasslands or converting these to industry deeply impacts the social-ecological dynamics of these regions (Vanak *et al.* 2017). In the Banni grassland in Kutch, Gujarat, seeding in the 1960s of *Prosopis juliflora* (*P. juliflora*), an alien invasive woody species, has over time greatly hampered grass production and the traditional livelihoods of nomadic pastoralists who have lived there for generations (Bharwada and Mahajan 2012, 76–77). In the context of climate change it is even more important to understand the dynamics between the socio-economics and ecology of such systems—to effectively address conflicting climate goals, such as increasing carbon sinks through afforestation while conserving pastoral livelihoods and grassland biodiversity, and to reach informed decisions on their management (Xu *et al.* 2014). In such a scenario, a systemic understanding—seeing the social-economic and ecological dynamics together as one system—is critical. This warrants the use of systems thinking and system dynamics simulation modelling methods.

Through this paper the authors demonstrate the potential of system dynamics for modelling complex social, ecological, and economic interlinkages in coupled human-natural systems such as Banni. The aim of this study is to estimate the economic cost of grassland degradation in Banni over a 15-year period (2015–2030). It achieves this through modelling the dynamics and feedbacks between the grassland, *P. juliflora* spread, livestock populations, and the economics of the Banni grassland.

The model highlights the interdependencies between different sectors and between variables within each sector. The model helps in developing a deeper understanding of the complexities of Banni and serves as a tool for generating what-if scenarios for various policies. 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 for developing sustainable management plans of the Banni grassland.

1.1 Banni Grassland

The Banni grassland, once known as Asia's best tropical grassland (Bharwada and Mahajan 2012, 6), spans an area of approximately 2,500 sq km in the district of Kutch on the northern border of Bhuj block (Koladiya *et al.* 2016, 9). The grassland has been degrading; productivity dropped from 4,000 kg per hectare in the 1960s to 620 kg per hectare in 1999 (Bharwada and Mahajan 2012, 76). While the evidence is still inconclusive on whether the dominant cause is increasing salinity or the spread of the invasive species *P. juliflora*, the most cited reason by the pastoralists (Maldharis) is the spread of *P. juliflora.* Livestock rearing is the primary occupation of the people, and grassland degradation poses a serious problem for sustaining the pastoral economy.

The Banni grassland is divided into Ugamani Banni or East Banni; Vachali Banni or Central Banni; and Aathamani Banni or Jat Patti, or West Banni (Bharwada and Mahajan 2012, 12). Its geographic area has been estimated, variously, at 1,800 sq km to 3,800 sq km (Bharwada and Mahajan 2012, 125); this study uses the recent estimate of 2,500 sq km (Koladiya *et al.* 2016, 20).

The dominant community is the livestock-breeding Maldharis. Many communities among them—Raysipotra, Halepotra, Pirpotra, Hingorja, Sumra, Mutva, Node, etc.—migrated several generations ago from Sindh, Marwar, and Baluchistan. The other community is the Meghwals, and their main occupations have been leather tanning and shoemaking and making artefacts from leather (Bharwada and Mahajan 2012, 14).

1.2. The Banni Grassland—A Brief History

The mainstay of the Maldhari community of Banni has been livestock breeding. Before independence the Maldhari communities lived a nomadic life and often wandered into what is now Pakistan for grazing their livestock (Bharwada and Mahajan 2012, 51).

Banni is largely flatland. As it is often flooded in the monsoon, especially west Banni, even spurring intra-Banni migration, it is sometimes referred to as a seasonal wetland (Mehta *et al.* 2014, 18). The government forest department reports about 254 small and large wetlands (Bharwada and Mahajan 2012, 41). In May 1955, Banni was declared a protected forest under the Indian Forest Act, 1927 (Mehta *et al.* 2014, 20). Climatically, it is an arid or semi-arid zone; annually, it experiences around 300–353 mm of rainfall on average (Bharwada and Mahajan 2012, 114; Geevan *et al.* 2003, 21).

1.2.1. Prosopis juliflora

P. juliflora is a species native to South America, the Caribbean, and Mexico. The forest department first introduced it over an area of 31,550 hectares along the border between Banni and the Great Rann of Kutch in 1961 to control the ingression of the Rann (salt marsh) into other land (Bharwada and Mahajan 2012, 83). But the invasive nature of *P. juliflora* and its spread over the past 55 years has led to the loss of native vegetation, including grassland; today, the Maldharis cite it as one of the dominant causes of grassland degradation.

In the summer, when grasses are in short supply, the livestock feed on *P. juliflora* pods. Seeds, rejected in their fecal matter, receive both manure and moisture in this way, and quickly take root and germinate (Kumar 2015, 47). This helps *P. juliflora* spread further. The open grazing system accelerates the process (Bharwada and Mahajan 2012, 83). *P. juliflora* apportions resources and also has allelopathic properties. Due to these reasons its spread has reduced the area under indigenous plants and grassland in Banni (Bharwada and Mahajan 2012, 81). The loss in grassland productivity has raised the amount of fodder that the Maldharis purchase and, thus, livestock expenses for the economy. Pastoralists opine that the grasslands would recover if *P. juliflora*—locally *Gando Baval*, or 'mad' *Acacia*—were to be removed.

1.2.2. Dairy

The Banni buffalo and Kankrej cattle are the dominant large livestock species in Banni. Traditionally, Banni was not a dairy-farming economy; its pastoralists were livestock breeders and involved in the trade of the Banni buffalo and Kankrej cattle and bullocks. Only after dairies began collecting milk in 2009–2010 did the pastoralists start selling milk in large quantities. In 2010, Banni's buffalo was recognized by the National Bureau of Animal Genetic Resources as a distinct breed; and this increased its value and spurred its rearing (Bharwada and Mahajan 2012, 98). Consuming the pods of *P. juliflora* is fatal for Kankrej cattle; therefore, their population has been decreasing (Bharwada and Mahajan 2012, 87) although, in recent years, the

Maldharis have observed that the Kankrej have been adapting to *P. juliflora* and surviving in areas that are dense with it. The Banni buffalo is unaffected by *P. juliflora*, and their numbers have grown, which has helped the dairy business since buffalo milk (which has greater fat content) fetches higher prices.

1.2.3. Charcoal Making

The Maldharis practice charcoal making to earn additional income and harvest the wood of *P. juliflora* for this purpose. It is illegal to cut *P. juliflora* in the grassland, as it is classified as a protected reserve forest. When this ban was lifted between 2004 and 2008, the Maldharis took to removing *P. juliflora* trees from the roots for making charcoal, which led to a huge reduction in the area under *P. juliflora*, as uprooting the trees freed up land and allowed grasses to grow. It is hard to calculate the exact increase in charcoal production in this period, but it is estimated at as high as 10 times (Bharwada and Mahajan 2012, 100). In 2008, this ban was re-imposed—some suggest because indigenous trees were also being harvested for charcoal; others suggest that the charcoal traders' cartel influenced it because they were unable to exercise control over production and supply of charcoal (Bharwada and Mahajan 2012, 101). The ban persists, but charcoal making continues.

1.3. Research Objective

The main research objective of this study is to model the economics of grassland degradation in Banni due to the invasion of *P. juliflora*. It focuses on the issue of grassland degradation, its key drivers, and what impact the removal of *P. juliflora* would have as a solution for halting grassland degradation. The study's objective does not include modelling climate change impacts on these future scenarios, although a sensitivity analysis of rainfall variation has been carried out.

2. RESEARCH METHODOLOGY: SYSTEM DYNAMICS

Banni's ecological and economic system is interdependent and highly dynamic. Thus, the research method uses system dynamics modelling to develop a base case and policy scenarios of Banni. System dynamics is a modelling approach aimed to understand the nonlinear behaviour of complex systems over time using stocks and flows, internal feedback loops, and time delays (MIT 1997). Beginning at the Massachusetts Institute of Technology (MIT) in the 1950s and 1960s (Forrester 1958; Urban Dynamics 1969), system dynamics as a method unveils the counterintuitive nature of complex systems and uncovers relationships between variables that are responsible for the behaviour of a system over time. System dynamics offers the potential for generalization since it provides a more transparent and consistent description of the underlying causal processes of the system (Gallati and Wiesmann 2011, 8). This is especially useful for developing policy insights and systemic decision-making.

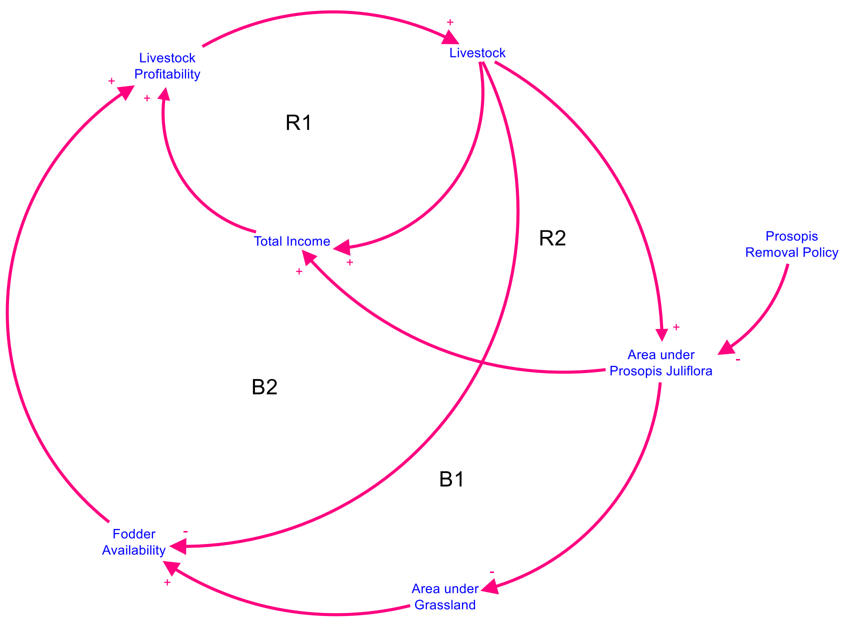
System dynamics and systems thinking have been used to study grassland-livestock systems worldwide. Some have been used to understand social-ecological dynamics in the agro-pastoral Sahel (Rasmussen *et al.* 2014; Sendzimir *et al.* 2011; Prado *et al.* 2014). Others have been used to model natural resource-based poverty traps in the context of small-holder farmers in highland Kenya (Stephens *et al.* 2011). It has been used in biodiversity conservation in semi-arid savannas in Central and Southern Africa (Perrings and Walker 1999), and in understanding the dynamics of urbanization and environmental policy on the future availability of grazing resources in the Mongolian plateau (Allington *et al.* 2017). In India, system dynamics has been used to understand the dynamics of social-ecological systems, most pertinently in studying the effect of *P. juliflora* on diverse agents in a national park (Dayal 2007), and in studying the grassland systems of Kutch, including Banni, from an ecological-economic perspective (Geevan *et al.* 2003).

Various aspects of the Banni grassland have been studied and documented (Koladiya *et al.* 2016; Jagruti *et al.* 2017; Shah *et al.* 2010), no study attempts a bottom-up ecological-economic model, and only a few studies integrate the ecology and socio-economics. Two such integrated studies (Bharwada and Mahajan 2012; Geevan *et al.* 2003) have been used as base papers for this study. This paper aims to partially fill this gap in the process of meeting its aim of studying the economics of grassland degradation.

We present a description of our system dynamics model, built in a bottom-up manner for the specific case of the Banni grasslands, taking inputs from academic experts, the Maldhari community, as well as NGOs working in Banni. The model considers Banni as one system and does not model the spatial differences within it. This model comprises livestock (Banni buffalo and Kankrej cattle); grassland and *P. juliflora*; and the pastoral and charcoal economy. We model the impacts of drivers of livestock growth and *P. juliflora* growth, their impact on the local environment, and the consequent multiple feedbacks that could impact the future of these sectors. The model runs from 1992 to 2030, recreating the major dynamics seen between 1992 and 2014 and simulating future scenarios up to 2030 under a base case; policy implementation of *P. juliflora* removal; and a five-year-delay in the implementation of the policy of removing *P. juliflora*. The paper presents the higher order causal loop diagram of the simulation model, its model description, key feedbacks and assumptions, and the simulation results and insights generated, respectively.

The higher order causal loop diagram (Figure 1) shows higher order linkages of our system dynamics model. There are two balancing loops (livestock–fodder–livestock, livestock–*P. juliflora*–grassland–livestock) and two reinforcing loops (livestock–total income–profitability–livestock and livestock–*P. juliflora*–total income–profitability–livestock).

Figure 1: Higher Order Causal Loop Diagram of the Simulation Model



The first balancing process (balancing loop B1) is concerned with the spread of *P. juliflora*. The growth in the area under *P. juliflora* is aided by the presence of livestock, which act as vectors, carry the seeds, and help in their widespread dispersal. As the area under *P. juliflora* goes up, the area under grassland comes down—leading to a negative impact on livestock due to falling fodder availability. On the other hand, an increase in livestock numbers raises the fodder requirement. With limited grassland, fodder availability falls, the Maldharis purchase more feed and fodder, input costs rise, and the profit per livestock falls. If it falls below a threshold, it results in a stress sale of livestock for recovering losses, balancing out the livestock numbers. As the livestock numbers drop, the fodder requirement falls, and livestock profitability rises. These dynamics form balancing loop B2. More livestock would yield more milk, thereby increasing income and forming reinforcing loop 1, R1. Higher prices for Banni buffalo milk constitute the key driver for the growth of profitability.

The other reinforcing loop, R2, is concerned with the charcoal income earned from *P. juliflora*. The *P. juliflora* spread is accelerated by the presence of livestock; they act as vectors, and increase the area under *P. juliflora* charcoal-producing potential, and income, which makes further stocking of livestock possible. But the increase in the area under *P. juliflora* reduces the grassland area and fodder, as discussed in balancing loop B1. Interestingly, thus, livestock is a common driver for both the reinforcing and balancing loops.

Currently, the reinforcing loops R1 and R2 are dominant, as Maldharis are earning enough from milk sales, livestock sale, dung, and charcoal to sustain their livestock, even with grassland degradation and the consequent fodder deficit. Good milk income and the presence of dairies in Banni provide Maldharis the economic incentive to retain and grow their livestock numbers. However, balancing loops B1 and B2, less impactful presently, could become dominant in the future, and greatly impact dynamics.

Policy testing is done for a case of *P. juliflora* removal, which is shown as an external variable in Figure 1. The removal of *P. juliflora* could potentially reverse the current trend of grassland degradation and increase grassland area and fodder availability.

2.1. Simulation Model and Sector Description

The model comprises three interconnected sectors: livestock (buffalo and Kankrej cattle), *P. juliflora* and grassland, and the economy. Important parameter values are provided in the Annexure.

The total area of Banni is taken as 2,500 sq km, i.e. 250,000 hectares (Koladiya *et al.* 2016, 20). Of this, 90 per cent is taken to be total possible productive land (includes grassland, *P. juliflora*-dominated area, and the area under other vegetation), while 10 per cent is taken to be wasteland where palatable grasses cannot grow (wasteland includes extreme saline land). In 1992 (the base year), the area of land dominated by *P. juliflora* is taken to be 41,180 ha (Koladiya *et al.* 2016, 20) while grassland area equals total productive area (less the area under *P. juliflora*).

During princely rule, the Banni grasslands had a more structured, customary regime of governance and management, including certain grazing regulations (e.g. kinds of animals and the period of grazing) which were followed by the Maldharis (Geevan *et al.* 2003, 27). In those times, Banni was more like a managed common property resource. These governance structures have weakened since; and now different communities use Banni for various purposes (constructing resorts, experimenting with rainfed agriculture). Uncontrolled growth of buffalo herds also implies exploitative use of the grazing land. The grassland system has evolved into an open access resource, and it has been considered as such in the model.

The dynamics between grassland and the area under *P. juliflora* is the key factor for changes in the grassland. The spread of *P. juliflora* is the main driver of land use change. As the area under *P. juliflora* grows, it invades the area under grassland. The normal spread rate of *P. juliflora* is taken to be 8.5 per cent per year of the total area under *P. juliflora* (Vaibhav *et al.* 2012, 3). However, this spread rate is enhanced by the presence of livestock which act as vectors, the seeds being carried by them and the passage through the digestive tract facilitating quick germination (Geevan *et al.* 2003, 17; Kumar *et al.* 2015, 47). This has been modelled as a multiplier through a graphical function in our model—the impact increasing with increase in livestock population, and ultimately levelling off at an assumed maximum. The graphical function is given in Figure 2. The growth of *P. juliflora* is limited by the total land area available.

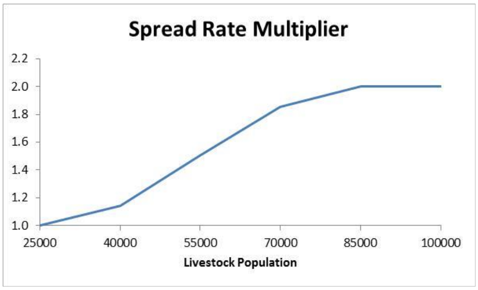
In the model, it is assumed that Maldharis use the above-ground wood of *P. juliflora* for charcoal making, which does not reduce the area under *P. juliflora*. Only once before has the *P. juliflora* area came down when the ban on making charcoal from *P. juliflora* was lifted and people uprooted the trees entirely. This was between 2004 and 2008, and has been modelled using a time-based "if-then" function. The difference equation governing the change in area under *P. juliflora* in a time interval ΔT (annually in our case) is given below.

$$\Delta Ap = [nEAp\left(1 - \frac{Ap}{L}\right) - R]\Delta T$$

Where,

n = Normal annual spread rate of *P. juliflora*
E= Multiplier on normal spread rate due to presence of livestock vectors (Graphical Function shown in Figure 2)
A_p= Area under *P. juliflora*
L= Total productive land area
R= Clearing of area under *P. juliflora* through uprooting (during period of uplifting of the ban and under the *P. juliflora* removal policy)

Figure 2: Impact of Livestock on *P. Juliflora* Spread Rate



The grassland biomass production in a year is calculated from the grassland area (total productive land less area occupied by *P. juliflora*) and the grassland productivity, the latter being a bell-shaped function of the rainfall. 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).

Rainfall data for the grassland is taken from three different sources, because publicly available data (free of cost) for all required years was not found at any one source. The website of the India Meterological Department (IMD) gives weather data for Kutch district from 2012 to 2017 (IMD, n.d.). Bharwada and Mahajan (2012, 143) collate rainfall data for 1981 to 2010 from two sources, Gujarat Institute of Desert Ecology (GUIDE) (up to 1994) and the Irrigation Department and Rudramata Dam site 1994 onwards (see pg. 143, appendix 9). The gap in data for year 2011 and 2012 is filled in from Gavalli (2015, 5). Rainfall data at the Banni grassland's spatial scale is not available for the model time period. For the business as usual (BAU) scenario, the rainfall pattern for 2015–30 is taken to be a repeat of 2001–15, to account for the cyclic variation that exists in Banni's rainfall (Bharwada and Mahajan 2012, 143). However, realizing this to be insufficient, sensitivity runs by changing rainfall parameters for 2015–2030 under three scenarios is done. Similar sensitivity runs are performed by changing the grass productivity parameter. Both are presented in the results section.

Further, a parameter 'fodder deficit' is calculated, 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 sustaining the livestock economy. As the deficit increases, the livestock input cost increases. This ratio also determines the migration of livestock from Banni in fodder deficit years, explained below.

2.1.1. 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 per cent). 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 giving birth to 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. Based on discussions with Maldharis, it is estimated that if the fodder deficit crosses 30 per cent in a certain year, 30 per cent of the livestock leaves Banni, and if it crosses 50 per cent, 50 per cent of livestock leaves Banni. Also, the livestock that migrate outside accumulate in stocks of migrated livestock which come back when the deficit falls below 10 per cent. A maximum residing time of two years is given to the migrated stock of adult livestock after which the migrated stock permanently migrates out of the Banni periphery. The second coping mechanism is sale of livestock in dry years. A livestock sale multiplier is built using graphical function which depicts the impact of falling profitability on the flow of livestock (stress) sales. This sale multiplier depends on the net income per livestock. As the profit per livestock in a year becomes negative, the stress sale multiplier increases and later levels off. The values are provided in Figure 3.

The Banni buffalo ageing chain is composed of two main stocks: Calves and Adults. 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 per cent of the total adult stock). 50 per cent of the births are female and 50 per cent male. The model considers only females, as males are generally not reared. The fraction of buffalo calf death every year is taken as 20 per cent (after discussions with Maldharis). Maturation time from calf to adult is taken as 3 years. The adult lifetime is taken as 20 years and sale rate of buffaloes is assumed at 1 per cent per year (based on interviews). The coupled difference equations governing the changes in stocks of buffalo calves and adults are given below for a time interval ΔT (annual in our case).

$$\Delta C = \left[fgB - dC - \frac{C}{Tm} - MC \right] \Delta T$$

$$\Delta B = \left[\frac{C}{Tm} - rB - MB - sPB \right] \Delta T$$

Where,

C= Stock of Calves
B= Stock of Adult Buffaloes
f= Fraction of adult buffaloes giving birth in a year
g=Fraction of females in the births
r = Retiring time of adult buffaloes
d= Death rate of calves
T_m= Maturation time
s=Normal sale fraction per year
M= Sale multiplier function from fodder deficit (Figure 3)
P=Sale Multiplier from net income per livestock

Figure 3: Impact of Net Income per livestock on Buffalo and Kankrej Sale

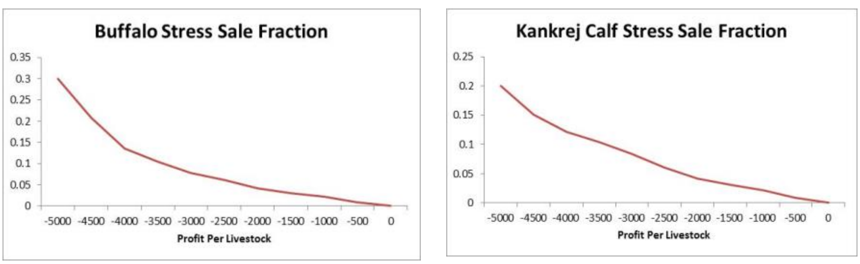
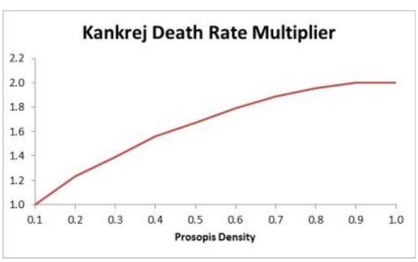


Figure 4: Impact of *P. juliflora* Density on Kankrej Death Rate



The Kankrej ageing chain and equations are very similar to the buffalo ones, having birth fraction, lifetime, maturation time, fodder requirement etc. The main difference is that 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 *P. juliflora*, 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 *P. juliflora* density. The values for two graphical functions discussed in this section are provided in Figure 3 and Figure 4.

2.1.2. The Economy Dynamics

This sector consists of livestock based income and charcoal based income. The model considers a uniform economic agent, the Maldharis, earning both from livestock based income and from charcoal based income. The milk income is composed of income from milk, dung, and livestock sale. The milk income is derived from the milk produced by the cows and the buffaloes, the livestock sale income from the fraction of cows/buffaloes sold in a year (which is a function of the profitability in a year, which is linked to rainfall, as described later in this section), and the income from dung sale from the existing number of livestock in a year. 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, prices have been assumed to be constant at 2015 levels. There are costs of rearing livestock (largely of feed and fodder purchased from the external market) which were calculated based on interviews, and are factored into the calculation of net incomes.

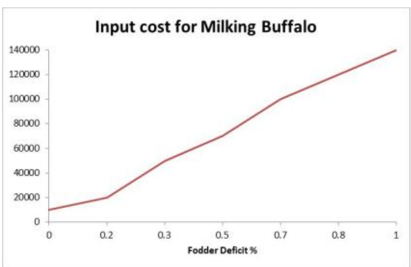
The charcoal annual income is derived from the annual charcoal production. Charcoal production in a year has been differentiated according to history. Before the ban on charcoal production was lifted (i.e. before 2004): the charcoal production is taken as 2,400 sacks of 40 kg each per day for 240 days in a year (based on discussions with local NGO and personal interviews with Maldharis). 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 and Mahajan 2012, 100), and 3) After the ban was again imposed (i.e. after 2008): the charcoal production is taken as 4,800 sacks of 40 kg each produced per day for 240 days in a year, the same as during the pre-ban period. A feedback function is created to increase the rate of production in the event of a fall in profits from livestock. The charcoal production numbers are difficult to collect from field owing to its fuzzy legal status. Thus, we believe the model numbers are conservative and underestimate the actual quantum of charcoal activity and income.

Summing the income from livestock and charcoal less the costs of livestock rearing and dividing by the total livestock population, a number for net total income per livestock is calculated. This number creates a feedback and governs the stress sales of adult buffaloes and Kankrej calves. As the net total income per livestock in a year goes negative, the stress sale multiplier increases, increasing the income from sales in the year, and reducing the buffaloes and cow numbers, both of which in the real world help the Maldharis to cope.

The remittances, in the form of income from milk sales from migrated livestock, are considered in the model, and both the costs of rearing them and revenue from their milk sale are included. It is assumed that the cost of rearing the livestock remains the same even after migration, and thus migration is important for the Maldharis in order to be able to have access to feed and fodder, which falls in dry years within Banni's geographic boundary.

2.1.3. Key feedback relationships

Figure 5: Impact of Fodder Deficit on Livestock input cost



There are six cross-sectorial feedback loops which govern the dynamics of the model.

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. The relationship is given in Figure 5.

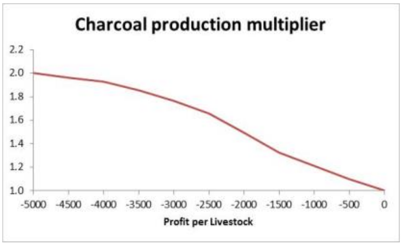
2) Impact of net income per livestock on livestock stress sale rate. As the profit per livestock becomes negative, the stress sale of livestock goes up, reflected in an increase in stress sale fraction. This is depicted in Figure 3.

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

4) Impact of livestock on *P. juliflora* spread rate. As the livestock population increases it leads to increase in the spread rate of area under *P. juliflora*. This is depicted in Figure 2.

5) Impact of *P. juliflora* density on Kankrej death rate. As the *P. juliflora* density (area under *P. juliflora* ÷ 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 *P. juliflora* dense areas. Thus the death multiplier evens out at high levels of *P. juliflora*. This is discussed in Figure 4.

Figure 6: Impact of net income per livestock on Charcoal Production



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. This is depicted in Figure 6.

2.2. Model Assumptions

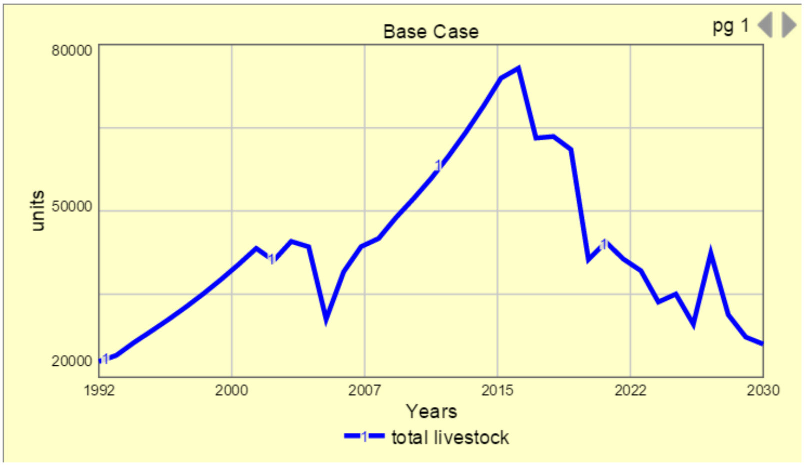
1. Prices for milk, livestock, feed, charcoal, and dung manure are kept constant at 2015 levels. Forecasting future prices, at local level, has lot of uncertainty which would add to the complexity of carrying out an economic valuation of Banni grasslands. Hence, here it is assumed to be constant at 2015 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's economy 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 (e.g. sheep, goat etc.). Buffalo and cattle constitute most of the Banni livestock. In 2011 their share was around 92 per cent of the total livestock (Bharwada and Mahajan 2012, 88). Hence, considering the small proportion of small ruminants they are excluded from the study.

4. Ecological impacts of *P. juliflora* removal: The model does not capture the ecological impacts of removing *P. juliflora* from Banni grassland as the scientific and practical knowledge on it is found to be inconclusive.

Figure 7: Base Case Livestock Population: 1992–2030



3. RESULTS

3.1. Base Run: Business as usual scenario

The business as usual scenario i.e. base run simulation, indicates that the total livestock population (sum of buffaloes and Kankrej) in Banni would fall between 2016 and 2030 (Figure 7). The primary reason for this is increasing livestock stress sales and out migration due to reducing area under grassland and consequently decline in fodder availability. 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.

The shrinking area under grassland, due to *P. juliflora* spread, is a cause of concern for Banni (Figure 8). If current conditions persist then by year 2030 the model shows that the area under grassland will reduce to approx. 27,000 hectares from 92,000 hectares in 2015, a reduction of around 70 per cent. The primary reason for reduction in grasslands is the increase in spread of area under *P. juliflora*. The model runs indicate that the area under *P.juliflor*a will reach 198,000 hectares by year 2030.

Figure 8: Base Case Land Use Change. All figures in hectares: 1992–2030

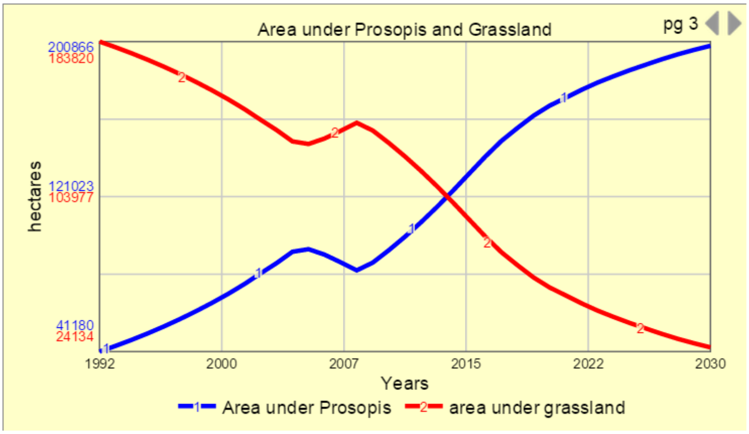
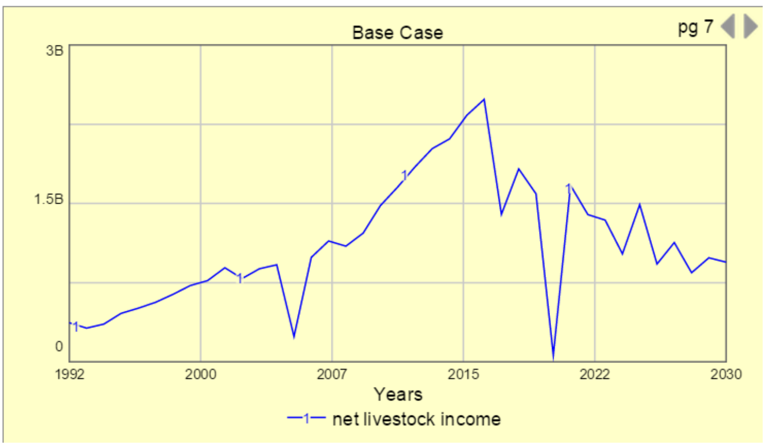


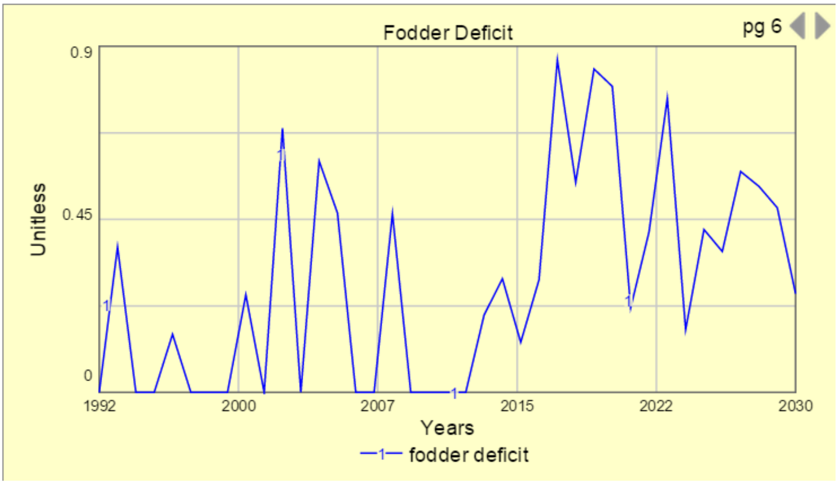
Figure 9: Base Case Net Livestock Income: 1992–2030



The period 2004–2008 shows a dip in area under *P. juliflora* 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 *P. juliflora* 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 *P. juliflora* while the grasslands continued to shrink.

Our base case simulation runs indicate that the net livestock income is projected to fall in future years. 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

Figure 10: Fodder Deficit – Base Case



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.

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 10 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.

The base case runs present a sorry picture for the livestock economy of Banni. If the current spread of *P. juliflora* 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 majority 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.

Figure 11: Total Livestock under *P. juliflora* removal policy

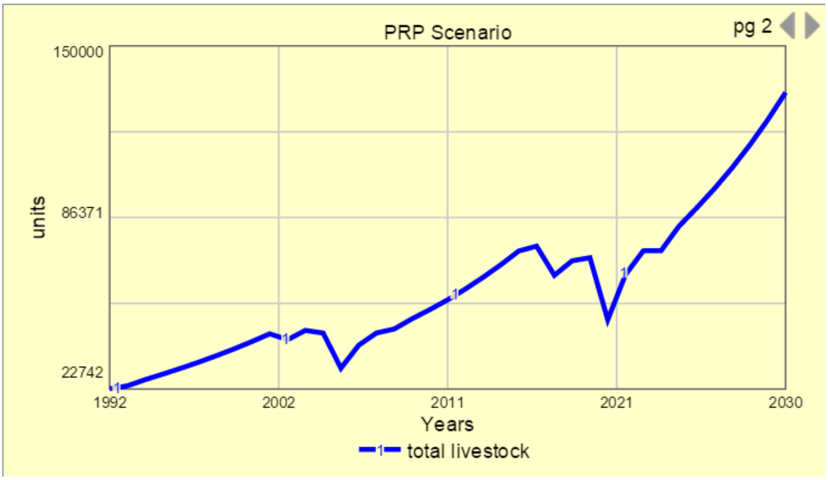
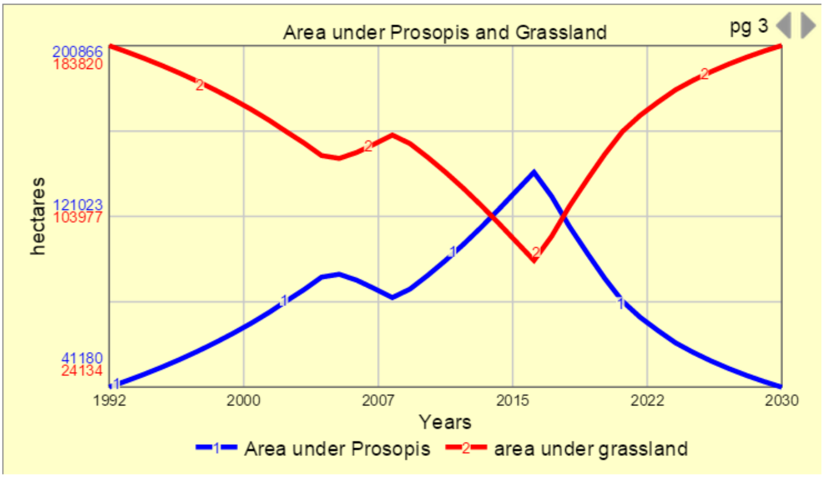


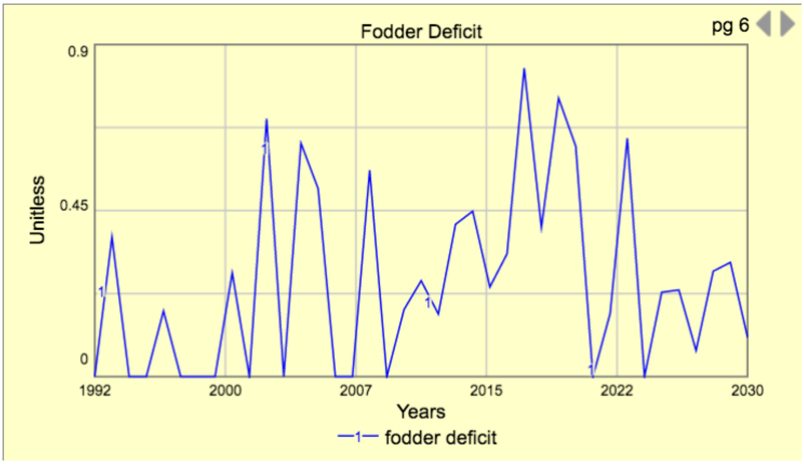
Figure 12: Land Use under *P. juliflora* removal policy



3.2. Policy testing: *P. juliflora* removal

Against this backdrop, we have modelled the impacts of a potential *P. juliflora* removal policy (PRP) either decided by the community or the government. The *P. juliflora* area removal rate is kept at 20 per cent per annum and the policy becomes active from year 2016 and takes full effect after a delay of 3 years. In this scenario the livestock population is estimated to increase between 2016–2030 (Figure 11). The main cause for the rise in livestock population is the increased fodder availability due to increase in area under grassland (Figure 12) due to removal of *P. juliflora*, increasing

Figure 13: Fodder Deficit under *P. juliflora* removal policy

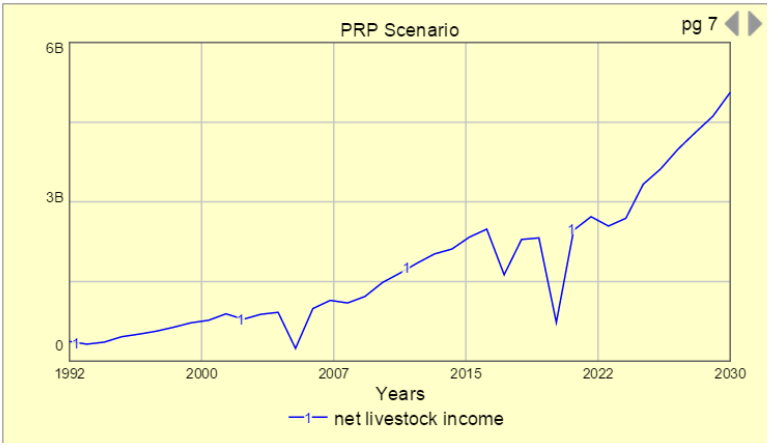


retention of livestock over sales and migration. Also removal of *P. juliflora* reduces the death multiplier on Kankrej, allowing the Kankrej cattle to grow more.

It is projected that the area under grassland would go up to 184,000 hectares by 2030 while the area under *P. juliflora* would reduce to 41,000 hectares and continue to fall. This would increase the grass availability leading to an increase in Banni's livestock carrying capacity. A key assumption is that grassland area currently occupied by *P. juliflora* still has grass seeds and that in event of complete removal of *P. juliflora* 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.

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 (seen in Figure 13). As can be seen from Figure 13, the fodder deficit variable returns to zero for multiple years, thus the fodder availability from Banni itself is able to sustain the livestock, making livestock rearing more profitable by reducing costs. 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 14).

Figure 14: Net Livestock Income under *P. juliflora* removal policy



3.3. Comparing the Scenarios

Here, the two scenarios are superimposed on each other to give a comparative picture, as shown in Figures 15 and 16.

Figure 15: Total Livestock Population Projections

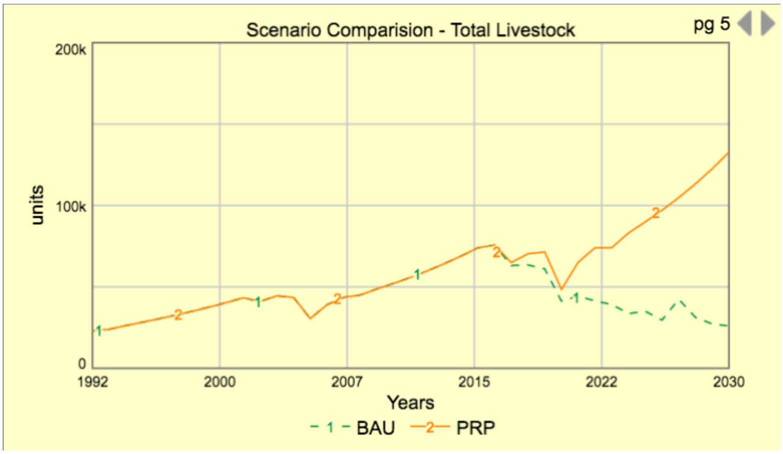
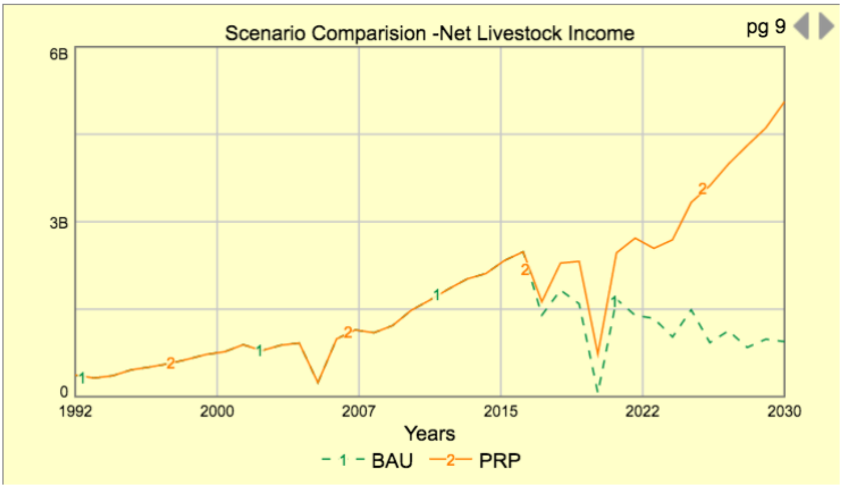


Figure 16: Net Livestock Income Projections (INR)



As can be seen in figures 15 and 16, *P. juliflora* 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 discount the future earnings to calculate the cumulative present value under base case and PRP scenario from year 2015–2030 using a discount rate of 10 per cent. The difference between the two can be assumed to be the partial costs of grassland degradation induced by *P. juliflora* spread in the Banni[1].

3.4. Economic Valuation of Income Flows from 2015 to 2030

As per the base run model results the total net annual income of Banni in year 2015 is around INR 250 crores. 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 1,295 crores and INR 1,500 crores respectively (ref. Table 1). If PRP is in place then the PV (Present Value) increases to INR 2,230 crores and INR 2,432 crores. This indicates that *P. juliflora* removal has a positive multiplier of 1.7 on the economy of Banni. Here it is assumed that the *P. juliflora* removed is not used for charcoal making which if it was then the net impact could have been even greater.

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[1] 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.

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

Table 1: Economic Analysis of Base Case and Policy Runs

Sr. No.	Present Values (10 per cent Discount Rate)	Net Livestock Income	Net Total Income
1.	Base Case	INR 12,950,355,676	INR 15,019,191,894
2.	*P. juliflora* removal policy (PRP) @ 20 per cent p.a.	INR 22,304,942,323	INR 24,326,493,926
3.	Policy Multiplier (PRP÷base Case)	1.7	1.6
4.	Difference i.e. costs of grassland degradation (No. 2 minus No. 1)	INR 9,354,586,647	INR 9,307,302,032
5.	Per ha costs of grassland degradation (No. 4÷2,50,000 ha)	INR 37,418	INR 37,229

Table 2: Economic costs of Policy Delay

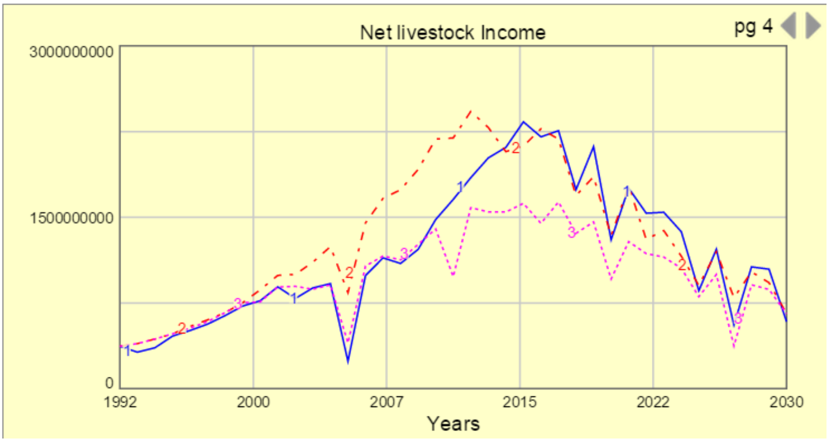
Sr. No.	Present Values (10 per cent Discount Rate)	Net Livestock Income	Net Total Income
1.	PRP with 5 year delay	INR 16,914,549,394	INR 18,984,784,140
2.	Loss due to delay	-32 per cent	-28 per cent

The costs of delaying the implementation of *P. juliflora* removal policy are substantial. The PV for net livestock income comes down by 32 per cent while the total net income comes down by 28 per cent due to the delay in policy implementation (ref. Table 2). This indicates that PRP is a time sensitive policy decision and any delays would result in economic losses for Banni.

3.5. Sensitivity Analysis

Three rainfall scenarios are modelled to test the sensitivity of rainfall on the overall results of the study. In the first scenario we assume that the rainfall for 2016 to 2030 would remain same as 2001 to 2015. In the second scenario we introduce stochasticity (using the RANDBETWEEN function in MS Excel) in the future rainfall keeping the range of the minimum and maximum values same as observed between 1992 and 2015, the historical duration of the simulation model. In the third scenario we use the min and max values from the range of rainfall data from year 1901 to year 2015. The data for year 1901 to 2002 is taken from India Water Portal (India Water Portal, n.d.). The minimum value is lower while the max value is higher in this case as compared to the other scenarios, while the mean value is higher. Thus, this scenario could be considered as an overall higher mean rainfall scenario. The results are discussed below (ref. Table 3). The values for annual rainfall for the three scenarios are given in the Annexure.

Figure 17: Grass Productivity Sensitivity Runs



The sensitivity analysis reveals that rainfall variability has an impact on the livestock net income and overall income of Banni, and the income levels go up in the third scenario which is a high rainfall scenario. But the PRP policy multipliers remain almost the same, thereby not impacting the policy analysis significantly. Same is true in case of testing the impact on PRP delay. Thus, rainfall variability does not change our policy recommendations even though the model shows sensitivity towards the rainfall parameter.

Further, Figure 17 shows the sensitivity of net livestock income towards the grass productivity parameter. Three sensitivity tests are performed, 1) BAU, 2) high grass productivity and 3) low grass productivity. As can be seen the net livestock income shows sensitivity towards the grass productivity parameter. At a higher grass productivity, the net livestock income increases (red line) while with a lower grass productivity, the income is lower (pink line). However, the shape of change remains the same i.e. growth, peak, and then decline. This indicates that the model is sensitive towards grass productivity, but variation in this parameter does not alter the shape of future projections.

Table 3: Present Value Analysis of Rainfall Scenarios

Sr. No	Particulars	Scenario 1		Scenario 2		Scenario 3	
		Net Livestock income	**Net Total Income**	**Net Livestock income**	**Net Total Income**	**Net Livestock income**	**Net Total Income**
1	Base Case	INR 12,950,355,676	INR 15,019,191,894	INR 13,572,232,336	INR 15,555,073,054	INR 14,504,560,716	INR 16,487,401,434
2	*P. juliflora removal policy*	INR 22,304,942,323	INR 24,326,493,926	INR 24,412,126,383	INR 26,394,967,102	INR 26,675,015,207	INR 28,657,855,926
3	Policy Multiplier (2÷1)	1.72	1.62	1.80	1.70	1.84	1.74
4	5 year delay in PRP Policy	INR 16,914,549,394	INR 18,984,784,140	INR 17,818,453,327	INR 19,801,294,045	INR 18,957,456,833	INR 20,940,297,551
5	Difference	-31.9 per cent	-28.1 per cent	-37.0 per cent	-33.3 per cent	-40.7 per cent	-36.9 per cent

4. DISCUSSION

The general perceptions of the people of Banni, on the reason for grassland degradation point to the growth of area under *P. juliflora*. It is also widely believed that if the *P. juliflora* is completely removed then the grasses would come back. A majority of Maldharis have 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 *P. juliflora* removal is a favourable policy option for sustaining their livestock economy and halting grassland degradation. The results indicate that livestock profitability goes up in event of *P. juliflora* removal and that in order to sustain livestock as the main occupation of Maldharis the land area under *P. juliflora* needs to be cleared. 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, as is seen through the sensitivity analysis. This is particularly important for Banni since the livestock sensitivity to grass availability is very high and *P. juliflora* density greatly influences the grass availability.

4.1. Cost of *P. juliflora* Removal

There has only been small scale intended *P. juliflora* removal for grassland restoration carried out in Banni, the extent of this being smaller than even a village boundary (there are more than 50 villages in Banni). Thus, extrapolating the costs of *P. juliflora* removal based on small scale removals done in past to whole of Banni seems inappropriate. Moreover all of those efforts were community driven and supported by local NGOs. Thus there exists no data on the cost of a formally organized large scale removal programme, and thus it becomes hard to account for the effects of economies of scale from the data of the small scale removal. However for the purpose of this study, an estimate of *P. juliflora* removal is calculated below, taking the example of a small scale removal case. An area of around 300 sq.m was cleared of *P. juliflora* by a local NGO with community participation in East Banni. The cost of *P. juliflora* removal was about INR 2 lac. If we use this example to estimate the cost of *P. juliflora* removal per hectare, a value of INR 6,000 is arrived at. Taking this as a constant value, the model simulates the cost of PRP over the period from year 2016 to 2030 as and discounting (at 10 per cent) to get the present value, a value of INR 57 crores is arrived at. Comparing with the increase of INR 935 crores in net total income due to PRP, it is evident that the cost of PRP can be recovered and that PRP is still a favourable policy option. Moreover, with the ready market available for excavated charcoal and wood, the costs could further come down. On another point, in the absence of forest rights being granted(current scenario), the possibility of community based implementation of the decision of large scale *P. juliflora* removal is unrealistic. Thus, unless a government authority decides to carry out a large scale removal it is very unlikely that this would happen anytime in the future until forest rights are given.

4.2. Limitations and further scope of research

This study needs to be strengthened with more data and information about the interlinkages between land, biomass, livestock, and economy 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, charcoal production, future price estimates etc. In order to strengthen the results of such a modelling 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 the unresolved issue of entitlement of land ownership, between the local community, the forest department, and the Revenue Department. 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 policy planning tools for consensus development on sustainable management of Banni grasslands.

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ANNEXURE

Rainfall Scenarios

Year	Scenario 1	Scenario 2	Scenario 3
1992	507	507	507
1993	106	106	106
1994	729	729	729
1995	326	326	326
1996	174	174	174
1997	259	259	259
1998	464	464	464
1999	450	450	450
2000	195	195	195
2001	540	540	540
2002	110	110	110
2003	700	700	700
2004	147	147	147
2005	139	139	139
2006	485	485	485
2007	641	641	641
2008	177	177	177
2009	370	370	370
2010	655	655	655
2011	650	650	650
2012	350	350	350
2013	652	652	652
2014	291	291	291
2015	450	450	450
2016	540	397	592
2017	110	264	433

2018	700	172	250
2019	147	326	634
2020	139	718	729
2021	485	512	483
2022	641	592	486
2023	177	330	473
2024	370	233	307
2025	655	252	204
2026	650	566	644
2027	350	377	720
2028	652	287	319
2029	291	472	461
2030	450	282	220
Mean Value	**408.31**	**393.51**	**423.64**

Scenario 1 = Future rainfall (2016 to 2030) same as past (2001 to 2015)
Scenario 2 = Future rainfall (2016 to 2030) with stochasticity based on 2001 to 2015 rainfall data
Scenario 3 = Future rainfall (2016 to 2030) projected with stochasticity based on rainfall data from 1901 to 2015(having a higher mean)

Parameter Values and Sources

S No.	Parameter	Value Taken	Sources and Explanations where necessary
1.	Initial Value (1992) of Adult Buffaloes	12,580	Taken as 75 per cent of the total buffalo population in 1992 (Bharwada and Mahajan 2012, 87)
2.	Initial Value of buffalo Calves	4,194	Taken as 25 per cent of the total buffalo population in 1992 (Bharwada and Mahajan 2012, 87)
3.	Fraction of adult buffaloes giving birth every year	0.5	Discussions with local NGO Sahjeevan and Maldharis
4.	Buffalo calf death rate	20 per cent p.a.	Data from personal interview with experts and pastoralists
5.	Buffalo calf maturation time	3 years	Discussions with local NGO Sahjeevan and Maldharis
6.	Normal buffalo sale rate	1 per cent p.a.	
7.	Buffalo lifetime	23 years (3 yrs. as calf and 20 as adult)	

8.	Fodder requirement per adult buffalo per day	30 kg	
9.	Fodder requirement per buffalo calf per day	7.5 kg	
10.	Fraction of milk producing buffaloes	50 per cent	
11.	Initial Value (1992) of Adult Kankrej	4,544	Taken as 75 per cent of the total Kankrej population in 1992 (Bharwada and Mahajan 2012, 87)
12.	Initial Value (1992) of Kankrej Calves	1,514	
13.	Kankrej birth rate	50 per cent of adult Kankrej cattle give birth every year	Discussions with local NGO Sahjeevan and Maldharis
14.	Kankrej calf death rate	20 per cent p.a.	
15.	Average Kankrej calf sale rate	60 per cent p.a.	
16.	Average male Kankrej purchase rate	25 per cent p.a.	
17.	Kankrej calf maturation time	3 years	
18.	Kankrej lifetime	12 years as adult and 3 years as calf	
19.	Fraction of milk producing Kankrej	50 per cent p.a.	
20.	Fodder requirement per Kankrej adult per day	15 kg	
21.	Fodder requirement per Kankrej calf per day	5 kg	

22.	Buffalo sale multiplier due to profitability	Increases from 0 to 30 per cent with profit per livestock falling from INR 0 to INR -5000.	Parameterized using sensitivity runs: Variables that are difficult to elicit through a survey or field estimation are determined through a series of plausibility tests. Parameters for such variables are assumed and tested through simulations. If the simulation outcome shows high deviation from real life trends then the parameters are optimized through sensitivity runs until the simulations generate plausible/verifiable with past data behaviour over time
23.	Kankrej sale multiplier due to profitability	Increases from 0 to 20 per cent with profit per livestock falling from INR 0 to INR -5000.	Parameterized using sensitivity runs
24.	Impact of *P. juliflora* on death rate of Kankrej	Increases from 0 to 20 per cent and tapers off as *P. juliflora* density doubles	Parameterized using sensitivity runs
25.	Rainfall	Rainfall from 2015–2030 assumed to be the same as from 1999–2014.	Rainfall data for 1992–2010 taken from (Bharwada and Mahajan 2012, 143), for year 2011–12 taken from, (Gavali 2015, 5) and for 2013–14 taken from IMD website for Kutch district from http://hydro.imd.gov.in/hydrometweb/(S(lmae0jvse31sb045m2gxd5i1))/DistrictRaifall.aspx
26.	Initial Value (1992) of Area under *P. juliflora*	41180 ha	Koladiya *et al.* (2016, 20)
27.	The total productive area of Banni	225,000 hectares	
28.	Normal spread rate of *P. juliflora*	8.5 per cent	Vaibhav *et. al* (2012)

29.	Impact of livestock on *P. juliflora* spread	Increasing from 1 to 2 when livestock population increases from 25,000 to 100,000	Parameterized using sensitivity runs
30.	Charcoal production	4,800 sacks of 40 kg each produced per day	Discussions with local NGO Sahjeevan and Maldharis
31.	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 until 2 at a loss of INR -5000 per livestock	Parameterized using sensitivity runs
32.	Average milk production per buffalo per day	12 litres	Discussions with local NGO Sahjeevan and Maldharis Milk production per buffalo ranges from 8 litres to 20 litres a day. Average taken as 12 litres a day.
33.	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. 2015 milk price taken from personal interviews with dairy industry. 2010 milk price taken from Bharwada and Mahajan 2012, 71) 2000 milk price taken from (Geevan *et al*. 2012, 56) table 6.9 1992 milk prices are assumed.
34.	Average milk production per Kankrej per day	9 litres	Discussions with local NGO Sahjeevan and Maldharis Milk production per Kankrej cattle ranges from 6 to 14 litres a day. Average taken as 9 litres a day.

35.	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
36.	Charcoal Price	Rs. 5/kg taken constant	Discussions with local NGO, Sahjeevan, Personal interviews with Maldharis
37.	Price of Dung	Rs 1,500 per truck load	Bharwada and Mahajan (2012, 74)
38.	Quantity of Dung sold	One truck load every 15 days- one truck load from 100 livestock	
39.	Kankrej sale price	Rs 10000	Average price varies from Rs 12,000 to Rs 30,000 for a pair of bullock. Taken as average Rs. 10000 per Kankrej. (Bharwada and Mahajan 2012, 65)
40.	Buffalo sale price	Varying from Rs 38,000 in 1992 to Rs75000 in 2015 (post-breed registration). Constant at Rs 75,000 in future.	Current buffalo price for year 2015 range from INR 50,000 to INR 300,000. 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
41.	Input cost for milk producing buffaloes	Graphical function of fodder deficit. Varies from 10000 at 0 fodder deficit to 140,000 at 100 per cent fodder deficit	At 50 per cent 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 fodder deficit and its corresponding impact on feed cost due to increase in supply
42.	Feed cost for non-milk producing buffaloes	One-third of No. 36.	Discussions with local NGO Sahjeevan and Maldharis