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DISCUSSION

Response to the Comments by C.P. Geevan, Arun Dixit and Chandra Shekhar Silori

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In this response, we will first address the general statements made by C.P. Geevan, A. Dixit S. Silori (this issue of *EES*; henceforth GDS) in the context of our paper published earlier in *EES* (M&S), and then move to addressing the specific points raised. The model presented in (M&S) indeed follows a highly coupled approach, refer Figure 1 (Higher Order Causal Loop Diagram of the Simulation Model) (M&S, 37), as is what GDS suggest should be the case for such an ecological-economic system, and unlike what they claim the model actually is. The sectors of livestock, economy and land area are interdependent through multiple feedbacks, some of which are described in the section 'Key Cross-sectorial Feedbacks' (M&S, 44). As is asserted incorrectly by GDS, the computation of livestock numbers as well as *P. juliflora* (PJ) area - referred to as MCA by GDS- is not done using a 'stand alone' approach, and both the sectors are interdependent on each other. PJ area is influenced by livestock numbers through an increased spread rate due to livestock acting as vectors in Banni; and, livestock numbers depend on PJ area as with increased PJ invasion, area available for grass growth comes down, thereby reducing biomass production, which leads to fodder deficit - named as such in our model - impacting livestock numbers. These impacts manifest themselves through three feedbacks: 1) by increasing migration of buffalo and cattle from Banni, 2) by increasing fodder and feed input cost, thereby reducing livestock profitability, and increasing the stress sale of livestock and 3)

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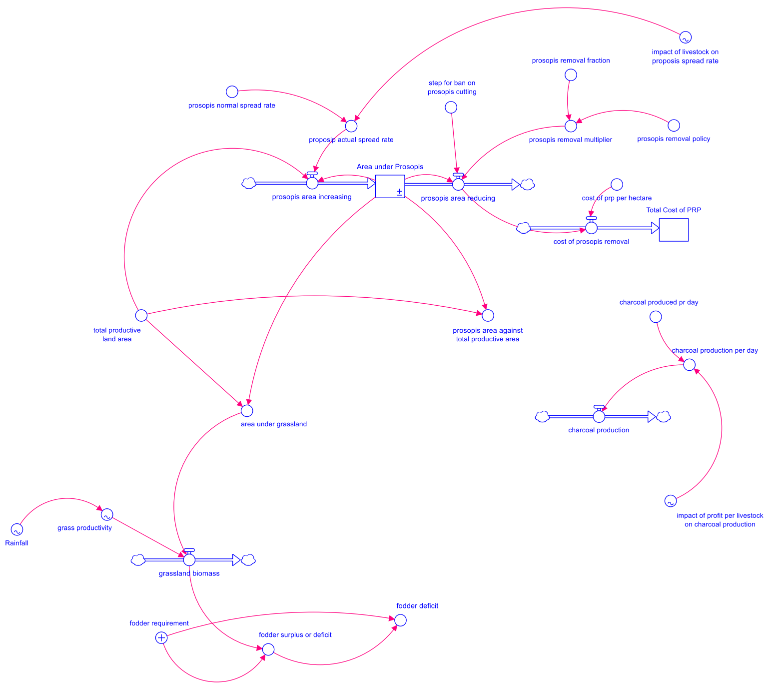
Editorial note: no further discussion on this matter can be published.

increase in the death rate of Kankrej cattle from consumption of pods of PJ (Bharwada & Mahajan 2012, 90). The results seen in (M&S) are the outcome of the tightly coupled dynamics between PJ area, area under grassland, economics and livestock management and manifest through the multiple feedbacks present in the model. In absence of such feedbacks, the model results would be very different from those presented in (M&S).

Figure 1: Prosopis and Grasslands

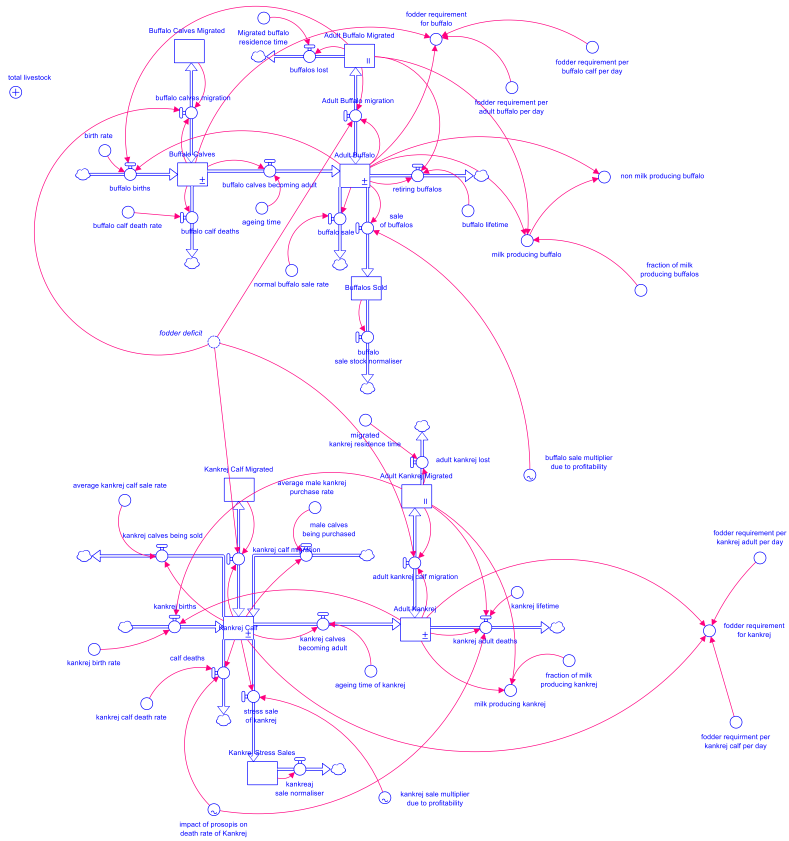


Source: Authors

Finally, the model described in GDS is very similar to the one in Geevan *et al.* (2003), which was in fact reviewed during the course of our study and is also referenced a number of times in our paper. Now, we will present responses to the specific points raised.

a) The spread of PJ in Banni has been rampant. Data from studies conducted specifically for Banni (Shah & Somusundaram, 2010) and (GUIDE, 1999) –as also tabulated explicitly in (Bharwada & Mahajan, 2012, 82) –show that the spread of area under dense PJ in Banni grew from 16133 ha in 1997(~6% of area) to 72074 ha (27% of area) in

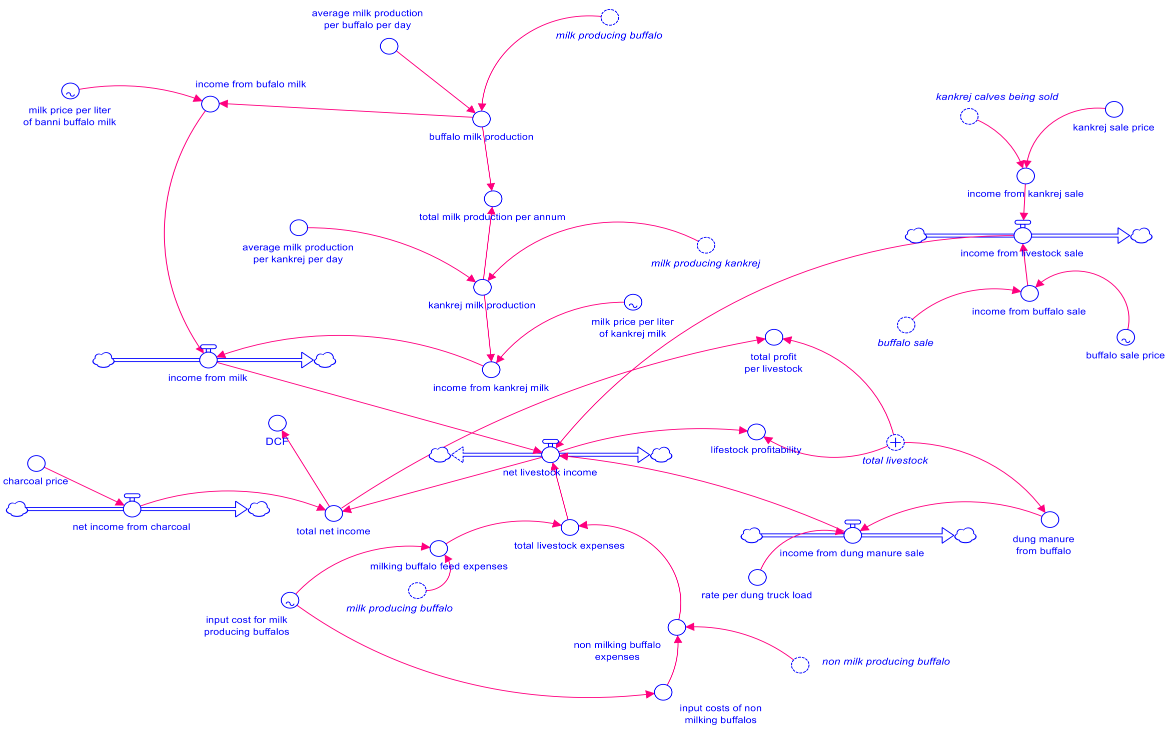
Figure 2: Livestock



Source: Authors

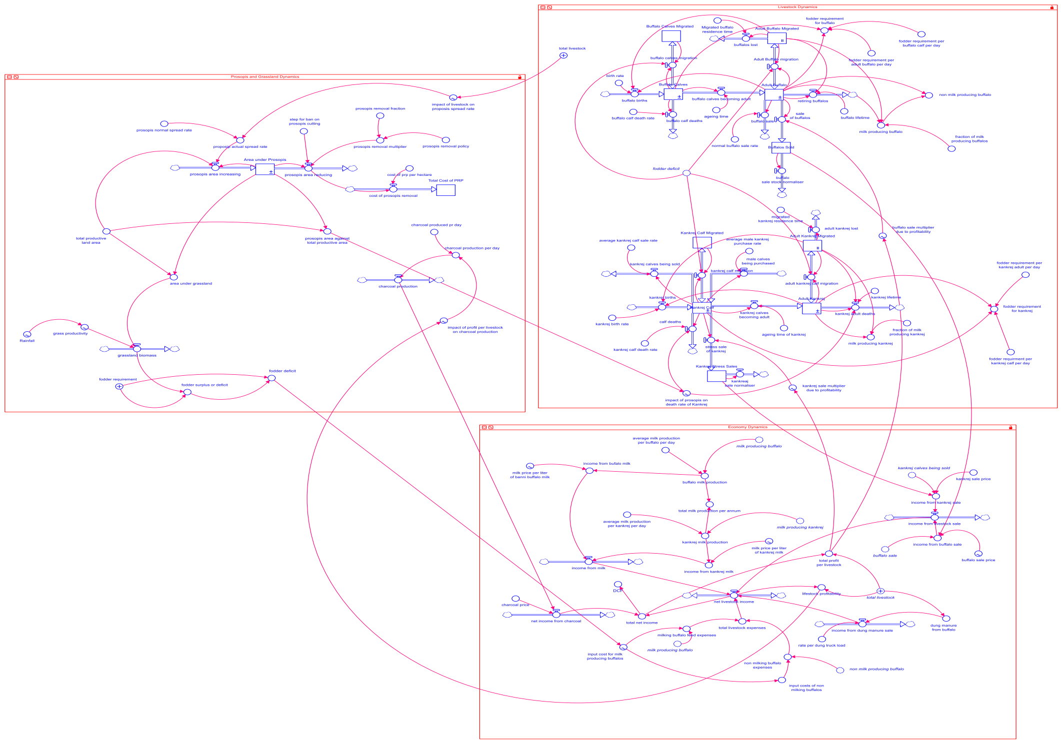
2008, giving a compounded growth rate of 14.58 % per year. Further, as these numbers are derived from satellite imagery, these are the 'net seen' values, which are effectively the net positive difference between the additional land invaded by PJ and land cleared of PJ through biomass removal (uprooting) practices. As also explained in (M&S, 34), between 2004 and 2008, the ban on chopping of charcoal was lifted and a significant portion of PJ area was cleared (Bharwada & Mahajan 2012). In this light, the actual spread rate would need to be higher than that mentioned above, which would then manifest itself as the 'net seen' value, after the effects of clearing land of PJ is accounted for. Thus, the dynamic annual spread rate taken in our study (including the

Figure 3: Economy



Source: Authors

Figure 4: Full model



Source: Authors

amplification by livestock), has a possible range of 8.5% to 17% (changing with livestock values), and varies between 8.5-12% for most part of the simulation run. Further, the model simulation runs begin from year 1992, and thus the time between 1992 to year 2015 served as back-casting for validating changes in land area in the simulation against observed values. This method was used for fine tuning parameter values of spread rate in the model such that it reflected area change as observed in Banni.

b) As correctly stated by GDS, there is no way to estimate 'unassisted spread rate', and it is a proxy number, which needs to be corrected for amplification by livestock in order to be comparable with observations. Thus, in our study, an estimated base rate is used, which is then amplified by livestock, as explained in (M&S, 39). The number of 8.5 % was taken from a range provided in (Vaibhav *et al.* 2012, 3) just in order to obtain a plausible reference value. Although the mentioned study may have focused on biomass regeneration, as pointed out by GDS, the concerned number is of area spread as observed by (Vaibhav *et al.* 2012) and not of biomass, as implied by GDS. Curiously, the paper cited by GDS (Pasha *et al.* 2014) in providing a number for spread rate, is a study carried out not exclusively for Banni, but for the Greater Rann of Kachchh(GRK) region, which has a geographical boundary overlapping only marginally with some parts of eastern Banni (Pasha *et al.* 2014, 1482). Since this study area contains regions with very different ecological conditions including saline areas and wetlands (Pasha *et al.* 2014, 1483) as well as varying economic use, numbers for this region are not representative of Banni. The authors of the study themselves (Pasha *et al.* 2014, 1484-5) note that among the areas within the GRK boundary, most (~96%) of the PJ invasion took place in the grassland area and only ~4% in other area types. They also go on to cite the same studies cited in point a) above, carried out exclusively for Banni (which reveal a growth rate of 14.58%), to emphasize the high spread of PJ in Banni (Pasha *et al.* 2014, 1486-7).

c) Graphical functions have been one of the distinguishing characteristics of system dynamics methodology since the inception of the field, and are important tools used by system dynamics modellers to represent non-linear feedbacks between variables in a system (Forrester 1973, 34; Sterman 2000, 551; Pruyt 2013, 120). Furthermore, as explained earlier on, our model is tightly coupled, and any change in PJ area due to livestock numbers reflects in the next time step on the livestock numbers through profitability and fodder deficit (causing livestock stress sale or migration). Thus, the assertion that this approach excludes feedback effects on the livestock sector is also unfounded.

d) PJ spread has indeed been modelled with the rate of change being proportional to the area, as has also been done by other studies (Dayal 2007). However, the effect GDS mention is interesting and we acknowledge that along with other approaches for modeling spread of PJ area, such as considering biomass as the driver of PJ area change, this approach could also be of potential importance to explore further.

e) Contrary to the claim, the point made here is unclear, and the explanation provided does not suffice. The livestock sector is not a 'standalone model', as the system of Banni is tightly coupled as a human-nature system. The livestock sector was modelled to closely represent the real dynamics of Banni. Both the livestock varieties (Banni Buffalo and Kankrej cattle) are modelled using ageing chains as is traditionally done in SD models (Sterman 2000, 470; Ford 2009). Breeding, selling and migration of buffaloes are all managed based on fodder and profitability and are modeled as such. Livestock both impacts and is impacted by the economics, shifts between grassland and PJ areas and biomass dynamics of Banni (Refer to 'Key Cross-sectorial Feedbacks' (M&S, 44)). Indeed, the death rate of livestock (as per their average dying age) is the only exogenously input variable. Finally, as explained earlier, back-casting (1992-2015) of the model was done for parameter calibration, and the model was found to capture observed data in Banni.

We have responded to each of the specific points raised by GDS as well as to the general statements made by them. We have demonstrated how their claim of certain formulations being flawed is unfounded, and also provided credible validating references for the parameter values they claim as inaccurate. We do believe, however, that some of these comments may not have arisen if the system dynamics stock-flow diagram had been provided along with the text. It is for this reason that the stock-flow diagrams of the sectors as well as the overall model are attached herewith (Figure1 to Figure 4). We hope this response and the model images will help readers to better understand our model, and the system dynamics approach of modelling.

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