Sheep and Ships: Modelling Grazing and Erosion in a Warming World.

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Abstract

Pastoralism is a major activity in the World's Drylands. It is often practised by marginalised communities in Common lands presumed fit for no other use by people in poverty. With global warming the resilient livelihood systems developed by pastoralists to cope with difficult seasonal and inter-annual climatic fluctuations may break down completely. Our premise is that vegetation cover is a key control on the rate of water erosion and that land degradation leads to a downward spiral in which more erosion leads to poorer pasture and consequently heavier grazing intensities as pastoralists are forced to herd on smaller and smaller available commons. Because of poverty they are forced to graze larger herds on smaller areas to avoid complete destitution. We have developed a digital model to investigate the probable impacts of lower rainfall on the balance between vegetative production and vegetal consumption. The model simulates a set of grazing 'styles' that comprise combinations of origins (sheds, farms, settlements), routes or transports (herded by shepherd, carried by wagons, or transhumant) and animal behaviours (walk, eat, rest,). We have developed an interactive P.C.-based programme in Java using an oops-UML approach to make accessible interactive software that is low in data and computing demands and designed to be user friendly for inexperienced users. This will be demonstrated. The results of simulations of the relationship between degradation and herd size for fixed grazing seasons (1) show that theoretical economic models of fisheries depletion by Schaefer, as modified by Clark for constrained catches, closely describe the behaviour of the grazing systems in common lands revealing yet another case of common-pool–resources (CPR) depletion, (2) provide a means for examining alternative management practices for the grazing in CPR and (3) offer a possibility of evaluating the impacts of climate change on grazing systems ranging from Nomadic to paddock, in the world's Drylands.

Key Words: *modelling, grazing, simulation, commons, resources, grasslands*

Introduction

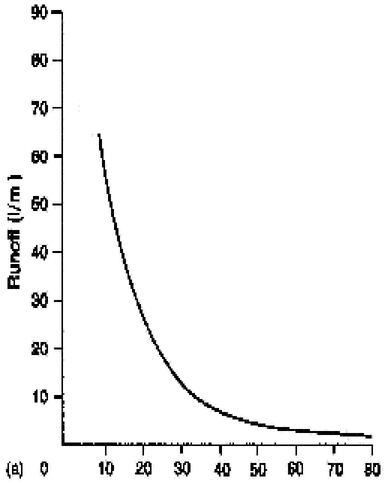
It has been asserted for many years that 'overgrazing' is the major cause of soil erosion by wash in semi-arid regions with pastoral economies. We have no doubt that any agency that removes the surface vegetation cover can and often will lead to catastrophic erosion as the cover falls about 30%. This has been demonstrated many times in the erosional literature (Elwell and Stocking, 1986, Francis and Thornes(2003) as shown in fig.1.

However we can and do object to the near automatic assumption that it is necessarily the cause without proper investigation. In reality the hypothesis was the subject of very little research. At the turn of the Century there was a lively and critical debate concerning the role of cattle grazing in Land degradation (see for example Behnke, Scoones and Kerven, 1993). This debate focussed on the issue of carrying capacity, the concept that there is a bounding value of the number of animals that can be grazed in a given area without causing catastrophic erosion and that this can be estimated and specified as a control on the utilisation of grassland resources. In some areas it was used as a mechanism to exclude grazers from common areas, sometimes leading to loss of livelihood, destitution and poverty. Thornes(1986,) started a project to examine in detail and to model the processes and styles of grazing that lead to catastrophic erosion, with a view to obtaining, not only a better understanding but also better management tools for mitigating the impacts of grazing on soil erosion. This led to a number of papers on mathematical models for grazing as a chaotic process using essentially a cellular automaton approach. Meanwhile Rowntree et al (2002) demonstrated that cases of severe erosion attributed to "overgrazing" in the Eastern Townships of South Africa were in fact the results of other causes and that inadequate historical research had mis-identified the real causes. The current paper describes the most up-to-date version of a model that simulates the grazing processes in the context of communal grazing where several communities share grazing rights in a fixed area. The model has been designed to be user friendly. That is, it is scientifically realistic, requires a minimum of inputs, directly addresses the processes involved, is easy to use and uses a simple, widely available computing platform and it requires virtually no training.

Basic premises.

The most basic proposition is that vegetation is a key variable in soil erosion. This has been demonstrated empirically, theoretically and in laboratory studies since the 1940s. Kirkby and Carson (1972) synthesised the relationship between vegetation and surface water erosion and Kirkby and Neale(1986) demonstrated the seasonality of these controls on splash and wash erosion by modelling them. The relationship used here is that defined by Elwell and Stocking(Fig.1) that summarises the empirical results of their own work in Rhodesia. It shows that the ratio of erosion on vegetated slopes to that of bare soils falls exponentially as cover increases, that most of the drop has occurred by the time a vegetation cover of 30% has been reached, and that the fall beyond that value is very modest. There have been some variations on this theme. For example Schumm and Beathard (1976) showed that with bushes, there may be an increase as the cover falls below 100% because flow tends to concentrate between the bush stems. Francis and Thornes (2003) also showed that the curvature depends on the rainfall intensity and that there is, in fact, a family of curves for different intensities.

Fig.1 Elwell and Stocking’s curve of vegetation cover (% 0n x axis) v. erosion



as a % of bare soil value(Y).

Our second premise is that ,with one exception (Sorian style), they leave a village or shed or overnight coral and are led by shepherd to communal grazing areas(paddock), that the shepherd moves in a quasi –random fashion, followed by livestock, and that they graze around him when he stops a for a rest.

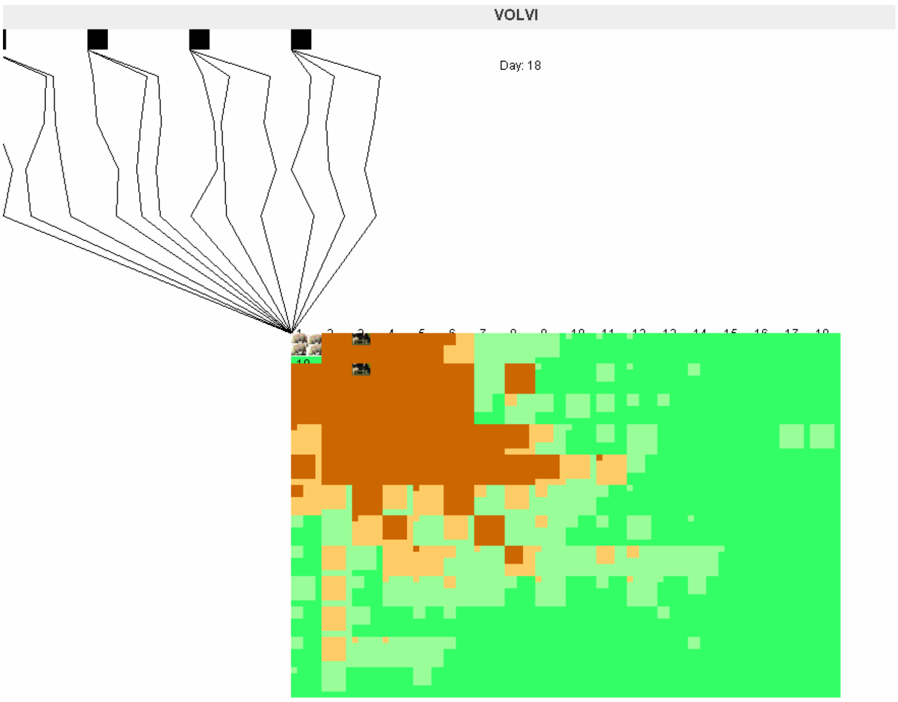
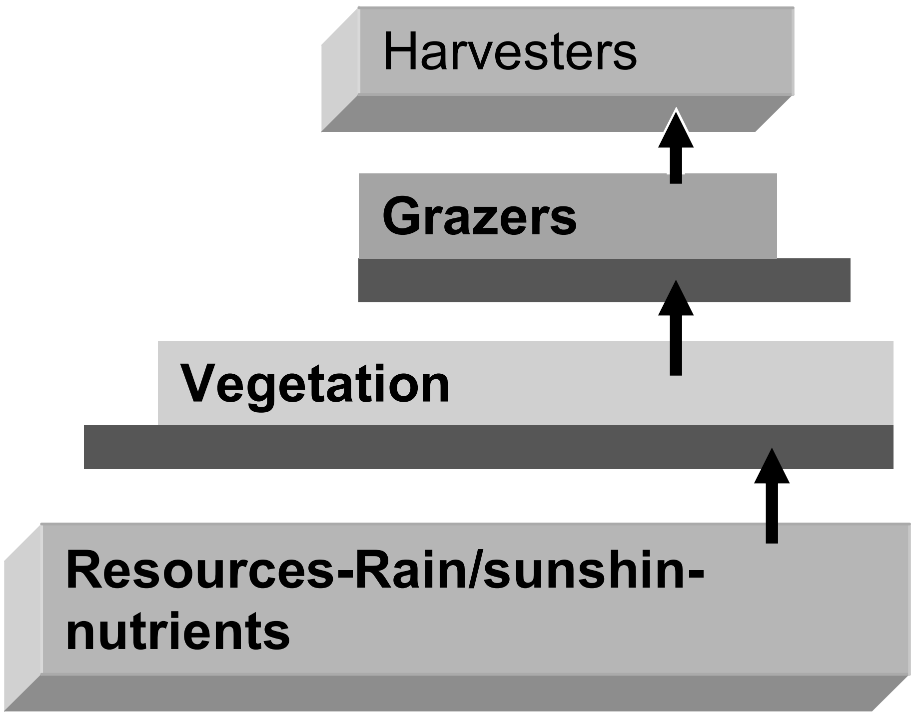


Fig.2 Schematic representation of Volvi-style, with 216 cells in the paddock and paths leading from sheds (black squares). The simulation is for 50 animals after 10 days of grazing. The colour-coding represents degree of biomass removed. Red is 75%, green is 0%. Red is regarded as severely degraded.

We also assume that the soil hydrology can be modelled by a simple single tank analogy with rain and leaf drip entering at the top and drainage leaving from the bottom. The resulting soil moisture is used to constrain evapo-transpiration and the plant growth (undifferentiated by species) is made a function of the ratio between estimated actual and potential evapo-transpiration as measured by the Thornthwaite method. The paddock(fig.2)is divided into 0.86 sq. km cells and the biomass losses are calculated on a daily basis. The iteration is continued for a grazing season. Cells are classified according to whether they have lost 75, 50 or 25%of their initial biomass. Cells with less than 25% are understood to be suffering catastrophic erosion i.e. more than 70% of the bare-soil value rates under identical conditions of slope, rainfall etc. By counting up the number of cells in the catastrophic condition, we obtain a measure of the seasonal degradation of the vegetation cover as a fraction of the total initial biomass over the entire paddock. (Space does not permit us to further elaborate on the details of the model. Nor is it appropriate here. Further details can be obtained from forthcoming papers in *Land Degradation and Development*, and *Catena* or from the first author. The model is in a state of continuing development and as yet the following components have **not** yet been elaborated:

- There is no topography.
- There are no energetic considerations for the calculation of gain of products, and loss of productivity.
- The infra-structural elements have not yet been introduced (such as water-points, no-go areas (cultivated and irrigated lands and overstep slopes.
- Nor have we yet introduced the supplementation of forage by feedstuffs that is a common practice in commercial l;ivestock grazing. (e.g. from European Subsidies).

Fig.3 Schematic representation of the trophic-web structure underlying the model

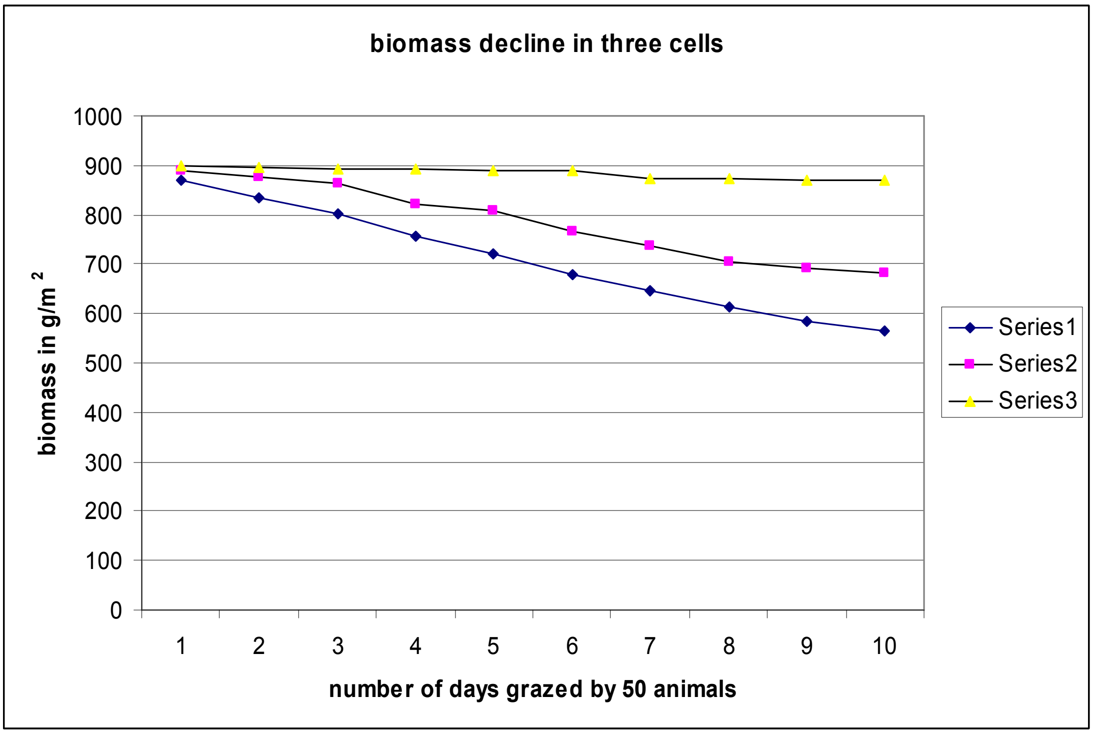


Some Results.

We provide a few results to indicate the behaviour of the model. The grazing style we have used is called Volvi and it provides several sheds from which animals cross a variety of routes to an upland Paddock. Fig.2 shows a map of the paddock. The term paddock is used to describe any common grazing area. Here it comprises a flat areas with 18x12 cells, each is made up of 30x30 pixels that are each 30.3x30.3 m. So each cell is 0.86km^2 and the entire paddock is 15 x10 km. The process structure is controlled by a 3-level trophic web (Fig.3). The shepherd moves at 1hr. intervals between the groups, occupying the central cells. The shepherd moves avoiding cells that have already been so heavily grazed that they have less than 25% of the initial biomass, or cells that are too steep for animals. At each stop, the livestock distribute themselves at random, in the surrounding 8cells. This is not strictly random; because it is biased by the available forage in the surrounding cells. That is the Cellular Automata component. The shepherd moves 8 times in each day, always starting (in the Volvi style) from the top left corner and avoiding over-grazed groups. As a consequence the heavily degraded pastures first appear in the top-left and spreads over the whole paddock as the season passes. Each day the growth is calculated using rainfall inputs and solar radiation inputs. A typical result, following 10 days is shown in fig.2 In this case the herd size is 50, the bite size is 2g dry matter/ bite and the frequency is 2 bites /pixel. Fig 4 shows the evolution of the net average biomass for two cells in the top left (heavily grazed) and the bottom right (lightly grazed).

By repeatedly running the model with different herd sizes and plotting land degradation against herd size, we obtain the graph shown in figure 5. This shows a steep rise in the harvest (degradation) with the increase in herd size until the graph 'levels off' at large herd sizes. This is the effect usually described in the overgrazing literature. The sinusoidal curve, rising slowly at low herd-sizes and levelling off with a very steep section in-between is also widely known from ecology where it is known as the logistic curve. Its properties were studied in detail in biology by May1986and for .bio-economics by Clark(2005). Clark's work is based mainly on the economics of common-pool fishery resources and we draw an analogy between that and the grazing case

Fig.4 Biomass removal (gm/m^2) daily for 10 days for 3 cells in the Volvi case (fig.2)



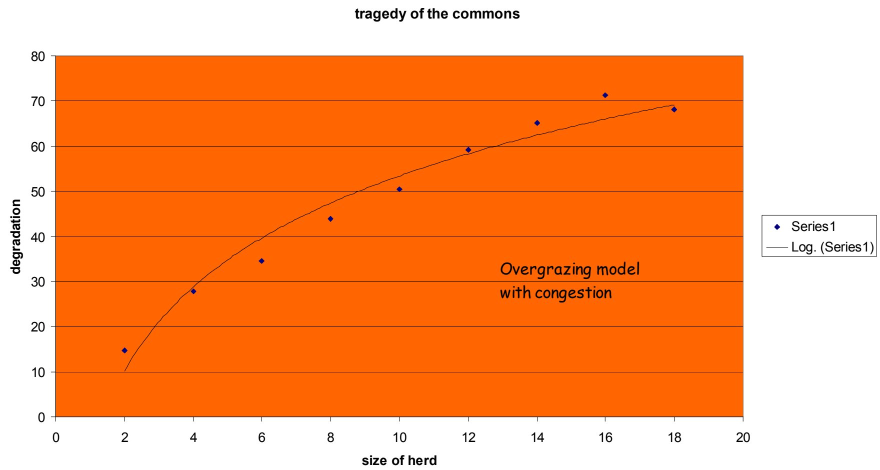


Fig.5 the degradation (forage yield, Y axis) plotted against effort(size of herd, Xaxis). Fitted curve is logarithmic and is upper part of Logistic model.

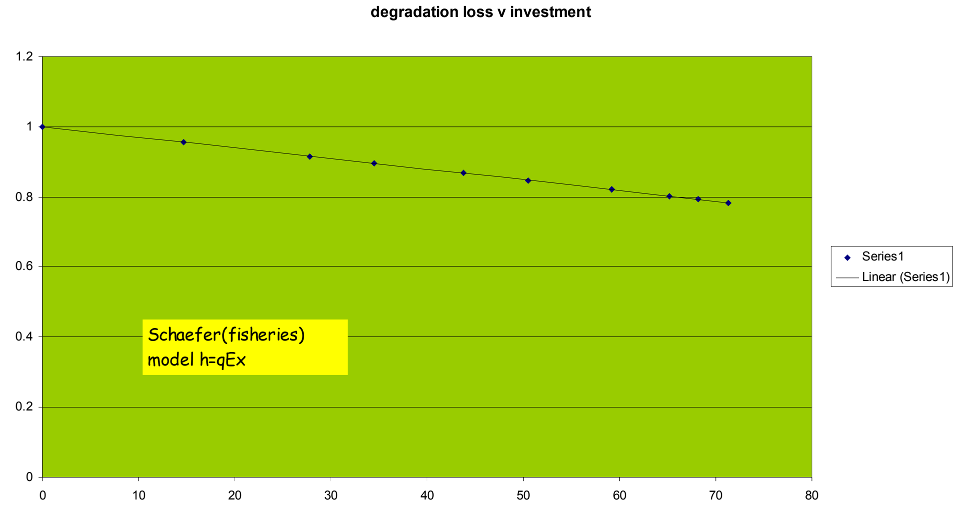


Fig.6 Classic yield-effort case of Schaefer

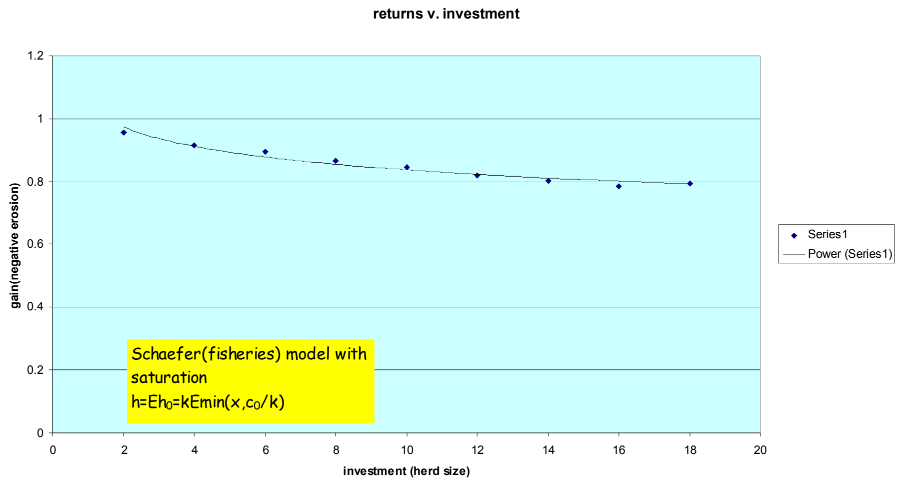


Fig.7 Yield –effort curve of Schaffer with congestion (after Clark, 2005). Dots are values from simulation in fig.2

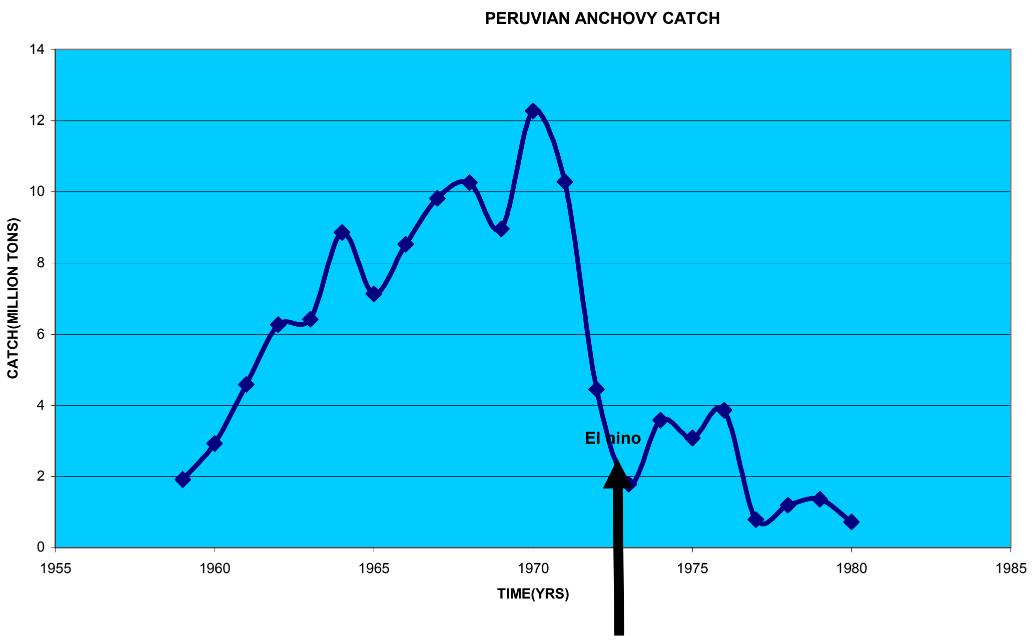
There is a direct analogy between fisheries and common-land grazing. Both are subject to a yield-effort curve. For fisheries this is the catch as a function of the population of fish stocks and the effort expended. Effort is proportional to the size of the fleet. If the natural growth rate is logistic (population growth is proportional to population size), each level of effort produces a unique and stable equilibrium population. The dynamical behaviour can be defined by analysis of the differential equations that describe the system enabling us to determine the stable and unstable equilibrium points.(see Thornes(2004) for a user-friendly account of this procedure).

In the grazing analogy, the natural resource stock is the biomass; the harvesters (fleet) are the sheep. The harvest is the biomass converted to meat, milk and wool. Therefore we can apply the yield-effort concept and describe yield as a function of effort. The equilibrium dynamical arguments also apply. Pursuing this argument further, the loss in forage is a gain in soil protection (as argued earlier). Expressing this gain as the inverse of biomass loss, fig.7 shows that the erosional gain from grazing decreases linearly as the herd size increases. This is the root of the tragedy of the Commons expressed for land degradation. Note also that the reduction inloss levels out as the ariel constraint of the paddock begin to be felt. The degradation does not continue to completion but, given the areal limit, the degradation 'bottoms' out. This is a form of regulation like that practised in fisheries . By excluding the sheep from heavily harvested areas, we have reduced the 'catch' by the sheep.

Another important dimension can be explored, the effect of climate. Fig.8 from based on data from the Peruvian Institute of Fisheries, shows how the fishing catch for anchovies climbed steeply in the sixties but that the system was so unstable that the impact of the El Nino of 1973 led to collapse of the anchovy fisheries which could not then recover. Our model is designed to test the likely impact of the coming global climate change on the global pastoral economies, subsistence and Commercial.

Conclusions.

We have presented a model that simulates the effect of grazing of the Commons by livestock in various styles. Though not yet thoroughly validated, the model shows parallels with the harvesting of fish stocks under uncontrolled and controlled conditions and reveals that the grazing problem is yet another case of the Common Pool Resources bio-economic syndrome.



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