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REPORT 4

Modeling livestock feed and fodder availablity in the ASALs of the IGAD region

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Building Resilience in the Horn of Africa
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1 Introduction

The Technical Consortium for Building Resilience in the Horn of Africa (TC) is a project of the CGIAR, which was formed in 2011 following the effects of the 2011-2012 drought. The main aim of the Technical Consortium initially was to provide financial and technical support to the Intergovernmental Authority on Development (IGAD) and its member states (Djibouti, Ethiopia, Kenya, Somalia, South Sudan, Sudan and Uganda) to formulate regional and national investment programmes for the long-term development of ASALS and to follow this with technical support, with particular focus on monitoring and evaluation and the targeting of investments within these plans. These investment plans became the Country Programme Papers (CPPs) for drylands projects for the Member States and the Regional Programming Framework (now the IGAD Drought Disaster Resilience Sustainability Initiative (IDDRSI)), which focused on investment plans to address regional issues for IGAD.

The focus of the TC's work at present is to collaborate with different partners, specifically including the governments in the region as their plans develop, to provide tools for measuring the impact of investments on enhanced resilience and to develop decision support tools for better targeting and prioritization of investments or projects. These tools will not only be useful for monitoring the impact of interventions within the national drylands investment plans and provide evidence for rational decision-making and prioritization, but will be applicable for donors, developments, NGOs and civil society when measuring or targeting their projects.

It has been noted that there is a gap between the strategies that decision makers use to allocate policy-related investments for ASALs and the analytical techniques that researchers use to model the conditions of ASALs and assess the impact of related interventions. To help bridge this gap, the TC has been working to develop and apply approaches to support evidence-based decision-making and investment prioritization to enhance resilient development trajectories in Horn of Africa (HoA). The result will be a toolbox of methodologies and application processes that facilitate the capacities of the IGAD member states to identify the investments with greatest potential for the highest impact to build resilience to shocks and stressors, in particular to drought, in the HoA. The toolbox will be tailored to elucidate the implications of more focused interventions, for a more specific sub-population of interest, as those details are specified by IGAD or the member states. It will also be able to test how well investments perform under different conditions (climatic and otherwise) and over varied time horizons.

The toolbox will be of use to multiple audiences, but the primary focus for application will be to provide tools for the Government of Kenya (GoK) National Drought Management Authority (NDMA), to assist with decision analysis and prioritization for investment proposed in the Kenya Ending Drought Emergencies

Common Programme Framework (EDE CPF) drylands investment plan. It is also assumed, however, that the conceptual analysis and knowledge gained in the provision of tools to the GoK NDMA will also be of use to other clients such as NGOs, donors and development partners to assist with their decision making processes and that these tools will also have potential for replication in the remaining IGAD member states.

As part of this initiative, and to avert future livestock population crashes in the Horn of Africa, a model was developed by Habitat INFO for the Technical Consortium alongside the spatial tool to simulate livestock population dynamics in the region, with which to inform food security early warning systems.

As livestock population dynamics are not solely influenced by drought, the model uses the balance/imbalance between livestock numbers and the available rangeland forage in arid and semi arid lands (ASALs) in conjunction with rainfall patterns, to capture livestock populations for the region. The model also provides an understanding of the lower trophic interaction between herbivores (livestock) and their vegetation food base, in gauging future livestock populations. It is based on various ecological studies and on remote sensing estimates of rainfall for Africa which are now available (since 1983) at a high resolution across the continent.

It is hoped that the model will prove useful as an early warning system for livestock mortalities in arid parts of Africa. For 2014, an input of rainfall data in a 'normal' year can forecast mortality patterns if rainfall follows an average course. The rainfall patterns have also been determined from strong El Nino and La Nina years, which can be fed into the model if sea surface temperatures in the Indo-Pacific indicate one of these patterns is imminent. There is thought to be a nine-month advance warning from these indicators. The model is in its pilot development stage, with ground truthing and expert consultation on its parameters still required as part of a larger validation of the spatial tool.

2 Background

In the arid parts of Africa there is a strong relationship between rainfall and plant production. This is especially prevalent in areas that receive less than 300mm rain per annum, where water is the principal limiting factor to plant growth. Above this amount of rainfall, other factors (in particular soil nutrients) play an increasing role in influencing plant production. The relationship between production and rainfall falls away in global grasslands receiving more than 1035mm rain per annum [1]. Above this level of rainfall, livestock population dynamics are also more heavily influenced by other factors such as vector-borne diseases. For the arid Horn of Africa, the cut-off of 1035mm corresponds most closely to the wetter margin of the pastoral and agro-pastoral land uses as defined by Cecchi et al. (2010) [2]. It is therefore chosen as the limit of functionality and usefulness for this model.

[1] Yang, Y., Fang, J., Ma, W., & Wang, W. (2008). Relationship between variability in aboveground net primary production and precipitation in global grasslands. Geophysical Research Letters, 35, pp. 1-4.

[2] Cecchi et al. (2010).

The arid and semi arid regions of Africa, so-defined, are characterized by high inter-annual variation in rainfall, and extended droughts have been known to cause dramatic livestock mortalities that may culminate in certain cases in wide-scale humanitarian emergencies. It is to diminish the risks of such emergencies that the Technical Consortium and ILRI are looking to guide agencies to build resilience, including ecological resilience in the region. This model is offered as a resilience-building mechanism by providing understanding of and promoting balance within the lower trophic interaction between herbivores (livestock) and their vegetation food base.

Natural vegetation in these arid regions is often made up of grassland pasture or dwarf shrubland or an inter-changeable mix of the two. Tall shrubs and trees (phanerophytes) are sparsely distributed in arid regions, often along water courses. Part of the vegetation phytomass exists as woody or inedible rhizome material that persists as standing crop from one season to another and which makes up the building blocks for subsequent fresh growth when the rains arrive. The building blocks are not fixed year to year but may accumulate in years of good rainfall or decline during drought. This separation of persistent phytomass and more variable fresh growth is analogous to the concepts of capital (which can appreciate or depreciate in value) and interest on that capital from financial systems.

Methods

3

Based on the observations of Le Houerou et al. [3], plant production in an arid grassland over an average year amounts to 37.362% of phytomass and the variability of production is generally 1.5 times the variability in rainfall. The assumption is therefore that livestock will have 15% more food available than in a 'normal' year if rainfall is 10% above average. Food supplies or carrying capacity for the livestock are then calculated as all of the fresh growth plus a portion (10%) of the phytomass. Carrying capacity was determined from this using the assumption that one tropical LSU consumes 2500 kg DM p.a. [4]. Outputs in an average year were validated by comparison with field research results on carrying capacities / stocking rates for known locations and given rainfall regimes.

Rainfall anomalies (the difference from the long term mean annual rainfall) were calculated on a cell-by-cell basis using the Africa-wide TARCAT v2 dataset from TAMSAT University of Reading. This is drawn from a high spatial resolution ($5km^2$) and high temporal resolution (dekad) remote sensing (cloud surface temperatures) estimate of rainfall for the period 1983 - 2013. The calculation of fresh growth / production was straightforward from these data, and this model was found to hold well for the Karoo, a semi-arid dwarf shrubland in southern Africa [5].

The start-point geographic distribution of above-ground net primary production (in gm-2) was then calculated using a high spatial resolution dataset of rainfall from Worldclim [6] in the equation of Schuur et al [7], referred to by Yang et al. [8]. The rainfall dataset was first filtered to exclude all areas receiving > 1035mm rain per annum.

$$\text{ANPP} = \frac{0.01249 \times \text{PRECIPITATION}^{1.7131}}{\text{EXP}^{(0.001255 \times \text{PRECIPITATION})}}$$

This value was multiplied by 10 to provide a value in kg DM per ha per annum.

With this high resolution ($1km^2$) dataset of likely total above-ground primary production in a normal rainfall year, it was then possible to reverse-estimate the likely biomass or phytomass values for each grid cell using the observation of Le Houerou et al. [3] that production is normally equivalent to 0.3736 of biomass. Food supplies or carrying capacity for the livestock can then be calculated as all of the fresh growth plus 10% of the phytomass, assuming that one tropical livestock unit consumes 2500 kg DM per annum [4].

It is important to note that not all phytomass will be relevant to livestock; much will be inaccessible in trees for instance. Biomass values per grid cell were therefore multiplied by their % tree cover values (calculated from the

[3] Le Houerou, H.N., Bingham, R.I., & Skerbek, L.W. (1998). Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. Journal of Arid Environments, 15, pp. 1-18.

[4] De Leeuw, P.N. & Tothill, J.C. (1990). The concept of rangeland carrying capacity in sub-Saharan Africa - myth or reality? Land Degradation and Rehabilitation, 29b, pp. 19pp.

[5] Davies, R.A.G. (1994). Predation by Black Eagles on Rock Hyrax and other prey in the Karoo. University of Pretoria, Pretoria, Republic of South Africa.

[6] Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G., & Jarvis, A. (2005). Very high resolution interpolated climate surfaces for global land areas. International Journal of Climatology, 25, pp. 1963-1978.

[7] Schuur, E.A. (2003). Productivity and global climate revisited: the sensitivity of tropical forest growth to precipitation. Ecology, 84, pp. 1165-1170.

[8] Yang, Y., Fang, J., Ma, W., & Wang, W. (2008). Relationship between variability in aboveground net primary production and precipitation in global grasslands. Geophysical Research Letters, 35, pp. 1-4.

MODIS Vegetation Continuous Fields product from NASA [9]) and then subtracted 90% of this 'tree biomass value' from the total biomass values. This revealed an estimate of understorey biomass at 0.5km² across the region.

Ecological studies indicate that livestock normally consume only 30-40% of available production [10,11] for the Sahel and southern Ethiopia respectively. However, in an earlier application of this model [12], field research indicated that Rock Hyrax consumed only 15% of the total production in their safe feeding zones around rocky habitat.

It was only when an estimate of 15% of understorey plant biomass was used as relevant for livestock that estimates of carrying capacity in normal years tallied with field observations on long-term stocking rates corresponding to the rainfall regime, e.g. 18-20 LSU /km² in the Sahel (Pratt & Gwynne, 1997); 8.4 LSU / km² in the Karoo [13]. The model assumes then, that only 15% of total understorey biomass is relevant to livestock [12] as much of it will either harden/lignify without being consumed, be removed by insects or be overlooked by herbivores in favour of fresh green growth.

It is acknowledged that this is a major assumption in the model and that livestock may consume much more than this in certain years, but it also represents a long-term sustainable stocking rate that caters for dietary components in the vegetation such as fermentable carbohydrate, or other protein/nutrient levels, that may become limiting during drought.

The model therefore provides a high spatial resolution representation of relevant phytomass or the plant building blocks for annual growth. In the ASALs, these 'building blocks' for fresh growth exist as woody or inedible rhizome material that persists as standing crop from one season to another. The building blocks are not fixed from year to year, but may accumulate in years of good rainfall or decline during drought. This separation of persistent phytomass and more variable fresh growth is analogous to the concepts of capital: winter phytomass = biomass = capital (which can appreciate or depreciate in value) and annual plant production = fresh growth = interest. The allowance for phytomass to appreciate over good years and depreciate during drought and for fresh growth to be a dynamic rainfall-related function on this changing phytomass offers a better approximation for long-term variation in the number of animals that can be supported on the land.

In order to allow these building blocks to appreciate or depreciate within realistic limits during consecutive good/bad years, an upper limit of 1.3 x relevant biomass and lower limit of 0.7 x relevant biomass was set. Phytomass at the end of a year was modified by a factor which varied between x 0.9 (driest years) and x 1.3 (wettest years). The value used was directly (linearly) interpolated from the rainfall anomaly. This created a rapid increase (by up to 30%) of the capital in wettest years and a steady decline in capital (by up to 10%) in the driest years. Rainfall was allowed to be the major driver of the increase in plant matter during good rainfall years and, in a further step, livestock were allowed to be the major driver of phytomass depletion during dry or overstocked years.

If prevailing food supplies for the year exceed total demand of livestock consumption, it was assumed that there was no depletion of capital due to livestock. If consumption exceeds food supplies, then the exact deficit (less 15% to be found elsewhere) was subtracted from capital.

[9] Hansen, M., DeFries, R.S., Townshend, J.R., Carroll, M., & Dimicelli, C. (2004). MODIS Vegetation Continuous Field ver 1. Maryland USA: University of Maryland.

[10] Le Houerou, H.N. & Hoste, C.H. (1977). Rangeland production and annual rainfall relations in the Mediterranean Basin and the African Sahelo-Sudanian zone. Journal of Rangeland Management, 30, pp. 183-189.

[11] Cossins, N.J. & Upton, M. (1987). The Borana pastoral system of southern Ethiopia. Agricultural Systems, 25, pp. 199-218.

[12] Davies, R.A.G. (1994). Predation by Black Eagles on Rock Hyrax and other prey in the Karoo. University of Pretoria, Pretoria, Republic of South Africa.

[13] Dean, W.R.J. & MacDonald, I.A.W. (1994). Historical changes in stocking rates of domestic livestock as a measure of semi-arid and arid rangeland degradation in the Cape Province, South Africa. Journal of Arid Environments, 26, pp. 281-298.

For each grid cell, livestock numbers at start (P) are compared with the carrying capacity (K), where K or carrying capacity is not a fixed long-term stocking rate but a highly dynamic measure that realistically represents prevailing food conditions based on rainfall for that year and cell. The P:K ratio is then used to scale both livestock recruitment and livestock mortality in a linear fashion ranging between the extremes of worst case scenario and best case scenario and values for a 'normal' year. The assumption is that mortality rates will be maximum and recruitment rates minimum when large livestock populations are stressed by drought; and that mortality rates will be minimum and recruitment rates maximum when small livestock populations experience good rains.

Map outputs were produced for phytomass and production in an average year. The coefficient was calculated of the variation of livestock mortality rate to highlight which parts of IGAD arid regions regularly face the most dramatic increases and decreases of livestock numbers due to rainfall patterns. This was used in the environmental sensitivity layer along with the expected mortality rate for 2014 (based on average rainfall pattern) and a measure of livestock overhead going into 2014. Animations were also produced to visualise the pattern of change in model parameters over the 30 years of rainfall data. Output layers were checked for particular grid cells from one year to the next to ensure the calculations were made correctly.

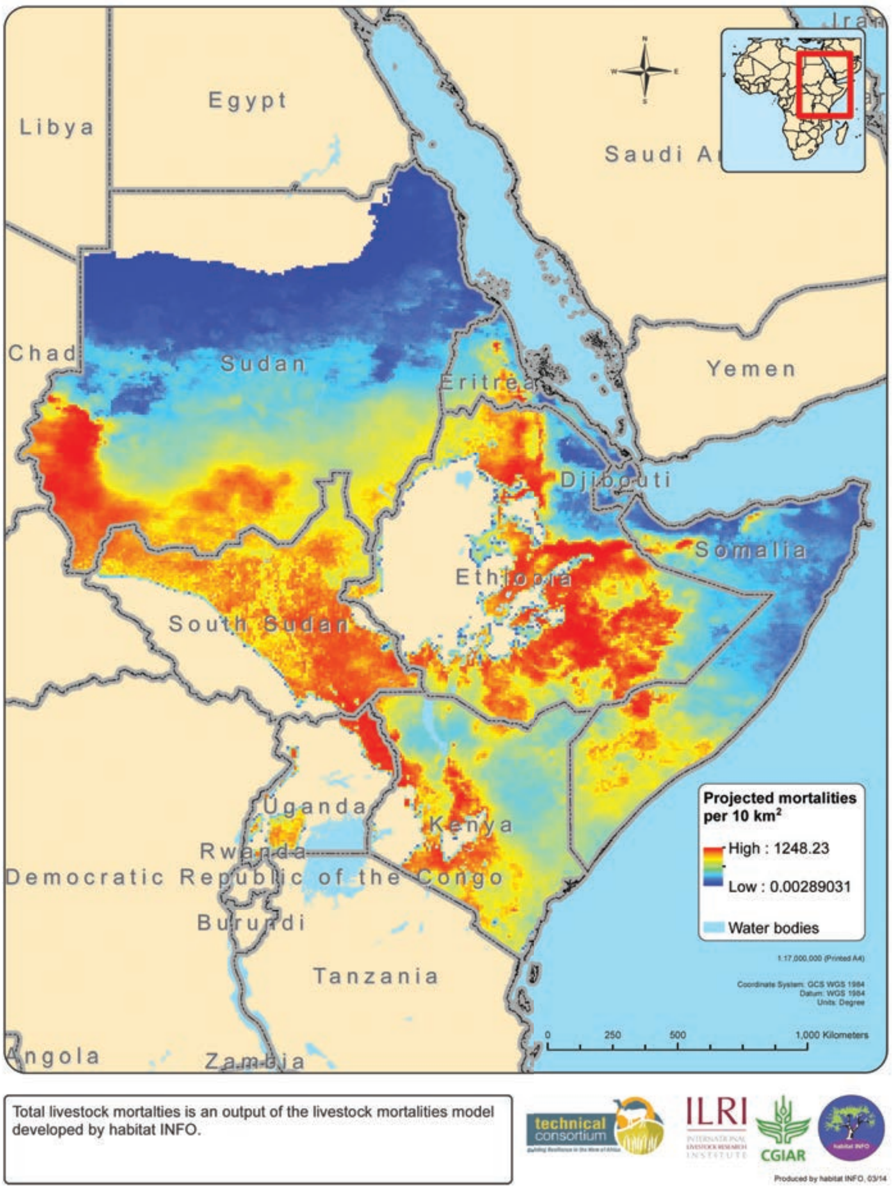
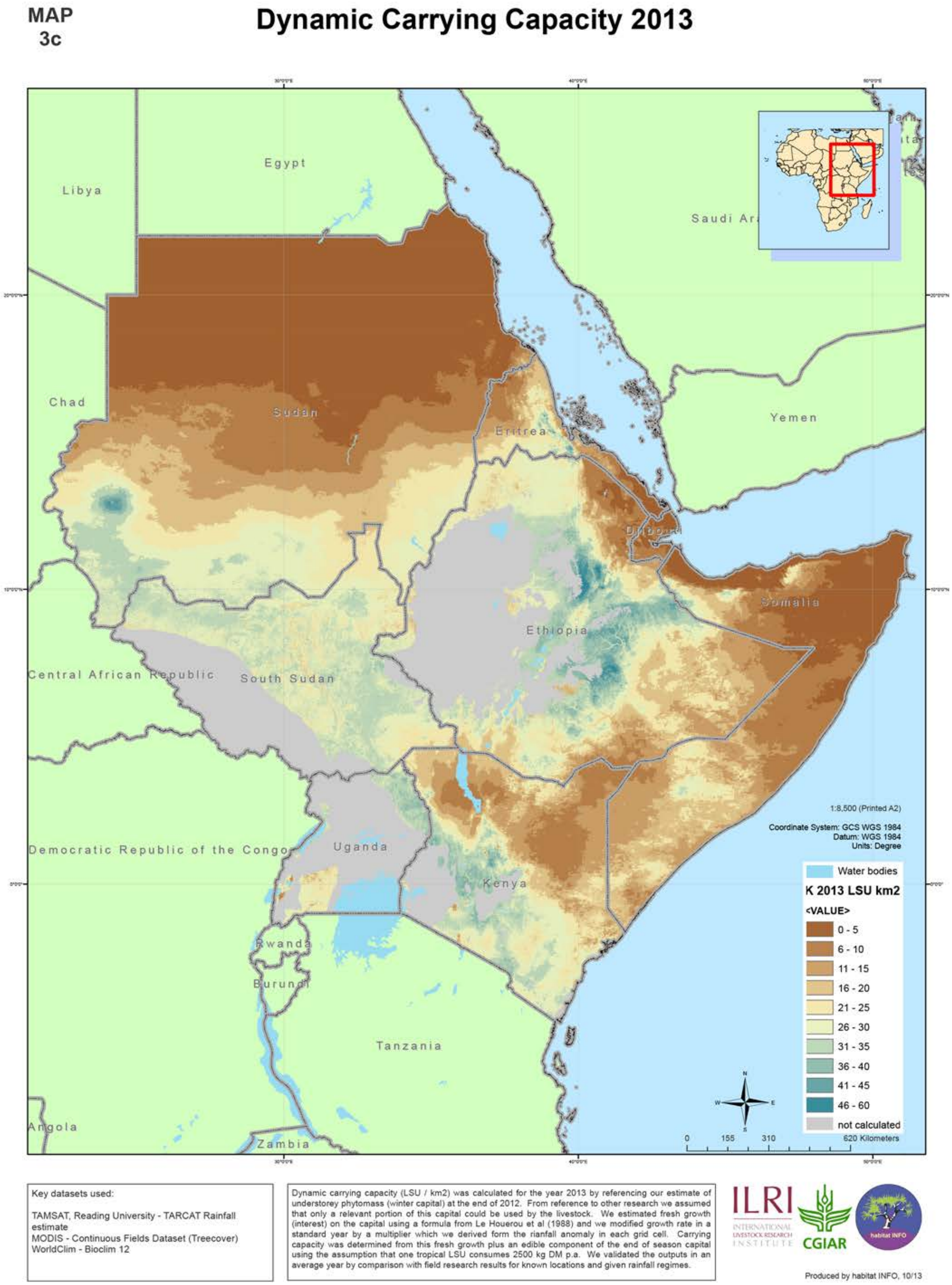


Figure 1: Pastoral drought risk - Projected livestock mortalities 2014.

Figure 4: Dynamic Carrying Capacity 2013



Use of rainfall estimates

Contemporary early warning systems and livestock insurance schemes are looking to remote sensing to assess forage condition. However, the use of NDVI signals to represent changes in plant production for arid lands has been problematic, especially where a lot of bare ground reveals differing reflectance signals. Furthermore, the increased cloud cover as a result of increased rainfall is likely to obscure vegetation response. We feel it is better to make rainfall estimates from the cloud surface temperatures and then make projections about the likely vegetation responses resulting from that rain. But there is no reason why NDVI and other direct signals might not be used to improve future versions of this rangeland model.

4

Application and limitations of model

Application

It is hoped that the model will prove useful as an early warning system for livestock mortalities in arid parts of Africa. For 2014, an input of rainfall data in a 'normal' year can forecast mortality patterns if rainfall follows an average course. The rainfall patterns have also been determined from strong El Nino and La Nina years, which can be fed into the model if sea surface temperatures in the Indo-Pacific indicate one of these patterns is imminent. There is thought to be a nine-month advance warning from these indicators.

Limitations

The model is in its pilot development stage, with ground truthing and expert consultation on its parameters still required as part of a larger validation of the spatial tool.

Major mortalities of livestock do not normally occur during extreme drought if that drought is confined to one year, but are rather associated with prolonged, multi-year drought. As a result, immediate values of rain or lack of growth do not tell the whole story. It is proposed that this rangeland model contains cumulative simulations that may come close to approximating the build-up and manifestation of pasture exhaustion but, at this stage, the model only deals with direct rainfall effects on the vegetation. It cannot yet cater for the effects of livestock population dynamics and how high numbers of livestock can cause depletion of the phytomass. In an earlier application of a similar model for rock hyrax in the Karoo, it emerged that a great build-up of herbivore numbers during very wet consecutive years of the late 1970s was as instrumental to the major mortalities experienced during the early 1980s as were the consecutive dry years during the latter [14]. The next step in the progression of this model will be to incorporate ratio dependence between livestock numbers and available forage.

At this time, comparisons can be made between the model's projections for available food with a static dataset that provides the best spatial representation of livestock numbers for the region, the FAO / ERGO Gridded Livestock of the World at 5km^2 resolution [15]. GLW density data (2005 data adjusted to FAOSTAT 2005 national totals except for camels which were received from Giulia Conchedda, AGAL, pers. comm. 2013) for camels, cattle, sheep and goats were combined into a single raster of livestock (tropical LSU). LSU equivalents of 1.1 were used for camels, 0.5 for cattle, and 0.1 for both sheep and goats. Livestock densities will naturally have changed since the GLW data were collated, but it represents the best spatial data currently available.

[14] Davies, R.A.G. (1994). Predation by Black Eagles on Rock Hyrax and other prey in the Karoo. University of Pretoria, Pretoria, Republic of South Africa.

[15] Robinson et al. 2007

External comment and review by dryland experts

5

JONATHAN DAVIES
Coordinator, Global Drylands Initiative, IUCN, the International Union for Conservation of Nature

The methodology for measuring vegetation, and associated livestock numbers, is less of a concern than the use of the concept of carrying capacity. In an area where the normal rainfall pattern varies from less than half the mean to more than 3 times the mean (leaving out drought years) the range of vegetation growth between years will be immense. Undergrazing and overgrazing both lead to loss in rangeland productivity, so what use could we make of carrying capacity figures? If it simply an indicator of rangeland condition (i.e. a resilience indicator) then the vegetation data alone will suffice and the conversion to TLU is unhelpful – although vegetation alone is inadequate and we need to know about species, since areas infested with invasive will distort the outcome.

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The model used a carrying capacity "determined from this using the assumption that one tropical LSU consumes 2500 kg DM p.a. [16]". However rangeland management literature generally considers a proper use factor of 50% or less, based on the consideration that not all biomass can be consumed by livestock and secondly that it is undesirable to consume all biomass. It is suggested the authors consult this literature and build in a proper use factor, which will reduce the carrying capacity

"The model assumes then, that only 15% of total understory biomass is relevant to livestock [17] as much of it will either harden/lignify without being consumed, be removed by insects or be overlooked by herbivores in favour of fresh green growth." Referring to the remark on proper use factor, this appears quite low. Advice would be to do a more rigorous consultation of the literature. Satellite imagery typically reveals a stark contrast in soil exposure between livestock grazed areas and protected areas, however difficult to imagine a 15% grazing would create such a stark contrast.

The model authors decided against the use of NDVI as they felt NDVI signals to represent changes in plant production for arid lands were problematic, especially where a lot of bare ground reveals differing reflectance signals. Furthermore the increased cloud cover as a result of increased rainfall is likely to obscure

[16] De Leeuw, P.N. & Tothill, J.C. (1990). The concept of rangeland carrying capacity in sub-Saharan Africa - myth or reality? Land Degradation and Rehabilitation, 29b, pp. 19pp.

[17] Davies, R.A.G. (1994). Predation by Black Eagles on Rock Hyrax and other prey in the Karoo. University of Pretoria, Pretoria, Republic of South Africa.

vegetation response therefore rainfall estimates from the cloud surface were used and subsequent projections about the likely vegetation responses from that rain made. There is a counterargument, however, that NDVI is strongly related to biomass over larger areas while the relation rainfall to biomass typically varies significantly between regions (see le Houerou [18]) partly because of differences in rainwater use efficiency.

[18] Le Houerou, H.N., Bingham, R.I., & Skerbek, L.W. (1998). Relationship between the variability of primary production and the variability of annual precipitation in world arid lands. Journal of Arid Environments, 15, pp. 1-18.

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