MARIS: scalable online scenario development tool for rangeland conservancy managers using high spatial-temporal resolution carrying capacity maps and livestock market data.

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Abstract
Although the management of livestock numbers within the bounds of carrying capacity of African rangelands is a way to manage risks, both scientists and practitioners, caution against a momentary and local use of carrying capacity as a management indicator. Carrying capacity should be seen in wider spatial and temporal/seasonal context as well as in a social and economic context. Given the large numbers of conservancies across Kenya, and its Maasai Mara region in particular, with many more landowner members, it is difficult for conservancies' managers to contextualize phenomena such as carrying capacity and market price over space and time.
We report the results of an investigation in the Maasai Mara rangelands, into functional characteristics a tool for spatial-temporal carrying capacity assessment and livestock markets prices monitoring should have to provide relevant management information to conservancy managers and conservancy members. A scalable web-application called the Mara Rangeland Information System, or MARIS, was developed, which assesses, at 23 meter resolution and 10 day historic or 1-day near-future intervals, both grassland dry matter production, and consumption by 19 wildlife and livestock species, as well as rangeland carrying capacity. MARIS facilitates managers to develop scenarios by varying input variables of either grass production or consumption, or by drawing different management blocks on a carrying capacity map assessing different management practices under scenarios of rainfall. Managers can relate the carrying capacity scenarios to offtake prices at different markets that MARIS monitors over time.
After testing MARIS in 6 workshop iterations across the whole development process, Maasai Mara rangeland managers concluded that the prototype is ready for pilot use in management plan development.

Introduction
Kenya has seen a 70% reduction of wildlife since the 1970s due to exponential human population growth, increasing livestock numbers, climatic change, and policy, institutional and market failures (Ogutu et al., 2016) and shocks due to droughts (Nkedianye et al., 2011). Eleven regional associations of conservancies, organized in the Kenya Wildlife Conservancies Association, coordinate 160 conservancies that manage 11% of Kenya's land, i.e. 6.3 million ha, affect 700,000 households, and aim to turn this trend (KWCA, 2019).
Although the management of livestock numbers within the bounds of carrying capacity of rangelands is a way to manage risks, both scientists and practitioners, caution against a momentary and local use of carrying capacity as a management indicator. They show and argue that carrying capacity should be seen in wider spatial and temporal/seasonal context as well as in a social and economic context (Briske, Coppock, Illius, & Fuhlendorf, 2020; Jakoby, Quaas, Baumgartner, & Frank, 2015; NRT, 2019). Obviously, conservancy managers and their members do contextualize. Yet contextualization over space and time of phenomena such as carrying capacity or market prices is difficult.
Given the large numbers of conservancies over very large areas and the difficulty for conservancies' managers to contextualize phenomena such as carrying capacity and market price over space and time, scalable widely accessible tools for understanding of historic and recent development of carrying capacity and market prices over large areas are in order. Besides the monitoring and evaluation of these management areas, also the development of spatial and temporal scenarios of management alternatives are required. Such tools and methods do not exist yet.
The objective of the work presented in this paper was to develop an online tool together with conservancy managers of the Maasai Mara, that would be scalable to other conservancies in Kenya. The research questions discussed in the short scope of this paper are which functional characteristics such tool should have and whether it provided relevant management information. The work resulted in a web-application called the Mara

Rangeland Information System, or MARIS. Development of MARIS took place between 2014 and 2019 within the Mau Mara Serengeti Sustainable Water Initiative.

Study site and methods

The Maasai Mara reserve, in the Southwest of Kenya, measures approximately 1500 km2. Outside the reserve, 15 conservancies have organized themselves in the Maasai Mara Conservancies Association, with 7091 landowners managing an area of 1150 km2 (MMWCA, 2020). Landowners lease land to the conservancies, which pay with part of tourism revenues thus providing an income sufficient to close the poverty gap (Osano et al., 2013). In return for this payment, conservancies expect ecosystem services from landowners who collaborate in management plans that conservancies develop, which limit livestock numbers and define pastoral practices.

Although the Maasai Mara is not the driest region in Kenya, past droughts have had a serious impact on livestock herds where 30% of livestock died (Nkedianye et al., 2011). Overstocking is a problem and degradation of grasslands can be found in the North East through vegetation mapping published in these proceedings (Toxopeus et al., in these proceedings). Apart from the pressure of droughts, overstocking (Lovschal, Hakonsson, & Amoke, 2019). and fencing (Lovschal et al., 2017), population growth is, according to Courtney, a time bomb (Courtney, 2016), with 90.8 births/1000 people/annum, compared to 28.3 for Kenya, amounting to a population doubling time of approximately 15 years.

Four algorithms form the core of MARIS, which were elaborated from earlier application in the Amboseli ecosystem, in Kenya (Toxopeus, 1996, 1997). The first algorithm establishes a high resolution (23 meter) pixel floristics vegetation map with percentage grass cover, explained by Toxopeus et al. in these proceedings. Since floristic composition of grasslands is known, nutritious value of dry matter production can be corrected for palatability. The next three algorithms calculate grasses available production, consumption, and carrying capacity. These three algorithms are implemented with the workflow functionality and client-server architecture of the ILWIS 4.0 GIS (Lemmens et al., 2018), calculating dry matter biomass production per 23 meter pixel over a selected period of time. The forage production (gr/m2) for each pixel is a function of rainfall over a certain period of time (mm) derived from a series of satellite products, rainfall effectivity (factor), value depending on soil texture, depth and run on-off (Van Wijngaarden, 1985), percentage grass cover (%), derived from the vegetation map, adjusted for palatability (factor) and proper use (factor) (Hunt, 2008).

Consumption is a function of number of grazers, both wildlife and livestock, and mixed feeders counted annually in dry or wet season by DRSRS aerial survey in the Narok county animal census, distributed with a species distribution model. The numbers of nineteen grass-feeding species in the census, including cattle, sheep and goats, and their daily dry matter intake (DMI) give demand over the selected period.

To estimate the carrying capacity (CC), first wildlife consumption has been subtracted from the total production, the remaining forage is deemed available for livestock. Then this remaining forage has been summed with actual livestock consumption (per pixel), resulting in either a surplus or deficit of forage. Finally, scenario development with either variables of production, or consumption or both can be done. Production can be varied in terms of rainfall, grass cover, palatability and proper use. Consumption can be varied by livestock numbers and their daily DMI. A carrying capacity table shows all possible sums of production and consumption scenarios and corresponding surpluses or deficits.

The central objective of development was scalability and replicability in other Kenyan and African rangelands. To ease scalability and replicability the application uses open-source software. It also uses a continuous stream of open access global satellite data and local empirical parameters. Where internet is limited or off-line, the backend workflow algorithms, can be run on the regular ILWIS desktop GIS, the same software that also runs on the application server. Therefore, calculations can be done off-line.

Results

The MARIS web-application can be found at http://mara.rangelands.itc.utwente.nl/. All output maps of the production, consumption and carrying capacity algorithms and their constituting input maps (Figure 1) are organized in a tree pane (left), and can be seen in a map output pane (middle) and a map input pane (right). Maps synchronously zoom and pan so that areas can be studied in detail and developments in production, consumption and carrying capacity output maps can be understood from their various input maps.

Additional information about time series of rainfall and vegetation greenness are presented in maps of respectively rainfall surplus or deficit or current NDVI and a graph for a selected location, possibly zooming to a period of particular interest, for instance a period of drought, as basis for scenario development (Figure 2). Time series of livestock price development are presented in a scatter plot where for instance price differences of the same cattle breed with the same body condition but in different livestock markets can be observed.

With understanding of the historic states of the grassland and market system as well the near future rainfall forecast, users can develop scenarios for their conservancy. They adjust production and consumption variables according to scenarios they name. These inputs and calculation results are then presented in production and consumption scenario tables and in a cross table showing carrying capacity resulting from all combinations of production and consumption scenarios. For example, conservancy management could assess which of different scenarios of numbers and breeds of cattle in combination with different scenarios of rainfall sum and proper use level would lead to exceedance of carrying capacity. Finally, users can also delineate management blocks on a map, for which production, demand and carrying capacity under current conditions are presented in a bar graph and table.

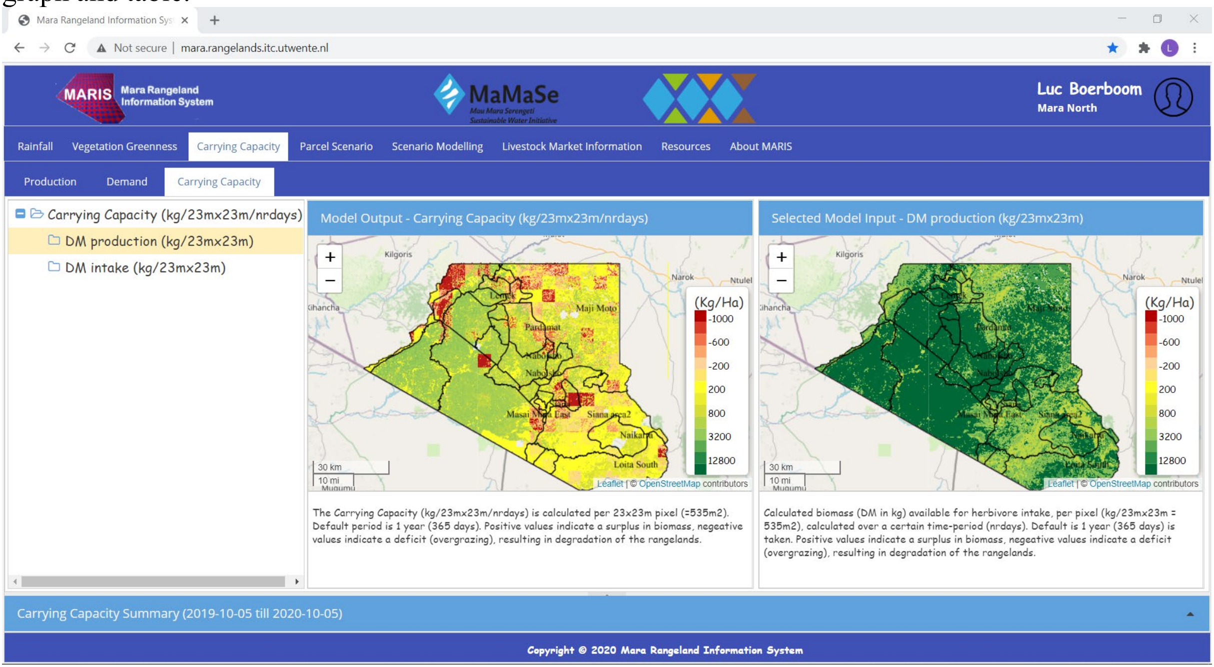

Figure 1 MARIS interface organized in a tree pane (left), an output map pane (middle) and an input map pane (right). The output map shows carrying capacity exceeds carrying capacity in red areas.

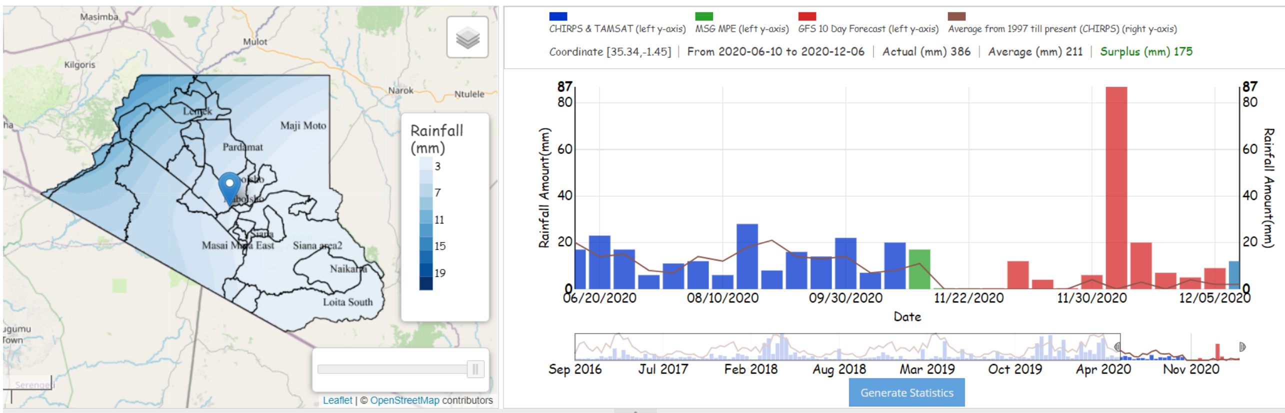

Figure 2 MARIS interface for rainfall where a map and graph show rainfall deficit over space and over time for a selected period and location.

The six workshops with managers from almost all conservancies that steered the development, lead to similar understanding of the concept of carrying capacity, a request for market price monitoring and for location specific temporal overview of rainfall and vegetation greenness. They found that workflows made algorithms transparent and testing lead to a recommendation to pursue funding for piloting in management plan development since MARIS information was deemed relevant.

Discussion

Given the positive response from conservancy managers, the aspiration exists to roll out to other rangeland areas in Kenya. However, validation by conservancies managers through piloting of MARIS in the regular preparation of management plans over several seasons will be necessary to learn and gain experience. Although price differences between markets, breeds and body condition could clearly be observed, the monitoring of those markets has been too short, 1 year, to show price patterns over time.

Scalability is important for roll out of this Rangeland Information System (RIS) to all 160 conservancies in the rangeland areas of Kenya, and beyond. The structure of the workflows can remain the same. The omnipresence of satellite data for rainfall and vegetation greenness would require minor technical adaptation. Also, the collection of market prices does not require major adaptation. The empirical relation for dry matter production appeared to work well in the Maasai Mara but would need validation under different environmental conditions or eco-regions. The main effort would be to develop the floristics composition vegetation map.

MARIS allows conservancy managers to consider the concept of carrying capacity in spatial contexts at different scales due to high-resolution vegetation mapping and in different temporal contexts. Moreover, it provides context of the livestock markets prices over time.

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References

Briske, D. D., Coppock, D. L., Illius, A. W., & Fuhlendorf, S. D. (2020). Strategies for global rangeland stewardship: Assessment through the lens of the equilibrium-non-equilibrium debate. *Journal of Applied Ecology, 57*(6), 1056-1067. doi:10.1111/1365-2664.13610

Courtney, C. (2016) The Mara's exploding population: Limiting population growth is crucial to address the pending population time bomb. In, *Voices of the Mara: Vol. 2*. Narok: Maasai Mara Wildlife Conservancies Association.

Jakoby, O., Quaas, M. F., Baumgartner, S., & Frank, K. (2015). Adapting livestock management to spatio-temporal heterogeneity in semi-arid rangelands. *Journal of Environmental management, 162*, 179-189. doi:10.1016/j.jenvman.2015.07.047

KWCA. (2019). *Strategic Plan 2019-2023*. Retrieved from

Lemmens, R., Toxopeus, B., Boerboom, L., Schouwenburg, M., Retsios, B., Nieuwenhuis, W., & Mannaerts, C. (2018, 29–31 August 2018). *Implementation Of A Comprehensive And Effective Geoprocessing Workflow Environment.* Paper presented at the FOSS4G 2018, Dar es Salaam, Tanzania.

Lovschal, M., Bocher, P. K., Pilgaard, J., Amoke, I., Odingo, A., Thuo, A., & Svenning, J. C. (2017). Fencing bodes a rapid collapse of the unique Greater Mara ecosystem. *Scientific Reports, 7*, 7. doi:10.1038/srep41450

Lovschal, M., Hakonsson, D. D., & Amoke, I. (2019). Are goats the new elephants in the room? Changing land-use strategies in Greater Mara, Kenya. *Land Use Policy, 80*, 395-399. doi:10.1016/j.landusepol.2018.04.029

MMWCA. (2020). Conservancies Profiles. Retrieved from https://maraconservancies.org/conservancies-profiles/

Nkedianye, D., de Leeuw, J., Ogutu, J. O., Said, M. Y., Saidimu, T. L., Kifugo, S. C., . . . Reid, R. S. (2011). Mobility and livestock mortality in communally used pastoral areas: the impact of the 2005-2006 drought on livestock mortality in Maasailand. *Pastoralism: Research, Policy and Practice, 1*(1), 17. doi:10.1186/2041-7136-1-17

NRT. (2019). *The Northern Rangelands Trust Rangelands Strategy 2019-2022*. Retrieved from

Ogutu, J. O., Piepho, H.-P., Said, M. Y., Ojwang, G. O., Njino, L. W., Kifugo, S. C., & Wargute, P. W. (2016). Extreme Wildlife Declines and Concurrent Increase in Livestock Numbers in Kenya: What Are the Causes? *Plos One, 11*(9), e0163249. doi:10.1371/journal.pone.0163249

Osano, P. M., Said, M. Y., de Leeuw, J., Ndiwa, N., Kaelo, D., Schomers, S., . . . Ogutu, J. O. (2013). Why keep lions instead of livestock? Assessing wildlife tourism-based payment for ecosystem services involving herders in the Maasai Mara, Kenya. *Natural Resources Forum, 37*(4), 242-256. doi:10.1111/1477-8947.12027

Toxopeus, A. G. (1996). *ISM : an Interactive Spatial and temporal Modelling system as a tool in ecosystem management : with two case studies : Cibodas biosphere reserve, West Java Indonesia : Amboseli biosphere reserve, Kajiado district, Central Southern Kenya.* (PhD), International Institute for Geo-Information Science and Earth Observation, Enschede.

Toxopeus, A. G. (1997). *Spatial and temporal modelling for sustainable management of semi - arid rangelands: the wildlife versus livestock issue in the Amboseli ecosystem, Southern Kenya. .* Paper presented at the Conference on geo-information for sustainable land management, Enschede, The Netherlands.