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Review article

Focusing on livestock improvement strategies that enhance adaptive and coping mechanisms in the context of climate change in southern Africa

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ABSTRACT

Climate change and variability is among the first and crucial limiting factors of sustainable livestock production in southern Africa. This is on the background that southern Africa is one of the most vulnerable sub regions to climate change and climate variability, a situation aggravated by the interaction of the multiple stresses that occur at various levels and the agricultural systems' low adaptive capacity. However, it is undisputable that many poor resource livestock farmers who are the majority in southern Africa are wholly or partially dependent on livestock for their livelihood, and livestock keepers will need to adapt to climate change for their survival. This development has spurred the need for creation and implementation of livestock improvement strategies aimed at overcoming the negative effect of climate change on livestock production. In addition, climate change induced environmental stressors will further accentuate heat, disease and water stress-related problems. The review explores some of the likely impacts of climate change on livestock production and discusses measures to react to the expected changes in climate through livestock improvement. This is followed by a discussion of how climate change may alter the approach to genetic improvement. The report then analyses the specific issue of selection and crossbreeding systems and their implication for livestock improvement. It is suggested that the focus on livestock

improvement strategies will need to take into account the alleviation of heat and water stress in the context of semi arid livestock production systems. Livestock improvement based on livestock adaptive strategies and coping mechanisms in the context of climate change are critical in this context. This is a result of the understanding that livestock productivity decline has become a problematic issue in southern Africa, particularly due to the long term effect of climate change. Climate change has risen to become one of the most challenging issues confronting the sub region through decline of livestock productivity. In order to lessen the extent of livestock vulnerability to climate change livestock improvement strategies should take into cognizance of enhancing adaptive and coping mechanisms in livestock production. In recognition of this threat to the sub region, this paper further discusses some of the pertinent issues which proffers possible solutions aimed at aiding appropriate livestock improvement in the context of climate change. Accordingly, developing new and innovative livestock improvement strategies to understand the relationship between climate change induced stressful environment and animal productivity, while highlighting livestock improvement strategies and livestock traits to target. Promoting local animal genetic resources will be part of the mitigation strategy.

1. Introduction

Changes in climate and climate variability will affect livestock production systems in all parts of the world, and will inevitably impact the 1.3 billion poor people whose livelihoods are wholly or partially dependent on livestock (Thornton et al 2009). Due to the rapid population increase there is a growing demand for livestock products which makes a good case for improving the livestock sector through climate change mitigation measures. Gains in appropriate mitigation strategies in the sub region will ultimately benefit the many small-scale farmers who collectively own more than 80% of the livestock in southern Africa (SADC RISDP, 2006). Livestock production currently contributes about 35 per cent of agricultural GDP in Sub Saharan Africa (and if non-food products and services were added this share would even be higher (Ehui et al., 2002) which is closely to more than 30 percent average contribution of livestock to agricultural GDP for southern Africa (FAOSTAT, 2000). This points to the fact that livestock production is thus an important activity in the agricultural economy of the sub region. This is on the background that evidence from research on climate change is now overwhelmingly convincing that climate change is real and livestock production is one of the sectors which will be greatly affected. This means that focusing on mitigation alone will not address the inevitable impacts of currently observed climate change on livestock improvement options. It should extend to adaptation, that is adjustments in breeding options which moderate harm or exploit beneficial opportunities in response to actual or expected climate stimuli or their effects is therefore imperative (IPCC, 2007b). Genetic improvement is a possible mitigation option whereby production efficiency can be improved (Wall et al., 2010). Therefore, Livestock improvement options which take into account mitigation and adaptation strategies need to be put in place if climate change that is related to animal production is to be contained within certain limits (Scholtz et al., 2013). In the future, climate change is expected to be a major force testing resilience of livestock production systems by ensuring that livestock systems remain productive and efficient while coping with climate change stresses. The basis of any future livestock improvement strategies should be a close correspondence between production and genetics of adaptability in a specific environment which will enhance the capacity of animals to survive and reproduce and hence pass on genes to the next generation. Ensuring that livestock systems remain productive and efficient while maintaining their flexibility in the context of climate change will be a major challenge. As a result harmonizing for productive and efficient livestock

production transformations will require a significant research commitment in livestock improvement which will play a critical role in the genetic measures taken for adaptation of livestock to climate change, as southern Africa is highlighted as a potential hotspot of change, with substantial drying and increases in temperature,

2. Developing new and innovative livestock improvement strategies to deal with the emerging climate change challenges

The primary focus of selective animal breeding has been on increasing the productivity of domesticated animals leading to substantial increases in productivity in meat, milk, eggs and wool from most species, however, undesirable effects have been due correlated response in other traits have been observed. Livestock improvement programs have traditionally been focused from the perspective of the increasing productivity (meat, milk, etc), rather than the livelihood of the livestock producer. Despite the efforts of many livestock improvement programs, this approach has persisted and meant there is a limited understanding by the breeders of the role and livelihood benefits received by small scale livestock producers from their livestock enterprises. Taking climate change factor in livestock improvement focus means developing new and innovative methods to understand the relationship between the stressful environment and animal productivity. Such an approach is based on building the context in which the adaptability of animals to stressful environment is embedded, rather than studying the productivity in isolation from that context then connecting the productivity to a climate change model. There is need to change the livestock improvement strategies focusing on animal characteristics related to adaptation to harsh environments than productivity alone. The resultant animal should perform in climate change induced stress environment in terms of behavioral and physiological adaptation. Livestock improvement strategies should focus on enhancing the ability of animals to cope during conditions of feed resource shortage, induced by unfavorable climatic conditions. Survival on low quality fodder and maintenance of body condition during drought as exemplified by slow emaciation rate during feed and water resource shortage becomes critical in future livestock improvement strategies. On the other hand, climate change has an indirect bearing on livestock production by influencing the emergence and distribution of livestock diseases in addition to exacerbating the frequency and distribution of adverse conditions and reducing water supplies. Therefore, traits such as high drought tolerant, heat stress and tolerant to emerging diseases should be integral part of an effective future livestock improvement strategy. This should be embedded in clear-cut breeding objectives which are often multi-faceted, which enhance the animal's ability to survive in harsh environments. This approach plays an essential role in enabling livestock's adaptation and fitness in such environments. The major components of livestock improvement strategies in this context is ranking of key traits in relation to genetics of adaptation to unpredictable environments and adaptability ranking of different livestock under extreme climate and adaptive characteristics. This approach can be quite different and sometimes challenging for livestock breeders because it removes animal productivity from being the focus and considers it as one component of a complex animal-climate change system. This will enable the development of livestock improvement strategies that address the inevitable impacts of currently observed climate change, rather than solely the desire to promote animal productivity in isolation of the producers own needs and issues. The harsh effect of climate change is expected to have maximum impact on vulnerable smallholder livestock sector engaged in extensive livestock production systems which are predominantly climate dependent. Therefore, it is imperative that livestock breeding and production options and strategies focus on reducing vulnerability and building resilience among these communities. The design of effective livestock improvement intervention measures for climate change adaptation for these communities can be hinged on comprehensive knowledge of livestock adaptation traits such as heat stress and performance under poor quality rangelands. The overall structure and dynamics in animal production traits in the smallholder livestock production systems, including key information about indigenous breeding strategies relating to animal adaptation and management in climate sensitive dry-lands. Recently, new methods have become available to assay adaptive variation in the genome of threatened populations, enabling the application of prioritization protocols to use unique adaptive variants as well as neutral, demographically mediated variation and even to test the association of this variation with environmental variables to identify geographic regions of priority (e.g. Bonin et al. 2007; Joost et al. 2007, 2011). This implies that optimization of the genetic and genomic resources for the adaptation of livestock to climate change is possible.

3. Implication for livestock improvement strategies

Livestock improvement strategies could not ignore the need to produce an animal which adapt to higher ambient temperatures, lower nutritional value of feed resources and new diseases and parasites occurrence due to changes in environmental conditions. The design of effective livestock improvement and production intervention measures for climate change adaptation for these communities can be hinged on comprehensive knowledge of livestock adaptation traits such as heat stress and performance under poor quality rangelands. The holistic and participatory approach taking into account overall structure and dynamics in livestock production traits in the smallholder livestock production systems, which include key information about animal adaptation and management in climate sensitive dry-lands will play a very important role. It is undisputable that present livestock production systems in southern Africa are based on rangeland grazing husbandry systems, ecological destruction through climatic variability and overgrazing due to high stocking rates in areas where feed and water has been compromised due to high temperatures caused by climate change does not augur well for future livestock productivity which will be gravely affected by climate change and variability. There is need to change the livestock improvement strategies focusing on animal characteristics related to adaptation to harsh environments than productivity alone. The resultant animal should perform in climate change induced stress environment in terms of behavioral and physiological adaptation. Livestock improvement strategies should focus on enhancing the ability of animals to cope during conditions of feed resource shortage, induced by unfavorable climatic conditions. Survival on low quality fodder and maintenance of body condition during drought as exemplified by slow emaciation rate during feed and water resource shortage becomes critical in future livestock improvement strategies. Adaptive strategies and coping mechanisms in livestock improvement and production options will likely accompany maintenance of animal genetic diversity, but questions remain which livestock adaptation and resilience indicators to and hence the livestock breeding goal may be totally different from previous breeding programs. An obvious option is to breed for traits associated with superior productivity and resilience in conditions expected to be prevalent as a result of climate change, such as heat and drought tolerance and resistance to certain diseases. In terms of livestock selection programs it is critical that animal selection objectives should not compromise important adaptational qualities such as disease and parasite tolerance, ability to survive and reproduce in harsh environment and the ability to exist on low quality feed and limited water supply. Increased productivity through selection should enhance their potential for productive traits without weakening their adaptational characteristics. Ensuring the survival of livestock by promoting their inherent genetic merit will minimize the competition to indiscriminate crossing with imported livestock genetic resources. However, sustainable livestock improvement cannot be guaranteed for some environments without the adaptive traits of these genetic resources. It is assumed that with the rate of developments in livestock breeding and production biotechnology suggests, it will soon be possible to identify and manipulate genes, including those which confer disease resistance and physiological adaptation in livestock production to environmental stresses. The study of genetic variation using DNA marker technology focusing on adaptability traits such as heat stress, disease and parasite tolerance, ability to survive and reproduce in harsh environment and the ability to exist on low quality feed and limited water supply may complement the vision of producing an animal which is able to cope with climate change induced stresses. Development of tools for genetics of adaptation will be necessary for unraveling the physiological basis for adaptation in sustainable livestock production. Marker Assisted Selection (MAS) has the potential to expedite both pure- and crossbreeding programs for adaptation, assuming phenotypes are available (Hayes et al., 2012); programs for performance recording of adaptation livestock traits in southern Africa are thus needed. However, livestock production system resilient to climate change is unlikely to be achieved with a single strategy. There is need for genetic changes in animals in terms of reproduction, nutrition, and health aspects. Preparation for these transformations will require a significant research commitment and molecular genetics playing a major role in the genetic measures taken for adaptation of livestock to climate change and variability. In southern Africa there is lack of specific research knowledge explaining why local animal genetic resources are adapted to a local environment in which imported animal genetic resources can not survive and flourish. This deficit calls for greater effort in characterization of local animal genetic resources, including their production environments, by using the most modern tools available such as molecular genetics. The output from the previous livestock genetic characterization attempt which disregarded climate change effect may be questionable in the study of adaptation. Therefore, reliable information may be sort from breeds characterized under climate change induced stresses livestock production environments. The study of adaptation implies the use of a “landscape approach,” with detailed information describing the production system (FAO, 2012), including socio-economic information (Drucker, 2010) and indigenous knowledge about management of specific animal genetic resources in

their own environment taking into account climatic change and soil, vegetation, and water resources. Livestock production may obtain greater benefits by improving output while maintaining their characteristic secondary traits, such as adaptation to the environment. On the other hand, climate change has an indirect bearing on livestock production by influencing the emergence and distribution of livestock diseases in addition to exacerbating the frequency and distribution of adverse conditions and reducing water supplies. Therefore, traits such as high drought tolerant, heat stress and tolerant to emerging diseases should be integral part of an effective future livestock improvement strategy. This should be embedded in clear-cut breeding objectives which are often multi-faceted, which enhance the animal's ability to survive in harsh environments. This approach plays an essential role in enabling livestock's adaptation and fitness in such environments. The major components of livestock improvement strategies in this context is ranking of key traits in relation to genetics of adaptation to unpredictable environments and adaptability ranking of different livestock under extreme climate and adaptive characteristics. Therefore, it is critical that livestock improvement strategies should be compatible with the goals of curbing the effects of climate change. In this regard the first step is the identification of traits to target which are compatible with the goals of curbing the effects of climate change. The conventional breeding strategies which targeted economic important traits in livestock will pose a lot of challenges where feed and water has been compromised due to high temperatures caused by climate change. Adaptive genetics should be the basis of any livestock improvement strategies. The introduction of livestock biotechnologies in molecular genetics can be engaged in the identification of adaptive traits. Application of new technologies, including genomic selection and advanced reproductive technologies, will play an important role in meeting the challenges associated with climate change mitigation. Genomic selection targeting genetics of adaptation, which enables prediction of the genetic merit of animals from genome-wide molecular markers, has already shown potential use in livestock breeding and is expected to double genetic gains for both productive and adaptive traits to counteract the negative effects of climate change. The use of marker assisted selection through the whole-genome sequence data should both accelerate the rate of gain and enable rapid discovery and enhance livestock adaptive and coping mechanisms in the context of climate change in southern Africa.

4. Approaches to selection and crossbreeding in climate change induced stressful environment

In the context of climate change there is need for selecting for 'environmental fit' which aim for a good match between the end result of the selection process, in terms of genetic change, and the environment, or system, in which animals are reared and maintained (Lawrence and Wall, 2014). This implies that research is required to measure the genetic antagonism between adaptation and production traits to evaluate the potential selection response. The selection methods in animal production should focus probably on animals increasing feed intake or decreasing metabolic heat production, those enhancing heat-loss capacities, and those involving genetic selection for heat tolerance. According to Boettcher, et al., (2015) directional selection for adaptive traits will likely accompany maintenance of diversity, but questions remain about indicators of adaptation and resilience and hence the breeding goal. An obvious option is to breed for traits associated with superior productivity and resilience in conditions expected to be prevalent as a result of climate change, such as heat and drought tolerance and resistance to certain diseases.

Livestock are homeotherms, which means, that they must regulate their body temperature within a relatively narrow range to remain healthy and productive. The ambient temperature below or above the thermoneutral range creates stress conditions in animals. Environmental heat stress, present during warm seasons and warm episodes, severely impairs livestock performance, particularly in semi arid areas. With the development of molecular biotechnologies opportunity exist to improve thermal tolerance of the animals using genetic tools. Innovations are available to characterize gene expression and identify key cellular responses to heat stress. Under heat stress, improved production should be possible through modifications of diet composition that either promotes a higher intake or compensates the low feed consumption. In addition, altering feeding management such as a change in feeding time and/or frequency, are efficient tools to avoid excessive heat load and improve survival rate. Methods to enhance heat exchange between the environment and the animal and those changing the environment to prevent or limit heat stress can be used to improve performance under hot climatic conditions. Berman, (2011) reported that warm climate breeds (Zebu and Sanga cattle) are adapted to the climate in which they evolved. Such adaptations might be exploited for increasing cattle productivity in warm climates and decrease the effect of warm periods in cooler climates. Evidence is clear for resistance to ticks and tick-transmitted diseases

in Zebu and Sanga breeds as well as for a possible development of resistance to ticks in additional breeds. Development of resistance to ticks demands time; hence, it needs to be balanced with potential use of insecticides or vaccination. In general, adaptations found in warm climate cattle breeds did not increase heat dissipation capacity, but rather diminished climate-induced strain by decreasing milk production. Indigenous livestock are more efficient in thermoregulatory especially in the dry season which is characterized by high ambient temperatures, low relative humidity and the near absence of rainfall. Variation within morphological traits provide ecological adaptation to climatic variability. Silanikove (2000) opined that the amount of heat absorbed by an object from direct (solar) radiated heat depends not only on the temperature of the object, but on its color and texture with dark surfaces radiating and or absorbing more heat than light colored surfaces at the same temperature. The propensity towards multicoat colors is an adaptation to withstand pronounced seasonal fluctuation in the intensity and duration of light, heat and cold in the semi arid tropics (Katongole et al., 1996). Climate change adverse consequences would be inflicted on livestock as a result of high temperatures which could be associated with decline in rainfall, increased evapo-transpiration or increase in the incidence of droughts. Although the vulnerability of the farm animals to environmental stresses varies with the genetic potential, life stage and nutritional status of the animals, the studies unambiguously indicate that the performance of farm animals is directly sensitive to climate factors. Possible benefits of climate change during cooler seasons, though not well documented, are likely to be less than the consequential negative hot weather impacts (Hahn et al. 1992), especially if the cold season is much shorter than the hot one.

Considerable water stress and dwindling feed resources, result from insufficient and unreliable rainfall is expected to increase the likelihood of livestock capacity decline (Ngigi, 2009). One of the impacts of climate change on animal production is availability of forage in terms of quantity and quality (Rotter and Van de Geijn, 1999). The predicted negative impact of climate change on southern Africa would also adversely affect livestock production by aggravating the feed and fodder shortages. Under arid tropical environments, where feed resources are restricted in quantity and quality, differences among ruminants in energy requirements and digestive efficiency are very important criteria for the selection of the most appropriate type of animal to be grown in particular circumstances (Devendra, 1990). This is reflected in the efficiency of the use of gross energy for production. Houghton et al. (2001) concluded that direct effects from air temperature, humidity, wind speed and other climate factors, influence animal performance, growth, milk production, wool production and reproduction. Despite these unfavorable phenomenon in the semi arid tropics, livestock indigenous to southern Africa have shown themselves to be an extremely adaptable livestock species, by being found at different agro-ecological regions.

There is sufficient genetic variation in southern Africa's animal genetic resources, including indigenous genotypes, to facilitate breeding for improved production efficiency. Improved production efficiency can also be attained through effective crossbreeding systems. Potential benefits of effective crossbreeding which might cushion livestock vulnerability from changing climate have thus already been reported in a number of studies (Koch et al., 1978; Cundiff et al., 1991, Gregory et al., 1992; Williams et al., 2010). Systematic crossbreeding which promote adaptive traits may save the vulnerability of livestock production systems from the deleterious effect of climate change. Instead of upgrading the local animal genetic resources there is need to down grade the exotic to an acceptable level which impact adaptability, while not completely compromising productivity. Livestock improvement can not disregard understanding livestock adaptation and other terms that describe general adaptation, to better understand the habitat, fodder and temperature range of livestock species and to shed light on the environments in which targeted search for adaptation traits could focus. This could be done through an analysis of a first mapping of a range of ascribed adaptation traits of national breed populations.

5. The role of smallholder livestock breeding strategies in the context of climate change

Local animal genetic resources should be considered as promising genetic resource taking into account that they comprise a considerable proportion of livestock and contribute substantially to the economic requirement of small scale farmers in southern Africa. They are tropically adapted and suited to low input range conditions, furthermore are reputed to survival on low quality forage. These characteristics are not adaptations to a feed-limited environment but are constitutive and useful in serving survival when feed is scarce and seasonal and high temperatures prevail. The smallholder livestock sector as a whole face unprecedented challenges to increase production while dealing with the negative impact of climate change. A number of countries in southern Africa already face semi-arid conditions that make livestock production challenging, and climate change is likely to

reduce livestock productivity with small-scale farmers being the most affected. The deleterious effect of climate change is expected to have maximum negative impact on smallholder livestock sector engaged in extensive livestock production systems which are predominantly climate dependent. Smallholder resource poor livestock communities are dynamic and they use all possible strategies to reduce the vulnerability to climate change. Roughly 70 per cent or 150 million of the rural poor in southern Africa are at least partially dependent on livestock to sustain their livelihoods (LID, 1999). This sector is characterized by a growing dichotomy between livestock kept by large numbers of smallholders and pastoralists for livelihoods and rural food security, and a small proportion kept in intensive commercial production systems. There are diversity of livestock species (cattle, sheep, goats, pigs, chickens), and breeds which are currently found in southern Africa, which are dominantly used in grassland-based pastoral and small-scale mixed crop-livestock systems where they deliver a wide range of products and services to the resource poor farmers, with low to medium use of external inputs. The perceived major constraint in the smallholder low livestock input systems which harbor the majority of livestock species is that animal species are usually not well characterized and described and seldom subject to structured breeding programs for genetic improvement. However, someone may argue that the lack of structured breeding programs in this sector is a blessing in disguise because the direction of most of the standard breeding procedures were not taking into account adaptability which is critical in the projected climate change events.

6. Genetic improvement of local animal genetic resources as a model for enhancing adaptive and coping mechanisms in southern Africa

Maintaining sufficient diversity of animal genetic resources is necessary to ensure adaptation potential in times of uncertainty. This is on the background that in the future, climate change is expected to be a major force testing resilience of global food production systems (Renaudeau et al., 2012). The previous livestock improvement approached in sub Saharan Africa focused on introduction of unsuitable high-maintenance imported breeds into communal areas is a recipe for a long term disaster taking into account the negative impact of climate in southern Africa. A demand for an appropriate solution to address low livestock performance in the rural areas is to target adaptive genetics in any livestock improvement program. There has been a misconception that indigenous livestock are inferior because of their small size however this is now indisputable in the events of climate change threats on livestock production. This is on the backdrop that the highly publicized continental breeds, however, lack adaptation traits necessary for survival and production in the climate change induced stressful environment where the resource poor livestock farmers operate. With appropriate livestock improvement strategies which take cognizance of the deleterious effect of climate change the inclusion of livestock adaptive traits will lead to increased efforts to use the local livestock genetic resources in southern Africa, especially in smallholder livestock systems. At present, the local livestock genetic resources are largely untapped resource despite having the potential to play a significant role in increasing local and export meat supplies in southern Africa. The major drive should be to increase outputs and off-take in smallholder livestock production systems through development efforts to promote production from local animal genetic resources. Genomic selection has the potential to expedite both pure- and crossbreeding programs for adaptation, assuming phenotypes are available (Hayes et al., 2012); programs for performance recording in developing countries are thus needed.

Small ruminants, especially goats have shown a tremendous potential through integration into a large variety of farming systems, often in complementarity with other livestock species. Their hardiness, resistance/tolerance to disease and productivity on low quality diets are generally superior to other livestock species. Despite the harsh environmental conditions associated with climate change goats have managed to produce and reproduce due to a short reproduction cycle and multiple offspring, allowing for faster return on investment for resource poor farmers. Such attributes may become very valuable in the future, given their link to sustainability and be of key importance in a time of rapid and unpredictable change in climate. This aspect is particularly relevant in southern Africa, where water availability is decreasing, pasture growing seasons are shortening, and climate change is leading to the expansion of the territory of vectors and the spread tropical disease challenges outside their endemic area. The differences in terms of productive and adaptive traits that exist between local and exotic animal genetic resources in southern Africa are enshrined in the effects of environmental stressors.

7. Implications

Given the vulnerability of southern Africa to perpetual droughts, rise in temperatures, water scarcity and unprecedented change into rangeland biodiversity which has resulted in impact of increased intensity of extreme events on the livestock sector would be large and devastating for the low-income rural areas. In the context of climate induced stressors there is need to promote the adapted animal genetic resources suited to the needs of the resource-poor livestock farmers for the survival of livestock production systems in southern Africa. Livestock improvement strategies are a very important driving force in livestock adaptation to future production conditions under changing environment. Previous focus in livestock improvement has made large contributions to improved efficiency however without taking cognizance of the impact of climate change. Therefore, for any future thrust in livestock improvement strategies should include the component of climate change adaptation in their definition of breeding objectives and breeding schemes. With the projected climate change effect on livestock production, it is imperative that livestock breeding and production options and strategies focus on reducing vulnerability and building resilience among these communities. Traits including the susceptibility to tick-borne diseases and droughts, and performance under harsh pedo-climatic and socio-economic conditions are the key to sustainable livestock production in future. In our drive to improve livestock production through genetic manipulation there is a need for a better understanding of genotype × environment effects both productive and adaptability traits in order to inform the development of breeding programs in the context of projected climate change stressors. Through genetics of adaptability the development of valid traits for assessing productivity, greater consideration of heat and water stress can also potentially affect sustainable livestock production and a need to consider the impacts of climate change on breeding programs. Molecular genetic approaches to improve the accuracy and the efficiency of selection for adaptability traits such as heat tolerance and water stress through regulation of gene expression could also be an efficient method to improve livestock productivity. Selection procedures which disregard genotype by environment interaction will create animals that fail to adapt successfully to environmental change will become extinct, albeit usually over extended periods of time.

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