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Preventing rangeland degradation: a shared problem for Australia and China

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Abstract. Rangeland degradation continues in Australia, China and elsewhere. The stocking rate/animal production relationship has been a successful concept for pastoralists wanting to avoid degradation and/or raise incomes. However, there are no means available of alerting pastoralists to the approach of critical thresholds that would 'flip' rangelands into alternative states when grazing-stressed. Critical threshold forecasting for avoiding degradation (and seizing restoration opportunities) could be made available online. Research has yet to find, assemble and test the set of indicators needed to forecast the approach of critical thresholds envisaged in State-and-Transition thinking. Forecasting at paddock, property and regional scales would have to involve high-performance computing because the thresholds will be space and time dependent. The case for Australia and China to contribute cooperatively to this research effort rests on the large number of contrasting rangeland ecosystems across the two countries that represent rangelands globally. A proven history of past collaboration is extant with existing research programs on plant population dynamics, landscape patchiness/leakiness and soil biota status, and their responses to the separate and combined effects of climate and grazing animals. The road to adoption would involve partnerships with pastoralists throughout the process, remote sensing to identify approaching thresholds in real time, application of high-performance computing and possibly artificial intelligence, and packaging of forecasts for different socio-economic rangeland systems.

Keywords: Australia, biodiversity conservation, China, defoliation, critical threshold forecasting, drought rangeland management, grazing stress, rangeland ecology, soil biology.

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Introduction

Rangeland degradation is a persistent global problem characterised by negative shifts in the state of indigenous vegetation (Westoby *et al.* 1989), reduction in landscape function (Ludwig and Tongway 1995) and local extinctions of biota (flora, fauna, fungi and bacteria). Some reasons for the continuing problem include failure to recognise socio-economic factors while promoting new grazing systems to pastoral communities (Li and Huntsinger 2011), weaknesses in the adaptive capacity of social and ecological systems (Walker and Janssen 2002), failure to benefit from technical efficiencies (Tan *et al.* 2018), and no access to real-time resource assessments and warning of approaching critical thresholds (McKeon *et al.* 2004). Knowledge gained from experience of pastoralists in highly variable climates is valuable (e.g. Hou *et al.* 2014; Berry *et al.* 2019). However, Australia's history shows that multiple factors coupled with over-expectation commonly result in degradation (Watson and Novelly 2011), even for experienced pastoralists (McKeon *et al.* 2004). Pastoralists have difficulty in perceiving changes in climate (Li *et al.* 2014). Differences in natural resources, climate, government policies and cultures between pastoral regions also influence managerial abilities. Where social or genetic values of livestock are high, pastoralists find it more difficult to operate at lower stocking rates and to destock when approaching critical thresholds. The stocking rate/animal production relationship of Jones and Sandland (1974) provides a method and conceptual framework for identifying stocking rates that do not degrade landscapes, and the additional conceptual economic modelling of Wilson and MacLeod (1991) indicates stocking rates that maximise profit. These relationships are increasingly used to underpin recommendations in semi-arid Australia and have been successfully introduced into China (Longworth and Williamson 1993; ACIAR 2019).

Here we develop a case for advancing cooperative research in Australia and China to develop the fundamental knowledge on biological and landscape effects of grazing pressure, and to forecast the approach of critical thresholds (Walker and Westoby 2020). There are other areas of rangeland science that could be brought forward for Australia/China cooperation, but here we discuss one problem that has not been adequately resolved, and for which the recent advent of high-performance computing could be the means of bringing the information to pastoralists, in addition to conventional on-ground transfer of new knowledge. The importance of stocking rate/animal production relationship thinking is unchallenged. However, we argue that clearer identification of approaching critical thresholds is needed, and that online availability should assist pastoralists in preventing degradation of rangeland and pastoral businesses. Australia has a strong record of innovative rangeland research, and China has a fast-growing scientific capability (Wu 2019), making available financial support for rangeland research, and science in general. The origins of rangeland research in Australia and China and the development of cooperation are briefly discussed. Here we use the word pastoralist, in the generic sense, for people who graze domestic large herbivores on rangeland. The international definition of rangeland is also used (Allen *et al.* 2011).

Rangeland research and Australia/China cooperation

Rangeland research began in USA during the 1860s with formation of 'Land-Grant Universities' (Wikipedia 2020). These were federally funded, established to address the widespread problem of land degradation on both farmed and pastoral land and were to inform governments on ways and means to prevent and repair degradation. Many developed range management departments for teaching and research (fundamental, applied and extension). By the early 1940s, sufficient research had been conducted to publish the first authoritative book on rangeland management (Stoddard and Smith 1943).

In Australia, rangeland degradation was recognised soon after pastoral settlers displaced indigenous land managers, and by the late 1890s degradation had become so severe in New South Wales as to warrant a Royal Commission (Anon. 1901) and subsequent policy development. Other States in the Federation and the Northern Territory followed with inquiries into the problem. The need for escalating rangelands research was advocated much later (Perry 1967). Australia then reached out to the USA and Southern Africa to grow research and extension programs, but did not develop underpinning university departments. Individual scientists, in many institutions, built rangeland science in Australia from the late 1960s. Four joint-meetings of Australian and USA scientists took place in early 1970s and proceedings from each were published (e.g. Australian Rangeland Society 1977). During this period scientists were exchanged between USA, Southern Africa and Australia institutions. Scientific progress was rapid and within a decade a national book on rangeland management was authored by scientists from many institutions (Harrington *et al.* 1984).

The Australian Rangeland Society formed in 1975 and one of the proposed aims for forming the Society was 'to develop an Australian philosophy for rangeland use taking into account all its alternative uses'. The sense that Australian rangelands function differently from others, and that an 'Australian philosophy' needed to be built, drove subsequent thinking and science.

Two major philosophical developments took place in the 1980s. First was the recognition (Westoby *et al.* 1989) that Australia's rangeland vegetation was best described by sets of 'states' with sets of discrete 'transitions' between 'states' at any point in the landscape rather than the equilibrium model of Clements (1916). Second was the development of the concept of landscape functionality (Ludwig and Tongway 1995; Ludwig *et al.* 1997) and linked restoration thinking (Tongway and Ludwig 2011) that replaced range condition methodology developed in the USA and which was used for a period in Australia. Significant contributions to an Australian philosophy continue to emerge, giving credibility and respect for Australia's rangeland scientists in other countries.

In China, a few institutes and universities began rangeland research in the late 1950s. This continued through the Cultural Revolution (1966–1976), but research knowledge transfer to pastoralists was limited. The Chinese Grassland Society formed in 1979, and China began engaging with other countries, including Australia, as science investment grew. In early 1979 a group from the Chinese Academy of Sciences (CAS) visited Australia, and later that year a high-level CSIRO group visited China (CSIRO 2005). Rangeland degradation was identified as a shared problem. The scientific relationship between Australia and China quickly developed with support from AusAID and the Australian Centre for International Agricultural Research (ACIAR). Initially the cooperative projects focussed on livestock health and plant and livestock breeding (CSIRO 2005), and more recently a rangeland management project was funded. Today, 35 of China's universities have grassland science departments and ~1500 students graduate each year. Exchange of ideas between scientists from 'rangeland countries' is encouraged (e.g. Yang 1990).

Today agriculture and environment students, both undergraduates and graduates, come to study in Australia, and Australian scientists help postgraduate students with editing research papers and sharing rangeland knowledge through lectures and speaking at national and international conferences in China. Many of China's scientists and students are now fluent in the English language, and increasingly Chinese scientists are invited to speak in forums and conferences outside of China. Modern China is able to further develop research cooperation with Australia and rangeland scientists globally.

At the heart of the shared rangeland problems is the search for grazing systems and stocking rates that do not degrade the natural environment (Zhu and Zu 1990), and that benefit livelihoods and regional economies (Hu *et al.* 2018). China has developed several policies to address the stocking-related problems of large-scale natural resource degradation, low individual livestock productivity and pastoral poverty. The 'Fencing and Limiting Grazing' policy of 2003 aims to prevent degradation and restore dysfunctional landscapes by transforming traditional nomadic systems to settled pastoralism. The need to consider social and economic systems as well as natural systems is well recognised. Research to evaluate and improve government-recommended stocking systems (e.g. Wang *et al.* 2018) and determine safe livestock carrying capacities (e.g. Wu *et al.* 2019) is underway. Both Australia and China are large countries with arid rangelands with high rainfall variability. China also has extensive alpine grasslands with regular short growing seasons and long cold winters. Together, Australia and China contain the major global rangeland types, and such differences in types inevitably generate synergy when cooperatively searching for better ways of management.

Knowledge required for preventing degradation

Although continuous stocking is common in rangelands, a recent global meta-analysis of grazing system studies (McDonald *et al.* 2019) confirmed that periodic rest benefits plant cover and herbivore production per hectare. However, the capacity of pastoralists to benefit from this research remains problematic, because of entrenched practices, the cost of required fencing, difficulties in identifying approaching critical thresholds and a poor capacity to learn from infrequent events. Watson *et al.* (1996) argued that pastoralists should consider a balance between infrequent, unpredictable events (e.g. drought), and more continuous processes occurring at longer timescales, such as periodic resting. In China, the privatisation of grassland use rights is thought to have weakened pastoralist and community ability to cope with non-equilibrium conditions by endangering feedbacks of past failures (Li and Huntsinger 2011).

Extensive examination of the effects of droughts and subsequent recoveries in Australia's rangelands found knowledge on timing of rest at the onset of droughts to be both critical and inadequately understood for natural resource maintenance and profitability of pastoral businesses (McKeon *et al.* 2004). Understanding and finding the relationships between total grazing pressure and key components of the vegetation, soil, faunal biota and performance of large herbivores for modelling is an ambitious task because rangelands are highly variable in space and time (Ash and Stafford Smith 1996). However we think that the critical thresholds for key plant species and vegetation, soil biota and landscapes in grazed non-equilibrium systems can be better understood. Australia and China have expertise in these areas.

Critical thresholds for maintaining populations of plants

The local extinction of plant species by degrading grazing pressures reduces animal performance and plant community productivity. Sheep performance in arid and semi-arid regions is dependent on the number of plant species available ahead of individual grazing livestock from which to select their diet (Wang *et al.* 2010). This is counter intuitive; most pastoralists would think that the level of plant biomass determines livestock productivity (Ash and Stafford Smith 1996). Furthermore, plant community productivity is best described by the humped-back model (Fraser *et al.* 2015) in which productivity rises with increased plant species richness and then declines. Moderate to large percentage losses of plant species can seriously reduce both community productivity and animal performance.

In many rangelands, the distance from watering points determines the grazing pressure on vegetation. Grazing gradients, or piospheres (Lange 1969) out from watering points, and the effects on plant species abundance can be modelled (Hess *et al.* 2020). This approach used by Hess *et al.* (2020) has value for modelling change (degradation or restoration) if critical thresholds are crossed. Images from drones could be used for determining changes in plant communities and surface soil features out from water points that are beyond the resolution of satellite imagery.

The two important critical thresholds for perennial grasses are the onset of drought when soil water stress becomes acute, and when grazing stress intensifies. Prolonged soil water stress kills plants, even long-lived non-grazed perennial grasses (Hodgkinson and Muller 2005). Defoliation also kills rangeland plants. There is a 'death trap' for perennial grasses where the 'trap' is set by grazing (long-term stress) and sprung by drought (short-term stress) (Hodgkinson 1996). The interaction between grazing and drought has been studied for one palatable grass species (Hacker *et al.* 2006), but further field studies on other grass species and plant communities are required because species may differ in response to drought and defoliation. Perennial grass loss is a serious issue because subsequent replacement by germination of seed is problematic in highly variable rainfall systems (Anderson *et al.* 1996).

To our knowledge, annual and perennial forb species have not been studied in a similar manner to perennial grasses. Reproduction and seed longevity in soil seed banks should be examined to identify critical thresholds for the survival of populations of those plants that are important components of livestock diets. There are also other effects of grazing by livestock that are poorly understood and apparently complex. For example, the effects of yak and sheep grazing on caterpillars differ; there is diet-mediated competition between yak and caterpillars, but facilitation between sheep and caterpillars (Pan *et al.* 2019).

Real-time data for rainfall and evaporation, coupled with improved long-range weather forecasting and landscape type and terrain mapping, could provide pastoralists with early warning of the critical threshold of drought onset. Necessary computing power is now available. Software for estimating land cover of vegetation in northern Australia, VegMachine, is increasingly used by agencies, natural resource management groups and pastoralists to produce paddock-by-paddock monitoring reports (Beutel *et al.* 2019). Further growth in pastoralists' use of these online programs is expected. Smith (2020) are developing a Planetary Computer for providing satellite data, a platform for leveraging predictive models, state-of-the-art learning tools, and user-contributed data for measuring and managing natural resources. This may be a means of cooperatively sharing data on critical thresholds in the public domain.

Critical thresholds for patchiness

In his classic paper, Noy-Meir (1973) identified the significance of water redistribution from rainfall events within landscapes for patches of plant production in water-limited environments. Loss of this patchiness by overgrazing means that many small rainfall events produce no plant growth for herbivores. In general, less water is trapped for plant growth in overgrazed landscapes. Patches at larger scales can be detected from satellite data (Pickup and Chewings 1988; Knight 1995), and patch density can be used to determine the level of degradation. Patchiness of vegetation can also relate to leakiness of landscapes using remotely sensed estimates of plant cover and terrain (Ludwig *et al.* 2007).

Patchiness within natural systems occurs at a range of scales, and there are different processes occurring in patches because they accumulate nutrients, litter and seed (see Ludwig *et al.* 1997 for the philosophical framework). The importance of maintaining patchiness for maintenance of biota from the micro to the macro-scale is poorly understood. Patchiness at larger scales is important as refugia for biota during drought stress and this deserves further study. Spatial differences in grazing intensity significantly affect reptiles (Howland *et al.* 2014). Reptile abundance, species richness and diversity are highest where grazing intensity is low. Here are critical thresholds to be investigated for selected biota. Intense and uniform grazing is probably not an appropriate objective for conservation of rangeland natural resources.

Accelerated soil erosion is also linked to patchiness and overgrazing, and its onset is an important threshold to estimate. The significance of soil erosion in reducing carbon sequestration is poorly understood. It has recently been estimated on average to be 5% annually of newly fixed organic carbon in the USA (Tan *et al.* 2020) and can be as high as 40%. Up to 12% of this transported carbon ends up in rivers and eventually the ocean.

Critical thresholds for soil biota

Surface and below-ground biota play important roles in shaping plant community structure and functioning. The abundance and spatial heterogeneity of biota are affected by grazing intensity (Eldridge *et al.* 2019), but are poorly understood in terms of grazing intensity and soil biota functional feedbacks on forage productivity. Surface cryptogram crusts are critical components of non-equilibrium natural systems and regulate important ecosystem functions. Cryptogam crust response to woody plant invasion and herbivore grazing is poorly understood (Soliveres and Eldridge 2020), but the role of crusts in regulating the delivery and retention of water for plant growth have recently been highlighted by meta-analysis. (Eldridge *et al.* 2020).

Soil biota are important for germination, survival and growth of plants as they mediate positive plant diversity-productivity relationships. An understanding of these processes has important implications for grazing management (Wang *et al.* 2020). The transfer of soil microbes from functional landscapes to soil from dysfunctional landscapes and vice versa affects the survival and growth of native and exotic grasses (Smith *et al.* 2018). Soil microbial communities play an essential role driving multifunctionality (Chen *et al.* 2020). The role of soil bacteria and fungi in growth of grasses grazed by several large herbivores is currently being studied in China. Heavy grazing reduced soil microbial biomass, activity and protozoan abundance, but increased soil nematode abundance and had no effect on soil microbial catabolic diversity in the semiarid steppe of Inner Mongolia (Qi *et al.* 2011). Continuous grazing at a moderate intensity is recommended for maintaining a healthy soil biome for these semi-arid landscapes. In a study of a Tibetan alpine meadow, grazing practices affected the relative abundance of specific bacteria and fungi taxa (Yang *et al.* 2019). The soil microbial community seems very sensitive to the impact of livestock grazing where abundances of N mineralisation and nitrification biota increased, whereas virulence, stress, and antibiotic resistance biota increased (Yang *et al.* 2013).

The means for remotely detecting the approach of critical thresholds in soil biota is a challenge but may be possible by detection of surrogates for soil biota and/or use of artificial intelligence.

Final comments

Use of the critical thresholds called for in 'state-and-transition' thinking was critically reviewed and discussed for pastoral management in Australia over two decades ago (Watson *et al.* 1996). The problem of infrequency of approaching critical thresholds in working lifetimes was identified. With such low frequency, pastoralists can rarely recognise the approach of critical thresholds and implement the optimal response in management. Since then, there has been little advancement in understanding the thresholds from a biological perspective, nor from sociological and mental modelling perspectives.

Given the infrequency of critical thresholds, there seems a compelling case for the use of high-performance computers to warn of approaching thresholds in terms of space and time. This is not a new insight. Wilson (1996) in a Foreword for a Special Issue of *The Rangeland Journal* on grazing management wrote 'Climate variability is now being accepted as a major driving force in rangeland management and explicitly addressed. And the complexity of the landscape, the production system, the ecosystem and peoples economic overlay, is at least being encompassed, if not understood, through the power of the computer.' The pathway to adoption would need to be flexible through considering cultural and social factors. If, however, remote sensing of data to identify approaching thresholds in real time is possible, high-performance computing coupled with use of artificial intelligence and packaging of information for different socio-economic systems would seem to be highly desirable.

The recognition of approaching critical thresholds and changing management in time to prevent degradation of rangeland remains a shared and serious problem for pastoralists in Australia and China. This is worthy of collaborative research and increased funding.

Conflicts of interest

The authors declare no conflicts of interest.

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