Using palaeoecology and system dynamics to inform conservation of a biodiversity-rich, but endangered, ecosystem

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Ecosystem Services (ES) upon which all humankind depends, come from ecological infrastructure (Cumming et al., 2014; Millennium Ecosystem Assessment, 2005) – i.e. healthy mountain catchments, wetlands, corridors of natural habitat, which together form a network of interconnected structural elements in the landscape. Plant biodiversity offers important provisioning ESs in the Cape Floristic Region (CFR), South Africa. The CFR is one of the world's 25 biodiversity hotspots (Goldblatt and Manning, 2000; Low and Rebelo, 1996; Mittermeier et al., 1998; Myers et al., 2000) and it contains >9000 plant species, of which ca.68% are endemic (Manning and Goldblatt, 2012). Human impact threatens its unique plant biodiversity with about 30% of CFR vegetation already transformed (Cowling et al., 1997; Fairbanks et al., 2000; Myers et al., 2000), making the CFR a global conservation priority. Current threats to biodiversity include urban development, agriculture, the spread of invasive alien plants and anthropogenic climate change (Allsopp et al., 2014; Goldblatt and Manning, 2000; Myers et al., 2000), however this landscape has been impacted by humans and climate variability for millennia (Fig.1). For example, the San hunter-gatherers were in the region from at least 25 000 BP to the historical period, while the Khoikhoi pastoralists introduced livestock to the Western Cape from approximately 2000 BP (Boonzaier, 1996; Deacon, 1992). The arrival of, and colonisation by, European settlers from the mid-17th century onwards resulted in increased grazing, the introduction of crop cultivation and increased burning. In the 20th century, agricultural intensification increased environmental impacts in some areas, while others became nature reserves and stewardship schemes aimed at conserving the CFR's unique biodiversity (Bergh and Visagie, 1985; Hoffman, 1997; Newton, 2008). Furthermore, over the last ca.10 000 years the CFR has experienced much climate variability (Fig.1): ranging from warmer and dryer conditions during the Mid-Holocene altithermal (9000-5000 BP) (Meadows and Baxter, 1999) and the Medieval Climate Anomaly (900–1400 CE), followed by the cold and wet Little Ice Age (1400–1800 CE) (Nicholson et al., 2013); with the latter part of the 20th century characterised by a warming trend due to anthropogenic climate change (Cronin et al., 2003; Haensler et al., 2010).

Conservation landscapes provide ES that vary over time in response to social and environmental drivers of change. Management often fails to consider this variability, with consequences for social-ecological systems sustainability. This paper investigates plant biodiversity variability and how to ameliorate negative impacts of climate change and land-use disturbance at a conservation site called Elandsberg Private Nature Reserve, CFR, South Africa. The transdisciplinary approach includes palaeoecology and participatory system dynamics and follows a past-present-future lens, with the objective of informing appropriate land-use governance. Changes in palaeo-proxies for vegetation, herbivory and fire (fossil pollen, spores and charcoal) from a 1300-year-old sediment core were analysed and used to define the historical range of variability and identify appropriate management baselines (Forbes et al., 2018) (Fig.1). Fossil pollen from the most abundant pollen types is used as a proxy for plant biodiversity: Asteraceous long-spine pollen (a pollen type which is indistinguishable at the family and genus level but makes up multiple Asteraceous plant species, of which some are palatable) and *Elytropappus rhinocerotis* pollen (Renosterbos, a single Asteraceous species that is unpalatable and when in high abundances is considered less desirable for conservation). Proxies for drivers of change associated with land-use disturbance include macro-charcoal (proxy for fire history) and coprophilous fungal spores (proxy for herbivory/grazing). The palaeoecological data shows two regimes (domains of attraction or alternative stable states) occurring over the past ca.1300 years. This data was used as reference modes (Fig.1) and stock and flow structure was developed to simulate the regime shift seen over time.

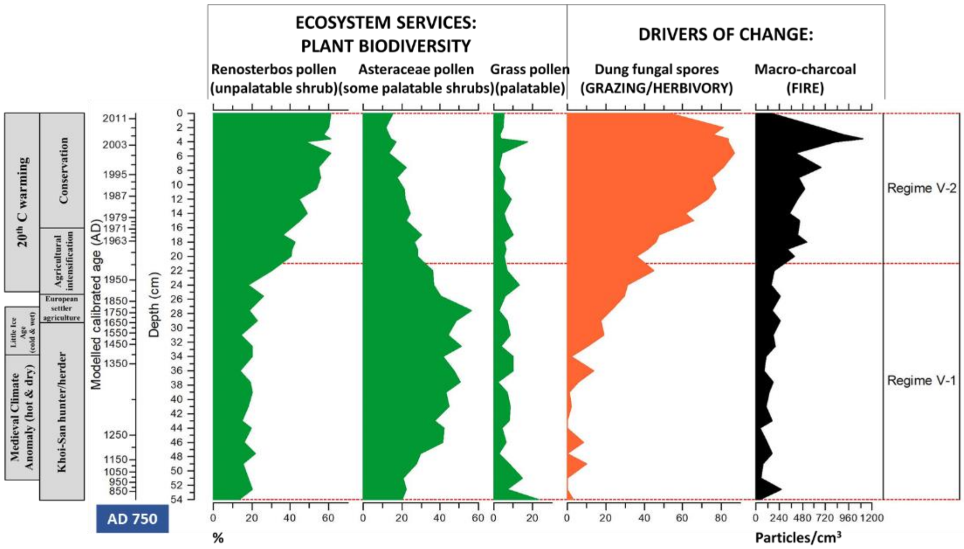

Fig. 1: Summary palaeoecological proxy data from Elandsberg Private Nature Reserve, South Africa (adapted from Forbes et al. 2018).

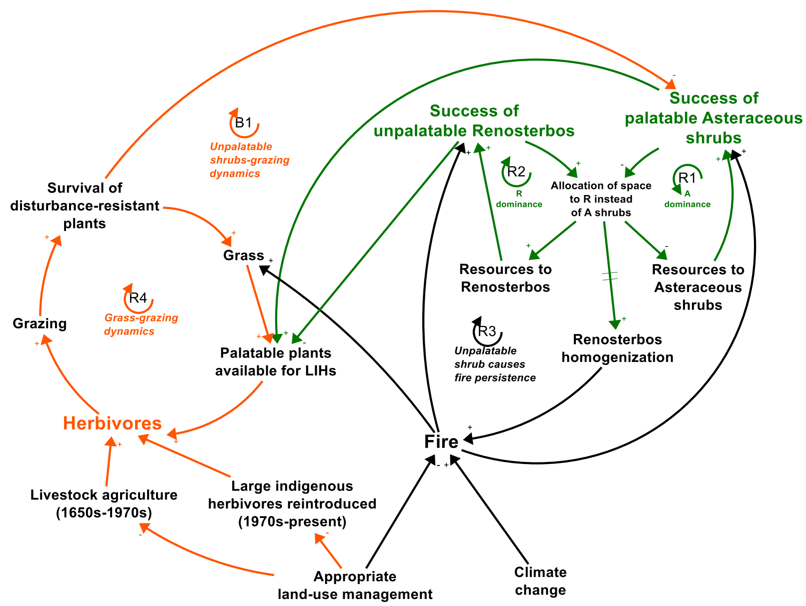

Fig.2: Causal loop diagram depicting the dynamic hypothesis for an Ecological Model for biodiversity conservation.

Participatory system dynamics included stakeholder engagement via workshops and semi-structured interviews with land-use managers working within the CFR. The stakeholder workshop used social learning techniques to elicit variables to inform model development. Together with an extensive literature review, stakeholder engagement played a significant role in developing the dynamic hypothesis (Fig.2) and the investigation of future policies and scenarios in the Ecological Model presented in this paper. The ca.1950s regime shift is characterised by a decrease in plant biodiversity, evident by a decrease in Asteraceous long-spine pollen (comprised of multiple Asteraceous plant species) and an unprecedented increase in *E. rhinocerotis* pollen (Renosterbos) (a shift in loop dominance from R1 to R2). Decreased biodiversity is driven by increased grazing and burning caused by agricultural intensification. Trends continued during the ca.1970s (when Elandsberg PNR was proclaimed) until the present. System dynamics provided critical insights: Simulation results show that as grazing increased, plant biodiversity decreased and fire increased. It may be difficult to return the ecological system to its pre-1950s historical range of variability even if grazing and fire are reduced but adaptive grazing-fire management is recommended to sustain plant biodiversity levels. Understanding the temporal variability and dynamic feedbacks between ES and drivers is essential for identifying safe operating parameters and management targets that enhance social-ecological resilience and sustainability during the Anthropocene.

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