State and Transition Models in space and time—using STMs to understand broad patterns of ecosystem change in Iceland

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1. Background

Land degradation in Iceland

- Extensive land degradation and soil erosion in Iceland have been linked to natural processes (rainless climate and frequent volcanic activity) and to human activities like agriculture and logging.

- Humans settled in Iceland in the 9th century, and the paleoenvironmental record suggests widespread shifts in environmental processes after the settlement.

State and Transition Models (STMs)

- Developed in the context of rangeland management to deal with discontinuities and irreversible transitions in vegetation dynamics in grazing systems.

- Applied to ecosystems worldwide but less extensively to high-latitude rangelands.

Using conceptual models in management

- Managing ecological systems sustainably requires a deep understanding of ecosystem structure and the processes driving their dynamics.

- Conceptual models can lead to improved management by providing a framework for organizing knowledge about a system and identifying the causal agents of change.

2. Methods

Landscape changes in Iceland over time

- We developed state-and-transition models (STMs) to describe landscape changes in Iceland over three historical periods with different human influences, from pre-settlement to recent times.

Application of conceptual models to management?

- We applied our present-day STM to a case study in the central highlands of Iceland, using an ongoing field experiment with two management interventions (grazing exclusion and fertilization) in areas experiencing contrasting stages of degradation.

3a. Using STMs to describe ecosystem change in Iceland over time

Our models identify the set of possible states, transitions and thresholds in ecosystems in Iceland and their changes over time, and suggest increasing complexity in recent times, with a clear influence of human activities in creating new ecosystem states and accelerating some transitions (Figure 1).

Before human settlement in Iceland in the 9th century, landscape changes were driven mostly by climates and natural disasters. Birthwoodlands were more extensive before settlement, although their extent fluctuated with variations in climate.

- The settlement brought with them livestock, and the use of natural resources (cloudberry, birchwoodlands) increased, especially in the lowlands. The extent of marginal degradation and soil erosion rapidly escalated in some parts of Iceland.

- Human population slowly increased since this late 9th century, flocks of small domestic animals (sheep) were common, particularly sheep, which peaked in the late 1570s, but declined sharply after the Laki eruption and additional reductions efforts occurred since the early 1990s.

3b. Application of STMs in the field

Based on our current understanding of the system (Barrio et al. 2018; Mulley et al. 2019), we predicted that fertilizers mediate the short-term effects of grazing exclusion, allowing grasses to establish more successfully, thereby reducing the area of bare ground and improving the vegetation structure.

The experimental treatments affected the amount of bare ground in gravelly desert (F = 16.35, p < 0.001) but not in the dwarf-shrub heath (F = 1.47, p = 0.295).

In the gravelly desert, the amount of exposed bare ground was reduced in fenced plots, whether fertilized or unfertilized. Fenced plots tended to have lower percent cover of bare ground than the corresponding non-fertilized plots when receiving fertilization (NPK: F = 1.22, 8.88, p = 0.09), but not in the non-fertilized plots (F = 2.10, 10.8, p = 0.08).

4. Implications

- Our use of STMs at a broad spatial and temporal scale provides a novel approach for better understanding of the forces driving the landscape change in Iceland.

- STMs provide a useful conceptual framework that facilitates a deeper understanding of the ecology of dynamic ecosystems in Iceland. Identifying what drives ecosystem change is essential to manage these systems, and can help prioritize inputs and management efforts. STMs can provide a solid base for nationwide monitoring systems like GLAD (www.glad.is).

- The development and use of conceptual models provides a framework for organizing our knowledge about a system, and targeted experiments can help refine these models.

- Our study provides a better understanding of the dynamics of ground lundja ecosystems and offers insights for management plans targeting the restoration and conservation of specific habitats across the rangeland system.

- A better understanding of how disturbed ecosystems respond to different management interventions is fundamental to develop effective management strategies. These responses might differ depending on the stage or severity of disturbance. For example, for systems where vegetation is still present but at risk of continuing degradation, applying management strategies before the area has crossed an ecological threshold may mitigate further and costly loss of ecosystem function.

Acknowledgements

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