

Lifting the secrets of pastures: Overview of animal-borne sensors to uncover processes unobserved by classical grassland research

Pauler C. M. and Schneider M. K.

Forage Production and Grassland Systems, Agroscope, Zurich, Switzerland

Abstract

Movement and foraging behaviour of grazing livestock strongly respond to pasture vegetation while being major drivers of grassland biodiversity. However, many underlying processes of these interactions are scarcely understood. In this article we focus on how animal-borne sensors can close this knowledge gap. We conducted three grazing experiments on heterogeneous pastures in the Swiss Alps. GPS-trackers, pedometers, nose-band chewing sensors and head-collar accelerometers were fitted to cattle, sheep and goats. Sensor data were combined with classical vegetation surveys. We found that (1) animal-borne sensors allow for monitoring activities of grazing animals continuously, objectively and without disturbing their natural behaviour; (2) sensors can monitor processes not directly observable by humans or aerial systems but sensed by livestock; (3) the high temporal and spatial resolutions allow for new algorithms of data interpretation. Combining these advantages of animal-borne sensors with classical measurements revealed novel ecological relationships of livestock behaviour and vegetation diversity. For instance, we disentangled interactions of cattle movement behaviour, their spatial distribution, anatomy, trampling pressure, plant trampling-adaptation and pasture vegetation and diversity. Animal-borne sensors indicate the underlying ecological processes of pasture parameters and not only their status quo, and thereby enable a holistic research approach into grassland systems.

Keywords: animal-borne sensors, GPS, pedometer, chewing sensors, herbivore-pasture interaction

Introduction

Modern sensing technology observes numerous processes in grassland. However, for pastures there is a lack of information, as they are not only influenced by climatic, edaphic and topographic factors but also substantially by herbivores. Grazers shape pasture vegetation and biodiversity by selective defoliation, trampling, nutrient translocation and even seed dispersal (Pauler *et al.*, 2019). Inversely, pasture forage quality, plant species composition and terrain influence animal behaviour. Common grassland sensing methods focus on the vegetation site of these fundamental interactions and thus, important ecological relationships are often overlooked in pasture sensing. Applying animal-borne sensors, the animal itself provides in-situ insights in the ecosystems parameters. Many ecological processes and relationships are not detectable without the animal – especially on heterogeneous pastures. However, the use of animal-borne sensors requires a thorough handling and interpretation to achieve meaningful results. This article demonstrates that animal-borne sensors are a valuable addition to classical grassland research focusing on vegetation parameters. We discuss opportunities and challenges encountered in several field studies.

Materials and methods

We refer primarily to three field experiments conducted on heterogeneous, (sub-)alpine pastures in the Swiss Alps (Homburger *et al.*, 2015, 2014; Pauler *et al.*, 2020a, 2020b) (plus a third study not yet published). Grazing behaviour of cattle, sheep and goats was observed applying various sensors (Table 1). Sensor data were combined with vegetation surveys, chemical analysis of soil and forage, other grassland sensing methods (e.g., calculating vegetation height based on drone pictures) and anatomical measurements (e.g., weight, claw size). Behavioural states in space and time were classified automatically. The accuracy of both sensor output and classification was validated against visual observations in the field.

Results and discussion

In our studies, animal-borne sensors disentangled numerous ecological relationships of livestock behaviour and vegetation diversity (Table 1). For instance, using GPS and pedometers we were able to identify drivers of animals' spatial distribution and movement intensity (Homburger *et al.*, 2015; Pauler

et al., 2020a). The movement behaviour was influenced by terrain (e.g., avoidance of steep slopes) as well as the forage on offer (e.g., preference of nutrient-rich areas; fewer steps in high forage quality paddocks). However, the herbivore-grassland relationship is reciprocal: by combining sensor data with vegetation surveys, we found that plant species richness and the proportion of trampling-adapted species are influenced by the movement and foraging behaviour of animals (Pauler *et al.*, 2019). Combining different sensing methods and classical surveys enlarges the knowledge gain considerably.

Table 1. Overview of pasture-relevant, animal-borne sensors, their output, the challenges to be considered and the ecological questions that can be answered by interpreting sensor output. All sensors provide temporal assignment and thus allow integration of different devices.

Sensor	Output	Challenges	Interpretation	Underlying process
GPS logger	Position	Insufficient accuracy due to shading; Insufficient robustness; High energy demand	Distance covered; Spatial distribution; Activity classification: resting, foraging, walking	Location of defoliation and nutrient deposition
Pedometer	Step frequency + intensity	Black-box data; Comparable only for animals of similar size	Movement intensity; Activity classification: lying, walking	Biomass and soil compaction
Nose-band chewing sensor	Bite rate + intensity; Rumination	Automated classification difficult or relying on black-box software; Error-prone at low temperatures	Activity classification: foraging, rumination	Amount of defoliation
Head-collar accelerometer	Position of the head	Automated classification difficult or relying on black-box software	Activity classification: foraging, browsing	Structure of defoliation (herbs vs. woody)
Under-chin cameras*	(Motion) pictures	Difficult automated classification; Identification of individual forage plant species not always possible	Activity classification: resting, foraging, browsing, rumination, walking, interaction	Selective foraging (species identity, developmental stage of forage)

* Not applied in the studies presented, but with high potential (e.g., de la Rosa, 2019).

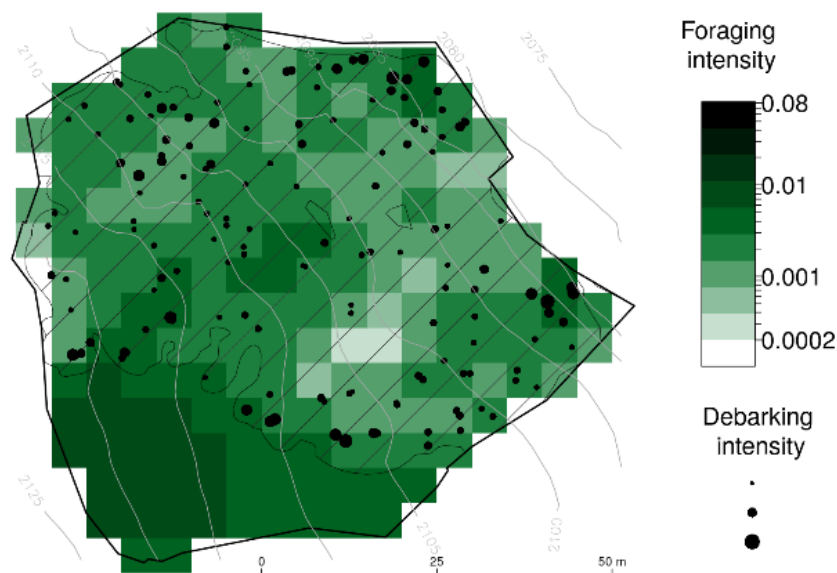


Figure 1. One example of combining classical vegetation survey and animal-borne sensors. Sheep grazed subalpine pastures partially covered by *Alnus viridis* stands (hatched). They prefer flat over steep slopes and open pasture over shrub stands, but when entering the stands, debarking intensity is a function of sheep occupancy. Debarking recreates open pastures and the more the thickets are thinned, the greater the species richness.

Another reciprocal interaction we could demonstrate was for nutrient flux: animal-borne sensors demonstrated that the spatial distribution of animals is more even during foraging than on average. Thus, animals ingest nutrients from all over the pasture, but mainly deposit them at only a few resting places, as confirmed by dung sampling (Koch *et al.*, 2018). Thus, livestock change the competitive conditions and thereby alter vegetation composition. Vegetation surveys show a high share of nitrophilous plants where animals rest. In return, the higher nutrient content affects livestock spatial distribution.

Animal-borne sensors record activities of grazing animals continuously, objectively and without disturbing the natural behaviour. Sensors can thereby monitor processes not directly observable by humans but sensed by the animal. However, meaningful results of animal-borne sensors depend on adequate handling and interpretation. Both can be challenging: (1) accurate fitting of sensors is time-consuming and error-prone, especially if sensors and halters were not developed for the species or breed of interest; (2) animal interactions and outdoor conditions can damage sensors, and since most devices were developed for in-house deployment, they need careful adaptation and testing in harsh environments; (3) assessing and validating the accuracy of data is crucial; (4) automatized behaviour classification is mandatory for large datasets but requires advanced programming skills. Alternatively, one has to rely on black-box classification of commercial software; (5) measurement uncertainty and the spatiotemporal autocorrelation of sensor data need to be accounted for in data analysis.

Conclusions

Many parameters of interest in pasture grassland research (e.g., nutrient deposition, trampling impact, vegetation reaction) depend on herbivore-pasture interactions. Classical grassland sensing usually measures a status quo of these parameters (e.g., nutrient content, vegetation composition) and thus it focuses on only one site of a complex interaction. Combining these methods with animal-borne sensors facilitates the understanding of underlying ecological processes (e.g., nutrient intake and excretion, movement behaviour, forage selection). Thereby, animal-borne sensors enable an holistic research approach into grassland systems.

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