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Quantifying and interpreting the utility of foraging behaviour metrics derived from on-animal sensors in extensive rangelands

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Abstract

The use of on-animal sensors to manage and monitor free-ranging livestock has advanced rapidly over the past decade, particularly with the emergence of virtual fencing technology to manage livestock distribution. Low-cost GPS tracking for purposes of virtual fencing creates new opportunities to monitor animal health and behaviour when combined with an accelerometer to quantify the animal's behavioural state. However, our understanding of how behaviors can be quantified via GPS plus accelerometer measurements, and how foraging behavior metrics relate to diet quality or animal growth rate remains in its infancy. Here, we provide an overview of multiple studies that use on-animal sensors to quantify daily foraging behaviour of both yearling steers and mature cows in semi-arid rangelands of central North America (Colorado and Wyoming). We examine analyses of behaviour at varying time steps (seconds to minutes) summarized over the daily cycle using both commercially available and custom-built GPS plus accelerometer combinations. Foraging behaviour could be most accurately predicted by analyzing both sensors at a time step of 90 seconds, but an accelerometer algorithm calculated at a 30-second time step could be linking to longer GPS fix intervals with nearly equivalent prediction accuracy. We then focus on the utility of three key behavioral metrics: (1) mean daily grazing bout duration (GBD), (2) mean velocity while grazing (VG), and (3) the tortuosity of grazing pathways quantified as the mean turn angle while grazing (TAG). Our analyses identify GBD and VG as key indicators of declining forage availability, which could be used to guide the timing of pasture rotations or provision of supplemental feed. Furthermore, VG and TAG are significantly affected by stock density (herd size relative to pasture size), and hence could potentially be used to identify a threshold density that inhibits selective foraging and reduces weight gain.

Introduction

On-animal sensors are increasingly used to monitor and manage livestock in intensive production systems, but have received less attention in extensive rangeland settings (Trotter et al. 2019). However, the emergence over the past decade of virtual fencing technologies that rely on GPS tracking of individual animals creates new opportunities to monitor animal health and foraging behaviour in extensive settings where managers do not have frequent visual checks of their livestock. Advancing the effective use of on-animal sensors in extensive settings will rely on understanding how GPS tracking and behavioral sensors such as accelerometers can be combined to quantify animal foraging behaviors, developing durable and cost-effective sensors and associated attachment to animals, and developing of cost-effective means to transmit sensor data to managers (Bailey et al. 2018). Here, we provide an overview of multiple studies that have used on-animal sensors to quantify daily foraging behaviour of both yearling steers and mature cows in semi-arid rangelands of central North America (Colorado and Wyoming). We examine (1) accuracy of calibrations of grazing, walking and stationary activities using varying models of devices, (2) use of resulting predictions to quantify metrics of daily foraging behaviour, and (3) how these foraging behaviour metrics vary in relation to factors such as forage allocation and quality, and paddock and herd size.

Methods

We first compare predictions of cattle (*Bos taurus*) activity states (grazing, walking, stationary) using (1) commercial GPS tracking collar with a 2-axis activity sensor (Augustine and Derner 2013), (2) commercial GPS tracking collar with a 3-axis accelerometer (Augustine et al. 2023), (3) in-house constructed collar with off-the-shelf GPS and 3-axis accelerometers (Cunningham et al. 2024), and (4) commercial GPS tracking ear tag with 3-axis accelerometer. All devices were capable of collecting GPS fixes at 5-min intervals. The in-house collar collected GPS fixes at 1-second intervals, allowing us to rarify the data to varying epoch lengths (e.g. 10 sec to 15 min), and examine the optimal length for prediction of activity states via GPS+accelerometer or accelerometer alone. The eartag device was the xTPro produced by 701x (Fargo, ND, USA; 701x.com). We fitted xTPros on 69 yearling steers (23 in each of 3 different pastures) at the Central Plains Experimental Range in northeast Colorado during May – Sept of 2024. The 3 study pastures differed in stocking rate (low, moderate and high), and in vegetation composition, where the light stocking pasture was dominated by C3 midgrasses, and the heavy stocking pasture dominated by C4 shortgrasses (Porensky et al. 2017). We conducted direct observations of behaviours of 24 different steers wearing these eartags during May – July of 2024, where activity (grazing, walking, stationary, other) was recorded at a 30-second time step as described by Cunningham et al. (2024). The eartags collected GPS fixes at 5-min intervals, and used a 3-axis accelerometer in combination with a proprietary algorithm to predict the number of seconds in each interval the animal was grazing, walking, stationary (sum of resting and ruminating), or unknown. We classified each 5-min interval based as whichever activity occurred for >=50% of that interval, based on both direct observations and eartag predictions. Intervals in which no single activity occurred for >=50% of the time were classified as mixed.

We compared metrics of foraging behaviour from three studies that deployed (1) GPS collars with a 2-axis activity sensor (Lotek 3300LR) on yearling steers grazing shortgrass rangeland (data from Augustine et al. 2023), (2) GPS collars with a 3-axis accelerometer (MOOnitor.com) on yearling steers grazing shortgrass rangeland (data from Augustine et al. 2022), and (3) GPS collars with a 3-axis accelerometer (MOOnitor.com) on 12 mature cows with calves within a herd of 120 pairs grazing mixedgrass rangeland in northeastern Wyoming. In the latter study, collars were deployed during the 2021 growing season, with GPS fixes at 5-min intervals. Collared cows and their calves were individually weighed at the beginning and end of July, when vegetation was greening up and near peak biomass, and again at the beginning and end of September, when vegetation was senescing and reduced in biomass. We used data from the collars to calculate mean daily velocity while grazing (VG, in m min^{-1}), mean daily grazing bout duration (GBD, in min) and mean daily turn angle while grazing (TAG, in degrees measured as deviation from a straight line), following the same methods as Augustine et al. (2022).

Results

Table 1. Comparison of different on-animal sensors for their efficacies to predict cattle grazing and other activities for yearling steers grazing shortgrass rangeland in northeastern Colorado. Activity categories are G = Grazing, NG = Not Grazing, W = Walking, S = Stationary, and M = Mixed. Data sources are [a]Augustine and Derner (2013); [b]Augustine et al. (2022); [c]Brennan et al. (2021), [d]this study, [e]Cunningham et al. (2024).

Sensors	Attachment	Model	Timestep	Activity categories	Misclass Rate	Source
GPS + 2 axis activity sensor	Collar	Lotek 3300 LR	5 min	G, NG	13%	a
GPS + 3 axis accelerometer	Collar	MOOnitor	5 min	G, NG	9%	b
GPS + 3 axis accelerometer	Collar	Columbus P1; Gulfcoast	1 min	G, NG	11%	c
GPS + 3 axis accelerometer	Eartag	701x	5 min	G, NG	9%	d
GPS + 2 axis activity sensor	Collar	Lotek 3300 LR	5 min	G, W, S, M	16%	a
GPS + 3 axis accelerometer	Collar	Columbus P1; Gulfcoast	5 min	G, W, S, M	18%	e
GPS + 3 axis accelerometer	Collar	Columbus P1; Gulfcoast	90 sec	G, W, S, M	10%	e
3 axis accelerometer only	Collar	Gulfcoast	90 sec	G, W, S, M	13%	e
GPS + 3 axis accelerometer	Eartag	701x	5 min	G, W, S, M	13%	d

Predictions of cattle grazing activity via different on-animal sensors

Misclassification rates for cattle activity were lower when making binary predictions of grazing vs. non-grazing activity, compared to predictions of four activity classes (grazing, walking, stationary, and mixed; Table 1). When distinguishing between all four activity classes, misclassification declined from 16-18% using GPS with an activity sensor at 5-min intervals, to 10-13% using accelerometer data at 90-sec intervals. Misclassification rates were similar for GPS plus accelerometers mounted on an eartag, compared to the same type of devices mounted on a collar.

Variation in daily foraging behavior quantified via on-animal sensors

Mean daily velocity while grazing, grazing bout duration, and turn angle while grazing all varied in relation to forage conditions, stock density, and animal type. For yearling steers, a reduction in forage quantity and quality that reduced ADG from 1.11 to 0.25 kg steer-1 day-1 (HQl, HQt vs. LQl, LQt in panels A,D,G) also reduced VG by >2 m min-1, increased GBD by >80 minutes, and reducted TAG by 8 degrees. For yearling steers, a 10-fold increase in stock density (which reduced ADG by 15%) was associated with a reduction in VG by 1.5 m min-1, an increase in GBD by 10 min, and a reduction in TAG by 6 degrees.

Discussion

Rangeland scientists have long recognized that foraging behaviours are likely to reflect variation in feed intake and the quality of herbage eaten, and hence could serve as indicators of animal growth rates (Stobbs 1973, Chacon et al. 1976, Carvalho et al. 2015). Today, the increasing deployment of GPS collars on cattle for purposes of distribution management via virtual fencing creates opportunities to additionally monitor animal foraging behaviour via the addition of other sensors such as accelerometers. A synthesis of studies calibrating these various types of GPS + accelerometer combinations to predict cattle grazing activity at time steps of 1.5 to 5 min shows that misclassification rates of less than 15% can be achieved, both with collar- and eartag-mounted devices, even when non-grazing activity is separated into stationary vs. walking vs. mixed categories.

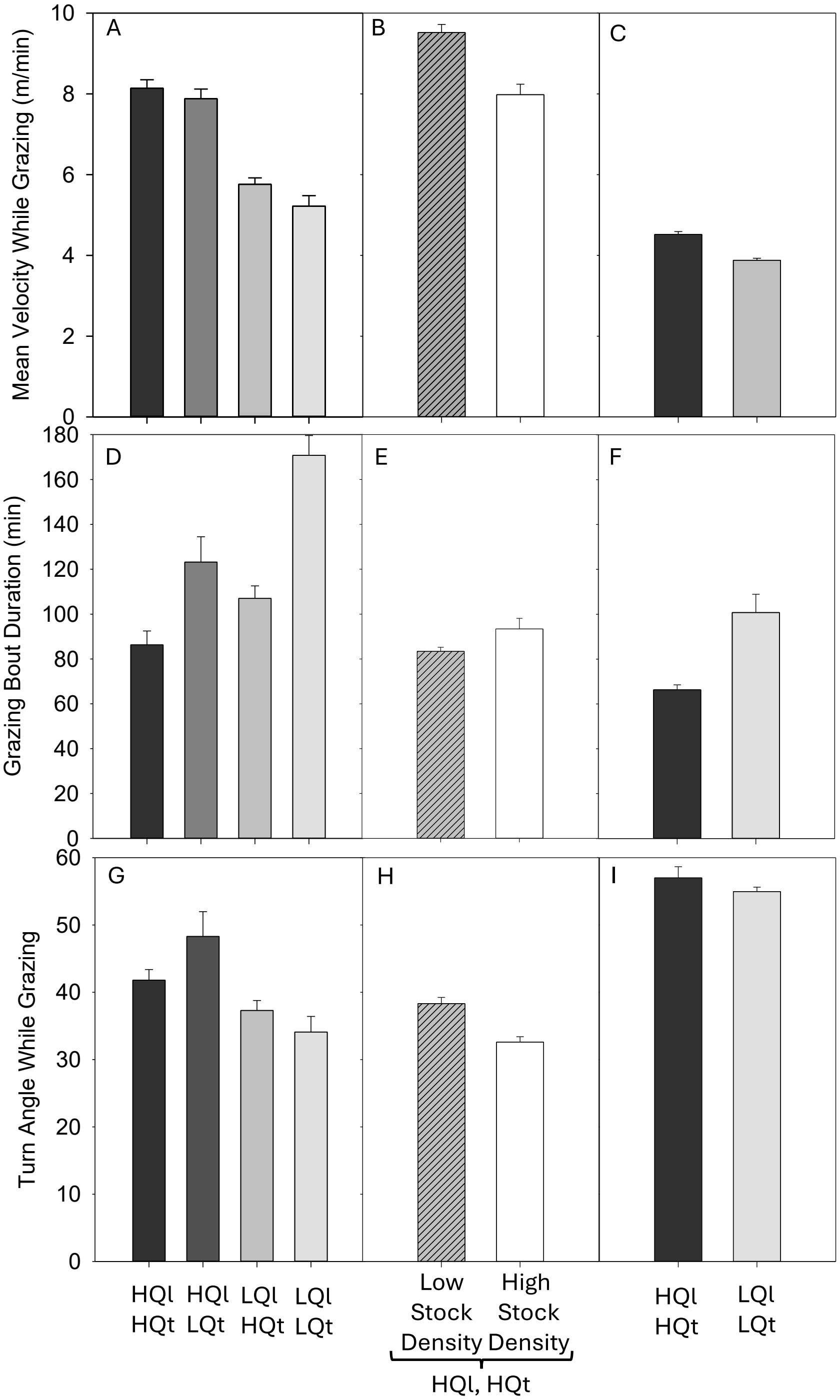

Figure 1. Comparison of three daily foraging behavior metrics quantified for free-ranging cattle in the semi-arid western Great Plains of North America using GPS collars combined with a 3-axis accelerometer. Panels A,D,G show results for yearling steers grazing shortgrass rangeland paddocks with varying forage conditions in 2020 (Augustine et al. 2022). Panels B,E,H show metrics for yearling steers grazing shortgrass rangeland with the same forage conditions early in the 2017 growing season, at high vs. low stock density (1.9 vs. 0.19 steers/ha; Augustine et al. 2023). Panels C,F,I show results for mature cows with calves grazing mixedgrass rangeland with varying forage conditions, quantified via MOOnitor

collars (GPS+3-axis accelerometer at 5-min intervals; this study). HQl = high quality forage; HQt = high quantity forage, LQl = low quality forage; LQt = low quality forage. Error bars show +1SE.

A key question is how to use these types of data to quantify foraging behaviour, and whether such behavioural metrics vary in response to foraging conditions and grazing management practices in predictable ways (Orr et al. , Carvalho et al. 2015). When we focused on 3 behavioural metrics calculated from collar data at a daily timestep (VG, GBD, and TAG), we found that VG is especially sensitive to both changes in forage conditions and management of stock density, both for yearlings and mature cows, in a way that reflects variation in cattle weight gain. Furthermore, VG was nearly equally sensitive to changes in forage conditions (both for steers and cows) as to a 10-fold increase in stock density. In contrast, TAG was more sensitive to changes in stock density, and GBD was more sensitive to changes in forage conditions. Findings also indicate that lactating cows graze at lower velocity and shorter GBD than steers for any given set of forage conditions, and cows exhibited more tortuous grazing pathways (greater TAG) compared to steers. As technologies for on-animal sensors to track foraging behaviour continue to advance and become more cost-effective, we encourage comparisons of consistent metrics such as VG, GBD, and TAG across varying rangeland conditions, animal breeds and age classes, and management regimes to develop a framework for real-time monitoring of animal condition and growth rates.

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