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Assessment of Animal-Based Methods Used for Estimating and Monitoring Rangeland Herbivore Diet Composition☆

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ABSTRACT

Researchers and managers need effective tools for monitoring the use of forages by large herbivores. Since 2000, the number of herbivore diet studies has nearly doubled. In this review, we determine trends in the field; assess the utility of key techniques against five criteria (cost, accuracy and precision, resolution, utility for long-term monitoring programs, and appropriateness for browsers and grazers); and make recommendations to give managers appropriate tools. Three techniques stand out: microhistology, near infrared reflectance spectroscopy, and deoxyribonucleic acid (DNA) barcoding. Microhistology has a long history of use in rangelands and is often considered the gold standard for understanding diet composition, albeit at a high cost of labor. Near infrared reflectance spectroscopy can resolve the presence of target groups or species more quickly than microhistology, especially for grazers. DNA barcoding provides the greatest resolution of dietary items with less quantitative certainty than microhistology. The costs associated with DNA barcoding come primarily from technology and sequencing, while in microhistology they are associated with labor. Therefore, an improved, streamlined microhistology method could provide rangeland managers a rapid and cost-effective method for diet monitoring. Ultimately, the complex challenges facing rangeland managers today may require the use of more than one method to achieve acceptable resolution within actionable time frames.

Introduction

Herbivorous mammals play a key role in the structure and function of rangelands (Hobbs, 1996), particularly in systems where predators are functionally absent (Vavra et al., 2007) and where native species interact with domestic livestock and exotic or feral herbivores (Schwartz and Ellis, 1981; Bakker et al., 2006; Vavra et al., 2007; Nuñez et al., 2010).The impacts of mammalian herbivores on rangelands depend on both environmental features such as aridity and history of disturbance and animal features including body size, diet type, and evolutionary origin (native/exotic/domestic) (Augustine and McNaughton, 1998; Bakker et al., 2006; Vavra et al., 2007). Diet is particularly important, as it gives insight into ecological and evolutionary processes like habitat selection, competitive interactions (e.g., coevolution of primary producers), and body condition in the typically nutrient poor environment of rangelands (Krebs, 1998). Forage for large herbivores consists primarily of graminoids (monocotyledons such as grasses and sedges), forbs (herbaceous dicotyledons), and browse (woody dicotyledons), with fruits, fungi, and seeds making up smaller components of the diet (du Toit and Olff, 2014).

Understanding and managing the complex relationships between herbivores and plants in rangelands requires effective techniques for monitoring herbivore diet. As all communities experience temporal change, one of the biggest challenges for monitoring programs is to distinguish among factors (e.g., natural climate change vs. over stocking) (Magurran et al., 2010). For this reason, long-term monitoring, ideally across 20- to 30-yr time frames, is desirable for making decisions about landscape management practices such as habitat modification through prescribed burning, managed stocking densities, and harvest regimes.

Methods to assess herbivore diet focus on measuring either the amount of plants that have been removed (plant-based methods) or physical/ chemical aspects of samples collected from animals (animal-based methods). Plant-based methods are of limited use for free-ranging animals, so they will not be discussed further here (Holechek et al., 1982; Mayes and Dove, 2000). Animal-based methods to assess diet composition in free-ranging mammalian herbivores range from

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direct observation of feeding activity to measures of markers and metabolites from the diet in feces (Holechek et al., 1982; Mayes and Dove, 2000; Barboza et al., 2009). Reported diets are affected by the method, material analyzed, and their interaction. Appropriate methodology may differ depending on whether the herbivore is domestic or wild, as the diets of domestic livestock can be more readily sampled by observation and invasive procedures (e.g., fistulas). For long-term monitoring programs, sampling should be noninvasive, as this allows for repeated measurements and is appropriate for common and rare species. Fecal collection is simple, repeatable, inexpensive, and applicable to both wild and domestic species. However, all techniques that rely on postingestive samples are subject to the effects of differential digestion (e.g., rates of flow and extraction of nutrients) of plant species and plant parts (Fig. 1). Increased fragmentation and breakdown of soft components (e.g., leaves), compared with harder components (e.g., stems) all impact the accuracy and precision of the diet estimate over and above any sources of error inherent in particular techniques.

Comprehensive reviews of techniques for estimating herbivore diets were published by Holechek and colleagues in 1982 and again by Mayes and Dove in 2000. Recent advances in technology, particularly the advent of deoxyribonucleic acid (DNA) barcoding, have increased the options available to managers to assess herbivore diets. It is therefore appropriate to revisit techniques for herbivore diet measurement and to make recommendations about timely and effective methods for answering key management questions.

In this review we:

- Survey the techniques used in recently published literature (since 2000), to determine trends in the field;
- Assess the utility of these key techniques for current applications against five criteria (cost, accuracy and precision, resolution, utility for long-term monitoring programs, and appropriateness for browsers and grazers); and
- Make recommendations to give managers appropriate tools for timely diet assessment.

Survey of Techniques

We focused our review on commonly used animal-based methods to assess free-ranging herbivore diets: behavioral observation, microhistology, near infrared reflectance spectrometry (NIRS), stable isotopes, cuticular wax alkanes, and DNA barcoding. Using Web of Science (an online database containing information from ≈8 500 research journals worldwide), we searched for papers published between 2000 and 2017 with the words "herbivore" and "diet." We only included records within documents classified as articles, data papers, database reviews, discussions, early access, or proceedings papers. Our search in February 2018 yielded 2 981 results. On the basis of the inspection of the top results, as well as our understanding of the field, we narrowed our search by including one of "bite count OR bite rate," "microhistology," "NIRS," "n-alkane AND wax," "stable isotope," or "DNA barcode" We also included either "selection" or "composition" to try to eliminate papers that looked solely at diet quality or digestibility. We excluded "insect," "reptile," "bird," "fish," "marine," or "carnivore" because we were interested in the use of techniques based on plant fragments. There were 417 papers included in our final survey.

There were almost twice as many papers published on herbivore diet in 2015−2017 ($n = 80$) as there were in 2000−2002 ($n = 45$). The relative use of behavioral observation and microhistology has declined slightly in the past few years, while NIRS and stable isotope methods have remained relatively consistent (Fig. 2). Use of cuticular

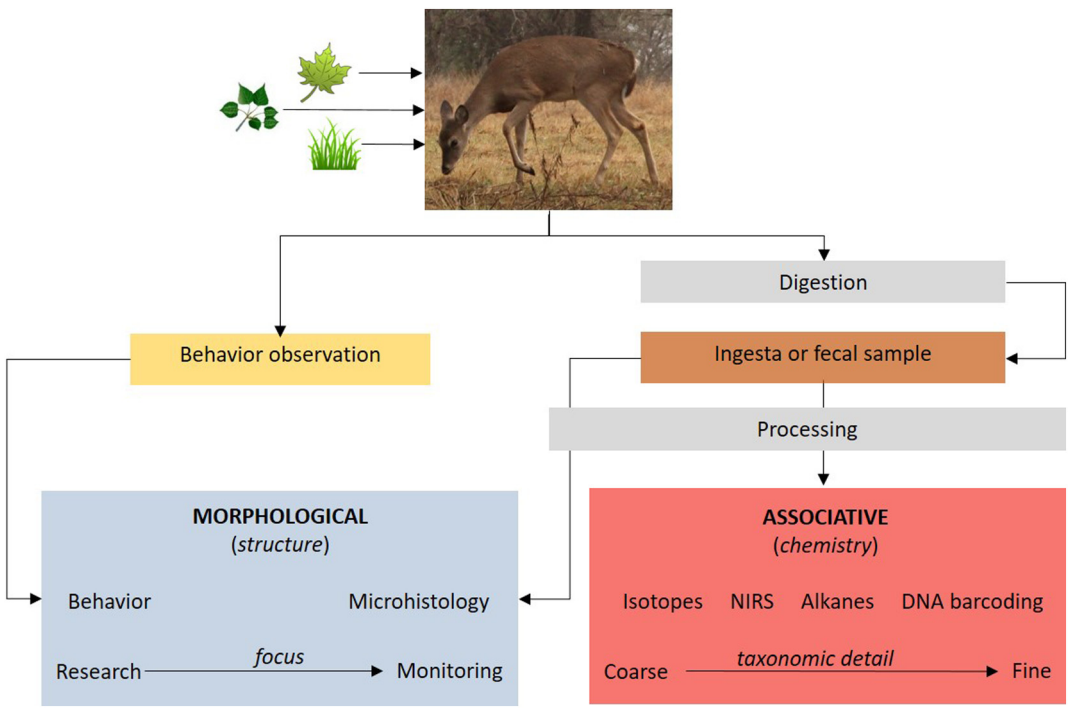

Figure 1. Noninvasive, animal-based techniques to assess free-ranging mammalian herbivore diet composition. Morphological techniques identify diet components based on structural characteristics of plants. Behavioral observation is the only technique that does not involve digestion of a sample by the herbivore before observation by the researcher or processing by the researcher before analysis. This means that this technique is uniquely unaffected by digestion of diet components. Due to the time involved in behavioral assessment, this technique is best suited to research questions. Microhistology is equally suited to research and monitoring. Associative techniques range in scale from chemically assessing elements (isotope analysis) to chemically assessing sequences (deoxyribonucleic acid [DNA] barcoding). Isotopic analysis gives the coarsest taxonomic scale (grass vs. browse), whereas DNA barcoding can identify plant subspecies in some applications.

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