***Q3: Can consumer foraging strategies and fitness be predicted using mechanistic foraging models that combine resource availability, variability, and nutrition with data on consumer physiological constraints and condition?***

***OR***

***Q3: How do realized dietary niches map onto the fundamental foraging niche manifold, and are associated fitness consequence predictable?***

***Preliminary Results.*** Our past and proposed research in Q1-2 quantifies the realized dietary niches and foraging strategies of small mammal consumers, however tools to estimate properties of the fundamental dietary niche and identify the ecological drivers of realized foraging strategies are not well-developed. To address this limitation, we propose a framework whereby an ensemble of potential strategies adopted by simulated consumers can be used to establish a fundamental niche-space against which observed foraging data can be compared, and from which predictions of consumer fitness will be made. To illustrate this approach, we developed a simple mechanistic foraging model parameterized by resource availability (ANPP) and consumer foraging strategies (e.g., specialist vs. generalist). The dietary dynamics that result from these simulated consumer strategies are then compared and evaluated using diffusion mapping, a dimensional reduction technique, and reduced to a two-dimensional embedding in order to assess differences between simulated and observed foraging strategies. This ‘niche manifold’ (Fig 8A) thus represents the fundamental dietary niche of a consumer based solely on resource availability and allometric constraints of the consumer, and will be treated as a null expectation against which empirical data of observed consumers will be evaluated – the realized niche. Mechanistic foraging models of additional complexity and realism will be used to establish this null expectation, however this simple framework serves to illustrate our approach.

We simulate a consumer foraging on a set of plant functional groups (; Fig. 8A) in a seasonal environment where resource distributions vary between fall (non-monsoonal) and spring (monsoonal) seasons, such that is the mean encounter rate of resource during season . Resource distributions are defined by the mean and variance of functional group ANPP per season using 20 years of LTER data. A consumer of mass forages within this resource landscape, and its foraging strategy is defined by its targeting a particular functional group with weight . For each consumer-resource interaction, the consumer will find and acquire its targeted functional group with probability (regardless of distance) or the nearest resource group with probability . this

fundamental niche manifoldemerges frome ensemble of simulated foragingies based on simulated We use a dimensional reduction technique known as diffusion mapping

This simple foraging model presents, to our knowledge, the first quantitative estimate of a fundamental dietary niche incorporating environmental and allometric constraints that can be directly compared to the empirical data as presented in Q1-2. We will integrate dietary information obtained from stable isotope ratios and isotopic mixing models (Q1) with information from fecal metabarcoding to reconstruct the proportional reliance on dietary functional groups. These empirical observations comprise the realized niche, which can be directly evaluated in the context of the quantified fundamental niche manifold, thus providing insight into the generative mechanisms directing observed consumer strategies. Furthermore, the underlying model from which we derive the fundamental niche manifold, while able to incorporate additional realism such as resource quality (Q2) and consumer behavior (see below), allows us to relate temporal changes in diet to the predicted fitness consequences of consumer strategies.

We next show how the coefficient of variation (CV) of nitrogenous returns of simulated consumers may be used as a predictive measure of fitness based on the consumed nitrogen from foraged plant resources. A lower CV reflects smaller fluctuations relative to the mean (higher fitness, red-yellow), and a higher CV reflects larger fluctuations relative to the mean (lower fitness, blue-green). Along the spines radiating from the central generalist, fitness values are generally consistent (Fig. 8B). Across spines, this fitness landscape is roughly partitioned by two opposing resource groups that result in lower fitness (higher CV; C4 perennial and annual grasses), moving away from which fitness increases towards two opposing resource groups that result in higher fitness (lower CV; C3 perennial forbs and shrubs).

Our demonstrative foraging model reveals that energy gains and our fitness measure are maximized by generalist strategies and the consumption of C3 plants, consistent with preliminary results indicating body condition (% fat) is driven by assimilation of C3 plants (Fig 5) and that generalists have higher monthly survival (Fig 6). We predict that the diet of an individual consumer foraging on C3 perennial forbs and shrubs (for which we will generate empirical data on diet composition via methods described in Q1) will map accordingly to the niche manifold as represented by the black rodent silhouette. Conversely, we predict that an empirical consumer foraging on C4 grasses will map near the hypothetical white silhouette. We also predict that there will be a significant correlation between the measures of fitness estimated in Q2 (body condition, survival) and CV, providing opportunities to predict diet-mediated fitness variation from simulated consumers. Further, the dietary niche manifold is well-suited to gain insight into the proximate drivers of foraging and fitness variation of consumers. For example, our foraging model predicts that fitness increases with the consumption of C3 perennial shrubs (Fig 8B), but this relationship is driven by the dominance of creosote, a resource with high secondary metabolite concentrations that require significant metabolic processing by the consumer. Integrating additional metrics of resource quality, consumer energetics, as well as individual-level data on species, ontogeny, or gut microbiomes will allow us to directly compare empirical and simulated foraging strategies to understand the importance of consumer and resource traits and their impacts on population dynamics.

***Incorporating Ecological and Physiological Constraints into Foraging Models.*** As we have shown how the foraging strategies of empirical consumers can be evaluated relative to simulations based on a minimalist set of foraging constraints, comparing strategies against models of any degree of complexity can be integrated similarly. We propose to expand upon a previously published modeling framework that we constructed to examine the consequences of body size and caching behavior on rodents at the Sevilleta, where foraging strategies are the product of a state-dependent fitness-maximization Stochastic Dynamic Program (SDP; Yeakel et al. 2020). Whereas our previous approach centered on the relative effects of endogenous (fat) versus exogenous (cache) energetic storage, we aim to develop a similar approach that is focused on the effects of a) energetic state (endogenous + exogenous), and b) microbiome state. While the former is fully explored in Yeakel et al. (2020), whether and to what extent a consumer’s microbiome impacts foraging behavior is not well understood. For example, while it is typically assumed that behavior dictates microbiome state (REFS), the reverse may be true as well: microbiome states directly facilitate enzymatic conditions within the consumer’s gut and could mechanistically determine the digestive efficiencies of different foods, potentially impacting behavior. Linking a low-dimensional descriptor of microbiome state (e.g., alpha diversity) to the physiological condition of the consumer in a dynamic model operating under the assumptions of fitness-maximization (Clark & Mangel 1996), will enable us to evaluate specific predictions regarding consumer foraging strategies. Empirical data on foraging, microbiome, and survival will enable us to iteratively verify and update the model.