Supplement S1: Equivalence of alternative vigilance parameterizations and derivation of travel time during cache retrieval

1. Equivalence of foraging models with vigilance

The notation in this supplement differs from the notation in the main text. To keep the discussion here as simple and focused as possible, we use only the minimal notation for a basic version of the disc equation, with additions for vigilance, attention, and prey conspicuousness.

Vigilance requires active attention, so we expect it to reduce foraging efficiency. Brown (1999) modeled this effect as a proportional reduction in the overall foraging yield,

$$f = (1-u)\frac{rn}{1+hrn} \tag{S1.1}$$

where $(1-u)$ represents the proportional reduction in foraging yield due to attention dedicated to vigilance behavior, r is a search rate, n is prey density, and h is handling time.

Dukas and Ellner (1993) also frame vigilance as a proportional reduction in attention. In their model the vector A itemizes the subjects that a forager might dedicate its attention to, so that vigilance necessarily reduces the attention that is available to search for prey. We have redefined A as a conditional (rather than marginal) proportion, so that it describes the allocation of available attention to different foraging strategies. Therefore, the attention that is dedicated to different foraging strategies in our model is defined as $A(1-v)$, where v is the proportion of attention dedicated to vigilance under our parameterization.

Following Dukas and Ellner (1993), and equations 1 and 5 in the main text, we define foraging yield as,

$$f = \frac{rnd}{1+hrnd} \tag{S1.2}$$

where,

$$d = \left(A(1-v)\right)^{1/K}\left(1-\left(\frac{r}{R}\right)^{K}\right) \tag{S1.3}$$

defines the probability of detecting a given prey item, assuming that $r < R$. Setting equations S1.1 and S1.2 equal, we can derive the proportional reduction in foraging yield due to a particular change in detection rate as,

$$u = \frac{1-d}{1+hrnd} \tag{S1.4}$$

2. Derivation of travel time during retrieval

Memory-based retrieval of caches differs from regular foraging activities. If hoarders remember the locations of their caches with reasonably high precision, they will be able to travel directly to a cache site and spend a minimal amount of time searching for exact location of the cache, rather than searching through a larger, general area for a resource whose location is unknown. To model retrieval, we multiply the base search rate, r, by a modifier, $m \geq 1$, that accounts for the hoarder's memory, and then add a component T to the handling time to account for time spend traveling to the cache site. We assume that hoarders can remember cache locations to within a given distance, l, which determines the maximum size of the memory modifier. Given that searches generally proceed at a maximum rate of R m^2/s, we define the maximum search rate for retrieval as $R \times 1/\pi l^2$. That is, the maximum base retrieval rate multiplied by the ratio of one square meter to the area of a circle of radius l. In the main text, we assume $l = 10$ cm, yielding a maximum retrieval search rate of $R_{\text{own}} = R/31.83$. Foragers may, of course, use slower actual rates if doing so produces higher detection rates.

Assuming that the focal animal's caches are uniformly distributed in space, and that the hoarder travels directly to the location of its nearest cache, we approximate the average nearest neighbor distance between the caches as $1/\sqrt{\pi n}$. Then, dividing by the rate of travel, t, gives,

$$\text{travel time per retrieval} = \frac{1}{t\sqrt{\pi n}} \tag{S1.5}$$

Finally, we multiply travel time by the number of retrieved caches to get,

$$T = \frac{1}{t\sqrt{\pi n}}\, rdn = \frac{1}{t\sqrt{\pi}} rd\sqrt{n} \tag{S1.6}$$

In the main text, equation S1.6 is multiplied by a binary indicator for each seed state, o_i, to ensure that it applies only to caches owned by the focal animal.

The inclusion of detection in equation (S1.6) implies that hoarders only travel to caches that they ultimately excavate. Provided that $K_{\text{own}} = 1$ (which it is, in our analysis), this assumption suggests that the foraging yield of retrieval is proportional the amount of attention that is paid to retrieval, and that hoarders always retrieve the seeds that they seek to retrieve. In other words, because T includes the same proportion of cache density as the numerator of Equation (S1.1), rdn, we have assumed that travel time is never wasted.

References

1. Brown, J.S.. Vigilance, patch use and habitat selection: foraging under predation risk. Evol. Ecol. Res. 1999, 1(1) 49–71.
2. Dukas, R.; Ellner, S. Information processing and prey detection. Ecol. 1993, 74(5), 1337-1346.