Behavioral and Spatial Response of the European Roe Deer to Supplementary Feeding Management

Nathan Ranc, Department of Organismic and Evolutionary Biology, Harvard University, and Department of Biodiversity and Molecular Ecology - Research and Innovation Centre, Fondazione Edmund Mach, San Michele all' Adige, Italy; Paul Moorcroft, Department of Organismic and Evolutionary Biology, Harvard University; Tobia Sforna, Department of Biodiversity and Molecular Ecology - Research and Innovation Centre, Fondazione Edmund Mach, Italy, and Life Science Department, University of Trieste; Whitney Hansen, Department of Organismic and Evolutionary Biology, Harvard University; Federico Ossi, Department of Biodiversity and Molecular Ecology - Research and Innovation Centre, Fondazione Edmund Mach, Italy; Priscilla Bonanni, Department of Biodiversity and Molecular Ecology - Research and Innovation Centre, Fondazione Edmund Mach, Italy, and Department of Biology and Biotechnology 'Charles Darwin', University of Rome 'La Sapienza', Italy; Alessandro Brugnoli, Enrico Ferraro – Associazione Cacciatori Trentini, Italy; Francesca Cagnacci, Department of Organismic and Evolutionary Biology, Harvard University, and Department of Biodiversity and Molecular Ecology – Research and Innovation Centre, Fondazione Edmund Mach, Italy

The supplementary feeding of ungulates, which is widespread across North America and Europe, typically seeks to improve individual and population performance, compensate for the loss of habitat, and improve hunting opportunities [1]. However, despite its prevalence as a management strategy, this practice can have significant impacts on individual movement and space-use patterns [2]. We aimed at evaluating the behavioral and spatial response of European roe deer (*Capreolus capreolus*) to spatiotemporal dynamics in supplementary feeding management. To address this question, we captured and tagged nine individual roe deer with GPS collars in an area with supplementary feeding (Eastern Italian Alps). We monitored the availability of food at the feeding stations on a weekly basis from January to May to obtain a temporal classification of feeding site management into two states: active (available feed) or inactive (unavailable). We examined each individual's space-use patterns in relation to temporally-dynamic food availability at intensively attended, focal feeding sites. We computed three metrics of space-use in subsequent alternate periods of food provisioning at focal feeding sites: home range size (95% multiple convex polygon, MCP), and spatial overlap and centroid distance between subsequent home range cores (50% MCP). Furthermore, we investigated the periodicity of movement recursions towards feeding sites using spectral analysis. For each existing feeding site, we generated a presence- absence (P/A) time series using a 50 m buffer. Individual feeding site time series were then aggregated based on management status to obtain both active and inactive feeding site P/A time series. We conducted two Fourier analyses on active and inactive time series to assess landscape-level response to management, and a wavelet analysis on focal feeding site time series to evaluate temporal patterns in periodicity [3]. The home range size was unaffected by feeding site management (active: mean = 46.78 ha, CI = 18.01 - 71.55; inactive: mean = 45.70 ha, CI = 32.67 - 58.73; paired *t* test: t = -0.10, df = 8, p-value = 0.92, n = 9). However, management influenced the location of the home range core: successive home range cores barely overlapped (mean = 20%, CI = 0 - 42%) and were relatively distant (mean = 284 m, CI = 145 - 422 m). Roe deer recursions showed a consistently clear peak at 24-h periodicity for active feeding sites, whereas this characteristic circadian signal was weak or absent for inactive sites (Fig. 1). In addition, disruptions of recursions towards focal feeding sites were consistently observed following supplementary feed depletion (Fig. 2). Our results suggest that roe deer shift space-use in response to spatiotemporal dynamics in supplemental resource availability. Specifically, we found a reallocation of movement and home range cores towards active feeding sites, and a temporary decline in movement recursions towards inactive sites. These findings are concordant with previous studies demonstrating a

high plasticity in feeding site use of the European roe deer [4], as well as space-use implications of supplemental feeding [5].

Figure 1. Typical Fourier power spectrum for the presence/absence time series in landscape-level active (a) or inactive (b) feeding sites. The 1% and 5% significant thresholds are shown respectively as blue and red dashed lines. These thresholds were obtained by bootstrapping. The raw periodograms were smoothed using a modified Daniell smoother.

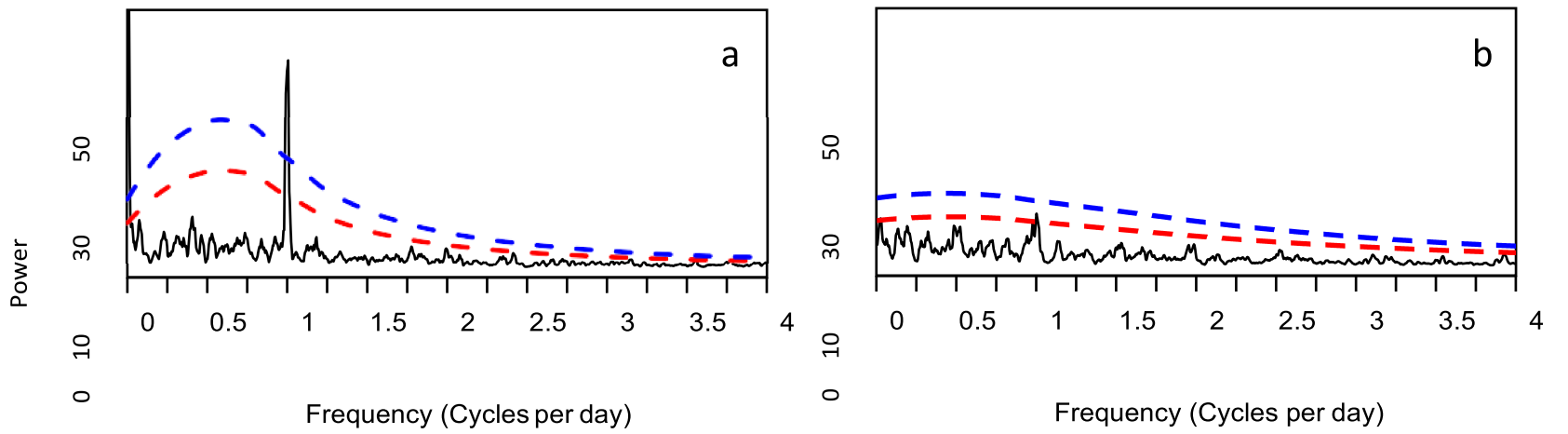
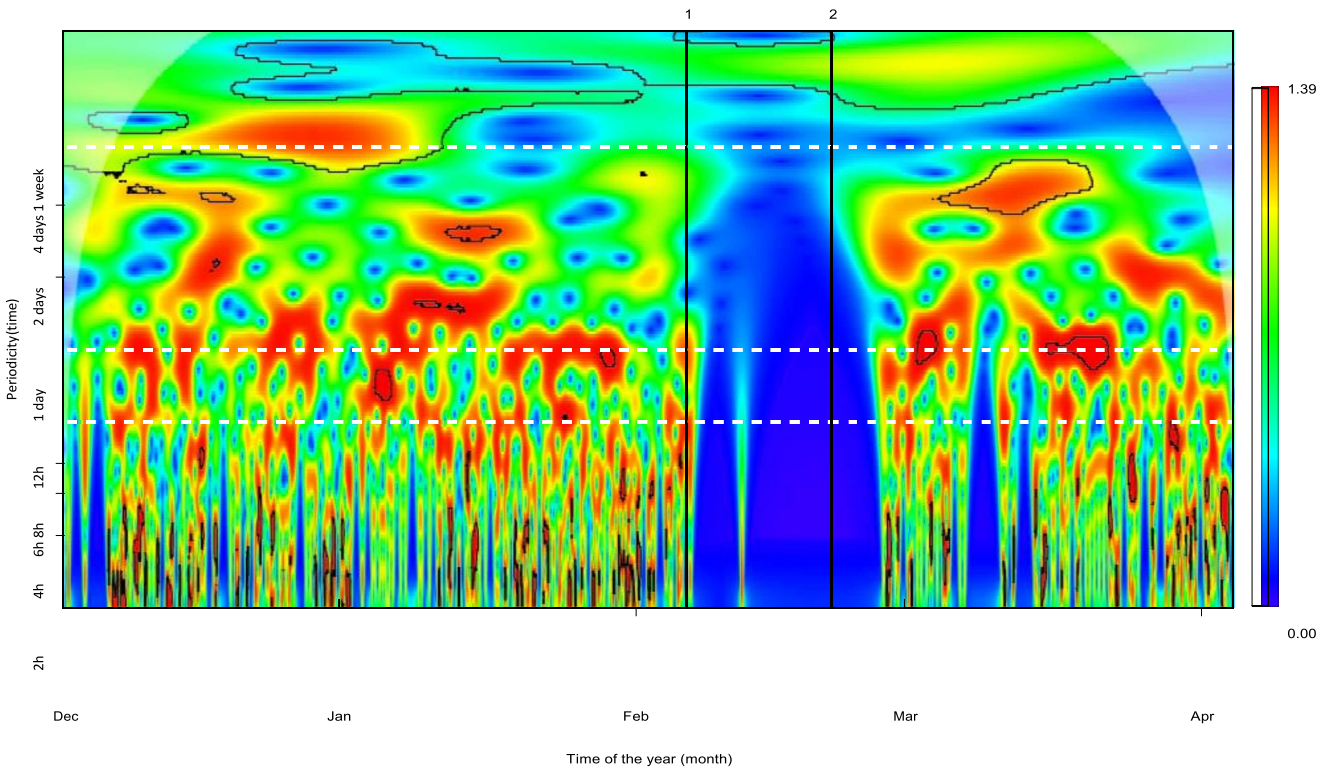


Figure 2. Typical wavelet power spectrum for a presence/absence time series at a focal feeding site. The colors ranges from low power value (weak periodicity, blue) to high power value (strong periodicity, red). The availability of supplemental feed was constant except for a period of about two weeks in February-March (limits: vertical black lines 1 and 2).

Horizontal dashed white lines represent characteristic periods of biological interest: 12 h, 24 h and 7 days. The areas of statistical significance at 5% levels are delineated by a solid black line contour. The "cone of influence", shown as a transparent mask in the margins, indicates time-periodicity domain where spectrum values are unreliable due to edge effects.



[1] Milner, J. M., F. M. Van Beest, K. T. Schmidt, R. K. Brook and T. Storaas. 2014. To feed or not to feed? Evidence of the intended and unintended effects of feeding wild ungulates. Journal of Wildlife Management 78: 1322–34.
[2] Selva, N., C. S. Teitelbaum, A. Sergiel, T. Zwijacz-Kozica, F. Zieba, K. Bojarska and T. Mueller. 2017. Supplementary ungulate feeding affects movement behavior of brown bears. Basic and Applied Ecology 24: 68–76.
[3] Riotte-Lambert, L., S. Benhamou and S. Chamaillé-Jammes. 2013. Periodicity analysis of movement recursions. Journal of Theoretical Biology 317: 238–43.
[4] Ossi, F., J.M. Gaillard, M. Hebblewhite, N. Morellet, N. Ranc, R. Sandfort, M. Kroeschel, et al. 2017. Plastic response by a small cervid to supplemental feeding in winter across a wide environmental gradient. Ecosphere 8.
[5] Kilpatrick, H. J. and W. A. Stober. 2002. Effects of temporary bait sites on movements of suburban white-tailed deer. Wildlife Society Bulletin 30: 760–766.