Final Report

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Introduction

Vultures and mortality by poisoning

Eurasian griffon vultures (*Gyps fulvus,* hereafter “griffons” or “griffon vultures”) are obligate scavengers (**ruxton2004?**) and social foragers (**harel2017?**). This means that they feed exclusively on carcasses, and they locate these food sources largely by following other individuals—using social information to locate food is essential in an environment where food sources are both ephemeral and spatiotemporally unpredictable.

However, vultures’ tendency to aggregate at carcasses makes them particularly vulnerable to poisoning. Carcasses are sometimes poisoned deliberately, usually with pesticides, to target livestock predators or scavengers . Occasionally, deliberate poisonings are directed at vultures themselves, due to the mistaken belief that they kill livestock . Another source of poisoning is non-steroidal anti-inflammatory drugs (NSAIDs), which are often used for veterinary treatment of livestock and can be toxic to vultures . Death can sometimes occur within after ingesting poisoned carrion. Poisoning is a major threat to griffon vulture populations. It is the leading cause of death in the griffon population in Israel, where the species is locally endangered (**anglister2022?**). It also threatens vulture species across the world (**ives2022a?**). Crucially, because vultures gather to feed at carcasses, poisoned carcasses can kill many individuals within a very short time period. For example, on in , of individuals died in a single poisoning event, and more were transported to a wildlife hospital and successfully treated.

Effects of mortality on social structure

Mortality events such as those caused by poisoning affect not just the raw number of individuals in a population but also the population’s social structure—the frequency and patterns of relationships between particular individuals. Social structure affects and , which are both of conservation concern. Therefore, it is important to understand how mortality affects these things.

There has been considerable study in the social network literature of how removing a node affects the network structure , with a particular focus on how the characteristics of the

Figure 1: A Eurasian Griffon Vulture (*Gyps fulvus*) and an Egyptian Vulture (*Neophron percnopterus*) feed at a carcass provided at a feeding site in Israel. Photo by Noa Pinter-Wollman.

removed node mediate that effect. This literature has also explored how networks react to sequential removals of multiple nodes; for instance, finds that . In behavioral ecology, (Shizuka and Johnson 2020) has distinguished between different types of mortality or node removals, arguing that the response of the social network should be different in cases where mortality can be reasonably anticipated by individuals in the population (such as mortality due to sickness or old age) than in cases of unanticipated mortality (e.g. predation or anthropogenic causes like shooting or poisoning). However, the existing literature has not explored the results of the simultaneous loss of several individuals (as opposed to the loss of one individual or sequential loss of several).

Which individuals die, and does it matter?

Social network analysis of GPS-tagged griffon vultures in Israel lets us study their population social structure. Past work by Nitika Sharma and Noa Pinter-Wollman shows that social networks differ between situations (co-flight, co-feeding, and co-roosting), and that each of these social situations contributes differently to the social network in aggregate (**sharma2022b?**). This suggests that changes to relationships in one social situation could affect those in other situations in complicated ways. This is particularly relevant in the case of vulture poisoning because mortality occurs in a specific behavioral situation (co-feeding) but has the potential to affect other situations and the aggregate network. For example, following a poisoning event in the Golan Heights in when of individuals were lost, a previously robust breeding and roosting colony was completely abandoned .

When modeling the effect of multiple mortality on the network, these social situations are relevant to the selection of which individuals are chosen to die. I expect that mortality of randomly-chosen individuals will affect the network structure differently than the mortality of the same number of individuals clustered on the co-feeding network.

Methods

Data: A Vulture Co-Feeding Network

The data that this model is based on comes from a GPS-tagged population of griffon vultures in Israel. The species is locally critically endangered (**efrat2020a?**) and is managed by the Israel Nature and Parks Authority (INPA), which runs supplemental feeding stations throughout the country (**spiegel2013?**). Israel's griffon vultures live mainly in the Negev and Judean deserts in the south. There is a small population in northeastern Israel and a declining population in the northwest. For this analysis, I restricted the data to the southern population, which is relatively well-mixed and somewhat separated from the northern populations.

As part of a collaborative NSF-BSF project between Orr Spiegel and Noa Pinter-Wollman, nearly 100 vultures have been fitted with GPS transmitters over the past two years. These tags provide location information at 10-minute intervals, with data automatically transmitted to and stored on Movebank. As of 2022, approximately 70% of the griffon population in Israel is tagged. This high coverage of the population means that the majority of a tagged individual's social interactions are with other tagged individuals, allowing us to study social interactions with greater certainty than is possible in many studies of free-ranging animals.

Results

Discussion

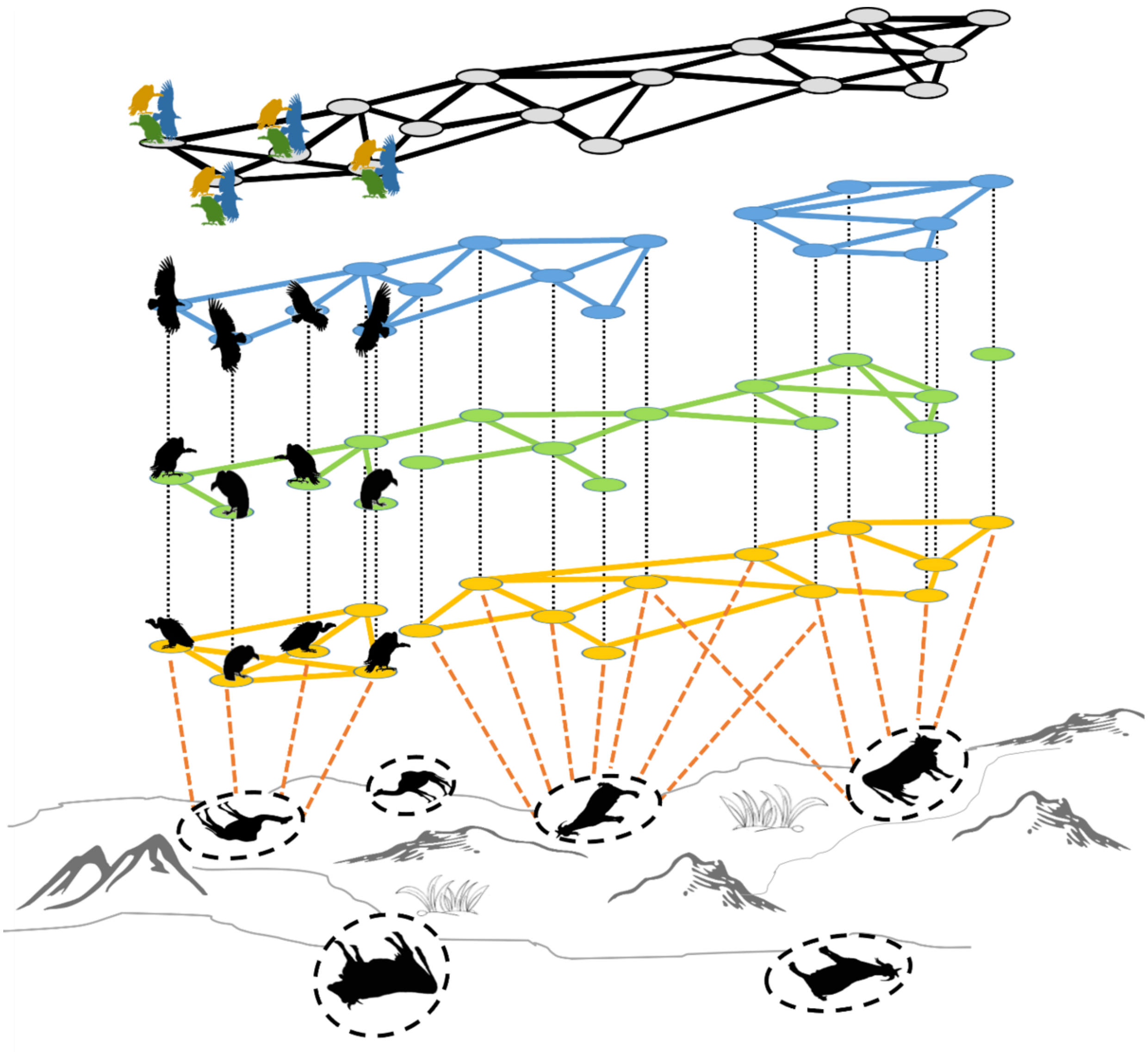

Figure 2: From : Social networks across multiple situations. A hypothetical example of social interactions among vultures in different social situations: co-flying in blue, nocturnal ground interactions, (i.e., co-roosting) in green, and diurnal ground interactions (e.g., co-feeding) in yellow. Solid lines within each social situation indicate interactions within the social situation and black-dotted lines between social situations connect occurrences of the same individual. Dashed orange lines connect individuals to food sites to show how spatial proximity can be used to infer social interactions, for example when co-feeding. An aggregate network at the top, in gray, combines all interactions from the different social situations.

1. Statement of problem you're studying. In one clear sentence, what question do you hope to answer?

2. Brief description of your model. Describe and justify your decisions with respect to choice of state variables, discrete or continuous time, deterministic or stochastic, spatial (or other) structure, etc.

3. Diagram and model equations for your base model, and for any extensions you are actively working on. (No need to list all the ideas that you probably won't have time to pursue in the next few weeks.)

4. R code for your base model. This doesn't have to include all the bells and whistles, but we want to see that you have the core model working. (It can be sent in a separate file, or you can do it all in markdown if you want.)

5. Basic results from your R code, which begin to address your central question (or at least, show the type of analysis you'd like to do to address your question). The results should be sensible, even if they're not fully refined yet. Show one or more plots with model output, and write a basic interpretation that explains why the results make sense. (Or highlight any puzzles you can't crack.) Show how far you've gotten and relate it to your goals.

6. Plans for your analysis. Summarize where you stand, and what your plans are to address your research question. In particular: what specific model outputs will you use to characterize your system's behavior? What model inputs will you vary to explore your central question? What relationships will you explore via sensitivity/uncertainty analysis, and how will you display them? What do you plan to accomplish in the remainder of the course? Are there extra features you need to add to the model? Are there specific technical challenges you face?

Shizuka, Daizaburo, and Allison E Johnson. 2020. "How Demographic Processes Shape Animal Social Networks." Edited by Leigh Simmons. *Behavioral Ecology* 31 (1): 1–11. https://doi.org/10.1093/beheco/arz083.