Article

Behavioural networks: a new methodology to study birds' habits

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Abstract

We introduce here a new methodology, named Behavioural Networks (BeNe), to thoroughly analyze birds' habits in space and time. Behavioural Networks are based on GIS technologies, association rules and network capabilities, all applied to GPS data. They return an information-rich and easily-interpretable synthesis of the activities taken by birds during a user-defined time interval. As a case study, we applied BeNe to the Lesser Kestrel *Falco naumanni* of the Santeramo in Colle colony (Apulia, Italy). Our methodology has been able to extract the main rules of the bird's behaviour during the most critical part of the chick-rearing period. BeNe can be applied to any bird species, to any time interval and to both local and migratory GPS data.

Keywords animal behaviour; association rules; behavioural states; behavioural transitions; bio-logging; *Falco naumanni*; Santeramo in Colle; networks.

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1 Introduction

There's an urgent need to thoroughly extract ecological and biological information from datasets offered by modern biotelemetry (data-loggers, light detection and LIDAR sensors) and thus enhance conservation strategies for animal species. One focal issue in behavioural ecology is the comprehension of animal behaviours in space and time, i.e. the frequency and timing of their daily activities. This goal can be achieved through expensive and time-consuming field surveys. We claim here that the same result can be achieved through low-budget bio-logging and an appropriate analytical framework. For this purpose, we introduce here a new methodology, named Behavioural Networks (BeNe), devised to extract ecological and biological information from bio-logging datasets.

As an illustrative case study, we have applied BeNe to the Lesser Kestrel *Falco naumanni* in the Alta Murgia National Park (prov. Bari, Southern Italy). The Lesser Kestrel *Falco naumanni* is a small falcon that declined considerably in the last decades due to agricultural intensification and use of pesticide which impacted its foraging habitats (BirdLife International, 2004). It is present among Annex I species of EU Wild Birds Directive (2009/147/EEC) and it is classified as SPEC 3 (Species of European Conservation Concern, level 3) according to BirdLife International (2017); it is also a priority species in steppic habitats and arable lands.

In Southern Italy, this species has been widely studied (Gustin et al., 2014; Gustin et al., 2014b; Gustin et al., 2014c; Giglio et al., 2016; Ferrarini et al., 2018a; Ferrarini et al., 2018b; Gustin et al., 2017; Gustin et al., 2017b; Gustin et al., 2017c; Gustin et al., 2018).

2 Materials and Methods

The study area (Fig. 1) is within the SPA (Special Protection Area) “Murgia Alta” IT9120007, and is included within the IBA (Important Bird Area) “Murge”. The studied female Lesser Kestrel belongs to the Santeramo in Colle colony (Fig. 1) and was surveyed in the period from 22 to 29 June 2017, corresponding to the most critical part of the chick-rearing period. Using accurate TechnoSmart GiPSy-4 data-loggers (23 mm× 15 mm× 6 mm, 5 g weight) that provided information about date, time, latitude, longitude, altitude and instantaneous speed, we collected data about its flight activities. The ratio of logger weight to body weight was less than 4%, which is consistent with the widely accepted 3-5% rule. The female Lesser Kestrel was captured and fitted with data logger at its artificial nest box. It was selected because it was in fit health conditions. To download the data from the data-logger, it was recaptured at its nest box after battery was exhausted. The GPS device was tied dorsally to the base of two central tail feathers (Fig. 2). The deployment of the transmitter did not take more than 15 minutes. Overall, we collected 3312 GPS points (Fig. 1).

Fig. 1 Santeramo in Colle colony (Apulia region, Italy), Alta Murgia National Park and 3312 GPS points (in red) of the tracked Lesser Kestrel are shown. In blue, the municipalities around the studied area.

Fig. 2 We used TechnoSmart GiPSy-4 data-loggers (23×15×6 mm, 5 g weight) that provided information about date, time, latitude, longitude, altitude and instantaneous speed.

Let S_t be the bird's behavioural state at the generic time t. S_t can assume 5 possible states detected through GPS devices: *flight*, *nesting*, *roosting*, *foraging*, *perching* (Fig. 3). Let S_{t+1} be the bird's behavioural state at the successive time step. In this study, the temporal lag between successive behavioural states is equal to 3 minutes because it corresponds to the interval between successive GPS fixes.

The behavioural vector $\boldsymbol{S}$ counts the number of times the surveyed bird has been in each behavioural state. Under the null hypothesis of equal probability of each behavioural state, the expected frequency S_{exp} of each state is thus

$$S_{exp} = N / 5 = 0.2 * N \qquad (1)$$

where N is the number of GPS points.

The chi-squared test to measure the significance of deviance from expected frequency S_{exp} is thus

$$\chi^2 = \sum_{i=1}^{5} \frac{\left(S_i - S_{\text{exp}}\right)^2}{S_{\text{exp}}} \qquad (2)$$

with 4 degrees of freedom (*d.f.*= 4).

Let $\boldsymbol{T}_t$ be the vector of bird's behavioural transition between S_t and S_{t+1}. For example, the bird could be in flight at time t and at nest at time t+1, thus $\boldsymbol{T_t}$ = <*flight*, *nesting*>. The number of transitions between behavioural states is equal to the number of GPS point minus 1, i.e. N-1. Because both S_t and S_{t+1} can bear 5 possible states, $\boldsymbol{T_t}$ can potentially assume $5^2 = 25$ possible values, when also transitions between identical states (e.g., $\boldsymbol{T_t}$ = <*flight*, *flight*>) are considered (Fig. 3).

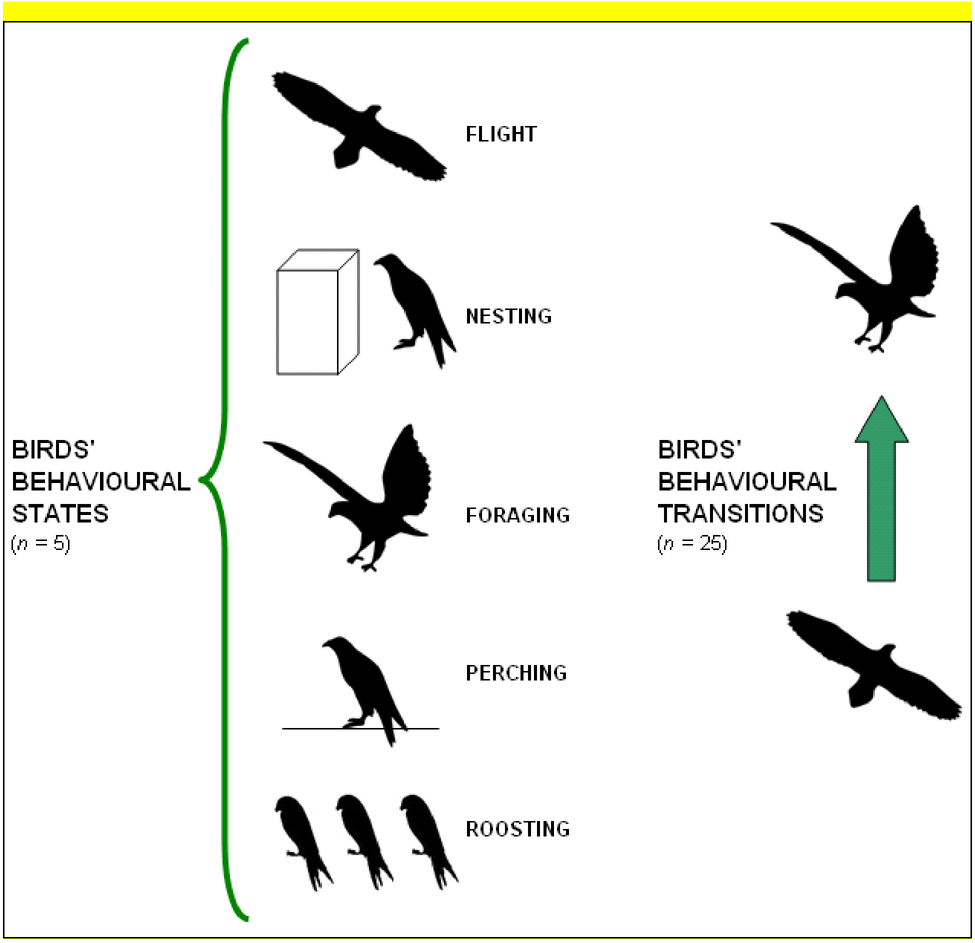

Fig. 3 Graphical representation of the suggested birds' behavioural states (on the left) and transitions (on the right), that can be detected through GPS devices. Given 5 possible behavioural states, there are 5^2 possible behavioural transitions among states.

The transition matrix $\boldsymbol{T}$ counts the number of transitions $\boldsymbol{T_t}$ from one behavioural state to another. In order to extract such transitions from the GPS dataset, we used the association rules methodology (Agrawal et al., 1993; Agrawal et al., 1994) which calculates

$$T_{j,k} = \#(\mathbf{T}_t =< j,k >) = \frac{\#((S_t = j) \cap (S_{t+1} = k))}{N-1} \tag{3}$$

where # is the number of times $\boldsymbol{T_t}$ = <*j, k*> (e.g. $\boldsymbol{T_t}$ = <*perching, nesting*>). Although association rules have been almost exclusively applied to market basket analysis, recently they were also used for ecological and biological purposes (Ferrarini et al., 2010; Rossi et al., 2014).

Under the null hypothesis of equal probability of transitions between states (i.e. perfect independence among behavioural states), each kind of transition should account for 4% (i.e. 1/25) of the behavioural transitions:

$$T_{exp} = (N\text{-}1) / 25 = 0.04 * (N\text{-}1) \tag{4}$$

The chi-squared test to measure the significance of the deviance from the expected frequency T_{exp} is thus

$$\chi^2 = \sum_{j,k=1}^{5} \frac{\left(T_{j,k} - T_{\mathrm{exp}}\right)^2}{T_{\mathrm{exp}}} \tag{5}$$

with 24 degrees of freedom (*d.f.*= 24).

Last, BeNe provides the network graphs of birds' behavioural states and transitions with the detected frequencies of each state and transition.

Behavioural networks have been computed through the software BeNe-Lab (Ferrarini, 2017) written in Visual Basic for Applications (Pattison, 1998).

3 Results

The tracked female Lesser Kestrel showed a clear differentiation among its different daily activities (Fig. 4). Both the behavioural states and transitions resulted significantly different from the null-hypothesis behavioural network (chi-squared test, $p < 0.01$). Flight and nesting resulted to be the dominant behavioural states (about 75% of the monitoring time was used for these 2 activities). Roosting, which is a typical Lesser Kestrel's nocturnal activity, was null because this female spent most of its nocturnal time at nest for parental cares (Fig. 5). Foraging and perching concerned about 13% and 12% of the tracked time respectively.

Flight and nesting resulted to be very continuous activities. When the tracked bird was at flight at the generic time *t*, almost 29% of times it was still flying at time *t*+1 (i.e. 3 minutes later), which is about 7 times more frequent than the null-hypothesis 4% continuity. When the tracked bird was at nest at the generic time *t*, almost 26% of times it was still at nest at time *t*+1 (i.e. 3 minutes later), which is about 6 times more frequent than the null-hypothesis 4% continuity. The most common interruption of the flight activity was for foraging (5.40%), followed by nesting (3.63%). The most common interruption of the nesting activity was for perching (5.68%), followed by flight (4.11%).

Perching and nesting resulted to be twin activities, probably because the tracked Lesser Kestrel was used to perch and monitor the situation before entering its artificial nest.

Foraging resulted linked to flight only. This interesting output of BeNe is due to the fact that the most suitable foraging sites (pseudo-steppes) are far apart from the nest of the tracked individual, thus foraging activities usually required long-distance flights, several minutes of foraging activity and then long-distance flights back. For this reason, foraging was never followed by activities like perching, nesting or roosting, and the flight activity occupied almost 40% of Lesser Kestrel's time.

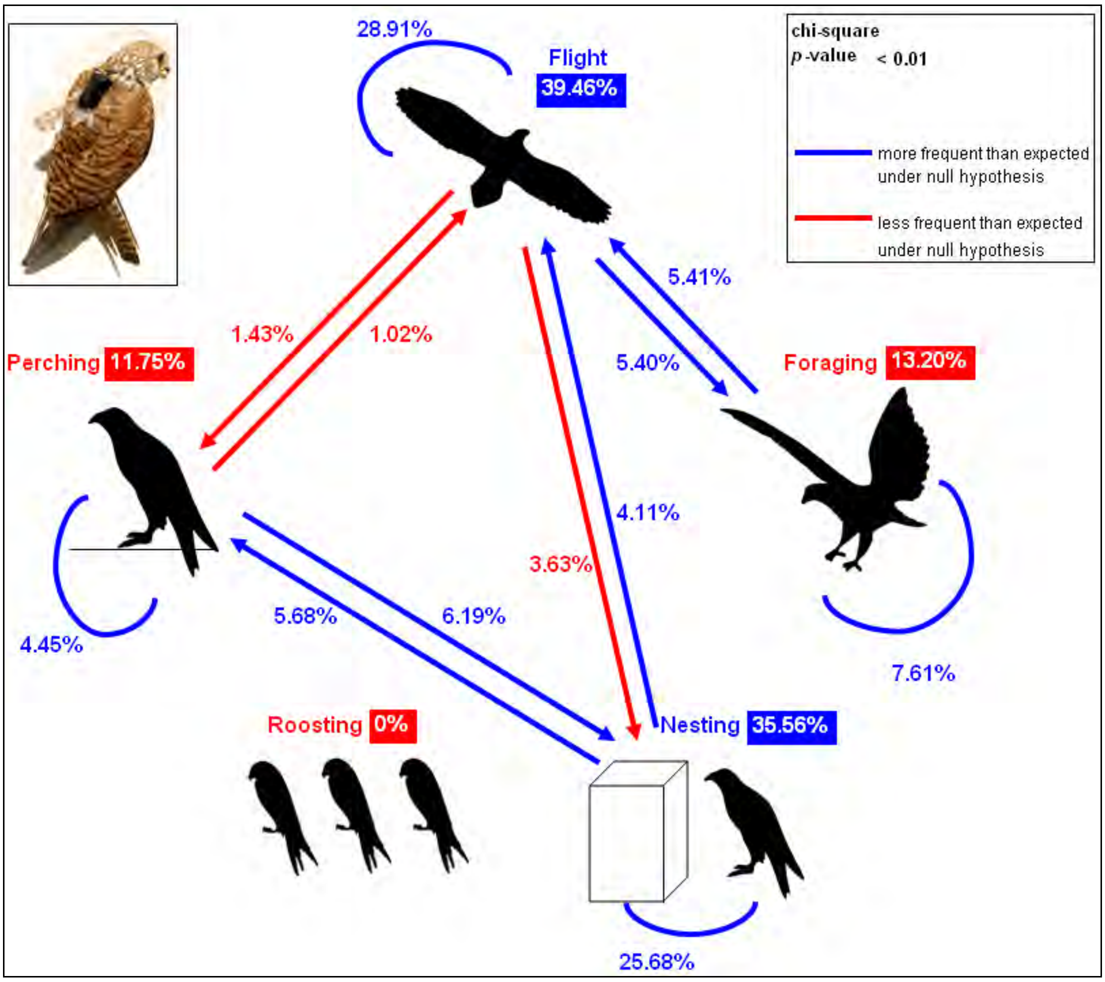

Fig. 4 Behavioural network representing the overall (diurnal and nocturnal) activity of the tracked Lesser Kestrel (3312 GPS points). Blue lines represent transitions that resulted more frequent than expected under the null hypothesis of equal probability of transitions between states (i.e. perfect independence among states). Transitions in red were less frequent than expected. Blue and red boxes provide the same information for behavioural states. The whole network resulted significantly different from the null-hypothesis network (chi square *p*-value < 0.01).

If we only consider nocturnal activities (Fig. 5), interesting differences emerge. Nocturnal foraging was null during the tracking period, and the bird showed only a very limited activity around the nest.

The tracked female Lesser Kestrel spent almost 64% of time at nest for parental cares. This activity was almost continuous, seldom interrupted by short flights and, mainly, by perching activity. The flight activity, besides limited in time, was also discontinuous because it was only used to move from the nest to sites in the surround for perching. Probably, perching was functional to monitor the situation around the nest. It is also plausible that the bird was sometimes disturbed by some kind of noise, which is typical in urban areas even at night, so it moved off the nest and then came back.

The nocturnal behavioural network resulted significantly different from both the null-hypothesis behavioural network and from the diurnal one (Fig. 6; chi-squared test, $p < 0.01$).

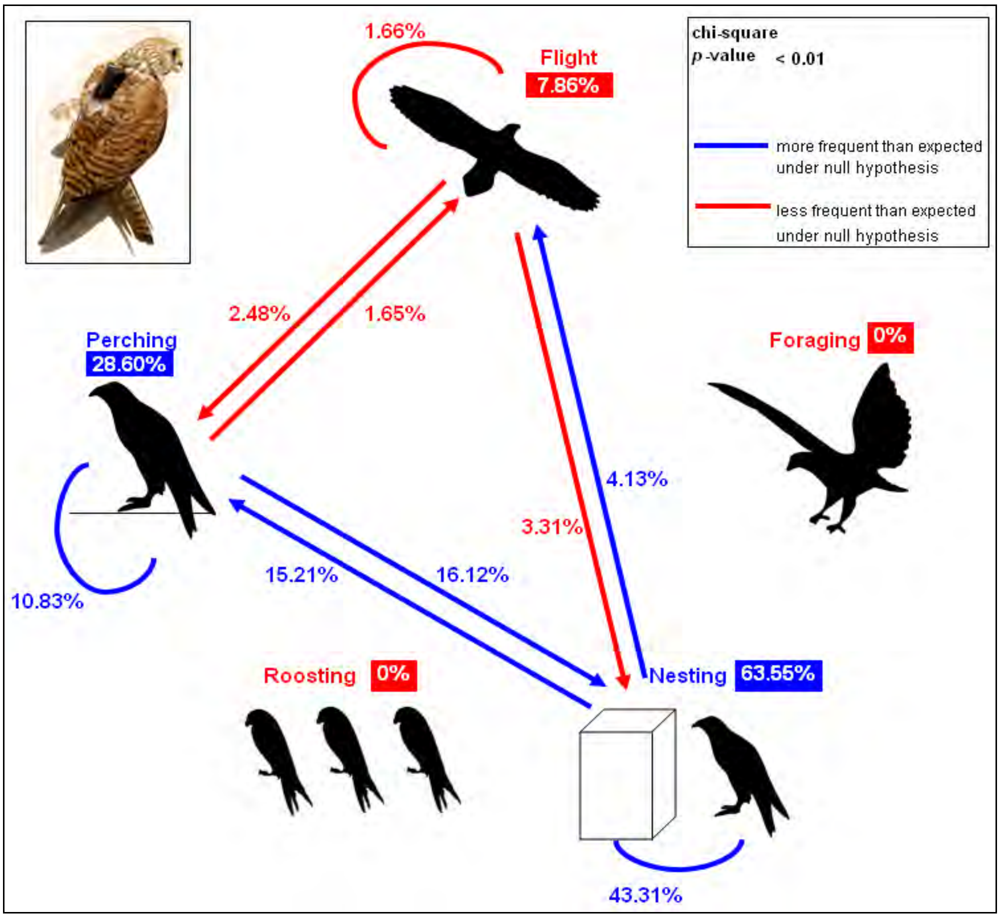

Fig. 5 Behavioural network of the nocturnal activity of the tracked Lesser Kestrel. Blue lines represent transitions that resulted more frequent than expected under the null hypothesis of equal probability of transitions between states (i.e. perfect independence among states). Transitions in red were less frequent than expected. Blue and red boxes provide the same information for behavioural states. The whole network resulted significantly different from the null-hypothesis network (chi square p-value < 0.01).

During the day-time (Fig. 6), the behavioural network resulted significantly different from the null-hypothesis one. Perching was an infrequent activity (2.09% of the tracked time). Flight and foraging were the most common bird's activity (about 78% of the tracked time). These two activity were strictly connected because long flights are usually required to Lesser Kestrels in these area to reach the pseudo-steppe areas. In fact, flight resulted to be a very continuous activity. When the tracked bird was at flight at the generic time t, almost 45% of times it was still flying at time $t+1$ (i.e. 3 minutes later), which is about 11 times more frequent than the null-hypothesis 4% continuity.

The nesting activity was reduced to only 19.43% of the tracked time, but it was rather continuous (15.01% continuity). It was limited to two intervals of time, i.e. after dawn and before sunset. In the remaining interval of time, the tracked Lesser Kestrel occupied its time with flight and foraging activities in order to feed itself.

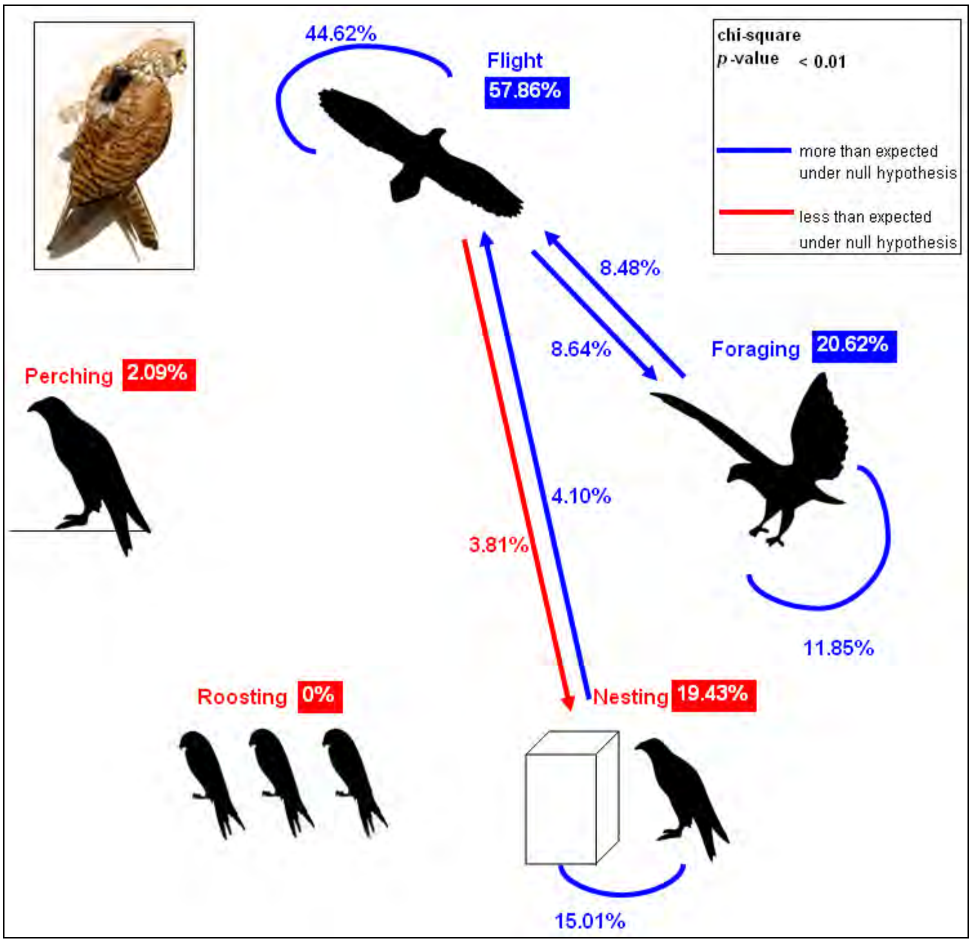

Fig. 6 Behavioural network of the diurnal activity of the tracked Lesser Kestrel. Blue lines represent transitions that resulted more frequent than expected under the null hypothesis of equal probability of transitions between states (i.e. perfect independence among states). Transitions in red were less frequent than expected. Blue and red boxes provide the same information for behavioural states. The whole network resulted significantly different from the null-hypothesis network (chi square *p*-value < 0.01).

4 Conclusions

We have developed a new methodology, named Behavioural Networks (BeNe), to thoroughly analyze birds' habits in space and time. This methodology returns an information-rich and easily-interpretable synthesis of the activities taken by birds during an user-defined time interval. For illustrative purposes, we have applied it to a single bird. However, BeNe can be applied to an arbitrary number of birds, all considered together, and also in comparative studies of birds belonging to different species, colonies and/or sexes.

We claim that, with an increasing amount of datasets about birds' movements at local and migratory scale, BeNe can serve as an expert data mining tool to extract valuable biological and ecological information for conservation purposes.

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