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UNDERSTANDING TIME SERIES OF RFID SENSOR DATA FOR PREDICTING MORTALITY IN LAYING HENS

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SUMMARY

Diseases and mortality early warning systems are warranted in the egg production industry. Tracking animal movement and resource occupancy using RFID sensor technology has the potential to create such early warning systems. In this study, we analysed a dataset of individual hens' behavioural time budgets of 9375 laying hens in relation to hen mortality using a custom-built RFID system in a commercial farm. The dataset consists of mortality data of each individual hen, the average time each hen spent in the key resources of the aviary system (feeders and nest box), and on the outdoor range. Based on the data, we constructed the corresponding individual time-series data with the mean time duration and the frequency of visits to the feeders, nest boxes and outdoor range for the entire production period. The hens were then grouped according to the time of their death during the production period into four distinct clusters. Subsequently, resource usage patterns from each individual mortality cluster were revealed for the entire production period. We investigated the resulting resources usage patterns in terms of trends and similarities with ARIMA models, autocorrelation and cross-correlation functions. We also correlated the obtained mortality clusters measures with activity patterns and body weight at placement of the hens. Our study demonstrates that mortality can be modelled using the hen`s activity patterns thus leading to the potential mortality prediction in the early stages of production period.

INTRODUCTION

Free range laying hens can be provided with the opportunity to access various structural areas including open floor space, feed areas, water lines, nest boxes, perches, aviary tiers, winter gardens and ranges (Larsen et al., 2018). Different individual location preferences can lead to the development of hen subpopulations that are characterised by various performance, health, and welfare parameters (Sibanda et al., 2020a, 2020b). Understanding the complexity of hen movement and hen interactions within their environment provides an opportunity to limit the disadvantages that are associated with housing in non-caged husbandry systems and aids in decision-making for farm staff, managers, and equipment designers. Flocks with higher prevalence of diseases have lower average movement (determined through the analysis of optical flow of surveillance footage) and that analysis of flock movements and production system usage might provide a method for predicting outbreaks (Colles et al., 2016; Courtice et al., 2018; Sibanda et al., 2020b). Common health and welfare concerns in free-range flocks

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such as Spotty Liver Disease, *Ascaridia galli*, plumage damage, beak damage and fractures to the keel bone caused by falls, collisions are related to individual hen movement and access to different resources in the barn and on the outdoor range (Courtice et al., 2018; Rufener et al., 2019). The clinical signs for several disease vary and include loss of appetite and inactivity that can potentially be detected through individual-level behavioural monitoring using sensor technologies. In previous studies we have demonstrated that usage of key resources provided to the hens is correlated to the disease and mortality (Sibanda et al., 2020b).

There are numerous ways in which farm disease surveillance and mortality can be monitored through the flock production system. The most popular method used is to manually collect a number of samples on the aviary systems, outdoor range (or a subsection of it) at a certain time points at different times of the day and age of hens, which usually starts when the farmers observe death in their chicken (Sellek et al., 1997). However, the accuracy of the values for the active disease surveillance is questionable, as it could reflect either a biased sub-sample of the flock, thereby reducing the chances of disease detection. Furthermore, this approach provides a high-level view for disease surveillance, but does not capture details for predictions at the individual level or vulnerable flock sub-populations such as reduced use of the feeders.

Advances in video cameras, sensor technology, Radio Frequency Identification (RFID) technology, and accelerometers, in combination with the reduction in cost, has provided massive prospects for in-shed disease surveillance of individual hens (Ahmed et al., 2021). Manual video annotation is time-consuming and does not identify individual hens without identifying features. Furthermore, automated computer-vision based approaches suffer from challenges such as occlusion, where hens and equipment block off individuals. However, RFID systems showed the potential to overcome this obstacle for monitoring in free-range systems, and have been widely used across agricultural production systems for identifying and tracking the movement of animals (Barnes et al., 2018; Bowen et al., 2009; Brown et al., 2014; Maselyne et al., 2014). Most recently there has been increase in use of RFID system in free-range hen production systems (Bari et al., 2020) for monitoring range and nest-box usage, along with movement within feeding system, by deploying a comprehensive system of RFID receivers and antennas throughout aviary systems and on the open range. Moreover, due to its capacity to individually identify each hen without disturbing the animals' activities (Campbell et al., 2020), these sensors have the potential to be used for early warning systems and help in decision-making to improve the welfare and health of animals. Real-time location systems can measure these parameters automatically and provide data for early detection of behaviour changes relevant to hens' health and welfare.

The use of automated systems for collecting data within such a production environment yields very large datasets with sufficient depth to apply more complex machine learning algorithms (Ruhnke et al., 2019). For example, time series analysis in combination with supervised machine learning can be used to predict future parameters such risk of mortality (Han et al., 2011). By monitoring behaviour time patterns of hens, it is possible to determine any deviations from regularity which could indicate individual health status, therefore allowing for early intervention, and improving on-farm productivity. In a previous study we have shown that the hens that used the outdoor range were three times less likely to die compared to the hens that stayed in the shed (Sibanda et al., 2020b). Therefore, we hypothesize that the use of the key resources over time on the aviary system and outdoor range might be used as an indicator of likelihood of mortality. This study builds upon this preliminary body of work by applying the time series algorithms to describe and predict mortality based upon aviary and outdoor range usage patterns as monitored with RFID monitoring system across the production cycle.

MATERIALS AND METHODS

Animal housing and management

All procedures carried out in this study were approved by the University of New England's Animal Ethics Committee (AEC 16-087). A total of three flocks (Flocks A – C) each housing 40,000 Lohmann Brown hens were kept on the same commercial farm. In each flock, 3125 randomly chosen hens were RFID leg-banded at 16 weeks of age for individual identification, and then placed in partitioned cross-sections of the shed, allowing for the monitoring of individual range access. Details of the experimental set up and the validation of the RFID system are provided by Sibanda et al. (2020a, 2020b). All the hens were fed the same diet according to the breed standard and they were exposed to the same management team and procedures. The shed was equipped with a three-tier aviary system, tunnel ventilated system, curtain sides and pop holes along the entire length of the shed wall, which allowed constant air flow and temperature control. Manure was removed frequently using automated manure belts, preventing any ammonia build-up.

Mortality cluster classification

A total of 7171 hens were used in this study with 4782 having a full dataset at the end of the trial. Hen mortality was recorded daily by physical evaluation and removal of dead hens in the shed by farm staff. The mortality data was segmented into four different groups based on the time of their death. The group of hens that did not die were filtered out of the data first. The hens that had died during the production period were then grouped using the optimal univariate *k-means* clustering in R programming language and the optimal number of clusters k was estimated at three with Calinski-Harabzs method. The data from the hens that did not die was then appended to the other three clusters of hens. The clusters were identified as follows: Cluster 1 spent 2 - 115 days alive, Cluster 2 spent 117 - 227 days alive, Cluster 3 spent 228 - 335 days alive. The hens that survived the whole production period when then appended to the dataset and labelled as Cluster 4 (Fig. 1).

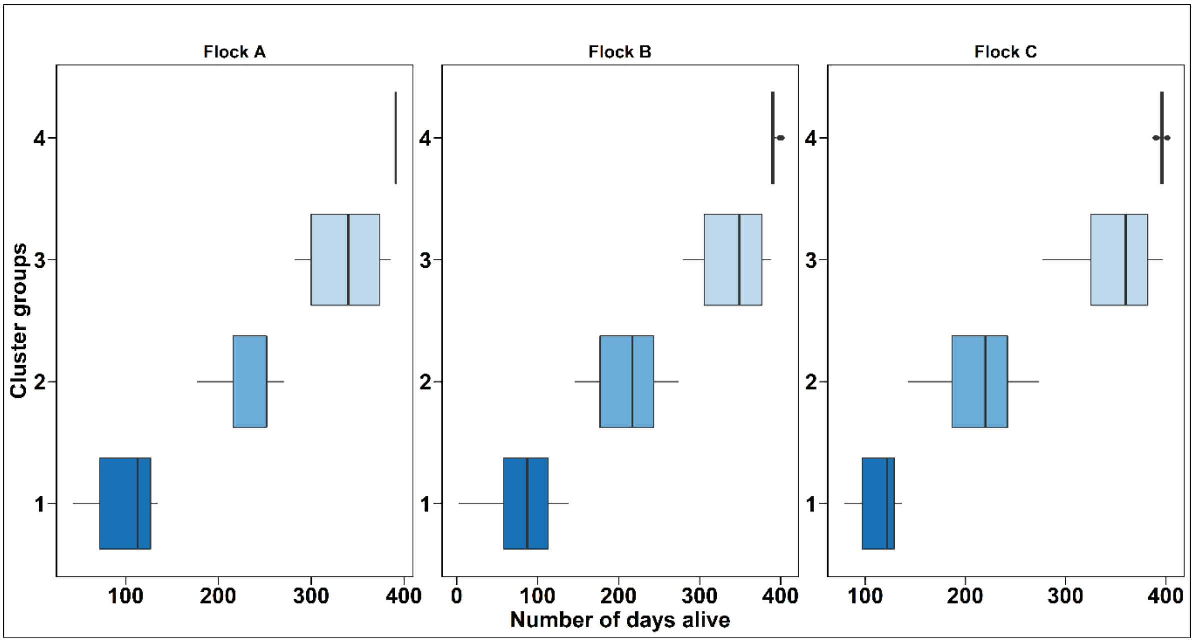

Fig. 1. Univariate cluster analysis and cluster description of hens according to their time of death. The cluster centroid for cluster 1, 2, and 3 were 68, 215, 338 days alive. The cluster 4 hens are the hens that survived the whole production period

Timeseries data creation

In this study we analysed activity patterns of laying hens in relation to hen mortality using a custom-built RFID system. The data analysed in this study consisted of 9375 hens individually tracked for the access to key resources (feeders, nest box and outdoor range) during the entire laying period (16-74 weeks of age). We created timeseries data based on the frequency of visits to, and duration on, the feeders, nest boxes and outdoor range for each individual hen from week 16-74 as shown Fig. 2. In brief, the raw timestamp data was aggregated to sum the frequency of visits and the total time each hen spent on the key resources (feeders, nest box and outdoor range) for each day the hens were alive.

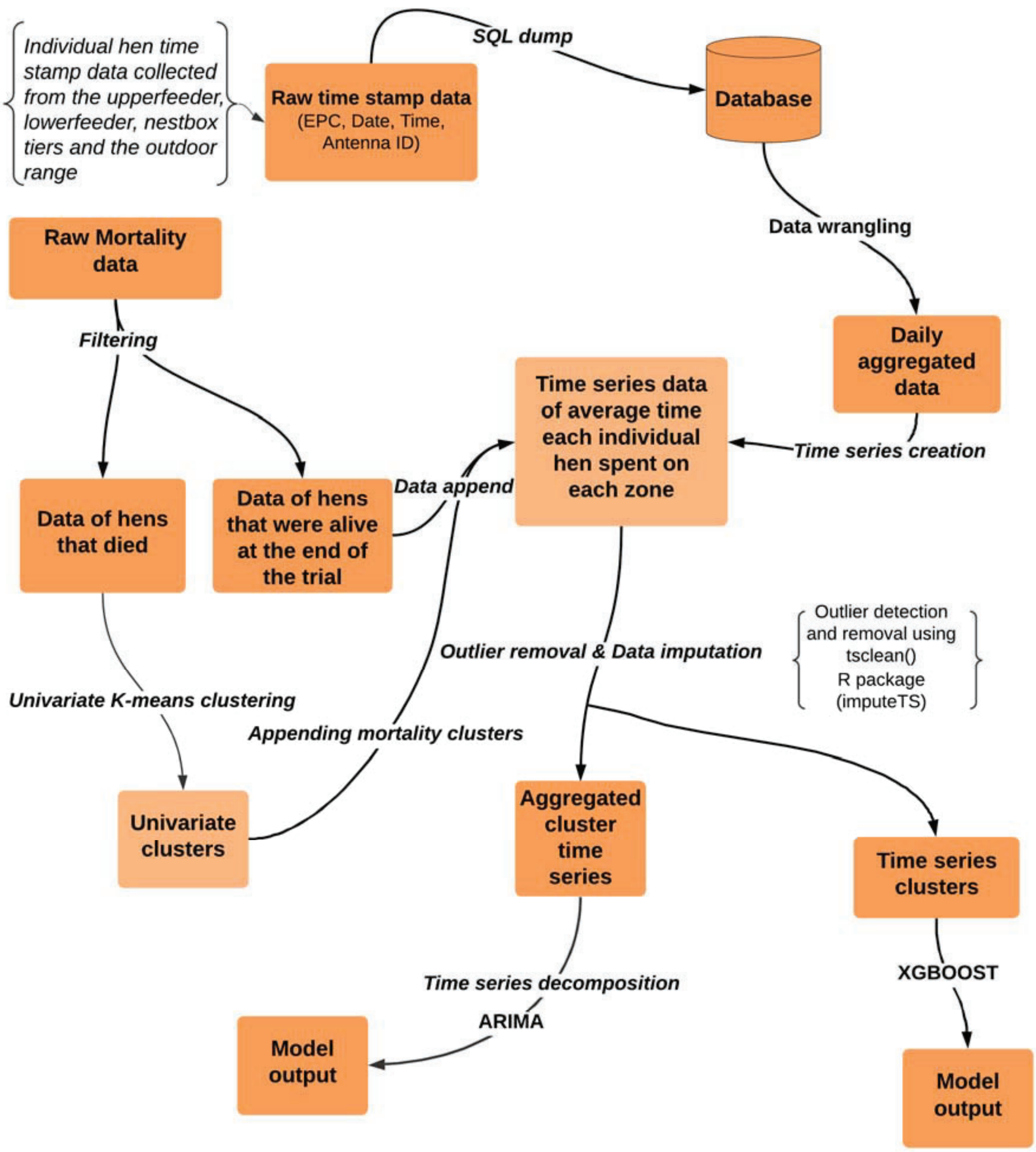

Fig. 2. The workflow for the time series analysis of the individual hen occupancy according to the mortality clusters

<u>Activity time series comparison and decomposition of mortality clusters</u>

In order to understand activity trend for the four separate clusters, each time series was decomposed into trend and seasonality. Secondly, based on the clusters and individual timeseries, we compared the average time duration data for each cluster to investigate daily activity patterns or use of the key resources in the hen house using the AutoRegressive Integrated Moving Average (ARIMA) models and cross-correlation function after pre-whitening with average time on each zone as the input series. Model parameters were estimated using the R programming language (R Core Team, 2021) and Rstudio integrated development environment (Rstudio Team, 2020) and the *forecast* package (Hyndman, 2022) to fit the ARIMA models.

RESULTS

Placement body weight

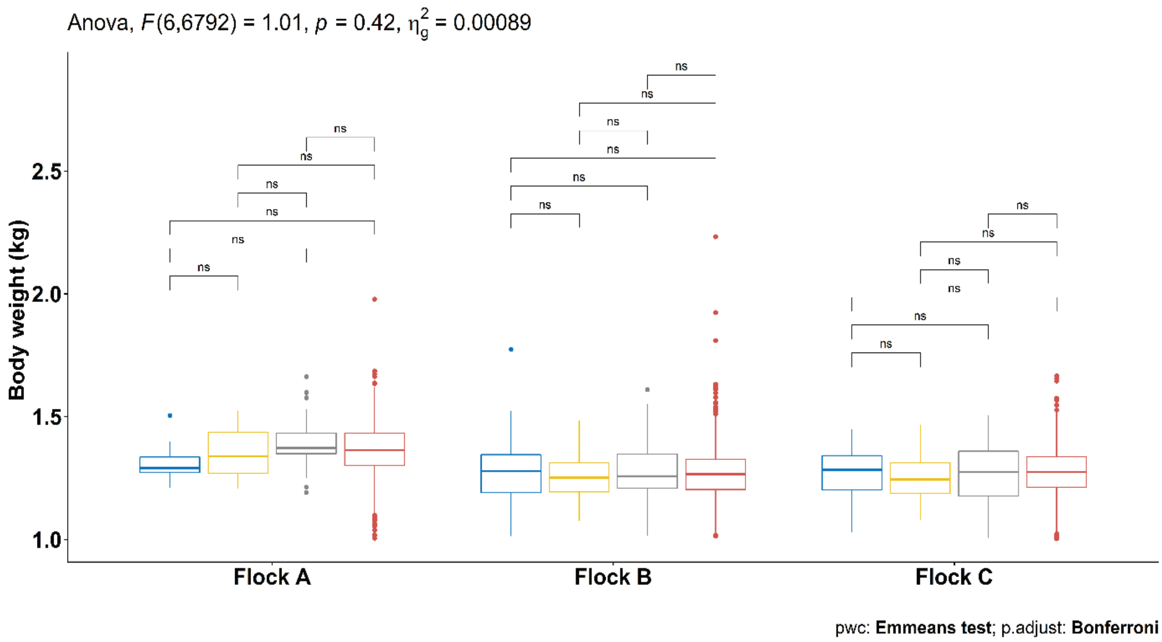

Fig. 3. The boxplot represents body weight of the 4 mortality clusters. The blue, yellow, grey and red boxplots represent hens of cluster 1 to 4 respectively. The ns in the plot represent statistical non-significance of differences between the clusters at significance level 0.05

As shown in Fig. 3, significant flock effects were evident on the average bodyweight of hens ($P < 0.0001$). There was no significant effect of the mortality clusters on the average body weight at placement ($P > 0.05$).

Aviary system and outdoor range occupancy for a single hen

The example time series (Fig. 4) shows that hen activity patterns were cyclic with random variations. The number of visits to the nest box was cyclic and consistent throughout the production period of the hen, however the total time duration at the nest box was upward shifted towards the end of the production period. The time the hen spent at the lower feeder showed multiplicate seasonal changes. The magnitude of using the lower feeder changed with the hen age.

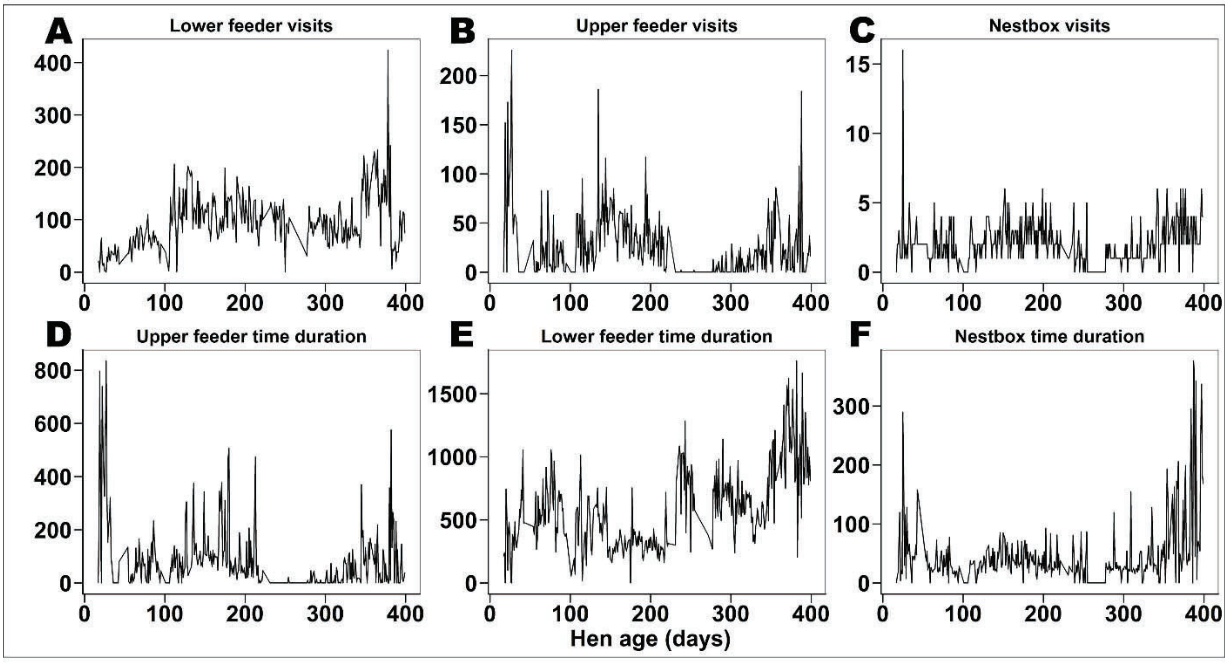

Fig. 4. An example of multivariate time series analysis of the individual hen occupancy of the aviary system during the production period demonstrating the number of visits (A-C) and the average time duration per day to the three key resources (D-F)

Time series trends for each cluster

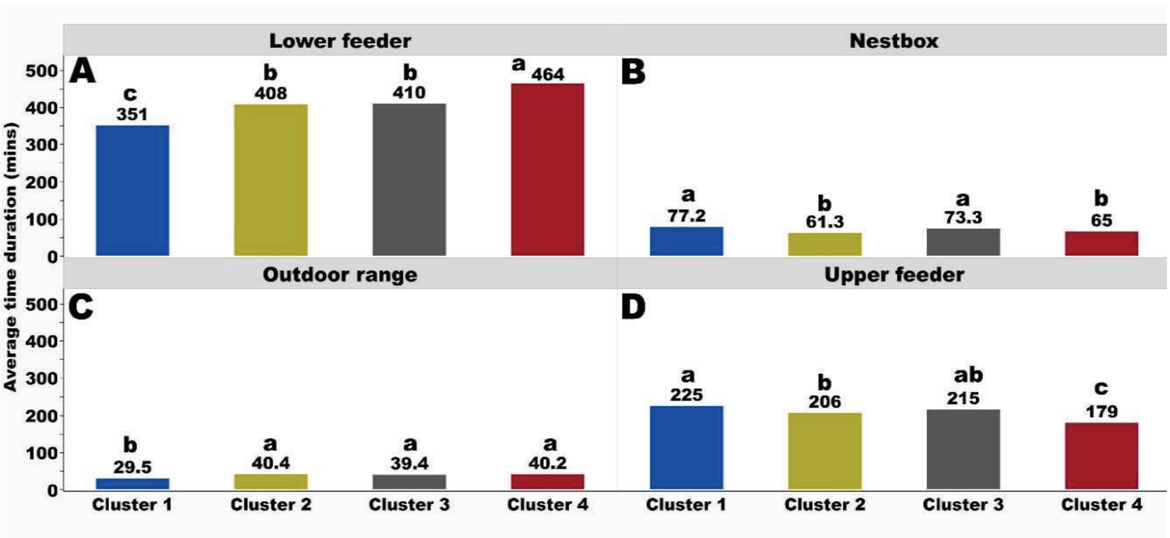

Fig. 5. Multiple comparison of the average time duration of hens on lower feeder (A), nest box (B), outdoor range (C) and upper feeder (D) for the 4 mortality clusters

Analysis of the time duration (Fig. 5) revealed a significant effect of cluster ($P < 0.0001$) with significant interaction between cluster and flock ($P < 0.0001$). In general, the hens spent the least time at the nest box and on the range. Hens of cluster 4 (hens that survived) spent significantly more time in the lower feeder tier ($P = 0.001$) and on the outdoor range ($P = 0.001$) compared to hens of cluster 1 (hens that died before peak production). On the other hand, hens of cluster 1 spent significantly more time at the nest box and upper feeder compared to the hens of cluster 4 (P = 0.001).

As shown in Fig. 6 the hens that died before peak laying period (Cluster 1) showed an upward shift in the use of the lower feeder and nest box while a downward shift in the use of upper feeder during the last few days before death. The hens that survived up to the end of the trial (Cluster 4) used the lower feeder tier and outdoor range more frequently compared to the hens that died during the trial period. There was no difference in the use of the nest box between the clusters ($P < 0.005$). The ARIMA models for the input time-series of lower feeder, upper feeder, and range duration for all four clusters required first-order differencing because the original time-series were not stationary (ACF range -15.6 to -5.5). The cross-correlation plots confirm that there was no statistical evidence of similarity between the timeseries of cluster 1 and 4 for the time spent by the hens on the lower feeders at lag 0 (CCF range -0.27 - 0.21). The cross-correlation plots displayed a 15-25-day delay by the hens of cluster 1 (hens that died early) in using the key resources compared to the hens of Cluster 4.

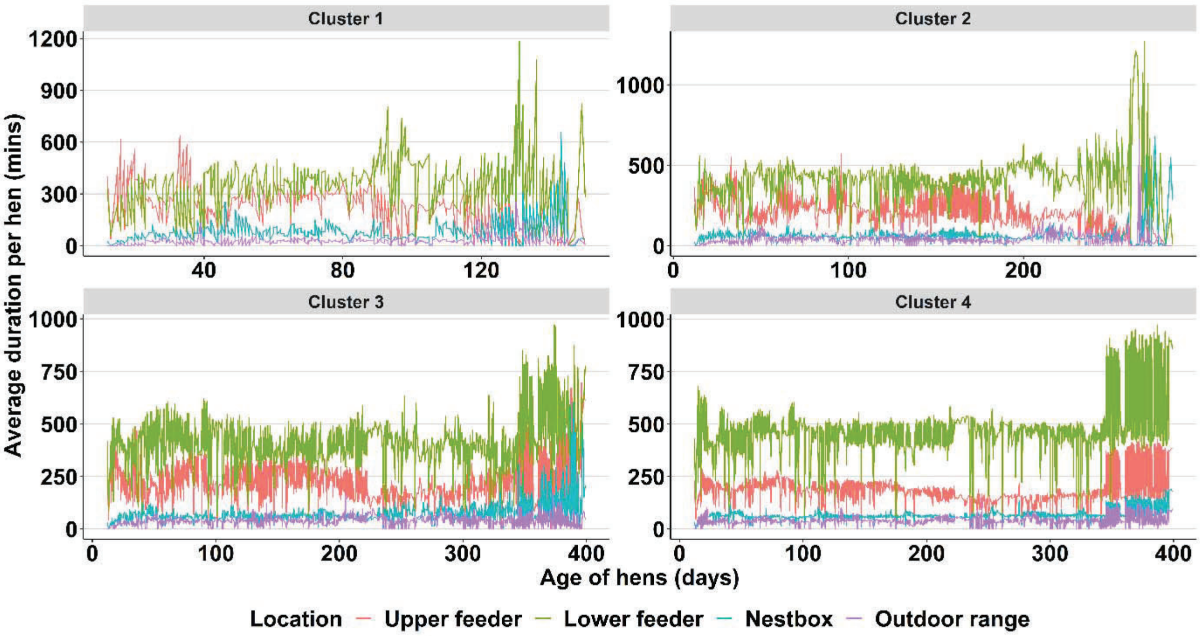

Fig. 6. The aggregated time series of daily activity patterns of hens for the four mortality clusters

DISCUSSION

We have demonstrated the potential of applying time series algorithms to describe risk of mortality based upon aviary and outdoor range usage patterns as monitored with RFID monitoring system across the production cycle. Early warning systems are used for detecting and forecasting future hazard events and reducing risks of poor health, welfare and mortality. This work is an initial example of sensor technology being used as an early warning system for mortality. The behavioural patterns in conjunction with epidemiological surveillance have a potential to reduce the high mortality rate in free-range systems. We demonstrated the mortality clusters exhibit different behavioural pattern during the last days before death such as increased use of nest box and feeders. This indicates that change in individual behavioural pattern can be used as an indicator for poor health and welfare.

Barn and free-range systems are often equipped with multi-tier aviaries, which increase the usable indoor area for hens, subsequently allowing for a greater number of hens per unit of land area, compared to systems in which hens are just housed on the floor. Traditionally, average flock performance (body weight, laying performance, egg quality and resource use) has been measured on a flock level, as resources are allocated based on the size of the flock. However, advances in technology have provided more robust methods for analysing some of these parameters on an individual bird basis, allowing for increased accuracy and a more differentiated view of the situation in the hen house, including individual variation in selecting resources (Larsen et al., 2017).

Despite individual variability, there are consistencies with resource use within the whole flock; for example, nest boxes, outdoor ranges are less frequently visited than areas that offer water and food, based on survival instincts (Rufener et al., 2018). In this study we have shown that the use of the nest box is consistent over time due to the high motivation of the hen to lay, therefore a deviation from the consistent use of the nest box might indicate the hen may be subjected to poor health and welfare conditions (Barret et al., 2019).

In conclusion, the cross-correlation function performed well in differentiating the use of resources between clusters of mortality. There is the presence of a substantial degree of intricacy and structure in the use of resources by hens in relation to mortality which requires further investigation using machine learning methods.

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