The behaviour of commercial broilers in response to a mobile robot

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Abstract

1. Modern broiler production, in increasingly large sheds holding upwards of 50.000 birds, controls indoor climate based on a handful of fixed location sensors, often well above the bird occupied zone. Significant deviations within a shed from the optimal climate conditions for the birds are common, but installing a higher density grid of fixed sensors is not cost effective. A robotic platform, moving through the flock of birds, collecting detailed spacial information on a wide range of climate parameters at bird level, will enable accurate decisions to optimise the climate in large sheds being made in real time.

2. A preliminary study investigated the feasibility of running a mobile robotic platform among a flock of broiler chickens for an entire 6-week cycle. Bird behaviour in response to the robot was also studied.

2. 1597 Ross 308 broiler chicks were housed in a room that was set-up to replicate a commercial environment. The robot was driven along a fixed route three times a day (Mon-Fri) for the whole cycle under manual control. Behaviour was studied using camera footage.

3. The birds showed very little startling behaviour in response to the robot and were quick to fill the area behind the robot as it moved past. Activity levels increased during robot runs, but to a lesser extent than during walks by a human stockman. The challenges of running the robot changed as the birds grew, with many individuals coming into physical contact with the front of the robot later in the cycle. Despite this, very few birds refused to move out of the way completely and mortality and production parameters remained acceptable throughout.

4. This study has shown that running a mobile robot among a flock of broiler chickens is possible between days 3-37 in a cycle and that this appears to cause limited disruption to bird behaviour. The next step is to repeat this trial on multiple commercial flocks to see whether running a mobile robot among the broilers can be achieved in a real setting, with limited disruption to bird behaviour.

Keywords: behaviour; broilers; robot; FCR; activity; mortality

Introduction

Chicken meat production is a huge industry worldwide, with 106.5 million broilers slaughtered in the UK alone last month (July 2018) (DEFRA 2018). There is no maximum flock size for broilers in the EU, and so flocks often exceed 100,000 birds. With flocks of this size, close monitoring of individual birds by a stockman is impossible. The intensification of poultry meat production has therefore led to a need for automatic monitoring equipment (Berckmans 2014, 2017). Such systems are continually being developed but examples include automatic weighing scales (Turner et al. 1984), climatic sensors (Corkery et al. 2013) and more advanced systems for measuring bird behaviour and activity (Aydin et al. 2010, Dawkins et al. 2012, Kashiha et al. 2013). Recent innovations for the poultry industry include detecting litter condition via cameras (Peña Fernández et al. 2016) and specific welfare issues such as lameness in broilers (Van Hertem et al. 2018).

Close monitoring of the birds' environment is critical for intensive broiler production. Birds are expected to reach slaughter weight in 5-6 weeks and in order to maximise growth they must not waste energy keeping warm or cool. Inappropriate environmental conditions may also increase the risk of disease ((Pan et al. 2005), with the first week being particularly important for bird growth and welfare in this regard (Henriksen et al. 2016). Environmental sensors placed in the house to record factors such as temperature, humidity, air speed and ammonia levels can only record in set locations and there is often a discrepancy in environmental conditions between human and chicken head height (Miles et al. 2008, Wheeler et al. 2000). This vertical stratification of conditions combined with sensors placed over a metre above the litter can lead to sensor readings that do not accurately represent the birds' direct environment.

A mobile robot that could move among a flock of birds equipped with sensors to constantly measure environmental conditions at bird head-height could solve this issue. Some attempts have been made to use mobile robots among poultry. A small robot was used in behavioural trials with very small groups of birds in Switzerland (Gribovskiy et al. 2018) and an egg-collection robot has been developed in the USA for use among laying hens (Joffe and Usher 2017). No mobile robots have been successfully scientifically trialled in an entire broiler flock cycle to our knowledge, likely because these birds pose a number of additional difficulties. Broilers change size and weight from 50g to 2500g in 6 weeks and this also results in changing stocking density, decreased physical ability and alterations in behaviour with time (Knowles et al. 2008). These changing factors mean that a robot must be able to adapt to deal with different obstacles and responses throughout the cycle. It is important to investigate the feasibility of such technology on a small-scale initially to ensure bird welfare will not be negatively affected.

The aim of this preliminary study was to:

(1) investigate the feasibility of running a mobile robot among a flock of fast-growing broiler chickens for a whole flock cycle under commercial-like conditions, and

(2) investigate the behavioural responses of the birds to the robot, with particular attention given to behaviours that might hinder the robot's progress.

It was predicted that behaviours indicative of birds struggling to get out of the way (e.g. contact events, blocking birds) would increase throughout the cycle whereas behaviours indicative of birds showing fear of the robot (e.g. startling events, poor back-fill) would decrease.

Materials and Methods

Animals:

A total of 1597 Ross 308 (Aviagen) broiler chicks were placed in a room at 1 day old (19 birds m^2). The maximum stocking density was 35 kg m^2 so 400 birds (approximately 25%) were removed from the flock at 30 days of age (a common commercial practice called thinning) to ensure that this stocking density was not exceeded.

Stocking density in the EU is limited to 33 kg m^{-2} but many farms get a derogation in order to stock at 38 kg m^{-2}. It was preferable to replicate the higher stocking density as this would be a greater challenge for the robot. However, as the room was smaller and birds could not move as far to get away from a stimulus as they could in a commercial sized shed, a density of 35 kg m^{-2} was selected following discussion with commercial broiler producers.

The birds were depopulated at 38 days of age and sent to a commercial slaughterhouse. The thinned birds were killed on-site.

This work was carried out under a home office licence (PD4FD332A) and approved by the Royal Veterinary College ethical committee (AWERB) in the home office application process.

Room setup and husbandry:

An experimental room measuring 5.50 m x 15.00 m was set-up to replicate a commercial broiler house with automatic lines of nipple drinkers and pan feeders (see figure 1 for a diagram of the room setup). As is typical in commercial houses, the feeder and drinker lines were arranged in a way that created multiple rows of clear litter where a stockman and in this case, robot, could travel. The drinker and feeder lines were height-adjustable and were raised as the birds grew. The floor was covered with approximately 3 cm of sawdust at the start of the trial and “play bales” (sawdust bales with the plastic removed) were placed in various locations in the room after 15 days as a source of enrichment. Play bales were not placed in the path of the robot.

The room temperature was maintained by controlled ventilation according to a set curve from 31 °C at day 1 to 20 °C at day 31. Relative humidity was maintained at a minimum of 65% until day 15 and from then onwards at 50%. The light regime in the room varied from 1 hour of darkness (day 1) to six hours of darkness (2/4 split) from day 7 (see figure 8). The light level in the room was 25 lux measured at floor level. The automated feed dosage was controlled to ensure ad libitum feeding.

The flock was walked by a stockman twice a day (the person varied) at 08:30 and 14:30 during the week. On weekends the stockman walked the flock at 09:30 in the morning and once in the afternoon (time varied). Any lame or unwell birds were identified and either culled or marked for observation using animal-safe paint spray. All mortality (birds found dead and culls) was recorded by the stockman twice a day.

Monitoring equipment:

Six CCTV cameras (SNT-V704, Sony Ltd) were fitted on the ceiling/walls to provide an overhead view of the entire room. Video images were recorded using Milestone XProtect recording software (Milestone Systems A/S). These cameras could be viewed live for the purpose of driving the robot but also recorded at set times (during robot runs and Saturday morning stockman walk) so that the data could be analysed later.

Temperature, humidity (HygroClip, Rotronics Ltd), ventilation rate (measuring fan, Fancom BV), water consumption (Aquadis, Actaris Ltd) and light level were recorded every 6 minutes using a datalogger (ADAM5000, Advantech). These were independent of the robot. Feed consumption (loadcell, Fancom BV) and bird weight (weigh scale, Fancom BV) were measured and recorded twice a day.

Bird activity was estimated using a system that compared subsequent images from the overhead cameras counting each pixel which changed in colour intensity.

Robot design:

A mobile robot of existing design (Ross Robotics Ltd) was modified for this study. A plywood cover was designed that would protect birds from any moving parts and ensure all four wheels were fully covered (see figure 2). The robot cover had a triangular-shaped nose to encourage birds to move sideways away from the robot instead of walking in front of it. There was a low bumper on the front of the robot that could pivot upwards to aid mobility over uneven surfaces.

There were three fixed cameras on the robot. Two cameras focused on the two sides of the wedge-shaped nose of the robot, and allowed the viewer to see whether birds were coming into contact with the front. The other camera was on the top of the robot and gave a general view ahead.

Experimental protocol:

A set route for the robot was decided (see figure 1) and the robot was driven along this route three times a day at 10:00, 13:00 and 16:00, respectively. The stockman was also asked to use this route when making their walks of the room.

The robot was under manual control by the experimenters (outside of the room) at all times. The overhead CCTV cameras and the robot-based cameras were used to navigate. Speed could be set before the run and the robot movement was controlled using the arrow keys on a standard computer keyboard. If the robot encountered a blocking bird (see table) the following protocol was initiated:

(1) Pause all movement. Wait 3 seconds and drive the robot towards the bird again. If the bird moves proceed as normal.

(2) If the bird still refuses to move, reverse approximately 0.5 m, wait for 3 seconds then advance again. If the bird moves proceed as normal.

(3) If the bird still refuses to move, attempt a ‘go-around’ routine.

(4) If a go around routine is not feasible pause the robot and enter the room to move the bird manually. Allow 2 minutes to pass after exiting the room before continuing with the robot’s movement.

For the first 4 weeks of the study the robot was placed in the room in a starting position (see figure 1) 15 minutes before performing the first run of the day. It was left in the room between runs and removed from the room after the final run. However, for safety reasons in the last 2 weeks of the study the robot was left in the room 24/7 with a cardboard barrier around it.

Three conditions were trialled and these were designed to be balanced across the runs. However, due to technical issues this was not the case (see analysis section). The three conditions were: slow speed (0.077 m/s) with ‘bobble’ (SB), slow speed (0.077 m/s)(S) and fast speed (0.1 m/s)(F). The ‘bobble’ was a dog tennis ball thrower installed above the robot with a hanging lightweight ball that moved when the robot moved to stimulate bird movement.

Behavioural measures:

See table for an ethogram of the recorded behaviours. These behaviours were chosen following an early trial of the robot on a commercial farm. This was a one-off trial in birds that had not experienced the robot before and helped to highlight which behaviours might be affected by the robot’s presence (unpublished data). Behavioural observation began on day 3 as the birds were expected to have acclimatised to their new environment by this point and the operators were familiar with the robot controls.

All behavioural observations were recorded within the ‘observation section’ of the robot/stockman route (the area between A and B on figure 1).

Latency to complete this section was recorded in seconds from the moment the robot first entered the area (marked A on figure 1) to the point it began the turn at the end of this area (marked B on figure 1).

Startle events were recorded continuously in the observation section with all incidences recorded using the overhead cameras. An event was counted when an individual bird startled within an area 1 m ahead of the robot or 0.5 m to the sides of the robot. These were recorded as events as it was not possible to determine whether the same bird startled more than once.

Contact events with the front of the robot were also recorded continuously using the robot-based cameras. All occasions that a bird made contact with the robot in the view of these cameras were counted.

The number of blocking bird events were also recorded continuously as well as the stage in the ‘blocking bird protocol’ described in the experimental protocol section that was required for the robot to deal with the situation. The number of birds that went underneath the robot was counted.

Bird use of the area directly behind the robot while moving was termed ‘back-fill’ and was recorded through scan sampling. At six points in the observation section the number of birds 1 m, 2 m and 3 m behind the robot was counted. The area sampled extended to the feeder/drinker lines on either side and, as these were 1.3 m apart each count was of a 1.3 m^2 area.

The birds’ use of the area directly ahead of the robot was recorded in a similar way to back-fill. At six points along the observation section of the route, the number of birds 1 m ahead of the robot (measured from the tip of the ‘nose’) was counted.

All complete robot runs were analysed and some behaviours were recorded once a week during a stockman walk (Saturday at 09:30) for comparative purposes. The behaviours recorded during the stockman walk were startling events, latency, back-fill and the area ahead of the stockman.

Analysis:

As this trial was a preliminary trial performed on a single flock it was not appropriate or possible to carry out statistical testing. However, summary statistics and graphs were produced to describe the results.

Graphs were produced for each behavioural measure with day on the x axis in order to explore how behaviour changed throughout the whole trial (days 3-37). Means were taken to summarise the data on a day basis. Two standard deviations were used for error bars to show the variation in the data. As some runs did not go ahead due to technical or practical difficulties the number of data points used to produce these means varied between 1-3. Where differences or trends appear to occur, the graphs have been included in the results section of this paper.

Graphs were also produced to look at the effect of time of day (runs 1-3 each day) and condition (SB, S and F) on behaviour. However, due to technical difficulties, many of the runs were incomplete or could not be performed and this resulted in poor balancing of the three conditions across the three times of day. Additionally, the fast speed (F) was not used after day 30 due to bird safety concerns. As time of day and condition are therefore confounded, any interactions between the two variables were examined and discussed. Condition and time of day were only analysed for the first 30 days.

To summarise the data for back-fill and birds ahead of the robot, the expected number of birds in a 1.3 m2 area was calculated based on all the birds being evenly spread throughout the room. This figure was calculated for each day based on the total available floor area and the number of birds at the start of the study minus cumulative mortality and plotted on the graphs alongside the actual counts.

To compare with the stockman data, means were calculated on a weekly basis.

The system used for recording bird activity produced a value for activity approximately every minute of the day. To detect if activity levels appeared to change during robot runs, data from the days where all three runs were performed were summarised into a graph showing average activity in 15-minute intervals.

Results

Out of a possible 75 runs, 53 full runs and 3 partial runs were completed. There were 13 days with 3 complete runs and 3 days (days 9, 14 and 21) where no planned runs were achieved. Runs were missed due to a combination of technical (for instance traction failure) and practical difficulties not relating to bird behaviour or response to the robot. However, the final run on the last day before depopulation (day 37) was not carried out because it was deemed too difficult to run the robot safely among the birds. This was due to high stocking density and increasing reluctance of the birds to move. Some individual behaviours could not be analysed for certain runs even if it was completed successfully.

Latency:

The mean latency to traverse the observation section across all runs was 436.26 s (+/- 85.97). As latency was affected by condition (speed) and also by early issues with the robot turning ineffectively on fresh litter it has not been analysed in any detail for this study.

Startle behaviour:

Startle behaviour was generally very low throughout the entire cycle with an average number of startle incidents per run of 4.21 (+/- 3.84).

See figure 3 for a graph showing mean startle incidents by day. Startle incidents were not detected before 9 days of age because the birds were not yet using their wings. Two noticeable peaks can be seen at 9 and 31 days of age although levels remained low throughout. For comparison, birds not previously exposed to the robot startled 30-50 times in a 10 minute period on farm (unpublished data).

There was a slight effect of both condition and time of day on startle behaviour. There were less startle events on average for the fast speed (F) than for the other two conditions in the first 30 days. Condition F had a mean of 3.21 (+/- 4.58) and conditions SB and S had means of 5.23 (+/- 4.15) and 5.07 (+/- 4.58) respectively. However, when time of day was accounted for, this effect was only apparent for the first two runs of the day (10am and 1pm).

In the first 30 days, startle events appeared to increase on average throughout the day with means of 2.88 (+/-2.71), 5.31 (+/-4.61), 6.00 (+/-4.36) for 10am, 1pm and 4pm respectively. However, when condition was accounted for this pattern became less clear with varied results for each condition.

Group startles were only seen on one occasion across all runs.

Bird contact with the robot:

The mean number of bird contact events with the robot across all runs was 97.87 (+/- 43.54). The mean number of contact events increased throughout the cycle (see figure 4) and peaked on day 30 just before thinning. There was no noticeable difference between the three times of day or the three conditions.

Blocking birds:

There was only a small number of incidents where birds refused to move out of the way of the robot. Only 2 blocking birds were recorded before day 24. However, from day 24 onwards there were 15 recorded, indicating that these incidents were more common towards the end of the cycle. Only one bird actually went underneath the front of the robot cover throughout the entire cycle. The robot was stopped straight away and the bird removed immediately unharmed. All other blocking birds were successfully manoeuvred around (step 3 in the blocking bird protocol, see methods) or moved after the robot reversed (step 2). Step 1 in the blocking bird protocol was not recorded as this became standard operating procedure later in the cycle in order to give birds a chance to move.

Back-fill:

Generally, back-fill remained consistent throughout the cycle (see figure 5). Up to day 18, there was a disparity between the number of birds in the 1 m area behind the robot compared with the 2 m and 3 m areas. There were many more birds than expected in the area 1 m behind the robot during this period, potentially due to birds following the robot as it traversed through the flock. The numbers of birds 2 m and 3 m behind were lower than the expected figure. At day 24 this evened out and remained relatively constant throughout the rest of the cycle. The calculated expected number of birds dropped after thinning (due to reduced flock size) but back-fill remained the same, meaning that it well-matched expected figures in the final week. Back-fill did not appear to be affected by time of day or condition.

Birds ahead of the robot:

The number of birds ahead of the robot was similar to the expected figure for most of the cycle (see figure 6). It was slightly below expected in the first half of the cycle, and slightly above expected in the second half of the cycle. It was particularly high on the first recorded day (day 3). This variable was not affected by time of day or condition.

Comparison with stockman:

As data for the stockman were only recorded once a week, 5 stockman walks were analysed for bird behavioural response. There was very little difference in number of birds in the area ahead of the stockman or robot. However, more birds appeared to back-fill behind the robot than the stockman in the first three weeks (see figure 7). As stockmen used different methods to move birds in each walk (e.g. clapping hands) which may have affected likelihood of startling, startle events have not been presented here.

Bird activity:

Bird activity increased throughout the cycle. This is typical for this activity measuring system as the birds grow because more pixels change with every bird movement. Figure 8 shows that activity increased immediately after the lights went on, and during each stockman walk and robot run, although the peaks for the robot runs were lower than those for the stockman walks.

General production:

Cumulative mortality was 4.2% by the end of the trial (day 37) of which 3% was found dead and the remaining 1.2% was culled under schedule 1. The feed conversion ratio was 1.52. These results are in line with commercial figures for this strain. Growth also matched commercial figures.

Discussion

The main finding from this study is that a mobile robot can be run through a flock of fast-growing broilers safely (under manual control) from 3-37 days of age. Only one bird went underneath the front of the robot in the entire study and this was due to operator error. The final run on day 37 did not go ahead as the operator deemed it unsafe to drive the robot. This was because the previous run had taken almost twice as long to complete and considerably more blocking birds were recorded than in previous runs. It may therefore be advisable that such a robot only runs until day 36/37 for fast-growing strains expected to depopulate at approximately 40 days of age. The challenges facing the operator when driving the robot changed throughout the cycle. In the first week, the birds were very small and fragile and so the operator needed to be extra vigilant (monitoring the cameras) to ensure that no birds got caught under the front. Though, at this age the birds were very agile and moved out of the way quickly. As the birds got older, the risk of being damaged by the robot decreased due to their increasing size and robustness, but they were less likely to move out of the way due to factors such as mobility and stocking density. It is also possible that habituation to the robot played a role. This finding means that if autonomous robots of this type are to be used in broiler sheds they must be able to adapt to these changing conditions and risks.

The second objective of this trial was to investigate bird behaviour in response to the robot. The behaviours studied were relevant to general bird welfare (e.g. fear levels) but also to risk of injury from the robot (e.g. contact events).

Startling behaviour was generally low and almost no group startles occurred. This was an interesting finding as more startling behaviour was seen in the pilot trial on a farm with older birds (personal observation). It is possible that as the robot was presented to the birds from day 2 onwards, they habituated to it from an early age, reducing fear associated with it. Most studies of chicken fear have focused on response to humans. A reduction in fear response due to habituation has been recorded in domestic chicks to human handling (Jones and Faure 1981) but also when contact is limited to visual only (Jones 1995). Assuming this can be applied to the robot, visual contact, which will be the extent to which most birds in a flock interact with the robot, may be sufficient for habituation. Jones and Waddington (1993) found that habituation occurred in chicks regardless of the age that habituation was applied, suggesting that even if the robot is introduced at a later point in the cycle, the birds will still habituate. However, the study reported here found that startling behaviour involving wing flapping and jumping did not occur before 9 days of age and as this type of startling can be physically damaging to the birds, it may be sensible to habituate as early as possible to avoid damaging startles later on. It is interesting that startle behaviour showed signs of increasing throughout each day from runs 1-3 despite no overall increase across the cycle. When startles did occur, it was typically seen in birds that appeared surprised by the proximity of the robot either because they were lying down when the robot nudged them or asleep (personal observation). This scenario may have become more likely throughout the day as time since the dark period increased and activity levels consequently decreased (see activity data) with resting becoming more likely. This may explain any increase in startles seen later in the day. However, the data were quite variable for this measure and it is confounded by condition so further work would be required to make any real conclusions about this effect. Startle events occurred less when the robot was run at the fast speed (up to day 30) at 10am and 1pm. This was an unexpected result as the opposite was seen on farm (unpublished data). The robot may have produced a louder noise that warned birds of its approach at the faster speed although this wasn’t tested. Additionally the robot may have moved more smoothly at the faster speed. Early in the trial technical difficulties were encountered with the robot struggling to turn on fresh litter. This problem seemed less pronounced at the faster speed which may have resulted in overall smoother motion. The criteria chosen for identifying startle behaviour in this study may not have been adequate to capture all fear responses. Early in the cycle chicks did not use their wings and so no startle response could be recorded in this study. The behaviour for a ‘startle response’ in this study is typically seen in response to humans in commercial flocks. It can cause injury to other birds (if the startling bird jumps onto the back of another) and reduce carcass value for the farmer. It was therefore a valuable measure for this study’s purposes.

Whether or not birds come into contact with the robot is important, as birds that do are at a higher risk of injury. Although the robot is designed to be safe around the birds, it is still possible for the robot to go over a bird if it is lying down in front of the robot and doesn’t move. The number of birds that did come into contact with the robot was relatively high and clearly increased throughout the cycle. This increase is not surprising when the increasing stocking density and size of the birds, and decreasing mobility of the birds is considered. Older, bigger birds require more time to get out of the way of the robot and are therefore more likely to be nudged by the robot as it moves past. Additionally, the increased stocking density meant that there may not have been a space for birds to move into immediately. This explanation is supported by the fact that a reduction in contact with the robot was seen after thinning, when stocking density was reduced. Despite the high number of contact incidents, only one bird actually went underneath the robot, and very few met the criteria of a blocking bird (i.e. it did not get out of the way after making contact). This suggests that contact may not be an issue, provided the operator can respond to birds in real time, or an autonomous robot can accurately detect struggling birds and respond accordingly. As many/most of the birds making contact were slow to move out of the way later in the cycle, it became standard protocol to pause intermittently when driving to allow these birds to move. If the robot paused for too long, birds would lie back down instead of moving so a balance was required.

In an early on-farm trial of this robot (not described in this study) birds did not back-fill behind the robot well at all, leaving many metres of empty litter. Poor back-fill suggests a disruption to normal behaviour. This may have welfare consequences but also economic consequences if birds stop eating and drinking. In this trial, back-fill was very good throughout. It was slightly lower than the calculated 'expected' figure but this was anticipated because the robot has to clear a path. In the first 3 weeks, back-fill in the area directly behind the robot was particularly high due to birds following. This suggests a lack of fear as approach tests are commonly used to measure fear in animal behaviour studies (Forkman et al. 2007). The younger birds may have been attracted to the robot. Moving objects can be attractive to chicks during the sensitive period for imprinting and following behaviour is often seen (Bateson 1964). It is possible that the chicks started to imprint on the robot through repeated exposure (Zajonc et al. 1973).

The number of birds 1 m ahead of the robot remained around the expected figure for the entire trial. Although this may indicate a lack of fear, for practical and safety reasons the robot should encourage birds to start moving out of the way before it comes into contact with them. Methods of doing this may be valuable avenues for future research.

Although the stockman data were limited, there were some indications that birds do not back-fill as well behind a stockman in the first part of the cycle. The robot moved in a very predictable and standard way where as a stockman may appear to be more erratic. This may have made the birds warier of getting close behind the stockman. The stockman was also taller. There is evidence that broilers find mechanical equipment less stressful than humans at depopulation (Duncan et al. 1986) so this may also be the case with stockmen.

Peaks in activity could be identified during both stockman walks and all three robot runs. Activity increased more during stockman runs than robot runs on average. There may be both positive and negative consequences of increased bird activity. Increased activity may promote good leg health (Bailie et al. 2013, Balog et al. 1997) and affect meat quality (Castellini et al. 2002). Additionally, the robot may act as a form of enrichment which has benefits on a number of welfare factors (Bessei 2006). However, increased activity in lame birds may cause pain, and excessive activity may increase the feed conversion ratio, an economic issue for farmers.

The purpose of this study was to investigate the feasibility of a mobile robot in a commercial setting. However, in order to collect the detailed behavioural data required, an experimental unit was used and the commercial setting replicated as closely as possible. Commercial feeders, drinkers, ventilation systems and husbandry were used throughout but there were some differences that may affect how much the results can be applied to the real setting. The flock was smaller than typically seen on a broiler farm with just over 1500 birds at placement and stocking density was slightly lower than some commercial farms. The birds in this study may have experienced more human interaction than normal commercial birds as people had to enter the room on a few occasions to fix issues. This may have affected their fear responses. However, research has shown that habituation to humans doesn't cause a general reduction in fear levels (Jones and Faure 1981)) so this may not have affected fear response to the robot. Mortality and growth matched what is typically seen on commercial farms.

The main issue with this study is the small sample size. As only one flock was used, the statistical analysis was limited and the results cannot be applied to the wider population. However, the results are still very relevant as this is the first study of its kind and will provide the foundation on which to carry out future work on multiple commercial flocks. There were some technical difficulties with the robot during the trial. This loss of data was not critical as data were still collected but it did lead to uneven balancing of the three conditions. This meant condition and time of day were somewhat confounded. When discussing the results of this study it is important to consider that due to the nature of the broiler chicken, many factors changed over the cycle. Many of the results have been presented as means per day. Day is affected by age of the birds, size of the birds, stocking density and bird mobility. It is therefore possible that any changes seen across time are a result of just one or multiple of these factors. It is not possible to tease these out within the confines of this trial.

The hypothesis that birds would show increasing difficulty to get out of the way throughout the cycle appears correct. However, the prediction that birds would show decreasing fear towards the robot (as measured by startle and back-fill behaviour) was not as birds showed very little evidence of fear from the start of the cycle and this remained the case throughout.

As this study has provided the vital pilot data for use of a mobile robot among a growing broiler flock, future work will now focus on trialling the robot on multiple commercial farms. Matched controls will be used so that the results can be applied to other farms and any effects on welfare such as lameness can be investigated.

Acknowledgements

We would like to thank Innovate UK for funding this work and our collaborators Ross Robotic Ltd for providing the robot and Applied Poultry for their advice and assistance.

References:

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Aydin, A., O. Cangar, S. E. Ozcan, C. Bahr, and D. Berckmans. 2010. "Application of a fully automatic analysis tool to assess the activity of broiler chickens with different gait scores." *Computers and Electronics in Agriculture* 73 (2):194-199. doi: 10.1016/j.compag.2010.05.004.

Bailie, C. L., M. E. Ball, and N. E. O'Connell. 2013. "Influence of the provision of natural light and straw bales on activity levels and leg health in commercial broiler chickens." *Animal* 7 (4):618-26. doi: 10.1017/S1751731112002108.

Balog, J. M., G. R. Bayyari, N. C. Rath, W. E. Huff, and N. B. Anthony. 1997. "Effect of intermittent activity on broiler production parameters." *Poult Sci* 76 (1):6-12. doi: 10.1093/ps/76.1.6.

Bateson, P. P. G. 1964. "Changes in Chicks Responses to Novel Moving Objects over Sensitive Period for Imprinting." *Animal Behaviour* 12 (4):479-489. doi: 10.1016/0003-3472(64)90068-5.

Berckmans, D. 2014. "Precision livestock farming technologies for welfare management in intensive livestock systems." *Rev Sci Tech* 33 (1):189-96.

Berckmans, D. 2017. "General introduction to precision livestock farming." *Animal Frontiers* 7 (1):6-11. doi: 10.2527/af.2017.0102.

Bessei, W. 2006. "Welfare of broilers: a review." *Worlds Poultry Science Journal* 62 (3):455-466. doi: 10.1079/Wps2005108.

Castellini, C., C. Mugnai, and A. Dal Bosco. 2002. "Effect of organic production system on broiler carcass and meat quality." *Meat Sci* 60 (3):219-25.

Corkery, G., S. Ward, C. Kenny, and P. Hemmingway. 2013. "Incorporating smart sensing technologies into the poultry industry." *Journal of World's Poultry Research* 3:106-128.

Dawkins, M. S., R. Cain, and S. J. Roberts. 2012. "Optical flow, flock behaviour and chicken welfare." *Animal Behaviour* 84 (1):219-223. doi: 10.1016/j.anbehav.2012.04.036.

DEFRA. 2018. "United Kingdom Poultry and Poultry Meat Statistics – July 2018." https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/735583/poultry-statsnotice-23aug18.pdf.

Duncan, I. J. H., Gillian S. Slee, P. Kettlewell, P. Berry, and Ailsa J. Carlisle. 1986. "Comparison of the stressfulness of harvesting broiler chickens by machine and by hand." *British Poultry Science* 27 (1):109-114. doi: 10.1080/00071668608416861.

Forkman, B., A. Boissy, M. C. Meunier-Salauen, E. Canali, and R. B. Jones. 2007. "A critical review of fear tests used on cattle, pigs, sheep, poultry and horses." *Physiology & Behavior* 92 (3):340-374. doi: 10.1016/j.physbeh.2007.03.016.

Gribovskiy, A., J. Halloy, J. L. Deneubourg, and F. Mondada. 2018. "Designing a socially integrated mobile robot for ethological research." *Robotics and Autonomous Systems* 103:42-55. doi: 10.1016/j.robot.2018.02.003.

Henriksen, S., T. Bilde, and A. B. Riber. 2016. "Effects of post-hatch brooding temperature on broiler behavior, welfare, and growth." *Poult Sci* 95 (10):2235-43. doi: 10.3382/ps/pew224.

Joffe, B.P., and C.T. Usher. 2017. "Autonomous robotic system for picking up floor eggs in poultry houses." 2017 ASABE Annual International Meeting, St. Joseph, MI.

Jones, R. B. 1995. "Habituation to human beings via visual contact in docile and flighty strains of domestic chicks." *International Journal of Comparative Psychology* 8:88-98.

Jones, R. B., and J. M. Faure. 1981. "The effects of regular handling on fear responses in the domestic chick." *Behav Processes* 6 (2):135-43. doi: 10.1016/0376-6357(81)90032-2.

Jones, R. B., and D. Waddington. 1993. "Attenuation of the Domestic Chicks Fear of Human-Beings Via Regular Handling - in Search of a Sensitive Period." *Applied Animal Behaviour Science* 36 (2-3):185-195.

Kashiha, M., A. Pluk, C. Bahr, E. Vranken, and D. Berckmans. 2013. "Development of an early warning system for a broiler house using computer vision." *Biosystems Engineering* 116 (1):36-45. doi: 10.1016/j.biosystemseng.2013.06.004.

Knowles, Toby G., Steve C. Kestin, Susan M. Haslam, Steven N. Brown, Laura E. Green, Andrew Butterworth, Stuart J. Pope, Dirk Pfeiffer, and Christine J. Nicol. 2008. "Leg disorders in broiler chickens: prevalence, risk factors and prevention." *PLoS One* 3 (2):e1545.

Miles, D. M., D. E. Rowe, and P. R. Owens. 2008. "Winter broiler litter gases and nitrogen compounds: Temporal and spatial trends." *Atmospheric Environment* 42 (14):3351-3363. doi: 10.1016/j.atmosenv.2006.11.056.

Pan, J. Q., X. Tan, J. C. Li, W. D. Sun, and X. L. Wang. 2005. "Effects of early feed restriction and cold temperature on lipid peroxidation, pulmonary vascular remodelling and ascites morbidity in broilers under normal and cold temperature." *Br Poult Sci* 46 (3):374-81. doi: 10.1080/00071660500098152.

Peña Fernández, Alberto, Tom Van Hertem, Vasileios Exadaktylos, Tomas Norton, Erik Vranken, and Daniel Berckmans. 2016. "Monitoring of litter quality in broiler commercial farms using camera-based technology." 2016 ASABE Annual International Meeting, St. Joseph, MI.

Turner, M. J. B., P. Gurney, J. S. W. Crowther, and J. R. Sharp. 1984. "An Automatic Weighing System for Poultry." *Journal of Agricultural Engineering Research* 29 (1):17-24. doi: 10.1016/0021-8634(84)90056-8.

Van Hertem, T., T. Norton, D. Berckmans, and E. Vranken. 2018. "Predicting broiler gait scores from activity monitoring and flock data." *Biosystems Engineering* 173:93-102. doi: 10.1016/j.biosystemseng.2018.07.002.

Wheeler, E. F., J. S. Zajaczkowski, R. W. J. Weiss, and R. M. Hulet. 2000. "Temperature stratification and fuel use during winter in three Pennsylvania broiler houses." *Journal of Applied Poultry Research* 9 (4):551-563. doi: 10.1093/japr/9.4.551.

Zajonc, R. B., D. J. Reimer, and D. Hausser. 1973. "Imprinting and the development of object preference in chicks by mere repeated exposure." *J Comp Physiol Psychol* 83 (3):434-40.

Tables and Figures

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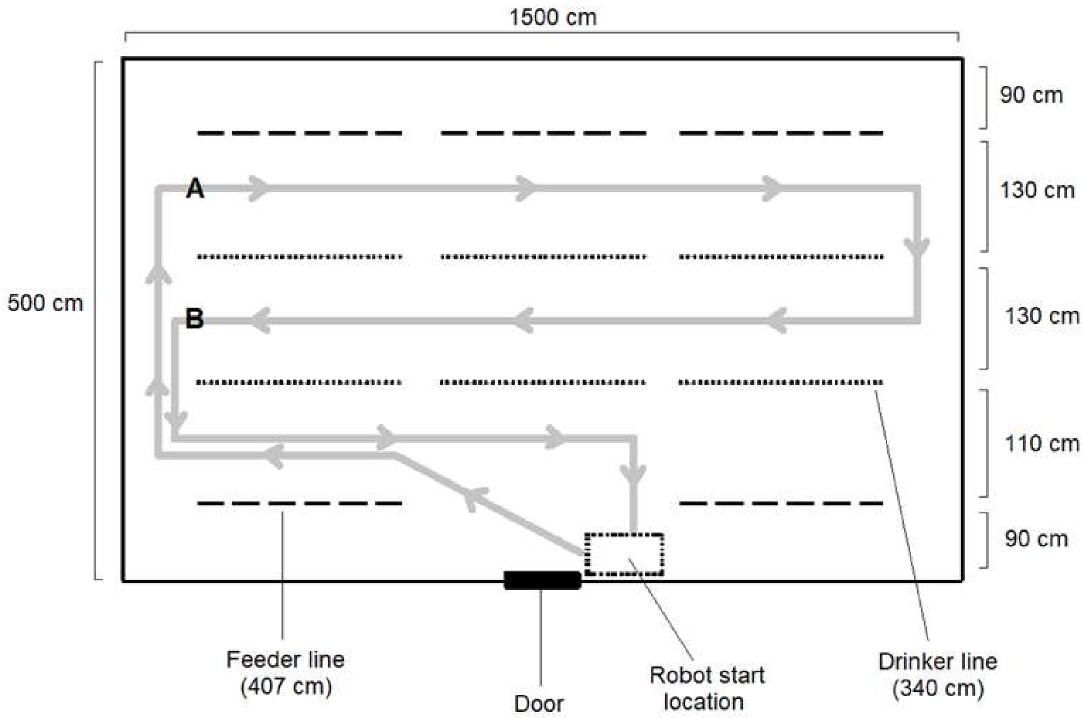
Table: Ethogram of observed behaviours

Behaviour	Definition
Startle (individual)	Bird moves away from the robot flapping its wings or flapping its wings and jumping. Birds had to be moving away from the robot (not towards or stationary) and wing flapping had to be present.
Group startle	3 or more birds perform startle behaviour in the same incident. Birds had to be within 1m of each other.
Contact with the robot	Instances of a bird touching the front of the robot with any part of its body. This may be the same bird multiple times provided it has come fully away from the robot before making contact again.
Blocking bird	A bird directly in the robot’s path that does not move on first contact with the robot and remains stationary (usually lying down).



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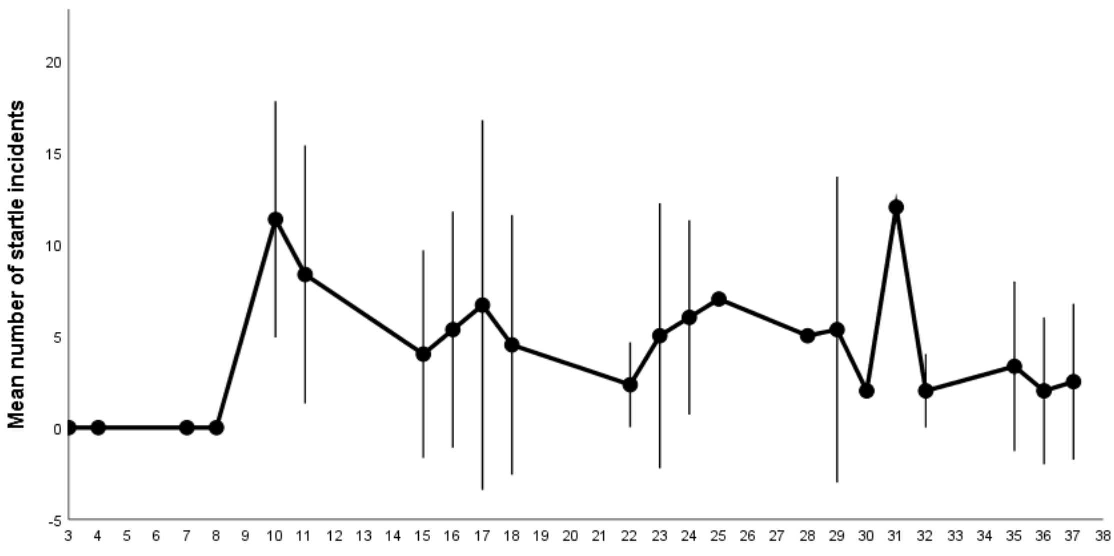

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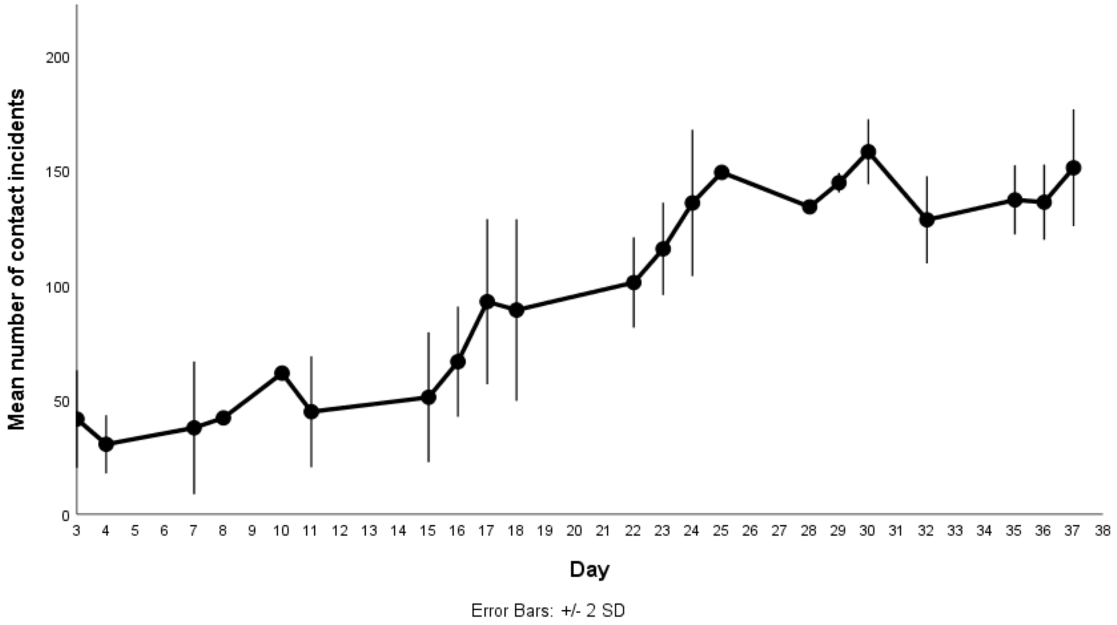

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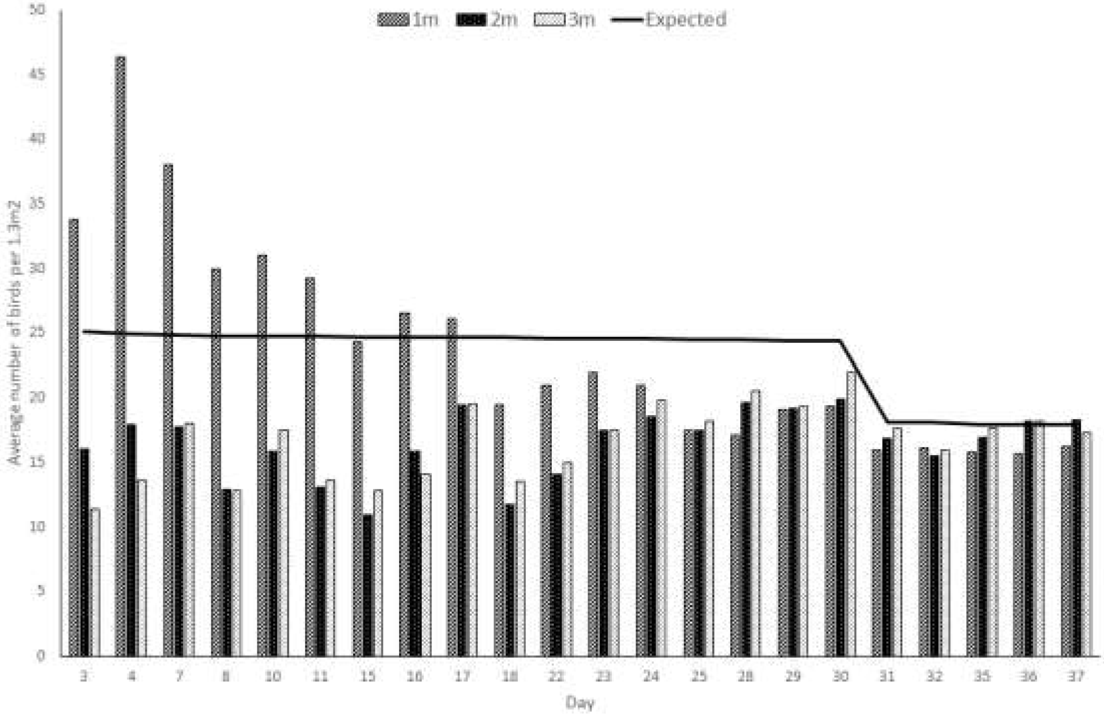

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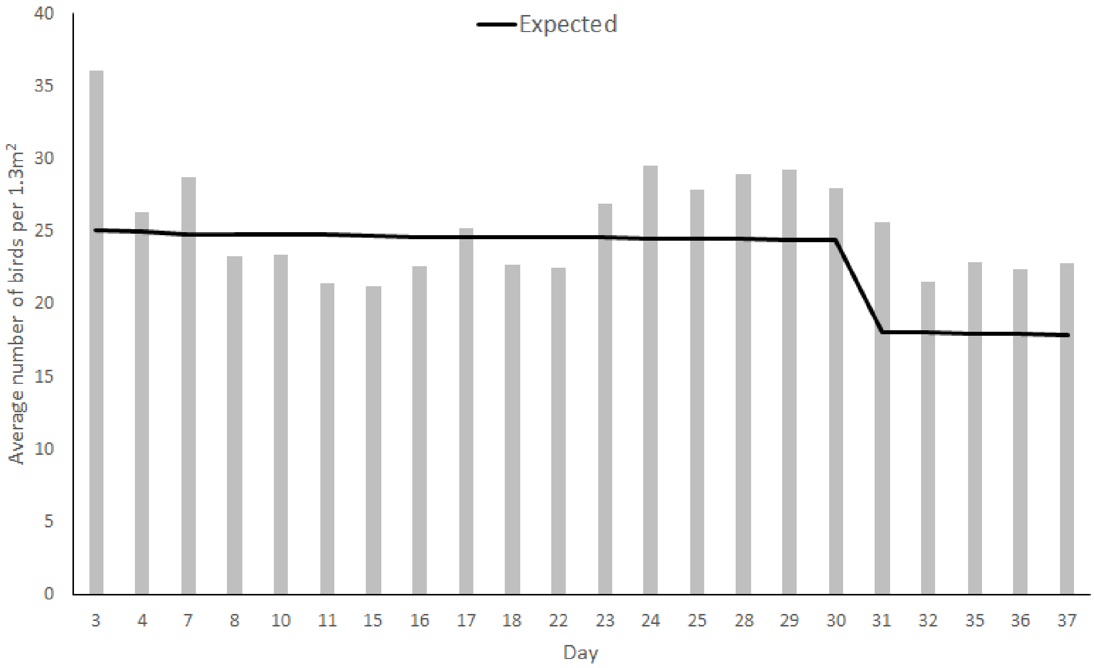

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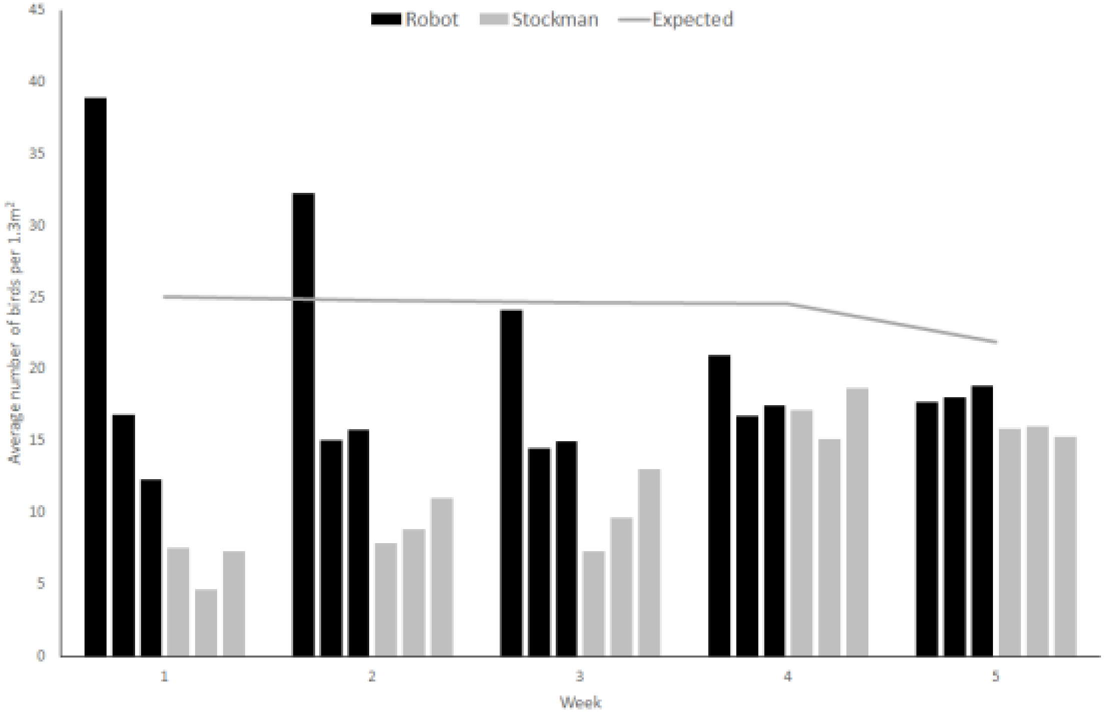

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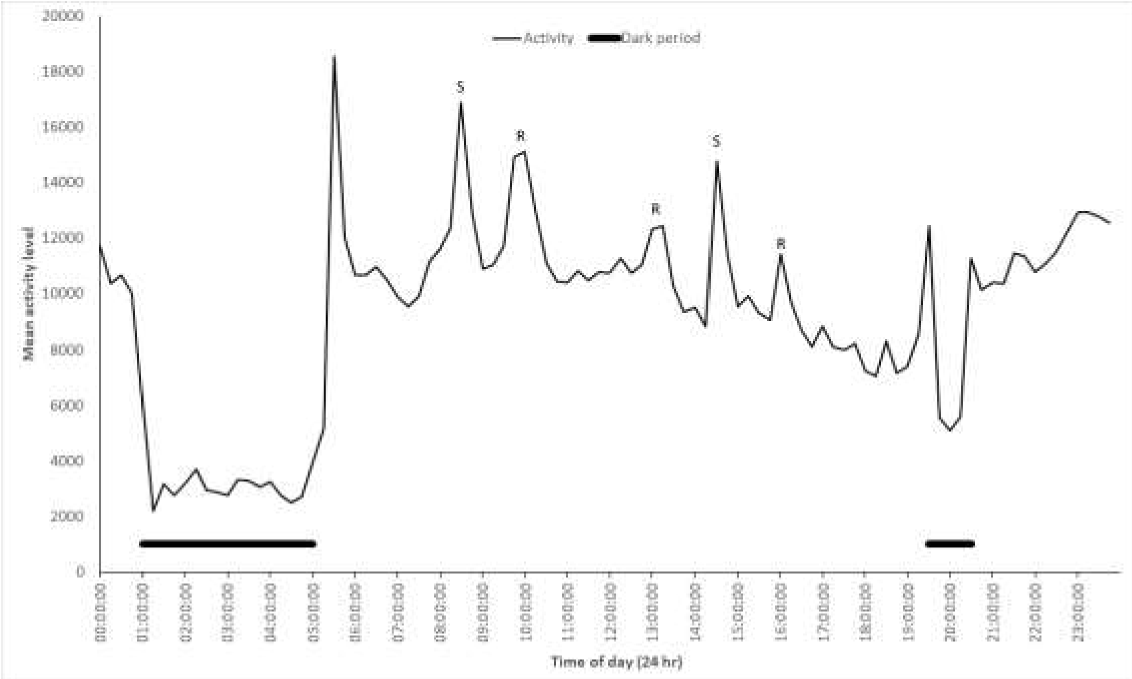

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