Predatory Bird Monitoring Scheme
http://pbms.ceh.ac.uk/

Population health indices for barn owls: a Predatory Bird Monitoring Scheme (PBMS) report

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THINK WILDLIFE
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1. Executive Summary

The Predatory Bird Monitoring Scheme (PBMS; http://pbms.ceh.ac.uk/) is the umbrella project that encompasses the Centre for Ecology & Hydrology's National Capability activities for contaminant monitoring and surveillance work on avian predators. The PBMS aims to detect and quantify current and emerging chemical threats to the environment and in particular to vertebrate wildlife.

Each bird that is submitted to the scheme is given a post-mortem examination during which approximately 60 macroscopic observations and measurements are made. The information gathered during this examination could potentially be used to monitor health status of the birds at the time of their death or at a particular stage of their development. In a previous PBMS report, we focused on examining potential health indicators for the sparrowhawk, *Accipiter nisus*. We were able to establish baseline "norms" for indicators that could be broadly categorised as indicators of change in: (i) population demography because of altered recruitment, survival and mortality (measures were sex ratio, proportion of first-year birds, and proportion of deaths from starvation or disease); (ii) nutritional status (measures were body weight, fat score, condition index) and (iii) physiological stress (fluctuating asymmetry).

In the current study we investigated whether these population health indices could be applied to barn owls, *Tyto alba.* With the exception of the fluctuating asymmetry (FA) metric, which did not comply with the assumptions of the methodology employed, we were able to establish baseline "norms" in the form of Shewhart charts in a format similar to those defined for the sparrowhawk.

For the majority of health indices considered it was necessary to present results separately for males and females. There were no differences between age classes and so combined indices for adult and first-year birds were presented. The exception to this was the metric reporting the proportion of deaths from starvation or disease (putative cause of death) where age classes had to be separated. Although presentation of indices for age classes combined may reduce some of our ability to interpret any change in the indices it does facilitate annual reporting, as the necessity to combine multiple year's data to satisfy statistical requirements may be less.

This report has demonstrated that the proposed population health indices generally can be reported for barn owls in same way as proposed for sparrowhawks previously. However, some indices, for example fluctuating asymmetry, differ in their applicability to specific species. Therefore, data analyses similar to those carried out in the current report would be necessary if health index metrics were to be defined for other additional species.

2. Introduction

2.1. Background to the PBMS

The Predatory Bird Monitoring Scheme (PBMS; http://pbms.ceh.ac.uk/) is the umbrella project that encompasses the Centre for Ecology & Hydrology's long-term contaminant monitoring and surveillance work on avian predators. The PBMS is a component of CEH's National Capability activities.

By monitoring sentinel vertebrate species, the PBMS aims to detect and quantify current and emerging chemical threats to the environment and, in particular, to vertebrate wildlife. Our monitoring provides scientific evidence of how chemical risk varies over time and space. This may occur due to market-led or regulatory changes in chemical use and may also be associated with larger-scale phenomena, such as global environmental change. Our monitoring also allows us to assess whether detected contaminants are likely to be associated with adverse effects on individuals and their populations.

Overall, the PBMS provides a scientific evidence base to inform regulatory and policy decisions about sustainable use of chemicals. In addition, the outcomes from our monitoring are used to assess whether effects are likely to occur in wildlife, whether mitigation of exposure is needed and what measures might be effective. Monitoring also provides information by which the success of mitigation measures can be evaluated.

Currently the PBMS has two key general objectives:

(i) to detect temporal and spatial variation in exposure, assimilation and risk for selected pesticides and pollutants of current concern in sentinel UK predatory bird species and in species of high conservation value

(ii) in conjunction with allied studies, to elucidate the fundamental processes and factors that govern food-chain transfer and assimilation of contaminants by top predators.

Further details about the PBMS, copies of previous reports, and copies of (or links to) published scientific papers based on the work of the PBMS can be found on the PBMS website.

2.2. Health indices and aims of the current study

Each carcass that is received by the PBMS undergoes a post-mortem examination (PM). In addition, tissue samples are collected both for chemical analyses in current projects and/or for retention in our long-term tissue archive (Walker *et al.*, 2014); archived samples are often used in retrospective ecotoxicological and ecological studies.

Approximately 60 macroscopic observation and measurements are made during the PM. To date, the main measurements that have been used have been those for species, age, sex and nutritional status as we have examined how these factors affect exposure to and accumulation of contaminants (for instance, Crosse *et al.*, 2013, Wienburg and Shore, 2004). However, the wider information gathered during the PM can potentially be used to assess the health status of birds at the time of their death. Shewhart (control) charts for various parameters can be generated from previously collected PM data and used to assess whether metrics collected in future years are within or without the normal range, or are changing systematically over time. Such evaluation, conducted for a range of PM metrics, could provide an overall indicator of the general health status of populations for any one year and over longer time periods.

To identify the suitability of different PM measurements for monitoring wider health status, a number of questions need to be answered, namely:

1. Is it possible to establish a baseline "norm" for various PM measurements?
2. Can all birds be monitored together or does demographic group (age and sex of the bird) have an influence on the values for any health index measurements?
3. Which demographic groups need to be monitored separately?
4. Is it possible to define "trigger values" for various health indices, deviation from which would indicate significant within year deviation from the norm?
5. Are the indices likely to be biologically meaningful?

In this study, we addressed the above questions for the following indices in barn owls (*Tyto alba*):

- Number submitted, sex ratio, age ratio and bodyweight of birds received by the PBMS
- the proportion of birds that have died of starvation and disease or were in a starved state
- the level of fluctuating asymmetry in morphological features

The current study built upon the work reported previously by the PBMS investigating the potential use of population health indices in the sparrowhawk *Accipiter nisus* (Walker *et al.*, 2016). We repeated the study using the barn owl to confirm whether our previous findings for sparrowhawks were equally applicable to barn owls. Unlike in the sparrowhawk, sexual dimorphism is not pronounced in the barn owl, but annual variation in survival and in body condition may be more marked because of potentially greater inter-year variation in the availability of prey species, such as the field vole *Microtus agrestis*. The barn owl provides a contrast to the sparrowhawk in terms of assessing how key parameters (for example sex ratio, age distribution, body condition) may vary between years and so affect the value of these measures as population health indices.

This study was designed to be a preliminary assessment of the potential to use different health indices to monitor the overall health status of predatory bird populations. The intention is to review the outputs from this report, in conjunction with those from our earlier report on sparrowhawk health indices, and seek the views of other potential users and stakeholders as to the value of the metrics outlined. The overall intention is to use these health indices to provide a holistic assessment of environmental health as indicated by sentinel predatory bird species.

3. Results and Discussion

3.1. Number of birds submitted to the PBMS

The number of barn owl carcasses received by the PBMS each year varied between approximately 50 and 150 over the period 1990-2015 (Fig. 1). The variation in carcass numbers received was similar to the variation in the British Trust for Ornithology (BTO) Breeding Bird Survey (BBS) index. The BTO BBS data for the period 1994 to 2015 indicates a peak in the early mid to late 2000s followed possibly by a more recent decline (Fig. 2).

To investigate the correspondence between numbers of carcasses received and the BTO BBS index, we assigned rank scores to the annual values for both measures over the period 1994 and 2015 and compared the correspondence of the ranks. There was a significant positive linear relationship between the rank scores ($r^2 = 0.44$, $F_{(1,19)} = 15.06$, P=0.001 (Figure 3), suggesting that trends in the numbers of barn owl carcasses submitted to the PBMS broadly reflect trends observed in the BBS index.

This correlation suggests that the number of barn owls received by the PBMS may be a useful metric of overall population status or productivity, as reflected by the BBS index. However, it is not necessarily informative to define a metric in terms of barn owl carcass submissions that would indicate a "norm", for which annual values above or below would indicate a meaningful change in population status. This is because the number of carcass submissions is likely to be affected by collector effort which may change in the future as the PBMS enters new collaborations (for example between the PBMS and other carcass collection schemes in Scotland[2] and elsewhere). Therefore, simple carcass numbers are unlikely in their own right to be a good candidate for a health index.

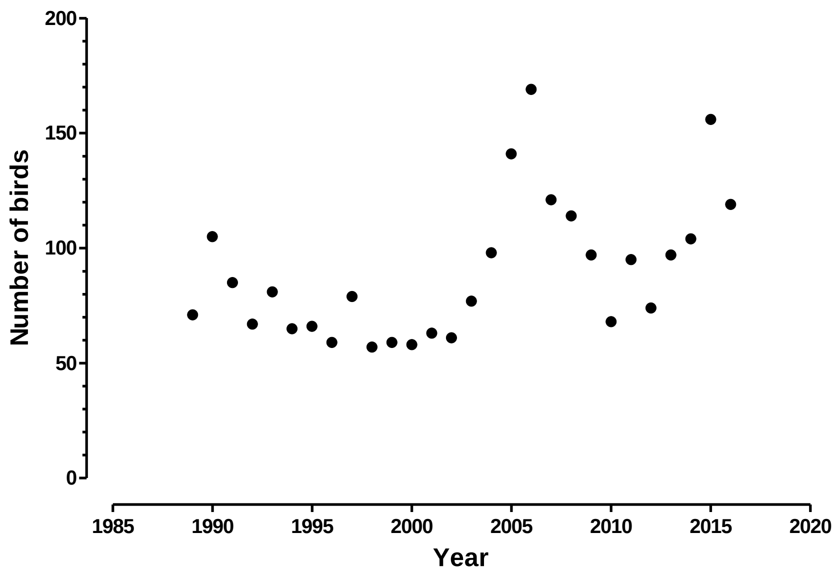

Figure 1. The number of barn owls received by the PBMS between 1989 and 2016.

2 https://wiki.ceh.ac.uk/display/pbms/2016/05/05/PBMS+involved+in+a+major+new+collaboration+on+Scottish+raptors

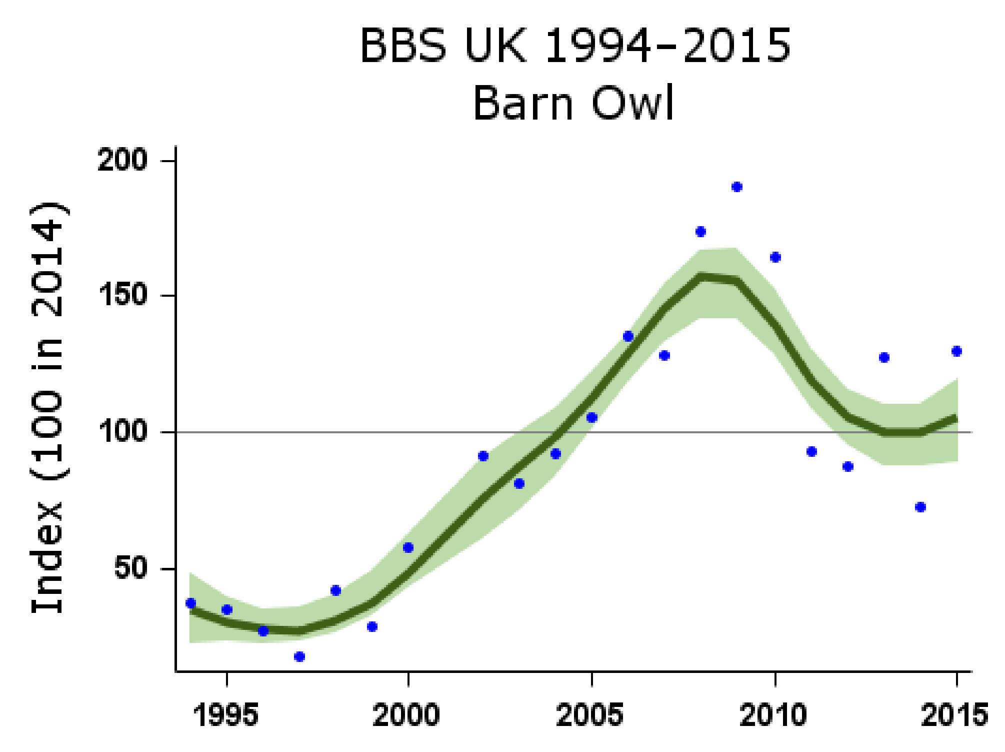

Figure 2. BTO population index for barn owls in United Kingdom based on the breeding birds survey (Taken from British Trust for Ornithology, 2017).

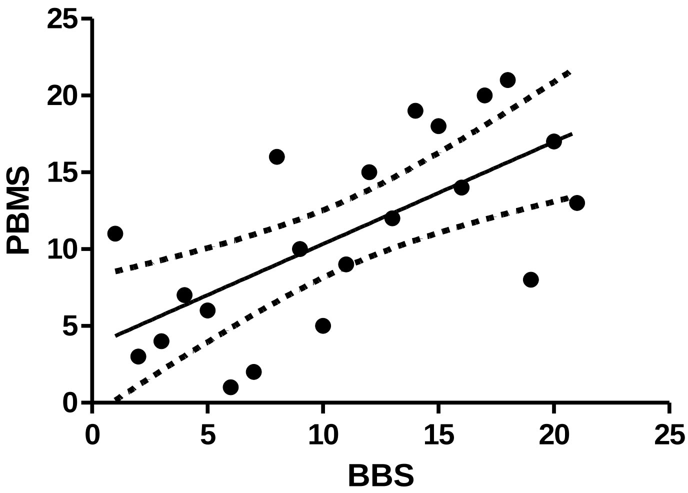

Figure 3. Rank of annual barn owl numbers received by the PBMS plotted against rank BBS index score for barn owls in United Kingdom for the periods 1994-2015.

3.2. Sex ratio

The sex of each bird submitted to the PBMS is determined during the necropsy and is based on body size, weight, plumage and positive identification of the gonads. Using our long-term data, we calculated the proportion of barn owls that were female for all years in which the number of carcasses for which sex was determined was ≥ 5. For the period 1996 to 2015, there was no significant linear relationship between the arscine square root of the proportion of birds received that were female and year ($F_{1,18}$=1.91, P=0.184). The average proportion of birds that were female over this period was not significantly different from 0.5, equivalent to an equal sex ratio (1-sample t-test t_{19}=1.51, P=0.147), and was similar to the sex ratio reported by Newton *et al.*(1997) for barn owls (49% female) received by the PBMS between 1963 and 1996. However, there was a significant positive relationship between the proportion of females and the number of birds received (arcsine-square root data analysed; $F_{1,18}$=6.43, P=0.02, Fig. 4). This suggested that the sex ratio would have a greater female-bias in years in which more carcasses were submitted to the PBMS, although the causes for this are unclear. Thus, if there was a significant deviation away from a "normal" sex ratio in future years, it would be important to determine if this was a simple consequence of variation in the number of carcasses received or due to other factors.

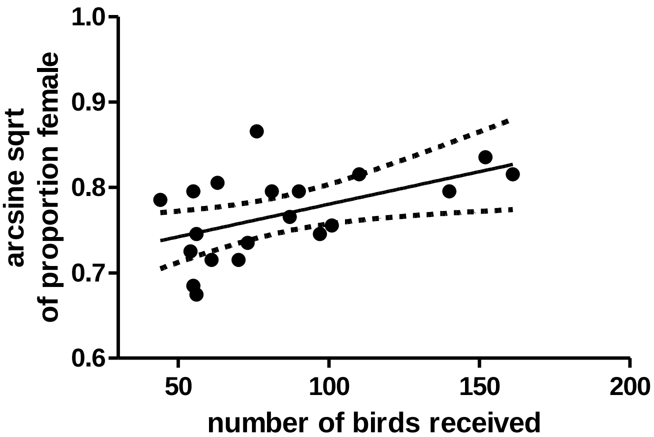

Figure 4. The proportion of birds received by the PBMS that were female compared to the number of birds received each year. Linear regression line shown with 95% confidence intervals.

The average proportion of females in an annual sample of carcasses was normally distributed when data for all years was considered and so we used mean 95% prediction intervals to establish a Shewhart chart for the proportion of barn owls that would be expected to be female (Fig. 5). Thus, future years in which the proportion of female barn owl carcasses submitted is <0.38 or >0.59 could be considered unusual years and may be indicative of other changes to the status of birds.

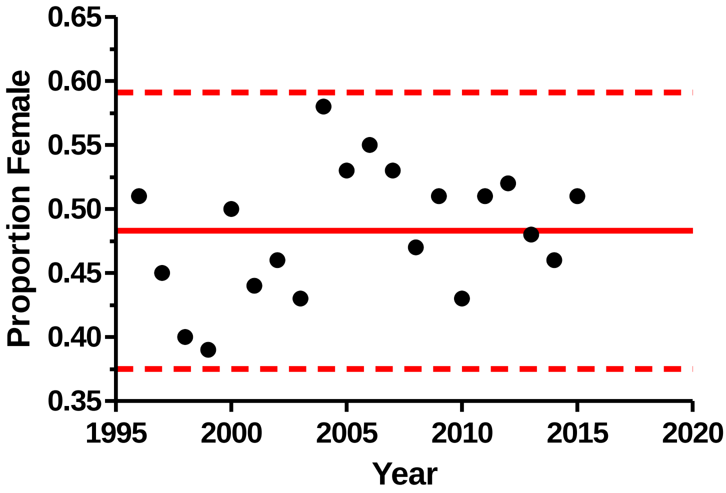

Figure 5. The proportion of barn owls received by the PBMS that were female. Red solid and dashed line indicates mean and 95% prediction intervals, respectively.

3.3. Age ratio

The number of barn owls submitted to the PBMS each year between 1996 and 2015 for which the age of the bird was confirmed ranged from 41 to 150. At PM, birds are classified as either first year birds or adults where first years are defined as birds that hatched in the current or previous year. Over the monitoring period the annual proportion of birds that were first years was higher for males than for females (Paired t-test of arcsine-square root transformed data, t_{19}=4.975, P<0.0001). There was no significant trend over time in the proportion of first-year birds for either males (R=0.004, P=0.99) or females (R=-0.001, P=0.996) and the mean percentage of first-year birds was 78% and 68% for males and females, respectively (Fig. 6). Newton *et al.* (1997) reported a similar age structure for barn owls (males and females combined) received by the PBMS between 1963 and 1996 with 76% of carcasses on average comprised of first-year birds.

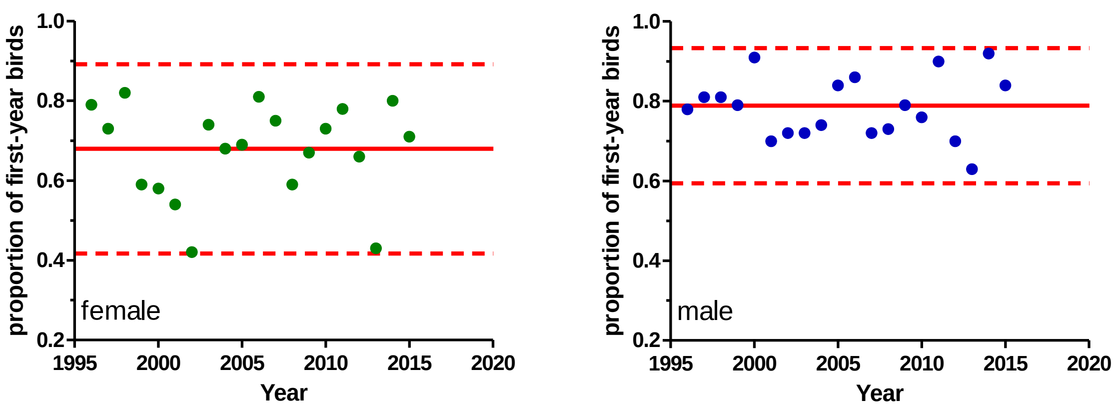

Figure 6. Proportion of female (●) and male (●) barn owls received annually that were first-year birds. Solid line indicates mean value and dotted lines are 95% prediction intervals, respectively.

3.4. Body weight

Exploratory analysis to investigate the effect of age and sex on the body weight of barn owls received between 1996 and 2015 was conducted by non-parametric methods as data was not normally distributed. There were statistically significant differences in body weight among the demographic groups (KW test statistic=61.16, $P<0.0001$); females had higher body weights than males but there was no significant effect of age (Fig. 7). Consistent with these analyses, we found that when body weights were averaged across age categories for each year, female barn owls had higher annual median body weights than males (Paired T-test, $t_{19}=6.17$, $P<0.0001$). We also examined whether median annual body weights of males and females were correlated, as might be expected if inter-year variation in body weight is strongly driven by fluctuations in prey availability — for instance, body weights of both sexes might be expected to be higher in years when prey were plentiful. While there was a positive correlation between the annual median body weights of males and females (Fig. 8), this association was relatively weak and not statistically significant ($r=0.38$, $P=0.09$). This suggested that inter-year variation in male and female body weights are at most only weakly associated and that any influence of prey availability on body weight may not be the same in both sexes.

For the purposes of using body weight as a health index, we calculated annual median body weights for males and females but did not separate the data by age class. The years included in the analysis were those in which the number of birds in a specific sex category was 5 or greater. Annual median body weights were normally distributed for both males and females and Pearson correlation analysis indicated there was no significant consistent change in annual median body weights with time for either sex ($P \geq 0.37$). Shewhart charts based on arithmetic mean and associated 95% prediction intervals are given in Fig. 9.

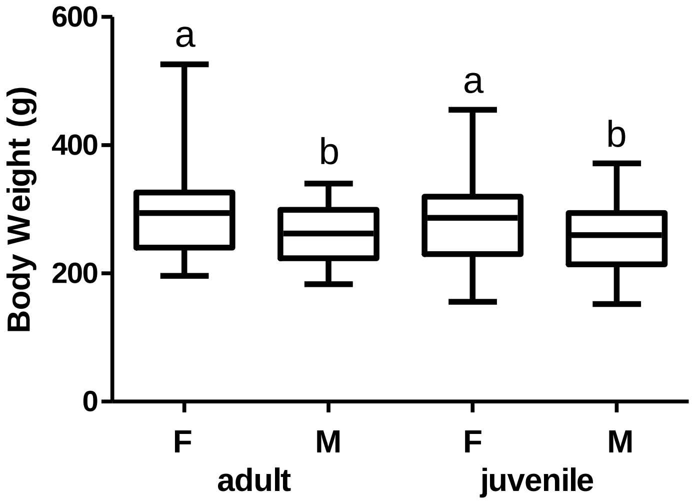

Figure 7. Box and whiskers plot (median, interquartile range and range) of body weight of adult female (N=166), adult male (N=120), juvenile female (N=387) and juvenile male (N=462) barn owls received between 1996 and 2015. Significant differences ($P<0.05$) between groups are indicated by different letters.

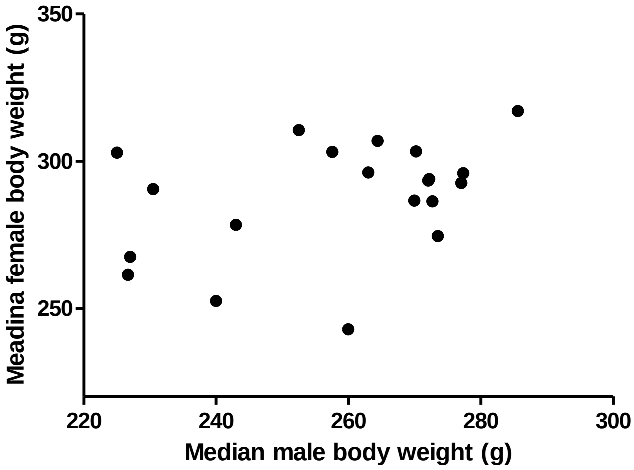

Figure 8. Median annual body weights for male and female barn owls plotted against each other.

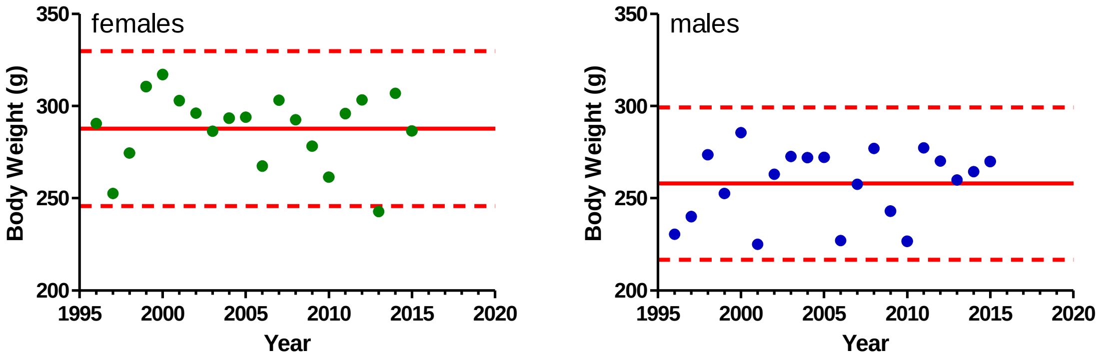

Figure 9. Annual median body weights of female (●) and male (●) barn owls where n is between ≥ 5. The solid line indicates the arithmetic mean value and dotted lines are 95% prediction intervals.

3.5. Putative Cause of Death

During the PM examination of the birds, a putative cause of death category is assigned to each bird based on a combination of the circumstances in which the bird was found and macroscopic observations of the carcass. Starvation and disease are clumped together into one putative cause, ("starvation or disease") partly because starvation may be a result of disease state, and it is recognised that only gross clinical sign of disease will be identified because post-mortem examination is limited to gross clinical observation. Hereafter, this cause of death is referred to for ease as starvation/disease.

Data were separated by age class and sex and a minimum annual sample size of 10 or greater was applied to the data set so that the absolute minimum resolution for proportion data was 10%. Where there were less than 10 birds in any year, data from consecutive years were pooled so that the minimum sample number of birds was ≥ 10 and the data were ascribed to the year that was the mid-point of the data-pooling period. This approach meant that while the number observations were reduced to 11 "years", it was possible to conduct a balanced analysis of arcsine-square root transformed values using a general linear model that included age, sex and year as terms; the residuals from this model were normally distributed (Anderson Darling test, P=0.295). Age ($F_{1,31}$=7.31, P=0.011), sex ($F_{1,31}$=13.55, P=0.001) and year, included as a factor rather that a covariate ($F_{10,31}$=4.63, P<0.001) each significantly explained variation in the proportion of birds that had died due to starvation/disease. There was a lower proportion of adult than juvenile starved birds, and there was a higher proportion of starved males than females, consistent with our earlier finding of males having a lower average body weight than females. Although there was significant variation among years, for adult birds of either sex and first-year females there was no significant linear trend in the annual proportion of birds that died due to starvation/disease (Fig. 10). For first-year male birds, there was a linear decline over the monitoring period in the proportion of birds that had died of starvation/disease (R^2=0.413, $F_{1,9}$=6.34, P=0.032). Therefore, it was possible to predict future proportions of starved/diseased first-year males on the assumption that this trend would continue. For the other age/sex categories, Shewhart control charts with mean and 95% prediction intervals, were calculated (Fig. 10). The reason for the decline in the proportion of first-year males that were in a starved/diseased state is unknown but it potentially could be because the number of birds submitted to the scheme that have died due to other cause, such as road casualties, may have become more common amongst first-year males.

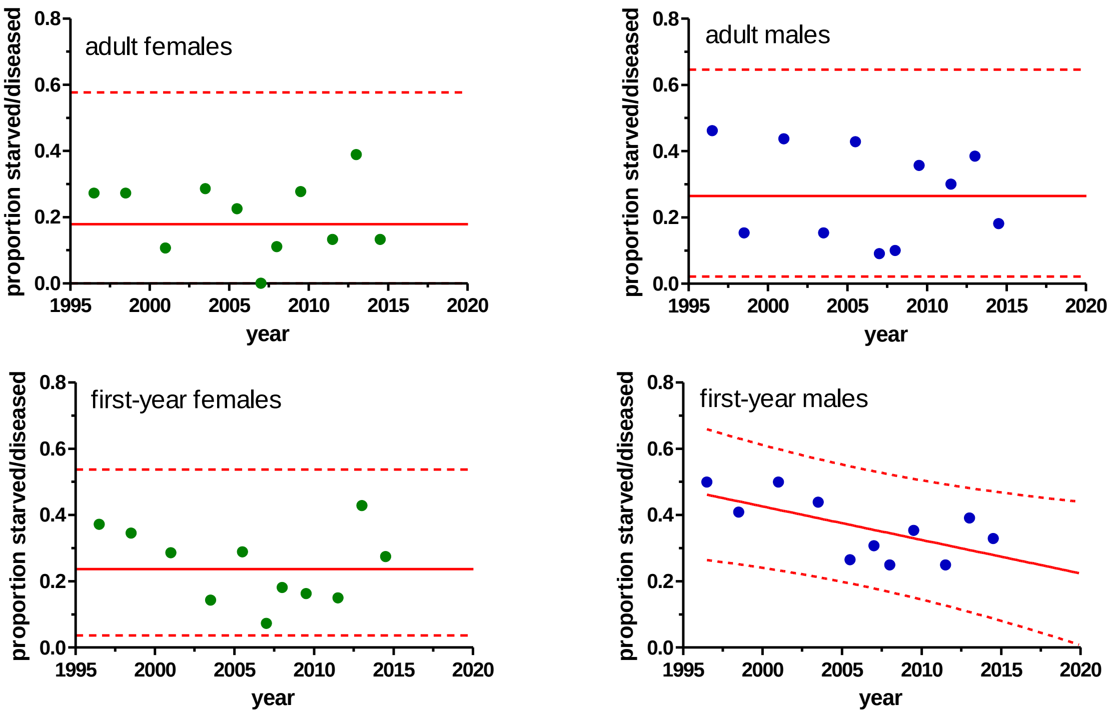

Figure 10. The proportion of female (●) and male (●) adult and first year barn owls that had died due to starvation or disease in each year of the monitoring scheme. The red solid line indicates the mean and 95th percentile prediction interval (dashed red lines).

3.6. Fat Score

During the PM examination, a non-linear semi-quantitative categorical fat score is assigned to each bird based on the fat deposits evident in the carcass (Table 1). For the purposes of the current analysis birds were categorized as “low” or “high” if they had a fat score of 0-1 and 2-5, respectively. This index could give a higher proportion of birds with low fat scores (0-1, equivalent of starved) than that estimated from cause of death because it includes birds killed by other causes while they were in a starved or near starved state.

Table 1. Criteria for assigning a fat score to birds based on fat deposits evident in the body

Fat Score	Description
0	No sign of fat deposits within the body including around the heart.
1	Trace amounts of fat deposits including deposits around the heart.
2	Small amounts of fat deposits evident, including around the pectoral muscle.
3	Moderate amount of fat deposits evident, including around the pectoral muscle.
4	Good amount of fat deposits, including intra-abdominal deposits.
5	Abundant fat deposits, would be able to recover greater than 2 grams of fat from body.

General linear analysis of arscine-square root transformed data for the proportion of starved birds with age, sex and year as factors indicated that there was a near significant effect of sex ($F_{1,28}$=4.10, P=0.052) with mean proportion of birds with low fat scores being higher in male than females. Because this analysis was based on a relatively small sample size, thereby limiting the power to detect a significant effect, and because sex was a significant factor explaining variation in the proportion of owls that died from starvation/disease (section 3.5), Shewhart control charts were calculated for males and females separately (Fig. 11). Age ($F_{9,28}$=1.09, P=0.398) and year ($F_{1,28}$=0.67, P=0.421) were not significant factors and so separate control charts were not produced for adults and juveniles.

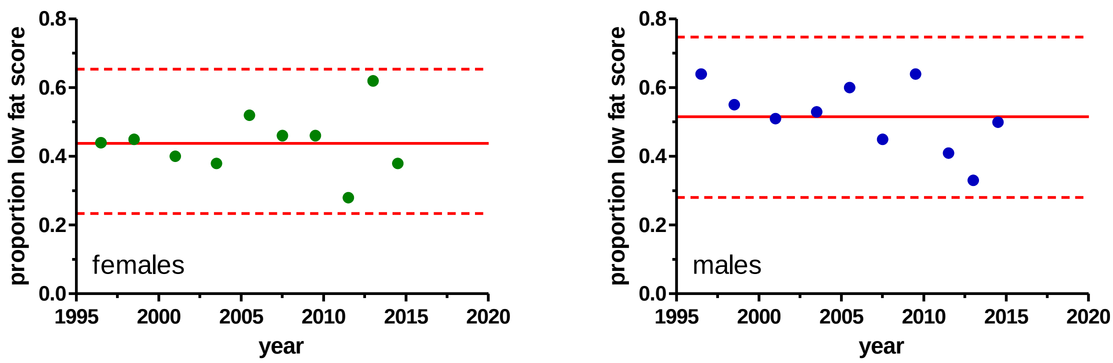

Figure 11. The proportion of female (●) and male (●) barn owls that had a low fat score (0 or 1) in each year of the monitoring scheme. The red solid line indicates the mean and 95th percentile prediction interval (dashed red lines).

3.7. Condition Index

The condition index (CI) is a quantitative measure standardizing body weight to account for variation in body size calculated as per equation 1.

Equation 1

$$CI = (Body_{wt} - Gizz_{wt}) \div Sternum\ Diag.^3$$

where

$Body_{wt}$ = Whole body weight (g)

$Gizz_{wt}$ = Wet weight of gizzard contents (g)

Sternum Diag. = Distance between posterior point of the sternum keel plate and the distal point of the clavical (mm)

Consistent with Walker *et al.* (2016), annual median CI was calculated for years where sample numbers for each adult females and males was ≥5. For years where sample numbers were less than 5 data from that year was combined with those from the succeeding years until the sample number requirement was met. If this was necessary then the same years were combined for juvenile in order to facilitate a balanced analysis, which resulted in 9 'years' between 2004 and 2015. General linear model analysis of median condition index values, including year, age and sex as factors and the interaction term between age and sex, demonstrated that year ($F_{8,24}$=6.68, P<0.001) and sex ($F_{1,24}$=8.32,P=0.008) significantly explained variation in annual condition index, but age and the interaction term between age and sex were not significant terms in the model ($F_{1,24} \leq 1.21$, P ≥ 0.282). Therefore annual median condition index values were analysed separately for males and females but data for first-year birds and adults were pooled. These annual medians were normally distributed and so the mean and 95% prediction intervals were calculated (Figure 12).

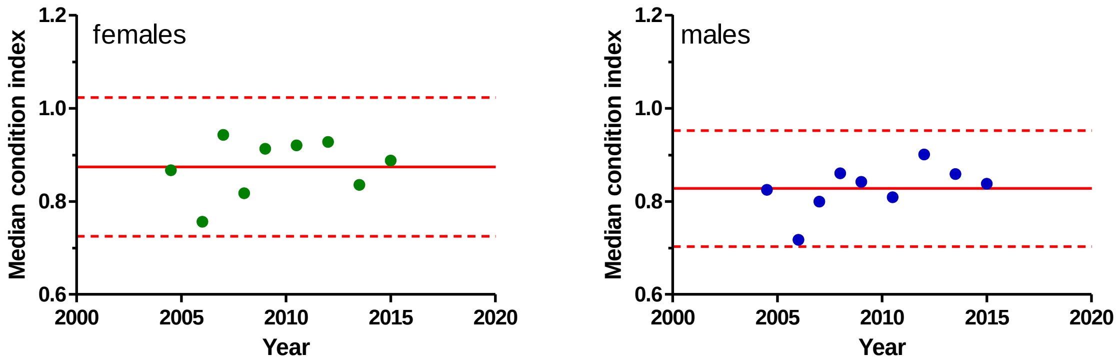

Figure 12. Annual median condition index values for female (●) and male (●) barn owls plotted against year that the bird died. Mean and 95th prediction intervals are represented by the solid and dashed red lines, respectively.

3.8. Fluctuating Asymmetry

Fluctuating asymmetry (FA), the random deviation from perfect symmetry in bilaterally paired structures was shown to be a potential population health index for sparrowhawks using 10th

primary feather weight (Walker *et al.*, 2016). However initial examination of the data for this trait in barn owls indicated that although the mean of the data set was not significantly different from 0 (One sample t-test, t_{475}=0.229, P=0.819) the distribution showed Kurtosis tending towards a peaked distribution (Kurtosis score = 11.34; Fig. 13). Therefore, this trait in barn owls is unsuitable for detection of fluctuating asymmetry in this species. Additional work would be required to establish whether other feathers might be used for the calculation of fluctuating asymmetry in barn owls.

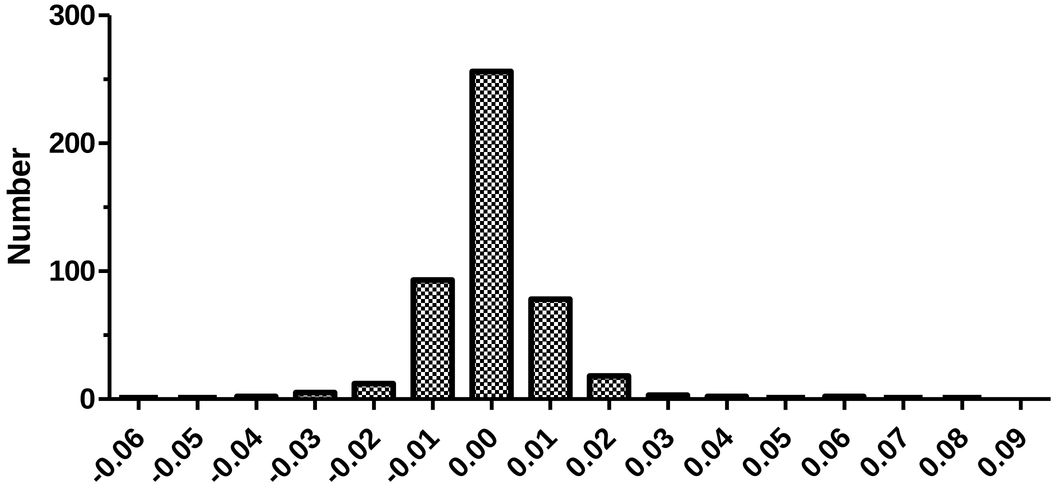

Figure 13. Histogram of difference in weight of left and right 10th primary feather in barn owls submitted to the PBMS between 2008 and 2015 inclusively (n = 476).

4. Conclusions

As with the previous report for sparrowhawks (Walker et al., 2016) most of the candidate indices investigated in this report would appear to be suitable for developing an annually updated population health index based on a classic quality control chart approach. For the majority of health indices considered it was necessary to present results separately for males and females while generally there were no significant differences between age classes; hence combined indices for adult and first-year birds were presented. While pooling data for different age categories has the advantage of increasing within year sample size, it can have a disadvantage in that any factors that affect first year and adult birds differently may not be identified.

Barn owl populations in Britain are known to fluctuate with the availability of their preferred prey field voles with increased owl productivity in years in which vole numbers are high (Newton, 2002). Therefore, availability of prey may be a source of annual variability in the health indices that reflect body condition and juvenile recruitment in barn owls. If data on relative vole abundance were available on an annual basis, it might be possible to normalise health index measurements for prey availability, and thereby improve the sensitivity of the health metrics to detect changes driven by other factors. However, this would only be possible if there were national, or at least widescale, annual monitoring of vole abundance but such data are not available.

Another aspect to consider when generating these population health indices is whether the period over which those indices have been established involved significant changes in population health/numbers/status. If this is the case then the health of the population may potentially continue to decline or improve without a significant exceedance from the prediction limits for the Shewhart charts for certain population health indices. Over the 20 year period (1995-2015) that the population health indices have been examined in this report the BTO BBS values have general increased (Fig. 2, page 9) and so the Shewhart charts established in this report may be representative of a growing barn owl population. Care is therefore needed when interpreting future exceedances of prediction intervals as they may simply reflect a change in population growth rate due to normal density-dependent processes.

There are various approaches highlighted in the current report that indicate further investigation may be merited. Unlike for sparrowhawks (Walker et al., 2016), the 10th primary feather weight could not be used to assess fluctuating asymmetry in barn owls. Further study is needed to determine if other feathers in barn owls may be of use for assessing fluctuating asymmetry and it may be that such measures need to be tailored to individual species in general. Furthermore, it may also be of value to explore relationships between the health indices described in the current report with measurements, such as body weight and number of pulli ringed, that are collected and reported by ringers licensed through the British Trust for Ornithology. Combination of such data may enhance the sensitivity of the health indices that are developed.

In our previous report, we discussed the relative merits of the different health indices that we examined and how they might be combined and presented to provide an overall dashboard describing the status of the health of the species. These aspects are not repeated again here. However, we did not discuss earlier which species it might be possible to use from the PBMS to provide health index information. Clearly, this can be done for sparrowhawk and barn owl, and potentially could be done for other core species for which carcasses are received annually in reasonably large numbers; tawny owl *Strix aluco*, buzzard (*Buteo buteo*), and to a lesser extent red kite (*Milvus milvus*) and kestrel *(Falco tinnunculus*). This spread of species covers terrestrial birds of prey that feed predominantly on small birds (sparrowhawk), small mammals (barn owl, tawny owl and kestrel), and on scavenge (red kite, buzzard). Replication across species with similar trophic strategies would help infer whether any changes in health metrics that may be seen are indicative of effects that are species-specific or that may be more widely applicable across habitats or food-chains. As discussed in our earlier report, it may also be possible to extend the approaches advocated here to encompass a freshwater sentinel, the otter (*Lutra lutra*) through collaboration with our WILDCOMS partner, the Cardiff University Otter Project. Collaboration with other WILDCOMS partners would also be likely to enhance the coverage and robustness of data for some of the terrestrial species such as buzzard.

In conclusion, our current and previous (Walker et al., 2016) report demonstrate the feasibility of using our PM measures on the birds received to provide measures of population health. The next step forward is to examine how this approach can be implemented in a resource efficient and effective manner and how it can be widened, as appropriate, to other species to provide as holistic a picture as possible to changes in the state and health of the environment.

Table 2. Possible metrics gathered during PM examination that can be used as indicators of health status in barn owls.

Metric	**General Indicator Category**	**Possible indicator of change in:**	**Demographic group**	**Potential reporting frequency**	**Limitations**
Sex ratio	Recruitment and survival	Relative recruitment or survival of males and female	Adults and first-year birds pooled	Annual, depending on sample size	May not reflect true sex ratios but indicative of change within sampling structure
Proportion of first year birds	Recruitment and survival	Recruitment success relative to adult numbers and/or change in relative mortality of adult and/or first year birds	Males and females birds separately	Annual, depending on sample size	Unclear whether indicates change in first-years or adults
Proportion deaths from starvation or disease	Mortality	Change in relative frequency of major causes of death. Possible indicator of change in nutritional status	Age and sex groups separately	Annual, depending on sample size	Unclear whether reflects change in relative numbers dying from this or other causes
Body weight	Nutritional status	Food availability/quality or other factors affecting nutritional status	Males and females birds separately	Annual, depending on sample size	Does not account for change in body size. Use in conjunction with other measures of nutrition
Fat score	Nutritional status	Food availability/quality or other factors affecting nutritional status	Males and females birds separately	Annual, depending on sample size	Categorical and subjective score. Use in conjunction with other measures of nutrition
Condition index	Nutritional status	Food availability/quality or other factors affecting nutritional status	Males and females birds separately	Annual, depending on sample size	Does not account for change in body size. Use in conjunction with other measures of nutrition
Fluctuating Asymmetry	Physiological stress	Change in stress levels in general populations	Not applicable	Not applicable	Other candidate structural traits need to be investigated for this species because 10^{th} Primary feather weight does not satisfy the assumptions for use in FA calculation.

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