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Novel ways of communicating museum pest monitoring data: practical implementation

Keywords

IPM; museum; pest monitoring; data analysis; Pest Occurrence Index; visualisation; communication

Abstract

In a bid to improve communication of data relating to the conservation of cultural heritage collections, the authors present a solution and technique that makes analysis and communication of pest monitoring data more user-friendly. This novel technique includes calculation of the new Pest Occurrence Index (POI), which integrates recorded pest occurrence numbers over number of pest monitors and room size, decreasing unintentional bias introduced by previously used analytical techniques. Calculation of POI requires that contextual information such as type of collection affected, room size, and number of pest monitors deployed also need to be reported during pest monitoring to enable meaningful data interpretation. Trials at National Museum Cardiff (NMC) using different types of illustrations, based on the newly developed POI and with messages targeted at specific recipients, indicated that risk perception based on visualisations is affected by user background, expertise in relation to pest management and familiarity with certain types of graphical representations. The introduction of novel and comprehensive forms of graphical data interpretation at NMC, including greater focus on developing visualisations with specific messages for different target audiences, resulted in increased staff buy-in and willingness to assist with pest management and a demonstrable decrease in pest occurrences in collections areas of the museum.

Introduction

Effective communication of pest monitoring data should result in the message recipient concluding that a preventive approach to collection care is the best tactic to protect heritage collections from pest damage. Consequently, messages should be targeted at shaping the recipient’s attitude accordingly, to encourage their support for pest management efforts. One hurdle to communicating IPM messages effectively is that recipient decision makers are understandably not as familiar as the IPM manager on issues critical to successful pest management such as the building, collections, collection vulnerabilities, pest species or the likelihood of damage resulting from a pest threat.

Visualisations are the quickest and most impactful ways of communicating data. As a result of a partnership project between National Museum Cardiff (NMC) and Cardiff University, Henderson et al. (2017) suggested the use of novel dynamic, visually attractive and meaningful graphical data representations to achieve improvements in communication. At present, the choice of graphical tools is frequently limited by a lack of effective data analysis. One reason for this is that standard advice on pest monitoring explains how to set up a monitoring programme, how to identify pests and how to record numbers, but stops short of suggestions about what to do with the resulting data. Data interpretation and communication are an essential step in a pest management programme with consistent data collection being critical to allowing the success or failure of pest prevention and/or treatment measures to be judged objectively.

Pest monitoring

It is an axiom of cultural heritage conservation that pest management is important. Most heritage objects comprised of organic materials are susceptible to being damaged by pests, and pests are regarded as the third agent of deterioration (Strang and Kigawa 2018). A rapidly increasing amount of research literature assists with the development of ever-refined pest management methodology (Crossman and Pinniger, 2013), which, during the past 30 years, shifted from previously reactive in response to now preventive with the intention of avoiding outbreaks in the first place (Henderson, Baars and Hopkins, 2019). Increasingly, the use of non-chemical means for monitoring and control of pests – driven in part by the negative impacts on human health from the use of chemical biocides, and the realisation that pest damage to cultural objects is more time-consuming and expensive to resolve than the prevention of damage – is resulting in preference for an Integrated Pest Management (IPM) approach (Child, 2013; Querner, 2015; cf. Kingsley et al., 2001).

One crucial element of an IPM programme is continuous monitoring of the occurrence, and frequency of occurrence, of pest insects with the aim of identifying change points, such as a sudden increase in pest counts that may constitute an increased risk to collections. The literature on monitoring methodologies is exhaustive, but a few examples serve to illustrate the volume of references available for monitoring methodologies ranging from visual inspections of pest activity to the use of various types of non-attractant and attractant pest traps: Child and Pinniger (1994); Pinniger, Child and Chambers (2003); Querner et al. (2013); Pinniger (2015).

Data capture

If undertaken regularly, and given a sufficiently large institution, pest monitoring can result in the creation of large amounts of data: the almost 200 pest monitors currently deployed at NMC are checked twice annually; data fields include room name, number of monitors in room, room size, and 18 fields for different pest species/pest indicators (Table 1), resulting in more than 8,000 individual potential data points per year. Setting out pest monitors and never checking them, or collecting data without analysing them are, at best, a waste of time and resources; at worst, this practice endangers the collection. Good data analysis is crucial to assist with interpretation and assessment of the effectiveness of a pest management strategy, and for communicating findings for the purposes of outreach, engagement and decision making.

Data analysis

Unfortunately, the literature lets the conservator down just at this crucial point of data analysis and communication. Beyond the general advice that 'over a period of time a record of what is caught (in pest monitors) will build up a picture of the distribution of insects' (Child, 2006), none of the references cited above contain any suggestions about what to do with all those data. Even the otherwise comprehensive standard BS EN 16790:2016 does not go beyond suggesting that 'data collected from monitoring can help to map the scale, type, location and seasonal cycles of a pest problem' – as in other documents on pest management in cultural heritage collections, how to achieve this is left to the individual conservator to figure out.

To the conservator tasked with monitoring pest activities, the all-familiar pie, bar and line graphs of pest counts provide hazard data about the ability of different species to penetrate the building envelope and establish populations within a building. They do not indicate the magnitude of risk arising from that pest occurrence which is dependent on, amongst other factors, which part of the building or collection is affected by what pest species, and the number of individual pest organisms. Species numbers alone present a restricted image of the problem. Crucially, if there are changes to the number of monitors or surface area sampled during a monitoring period, the data are rendered almost useless.

An example illustrates this problem. Pest monitoring data from NMC appeared to suggest that there was a dramatic increase in the number of pests recorded during the five years since 2014 (Figure 1.A). Staff knowledge and a review of data collection methods (Henderson et al., 2017) prompted a review of how data were presented (Figures 1.B-D). Correlating pest numbers with the number of pest monitors, the number of rooms and total floor area monitored showed that there was a risk of data interpretation being skewed by gradual improvements to the monitoring programme, resulting in the potential to draw incorrect conclusions about the size of pest populations based on a simplistic interpretation of Figure 1.A. The tendency to confirmation bias, from an apparently plausible narrative about a pest increase over time, would be tempting for staff who were evidently increasing their focus on pest management. An examination of the correlation coefficient between pest numbers and a range of factors (Table 1) exposes the danger of seizing on an initial plausible explanation, the apparent increase in the size of the pest population (Figure 1.A). Examination of a range of correlations exposes many other relationships, suggesting the more compelling explanation that the increase in numbers of pests detected is best explained by an expansion in the pest monitoring programme (Figures 1.B-D).

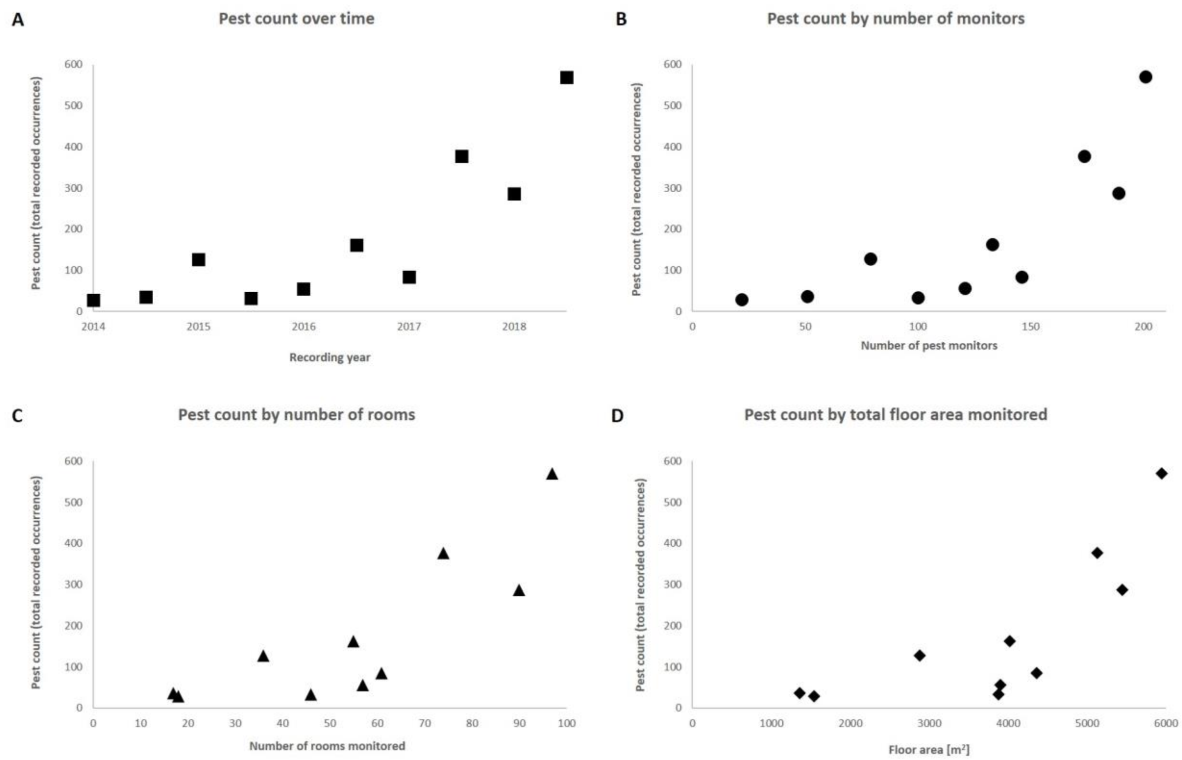

Figure 1: An increase in pests detected over time since 2014 at NMC (A) may suggest an increase in total pests. Further investigation revealed many other plausible correlations: pest count over number of pest monitors (B) number of rooms monitored (C) and floor area monitored (D; see also Table 1).

Table 1: The correlation coefficient (r) indicates that there is a positive correlation between pest count and time, number of pest monitors, number of rooms and total floor area monitored.

Correlation between pest count and …	**Correlation coefficient (r)**
time	0.82
number of monitors	0.80
number of rooms	0.82

total floor area	0.77

The current practice of only recording the numbers of individuals of each pest species detected is more suited to mapping the hazards than to demonstrating the resultant risks. This poses a problem for the conservator attempting to make sense of pest monitoring data – does an increase in the number of pests recorded relate to changes in the pest population or to changes in the monitoring technique? Conversely, how is it possible to measure the success of a pest management programme if presentation of the monitoring data – one of the crucial elements of any evaluation – is biased in such a dramatic way by the monitoring programme methodology? One answer is to collate and present information in addition to the numbers of pest occurrences, such as numbers of pest monitors, numbers of rooms monitored, floor area monitored, historic numbers of pests over time and types of collections or materials affected. Commercially available software commonly used for pest data analysis, such as ZPEST or KEMU, whilst offering an off-the-shelf data recording, analysis and visualisation tool, do not account for the number of monitors in a given space, or the size of the space monitored. Consequently, the options for meaningful data analysis are limited, and the resulting graphs are not helpful in addressing the needs of target audiences, as outlined by Henderson et al. (2019). The initiative to create a national repository for pest monitoring data via the website 'What's Eating Your Collection' is an incredibly positive step in sharing and responding to data on pest activity, but the lack of data fields in this database limits the scope for exploring these data and eliminating any biases such as the one demonstrated above.

Pest Occurrence Index POI

An alternative approach to analysing pest monitoring data was developed and tested successfully at NMC. The Pest Occurrence Index (POI) integrates the number of individual pest counts with the number of monitors deployed and the area monitored in square meters. This requires the collection of a small amount of additional data during pest monitoring than was previously the case. To facilitate this, the existing Microsoft Excel data recording sheets are augmented by adding one column for the number of monitors per room, a second column for the size in square meters of the room, and a third column for the calculation of POI (Table 2).

Table 2: The minimum data fields required in a pest monitoring record data table include the number of monitors per room and the room size. Insert as many columns under ‘F’ (pest species) as relevant to the property.

A	**B**	**C**	**D**	**E**	**F1**	**F2**	**F3**	**G**
Room name and/or number	Date checked (previously)	Date of current inspection	Number of monitors	Room size [m^2]	Pest species 1	Pest species 2	Pest species 3	POI: pests per monitor per m^2

The resultant Pest Occurrence Index POI (Figure 2) with the unit [pests $trap^{-1}$ $meter^{-2}$] is comparable across rooms, collections, buildings, organisations and time. Using the same data as in the example above, closer analysis of the POI at NMC (all data for the entire building) over time illustrated a rapid decline in pest numbers between 2014 and 2016 due to successful introduction of a comprehensive IPM programme in the building. The increase in POI from 2017 is explained by the fact that at NMC the IPM programme was, from 2017, extended beyond collection areas. The extension of monitoring to kitchens and offices revealed a greater pest density in those spaces, resulting in an overall increased POI for the building. Introduction of the POI enables comparisons between collection and non-collection areas – the latter, such as kitchens, offices and corridors, may have considerably larger pest problems than those spaces where collections are stored (see also Figure 4). The POI also reveals that pest counts were generally slightly higher during the summer months (autumn data) compared to the winter months (spring data).

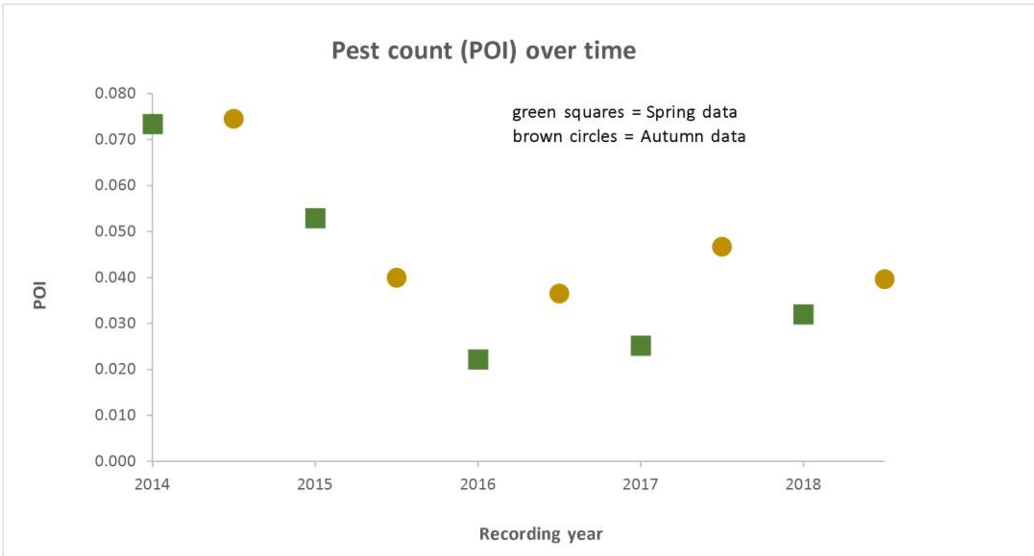

Figure 2: The same data as used in Figure 1 were here calculated and represented as POI.

The greatest benefit of a coherent index of pest occurrence is that it allows easy analysis and communication of a pest problem. These findings helped shift the emphasis of the IPM strategy towards training and awareness-raising for all museum staff to share in pest management in every space within the museum.

Calculating the Pest Occurrence Index (POI)

The POI (column 'G' in table 2) is calculated by initially computing the sum of the numbers of all pest species in each row (all 'F' fields for the same row):

Equation 1: $$pests_{sum} = \sum_{i=1}^{n} F_i$$

The resultant sum '$pests_{sum}$' is then divided by the number of monitors per room (column D) and the size of the room (column E):

Equation 2: $$POI = \frac{pests_{sum}}{D \times E}$$

F = number of occurrences recorded for each pest species,

D = number of monitors in this room,

E = the room size in m^2.

The resultant POI is a rational number expressed as a decimal. It is widely known that many people have considerable difficulties with numbers expressed as decimals (Hiebert and Wearne 1986, Putt 1995, Lortie-Forgues et al. 2015). Because our emphasis is on communication in an easily understandable format to broad types of audiences who do not necessarily have specific mathematical expertise, the result of equation 2 is multiplied by a factor of 1000 to create a natural number for POI (POI_n).

Equation 3: $$POI_n = POI \times 1000$$

The decision to introduce a factor is therefore communication-led with the intention of decreasing natural number bias.

Figure 3: Calculation of the Pest Occurrence Index.

One advantage of calculating POI as explained in figure 3 is that no specialist software is required – a spreadsheet may be set up using widely available software such as Microsoft Excel. A template spreadsheet is available on the National Museum Wales website under the document title 'Pest Record Datasheets NMC Template' (permalink: https://museum.wales/media/45874/Pest-Record-Datasheets-NMC-Template-2018.xlsx; see also Table 3). This template contains one workbook with several sheets: a licence agreement, notes and instructions on use of the spreadsheet, a summary data table with conditional formatting and template visualisation that is populated automatically as data are entered into the data sheets, and a number of data sheets. Each sheet represents a different collection area; formulae are already inserted into the relevant fields. The data tables in each sheet may be expanded by the user by inserting additional rows, for example, more rooms, and columns, for example, more insect species, and then copying and pasting the relevant formulae. Advice on how to adapt the template is given on the first sheet of the template file.

Table 3: Screenshot of one of the data entry sheets in the 'Pest Record Datasheets NMC Template'. The final column contains the POI formula; once the sheet is populated with data, the POI fields will update automatically.

Collection Area A																											
								Dermestidae					Lepidoptera				Anobiidae				Tenebrionids	Silverfish	Psocids	Isopods			
								Anthrenus verbasci	Anthrenus fuscus	Anthrenus larva	Reesa vespulae	Reesa larva	Tineola bisselliella	Clothes Moth larva	Tinea pellionella	Case-bearing Clothes	Anobium punctatum	Stegobium paniceum	Lasioderma serricorne	Frass (1 = yes)	Fungus/plaster beetles	Lepisma saccharina	Liposcelis bostrychophila	Woodlice			
Row Number	Room Number	Floor level	Room Name	Date checked (previous)	Date of inspection	No. of traps	Room size [m2]	Varied Carpet Beetle	Dark Carpet Beetle	Woolly Bear	Museum Nuisance Beetle	Woolly Bear	Webbing Clothes Moth	Clothes Moth larva	Case-bearing Clothes Moth	Case-bearing Clothes Moth larva	Furniture Beetle	Biscuit Beetle	Tobacco Beetle	Frass (1 = yes)	Adostemia watsoni	Silverfish	Booklice	Woodlice	Other	Total pests per room	Pests per trap per m2
1																										0	#DIV/0!
2																										0	#DIV/0!
3																										0	#DIV/0!
4																										0	#DIV/0!
5																										0	#DIV/0!
	Mean					0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	#DIV/0!
																										0	

The datasheet may be adapted to account only for those pests that are most relevant to a particular collection. This means that indicator species (for example those indicating high relative humidity) are recorded as part of routine pest monitoring but not counted in the analysis of pest occurrences unless they also present a specific risk in that context. For example, in libraries, silverfish are counted as a museum pest but in an inorganic archaeological collection would be regarded as an environmental indicator and are therefore not added to the number of pests. Previous forms of representing the risk to a collection included pie charts showing the proportions of all insect species recorded, the interpretation of which in relation to particular collections assumed the recipient had relevant expertise to decide which of the species constituted a risk to the collection. The practice of only including species posing an actual risk facilitates easier data interpretation by the recipient and assumes no prior knowledge which, in the case of many non-curatorial and non-conservation staff, is frequently the case.

Data Communication

The recently (2014) implemented IPM programme at NMC presented an opportunity to experiment with novel forms of graphical data visualisation, as suggested by Henderson et al. (2017), and undertake some basic user testing to assess the most effective way of establishing awareness amongst museum staff. Two goals were set: firstly, to achieve staff behavioural changes that would result in improved cleanliness, and secondly, to provide managerial authority to support the IPM coordinator's recommendations (cf. Henderson et al.; 2019). Museum staff were presented with the same data from pest monitoring at NMC visualised in two different graphs: as a bar chart and bubble chart. Feedback from these informal discussions with colleagues suggested that bar graphs were preferred by those with higher levels of technical knowledge and engagement in the topic.

Appropriate messages for different audiences

Figure 4 shows an early output of experiments with different visual representations of pest data that attempted to represent pest counts in different parts of the building for one monitoring event. This graph was distributed around the building in staff rooms and kitchens for general staff information and used in internal IPM training sessions.

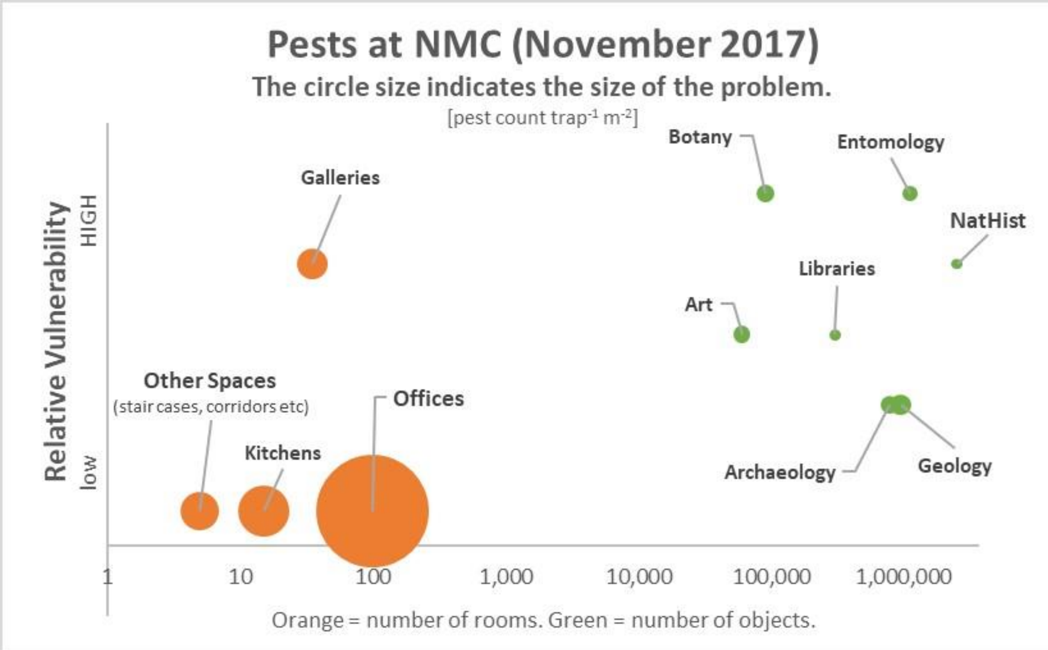

Figure 4: Early graphical output capturing a lot of data but aimed at more than one audience.

This 'all things to all people' approach was revised subsequently based on a consideration of the goals of IPM in context. Whilst the graph captures a great deal of information, it does not target the information at specific user needs. Subsequent user testing at NMC demonstrated that at least three different groups of users of pest monitoring reports exist:

1. Users with little prior awareness of pest management. The communication goal here is to raise awareness of the scale and general consequence of pest infestation and provide issue relevant information about actions they can take.
2. Informed users: those who care for vulnerable collections and have experience of pest management.
3. Decision makers responsible for allocating resources.

The goal for group 1 users is to encourage behaviour change, especially in non-collection areas where awareness is lowest. The main concern of group 2 users is for the collection they are responsible for. This group of well-resourced specialists welcome tailored and detailed information, which is targeted to their specific needs and concerns; some of this group may welcome bar graphs due to their familiarity with the IPM literature. The continued support for IPM from managers is the goal from communication with group 3 users whose backing during a period when finding more pests, as outlined above under 'Calculating the POI', actually reflects an improvement in practice requires a technical understanding of the data collection process. This message may include the request for support to extend the pest monitoring programme beyond the 'traditionally' monitored collections areas, and for additional resources to implement and sustain increased monitoring and associated data analysis.

For group 1, the goal is to achieve a behavioural change rather than give detailed information and Figure 5 is the response to this challenge. By identifying where the greatest density of pests exists, it focuses attention on the perhaps surprising core of the current pest problem (non-collection areas) and motivates staff to act to contribute to pest management through their own practice by maintaining a clean workplace. This message is appropriate for all users but as Figure 5 communicates a simple message quickly and intuitively, it particularly satisfies the needs of group 1, explaining that pest management is everyone's concern and that staff behaviour in non-collection spaces forms an important contribution to IPM. The use of infographics maximises the audience who can comprehend the message. The use of pest symbols contributes to focussing attention and reinforces that this is an institutionally authorised message.

Figure 5: Use of symbols focuses attention at a single glance on areas affected by pest occurrences, based on data generated by calculating POI.

Traffic lights

Going beyond the location of threats, group 3 users need to understand where to invest institutional resources in pest management activities. A traffic light system was experimented with to graphically represent the point beyond which an occurrence becomes an infestation. This requires the evidence-based determination of risk thresholds. Conducting a full loss in value calculation takes considerable time and has not yet been completed, hence for the purposes of this current paper a simple arbitrary and subjective scale was used. The assumption is that occurrences below a threshold of 0.039x1000 pest counts $trap^{-1}$ m^{-2} were 'safe' (green), between 0.04 x 1000 and 0.099 x 1000 counts $trap^{-1}$ m^{-2} critical (amber), and above 0.1 x 1000 counts $trap^{-1}$ m^{-2} 'in danger' (red). Initial tests on traffic light representation of risk (Figure 6) suggest that many users accepted the conservator's presentation of risk without questioning threshold levels. The underlying mechanism for such a decision-making process is heuristic – the process generally dominant over an analytic-deliberative approach. Henderson and Waller (2016) explored how decision making by conservators may be improved by respecting the power and importance of heuristic processes in establishing judgments and communicating effectively with higher level decision makers. In the context of pest monitoring data presentation this would mean to carefully consider the data, the intended message and the target audience when designing a visualisation. Knowledge of the psychological effect of such colour schemes therefore offers an opportunity to use colours to highlight certain messages within a graphic that may guide decision-making.

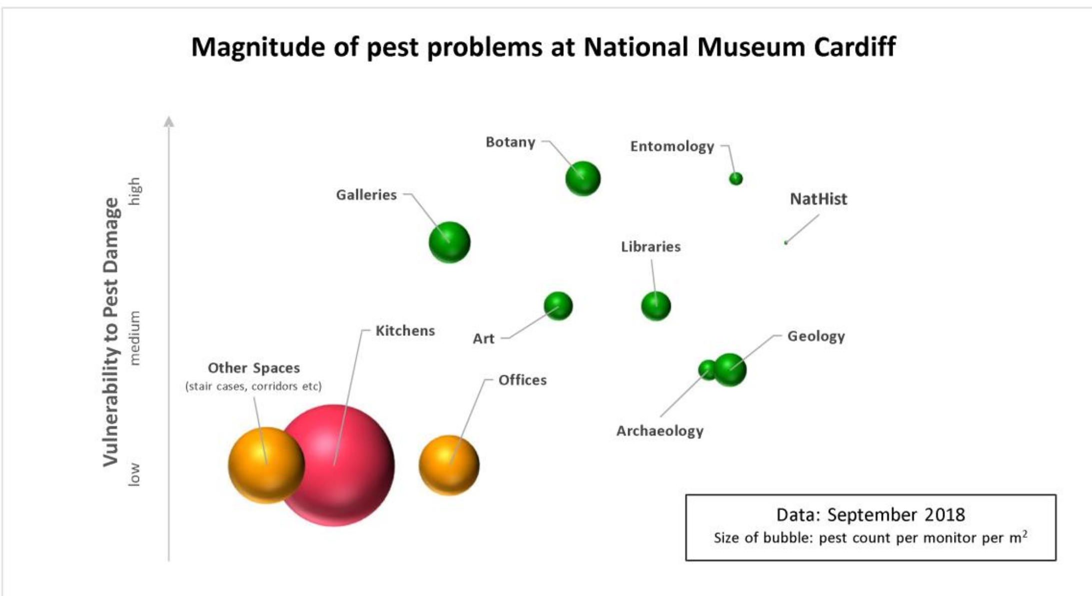

Figure 6: Similar data as Figure 3 (but for 2018) represented as a more comprehensive message for managers.

Achieving managerial support for the IPM coordinator's recommendations

Different users demand different levels of data analysis and presentation. For most users, the use of a traffic light scale created an immediate effect generating an impression of urgency requiring an immediate response and significant resources to address the underlying problem – this marks the transition from the information seeking stage to the discrimination stage (cf. Henderson et al., 2019). On the other hand, group 3 users with access to the additional information about collection vulnerability from the bubble chart (Figure 6) correctly and quickly identified the location of the largest pest problem as being in kitchens. These colleagues understood that while not ideal, the high occurrence in non-collection parts of the building did not necessarily constitute a direct risk to collections. User perception clearly plays a role in the interpretation of these visualisations (cf. Henderson and Rumsey, 2015).

Conclusions

IPM has been implemented holistically at NMC since 2014, including building maintenance with the aim of excluding pests, improved housekeeping in stores and galleries, updated guidance to staff, comprehensive pest monitoring, object quarantine and treatment, and staff training. The application of pest management zones is currently being planned. Starting in early 2018, visualisations of pest monitoring data have been publicised routinely around the building – for example, in staff kitchens – and used as part of staff pest awareness training. The successes achieved by the introduction of IPM are demonstrated by a reduction in the numbers of pests in collections areas during the first two years of the IPM programme. More recently, attention has shifted towards achieving the same results in non-collection areas, which is expected to be more challenging. To assist behavioural changes, new ways of communication were developed at NMC in partnership with Cardiff University. This required the development of a measure of pest activity that allows comparison of areas with different uses across a large and complex building: the Pest Occurrence Index (POI) which integrates pest counts as well as the numbers of monitors deployed and the size of rooms monitored. This index provides data that are comparable across rooms of different sizes, different collections, different areas of use within a building and even across buildings and institutions. Collecting data on pest occurrences is a time-consuming task, which needs to be justified to museum management. If pest monitoring data are collected, they ought to be analysed appropriately to be of any valid use. POI can be used as a real and objective measure of the success of pest management efforts, and visualisations based on POI may be used to engage staff in new ways. There is no one-size-fits-all solution for this type of communication; instead, reports with specific messages need to be tailored to definite target audiences.

Acknowledgements

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