Integrated pest management: from monitoring to control

Christian Baars and Jane Henderson

ABSTRACT The purposes of pest monitoring are (1) quality control of a pest management programme and (2) communication of pest occurrence information to different user groups. Good pest monitoring practice requires unbiased data analysis and interpretation which, in turn, relies on data being collected in a consistent manner. The Pest Occurrence Index (POI) was developed to open up a discussion on the managerial, psychological, analytical and communication practices that are in danger of being overlooked when the focus of pest management is the counting of insects. This paper offers an overview of the development of the POI in integrated pest management (IPM) in the cultural heritage sector, considers progress to date and examines two major updates: that pest monitoring data are sensitive to the frequency of monitor inspection; and how to integrate into systematic pest monitoring any incidental encounters of pests not collected on monitors but found randomly. Clear parallels between pest monitoring in cultural heritage properties and population studies in ecology demonstrate that effective and unbiased analysis of results requires standardised monitoring approaches and data collection.

KEYWORDS IPM; museum; pest monitoring; data analysis; pest occurrence index; communication

Introduction

Integrated pest management (IPM) is an umbrella term for a wide range of activities to protect museum or cultural heritage collections against pest infestation. Despite the clarity with which IPM is described, we have experienced some practitioners conflating monitoring with management. Within preventive conservation, it is not unusual for data collection to become the end point of environmental management practice (Henderson 2018). In IPM practice and literature there appears to be a focus on pest identification and counting (Henderson et al. 2017). Unfortunately, the familiarity of data collection can mask a lack of efficacy in pest management because monitoring alone will neither manage a population of insect pests to safe levels nor necessarily lead to any changes in practice.

Data collection without analysis, interpretation and presentation omits the critical stages necessary for reflective scrutiny of the success of pest management. Conservators seeking support for pest management from managers and colleagues should attend to the creation of appropriate messages for distinct audiences. Effective messages are better characterised by their ability to satisfy the needs and interests of their audience than to represent the expertise of those offering the message (Henderson et al. 2017). Many IPM questions identify dynamic challenges, such as the spread of an established pest within a collection over time or climate change-induced distribution patterns, but data are not always comparable across rooms, collections or buildings, leading to problems with data management and interpretation.
Principles of population monitoring

Monitoring pest populations over time yields important information for decision-making with regard to protective measures which may be costly and inconvenient, hence the quality of the information on the population density is of primary importance (Petrovskii et al. 2011). Most insect monitoring methods are subject to biases impacted by a variety of factors (see McCravy 2018). In our experience, there is some evidence that blunder monitors tend to over-represent large-bodied species; for example, psocids are frequently too small to climb onto the card. We can learn much about population monitoring from ecology, where the fraction of sampling units in a landscape in which a target species is present is an extensively used concept. Detection probabilities are affected by the size of the sample area (Anderson and Marcus 1993), the number of monitor days (i.e. the number of monitors multiplied by the number of days sampled) (see McComb et al. 2010), potential food sources and habitat. Capture probabilities must be considered to allow an unbiased estimate of relative abundance (Menkens and Anderson 1988). This is particularly important when assessing trends over time during circumstances when conditions affecting detection probability vary from year to year.

Influence and communication

A review of IPM practice at National Museum Cardiff concluded that work was needed to present data in a way which considered the needs of the audience receiving the information. Henderson et al. (2017) suggested the use of novel dynamic, visually attractive and meaningful graphical data representations to achieve improvements in communication. Additional work described the process undertaken to categorise and support a range of receiver needs and abilities prior to communicating a pest monitoring message (Henderson et al. 2020). In striving to organise and represent data which changed the mode of communication, the authors identified much of current data quality and data analysis were not fit for purpose. One flaw undermining our data representation was the impact of the changing density of pest monitors on the number of insects identified. Fluctuations in the number of pest monitors are common to many IPM programmes, highlighting a need for a consistent approach to analysing pest monitoring data which would remove variability.

The introduction of the Pest Occurrence Index

A novel approach to analysing pest monitoring data by way of calculating an index was developed and tested successfully at National Museum Cardiff. The Pest Occurrence Index (POI) is a measure of pest activity which integrates the number of individual pest counts with the number of monitors deployed and the area of each room monitored, decreasing unintentional bias introduced by previously used analytical techniques (Baars and Henderson 2020). This abundance index provides data that can be used to compare populations in different places or times.

Calculation of the POI requires that contextual information – such as type of collection affected, room size and number of pest monitors deployed – must be reported to enable meaningful data interpretation (the development of the POI is described more fully in Baars and Henderson 2020). Application of the POI results in data interpretation which more closely reflects actual trends in pest populations, rather than artefacts of monitoring methodology. The result of the POI calculation is a rational number expressed as a decimal. Due to the widely prevalent natural number bias (Lortie-Forgues et al. 2015), Baars and Henderson (2020) suggested including a factor to create a natural number POI (POIn) with the intention of aiding communication.

The POI represents a paradigm shift in the reporting of pest management and has been adopted by the start-up environmental monitoring and management company Conserv as the basis for analysing pest occurrences. As part of Conserv’s free integrated pest management software, Conserv Cloud, the POI has reached hundreds of collections care professionals since its launch in April 2021.¹
Calculating the Pest Occurrence Index (POI)

The POI is calculated by initially computing the sum of the numbers of occurrences for all pest species observed on pest monitors:

Equation 1: \( \text{POI}_{\text{sum}} = \sum_{i=1}^{n} F_i \)

\( F \) = number of occurrences recorded for each pest species,
\( i \) = index of summation,
\( n \) = the upper bound of summation (read as ‘sum of \( F_i \) from \( i = 1 \) to \( n \)’, meaning: add up the number of all recorded occurrences from the first to the \( n \)th).

The sum ‘\( \text{POI}_{\text{sum}} \)’ is then divided by the number of monitors per room, the size of the room, and the length of time the monitors were exposed between pest checks:

Equation 2: \( \text{POI} = \frac{\text{POI}_{\text{sum}}}{D \times E \times t} \)

\( D \) = number of monitors in this room,
\( E \) = the room size in \( m^2 \),
\( t \) = the length of time (in days) of exposure of the monitors in this room between pest checks.

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, for example, 1000 to create a natural number for POI (\( \text{POI}_n \)).

Equation 3: \( \text{POI}_n = \text{POI} \times 1000 \)

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

POI 2.0: making time a factor

Detection probabilities are affected by the number of monitor days (i.e. the number of monitors \( \times \) the number of days sampled) (McComb et al. 2010), so the time elapsed between successive observations should remain constant (Engeman 2005). In cultural heritage institutions this is difficult to achieve as the interval between monitor checks is rarely exactly the same number of days. Different institutions inspect their monitors on different time scales, hence data between collections, buildings and institutions are not necessarily comparable. This lack of standardisation presents a challenge for the assessment of regional or national trends which require the aggregation of data from different institutions.

A pragmatic solution to avoid detection probabilities being affected by the number of monitor days is to integrate time as a factor into the POI calculation. This can be achieved by the inclusion of time (in days) in the POI formula and has the effect of standardising detection time in addition to the already existing spatial factors.

Incidental encounter data

Once the application of the POI was scaled up, questions about its use began to arise. ‘One thing we heard repeatedly from potential users was that they also wanted to be able to record pest sightings and counts directly in spaces. Say, for example, a windowsill, or other place in a space where pests are seen that are not places where monitors have been put down. How would you include pest counts taken in a space, but not in a monitor, in the POI calculation?’

While the identification and retrieval of any insect pest in a cultural heritage collection setting provides reliable evidence of presence, randomly encountered insect finds are very difficult to integrate into any systematic pest analysis and provide little value for
trend analysis. If a volunteer reported finding three larval casings near a window in the store one week but it was unknown whether they were there the previous week, we could not use this information to determine population trends. There are three possible responses to these data.

1. Ignore any data not originating from pest monitors

Data from incidental observations constitute a sampling methodology that differs from that of the use of blunder monitors: the former is a type of active visual survey, the latter is passive sampling. In any systematic monitoring programme, monitoring methods should not be mixed. Montgomery et al. (2021) provided simple guidelines for maximising return on insect benchmarking data with a recommendation that the locations of visual surveys remain fixed to enable surveys to be compared from year to year, but in most museum environments incidental observations remain one-off observations. This means that the same location is very unlikely to be surveyed repeatedly, thereby introducing variation and inconsistencies into the monitoring programme that may result in data becoming skewed, leading to either under- or overestimation of the level of pest activity.

We acknowledge that it is psychologically counterproductive to treat incidental encounters as irrelevant because IPM managers have worked hard to encourage colleagues to engage with pest management and inform them of any insect finds, not least through the ubiquitous and popular English Heritage pest posters (English Heritage 2021). But for the purposes of data analysis, incidental finds should be omitted from datasets.

2. Treat incidental observation as a separate report

By creating a separate entry on the monitoring spreadsheet for random finds it would be easy to integrate these data into the calculation of the POI. In this scenario, all finds would be accounted for and reported. This is likely to be a psychologically satisfactory method as it appears to respect diligence and completeness for those reporting the data, ensuring that everyone who has participated in reporting feels validated. In mathematical terms however, these data remain questionable because just as the number of pests found in a space sometimes correlate to the number of pest monitors (Baars and Henderson 2020), the number of random finds may correspond with certain factors, such as the presence of engaged and observant staff. Such a measure may be a better indicator of the impact of IPM training rather than the threat from insect pests to the collection. If pest monitoring aims to monitor trends, the approach of integrating random finds into the POI calculation would undermine the quality of the results.

3. Use incidental observations as a gateway for additional IPM decision-making

The two approaches above indicate the joint criteria of the need for consistent data collection and the necessity to maintain the enthusiasm of stakeholders in the monitoring process. The third solution offered here aims to satisfy both needs by identifying a series of decisions triggered by random reports but not including the finds in the POI. This may be developed into a flowchart based on the location, scale and identity of pests found, but requires testing in practice. For now, it is sufficient to identify a series of questions to be addressed if random finds have been entered into a database. The trigger questions may include the following:

- Does this find represent a threat to your collection?
- Is there anyone who should be notified (for example, the owners of loan objects)?
- Is there an immediate quarantine or housekeeping need?
- Is a pattern emerging for the species, location or season – or can the data be used to establish a pattern?
- Are you monitoring in the right number of places within that space?
- Should the location of the find become a permanent monitoring point?
Is it likely that this problem has gone undetected for some time and if so, is there a need for a strategic response such as training or a review of staff responsibilities?

**Summary and outlook**

The purposes of pest monitoring are quality control of a pest management programme and communication of pest occurrence information to different user groups. This requires unbiased data analysis and interpretation which, in turn, relies on data being collected in a consistent manner. There is currently still a bottleneck for insect monitoring in getting from the insects on the monitor to accessible data. We need to build tools for the efficient capture of all data and metadata associated with observations (Montgomery et al. 2021). The POI was proposed as a tool to achieve this. Our focus has been on standardised data collection and effective communication. This latest work considers that the length of time between pest checks, in addition to the density of pest monitors, affects the conclusions drawn from monitoring data. We also addressed the issue of incidental pest encounters, and how to integrate them usefully into a systematic pest monitoring programme. The POI is now a valuable tool for intra- and inter-institutional comparisons based on robust and consistent data such as, for example, for the assessment of emerging threats in the context of climate change-induced distribution patterns. If adopted widely, the cultural heritage sector will create greater opportunities to collaborate, communicate and act upon their hard- won pest data.

**Notes**

1. A. Senseman, Conserv, personal communication 2021.
2. N. McMinn, Conserv, personal communication 2021.

**References**


**Authors’ addresses**

▷ Christian Baars, National Museums Liverpool, UK (Christian.Baars@liverpoolmuseums.org.uk)

▷ Jane Henderson, Cardiff University, Wales, UK (HendersonLJ@cardiff.ac.uk)