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Honey bee surveillance: a tool for understanding and improving honey bee health

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Honey bee surveillance systems are increasingly used to characterize honey bee health and disease burdens of bees in different regions and/or over time. In addition to quantifying disease prevalence, surveillance systems can identify risk factors associated with colony morbidity and mortality. Surveillance systems are often observational, and prove particularly useful when searching for risk factors in real world complex systems. We review recent examples of surveillance systems with particular emphasis on how these efforts have helped increase our understanding of honey bee health.

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Surveillance in honey bees

'Observation sets the problem; experiment solves it'
Jean-Henri Fabre, (1823–1915)

Surveillance is an observation-based method of quantifying levels of 'disease' in a population. At their core, surveillance efforts quantify disease prevalence and incidence over space and time, which can help identify risk factors that contribute to disease incidence when coupled with other data. Data from surveillance efforts can identify or confirm risk factors that predict disease outcomes, and can guide the development of experimental approaches to demonstrate causation. Further, identification of risk factors can inform disease mitigation practices that can improve health at the population level [1,2••].

Health and/or disease surveillance systems exist for most human and production animal health programs. When implemented sustainably, they help mitigate and prevent important diseases in populations. Considering the importance of honey bees (*Apis mellifera*) for pollination of agricultural crops [3,2••,4,5], it is not surprising that many surveys have quantified health and disease burdens. Surveillance of non-apis species also exists, but is less developed compared to honey bees (Box 1). Surveillance system design is dictated by many factors, most importantly by the objectives of the study and availability of resources (Figure 1). Here we review examples of honey bee surveillance efforts, emphasizing their contribution toward understanding and improving honey bee health (summarized in Table 1).

Detection, characterization, quantification of disease

Monitoring is a regular, repetitive and intermittent series of measurements designed to detect changes in the health status of a defined population (see Table 1 for examples). Apiary inspections are an example of monitoring as they have long been used to estimate disease in managed honey bee populations. These inspections quantify disease prevalence and range by sampling a number of 'analytic units' (individual bees, colonies, apiaries, or operations [1]) over a defined period of time and population. Traditionally, apiary surveillance was used to identify disease outbreaks in order to enforce regulations aimed at eliminating or containing disease spread. This approach is largely credited for reducing the incidence of the bacterial disease American foulbrood (*Paenibacillus larvae*) in the US [2••]. More recently, disease surveys have expanded to include early detection of non-extant (or recently introduced) disease threats such as *Tropilaelaps clareae* mites in the US [6,7], small hive beetles (*Aethina tumida*) in Europe [8••], or *Varroa destructor* mites (*Varroa*) in Australia [9]. Determination of disease free status for particular pests has implications for trade of bees and bee products [7]. Early detection of a new organism can permit containment efforts, such as the Australian effort to contain *Apis cerana* [10]. The utility of surveillance efforts in epidemiologic studies is dependent on numerous factors, including how samples are

Box 1 Non-apis bee surveillance

Non-apis bee species are major contributors to agricultural and natural pollination systems [4,57–59]. These species are largely unmanaged and have multiple different life histories, thus requiring specialized surveillance techniques.

Recently there have been several efforts to standardize survey effort approaches that document the abundance and diversity of non-apis species [60]. Application of standardized collection methods allows for ecological network analyses to help quantify the structure of bee-plant networks in various landscapes [61–64]. When standardization is not possible (such as in the case of comparing changes in abundance and diversity over time by using historical collections), statistical analyses can help elucidate important drivers of changing populations, including changes in agricultural policy and practice [65], ecological succession [66], landscape [67] and climate change [68].

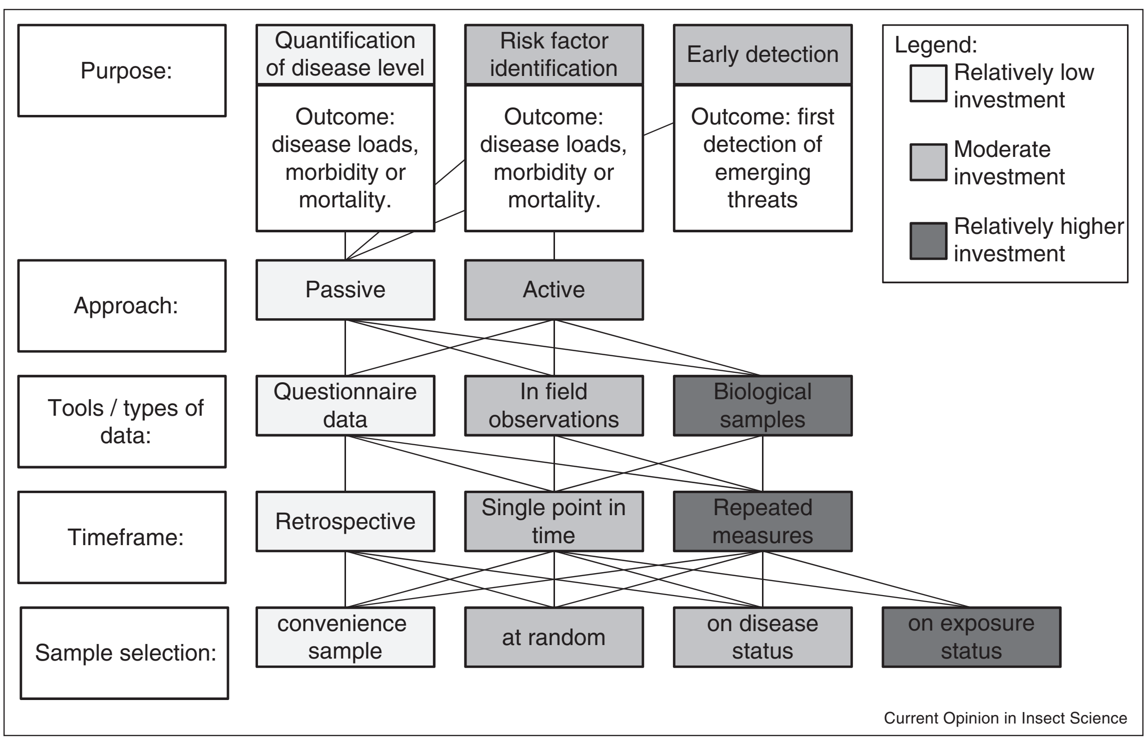
Surveys of non-apis bee populations have been conducted to identify disease loads in populations [69–72], although generally these studies have concentrated on possible disease spillover from honey bees. Further surveillance on non-apis bees and their diseases is much needed.

selected, number of analytic units sampled, specificity of the diagnostic test, and sample collection methodologies [2••]; all of which are constrained by the pragmatic reality of limited resources.

A notable monitoring program quantified disease load and colony mortality by inspecting randomly selected apiaries in 17 different European countries [8••]. By randomly selecting colonies and implementing a standardized inspection approach, the resulting data avoided selection biases inherent with many survey efforts. The ability to randomly select colonies from a known population is a central tenant of good survey design, but in practice is problematic as random sampling requires a near-complete description and access to the honey bee population, which is often difficult to attain or create.

Modified apiary inspections can be used to perform more directed surveillance for the discovery and characteriza-

Figure 1



Describes different approaches to honey bee surveillance and the corresponding relative degree of investment (time and monetary). *Purpose*: objective of the surveillance program. *Outcome*: measure of health under surveillance. *Passive*: approach: no intervention imposed on the regular management of the colonies under surveillance. *Active*: approach: implicates manipulation of the conditions experienced by (at least part of) the colonies under surveillance. *Questionnaire data*: interview or self-reported recollection from the stakeholder. *In field observations*: the overt symptoms expressed in the colonies under surveillance. *Biological samples*: clinical diagnostics from a physical sample collected from colonies under surveillance. *Retrospective*: collection of data regards exclusively past events. *Single point in time*: cross-sectional design where the collection of data (exposures and outcomes) are made at the same unique point in time. *Repeated measures*: the same colonies under surveillance are assessed repeatedly through time. *Convenience sample*: sample from the target population is only determined by the availability and willingness of the stakeholders. *At random*: selection of the sample from the target population is completely randomized, meaning all individuals from the target population have the same probability of being sampled. *Selection on disease status*: case–control studies comparing individuals classified as 'diseased' versus individuals classified as 'disease-free' for the disease of interest. *Selection on exposure status*: cohort studies comparing individuals classified as 'exposed' to individuals classified as 'non-exposed' for the risk factor of interest.