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Protocols

Collecting and Monitoring for Northern Fowl Mite (Acari: Macronyssidae) and Poultry Red Mite (Acari: Dermanyssidae) in Poultry Systems

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Abstract

The two most economically important poultry ectoparasites are the northern fowl mite, *Ornithonyssus sylviarum* (Canestrini and Fanzago), and the poultry red mite, *Dermanyssus gallinae* (De Geer). Both mites are obligate blood feeders but differ in where they reside. Sampling methods thus focus on-host, especially the vent feathers, for northern fowl mite and off-host, especially cracks and crevices near the nighttime roosting areas, for poultry red mite. Much remains unknown, however, about the basic biology and ecology of both mites. Here we discuss mite detection, quantification, and decision making and provide thoughts on future directions for research.

Key words: northern fowl mite, poultry red mite, integrated pest management, laying hen, monitoring

The northern fowl mite, *Ornithonyssus sylviarum* (Canestrini and Fanzago), is a widespread key poultry pest that is particularly important for commercial poultry in the United States (Axtell and Arends 1990). Its biology is recently reviewed by Murillo and Mullens (2017). These mites are obligate blood feeders that spend most of their time on-host. Northern fowl mite is a wild bird parasite, found on over 70 species of birds (Knee and Proctor 2007). Mites may be introduced to farms via wild birds, but once on a property they tend to persist on the facility and on poultry long-term (see McCulloch et al. 2020). Mites are readily spread among flocks by rodents, equipment, and people (Kells and Surgeoner 1996). Northern fowl mite protonymphs and adults require a host bloodmeal to develop and reproduce; the entire life cycle can be completed in as few as 5–12 d (Sikes and Chamberlain 1954). While off-host survival usually is less than 1–2 wk, northern fowl mite can survive off-host without a bloodmeal for up to 4 wk under favorable conditions (Chen and Mullens 2008). High mite infestations cause economic damage including decreased egg production and decreased feed conversion efficiency (Mullens et al. 2009, Murillo et al. 2016).

Dermanyssus gallinae (De Geer), generally called the poultry red mite or chicken mite, is regarded as the most important ectoparasite of poultry in many parts of the world, and its biology is reviewed by Sparagano et al. (2014). Prevalence in Europe is estimated at around 90% of layer facilities (Flocklay et al. 2017). Like northern fowl mite, it can be found utilizing a number of wild bird species and may be found at least temporarily (i.e., phoretic) on mammals (George et al. 2015). The poultry red mite resides off-host in the environment of the birds, especially in small cracks or crevices near the perching areas where the birds sleep at night (Sparagano et al. 2014). At typical poultry house temperatures, this mite has a generation interval of 1–2 wk and leaves the hiding areas to feed briefly at night on blood every 2–4 d.

Poultry red mite is durable in the environment, particularly the protonymph stage (Nordenfors et al. 1999). At temperatures of 25°C, most starved adult mites die within 2–3 wk and most protonymphs die within 4–5 wk. However, at cooler temperatures and higher humidity, maximum survival of protonymphs can be over 5 mo in the absence of hosts for blood feeding.

Despite the need for mite management, much remains unknown about the basic biology and ecology of these two species. For practical and research reasons, the ability to detect and quantify poultry mites is important. Here we describe different methods to achieve these goals, and further discuss the decision-making process for mite management.

Mite Identification and Detection

The first and arguably most important metric for northern fowl mite and poultry red mite is its presence or absence on a poultry facility. It is critical that any mites found in a poultry facility be properly identified. The location of poultry mites (on-host or off-host) is a good initial indicator of the species, but it is always best to confirm the species. Northern fowl mite can be easily confused with the tropical fowl mite, *Ornithonyssus bursa* (Berlese), a potentially severe poultry pest in tropical regions, which is inseparable from northern fowl mite by eye. Being on the host greatly increases the probability that mites from a chicken are parasitic, although that is not a guarantee. Identification of mites in the general habitat is

particularly critical. Poultry red mite may be easily confused with harmless free-living mites feeding on things like fungi or organic debris or even beneficially serving as predators of poultry red mite.

Mites must be properly slide mounted and chemically cleared before the diagnostic characters are visible. Preparation and identification of mites does require some specialized training and equipment (Krantz and Walter 2009). The characters separating northern fowl mite and poultry red mite are detailed in Murillo and Mullens (2017).

Northern fowl mite detection is made easier by the fact that the mites are primarily on-host in a specific body region. Although mites can be found widely on the body, especially at high densities (Lemke et al. 1988), the vent region is strongly preferred. The vent area can be quickly examined for the presence or absence of mites (Fig. 1). Mites themselves may be seen crawling on the skin surface or on the feathers, but heavy soiling (caused by eggs, cast skins, and feces) is also indicative of a northern fowl mite infestation. Initial mite outbreaks in a new flock typically are very localized at first, then spread from the focal infestation locations to infest essentially all birds in the flock over a period of a few weeks (Mullens et al. 2009). Depending on the flock size, it would be ideal to check all birds biweekly to catch an early infestation, since early treatment is far more effective. However, this is not practical advice for most chicken flocks, especially large commercial operations. In a mixed-sex flock, roosters should be examined at a 2:1 ratio to hens, as males will harbor higher mite populations (Axtell and Arends 1990).

Several different sampling methods have been proposed for northern fowl mite over the years. In general, regular monitoring is best in order to detect northern fowl mite early. Axtell and Arends (1990) recommended a fixed sampling schedule where some birds in all flocks were examined weekly or biweekly. Rutz (1981) suggested 0.1–0.2% of birds in a flock be examined, though this became impractical as poultry farms grew to house hundreds of thousands of birds. Hall (1979) recommended the use of sentinel birds within a flock. Harris et al. (2000) developed a presence/absence sequential sampling method, which suggested that, with a treatment decision as the goal, as few as 18 birds in a single flock could be examined for northern fowl mite detection. However, if detection of low-level infestation is a high priority, especially given the focal nature of incipient infestations, the actual minimum number of birds that need to be checked to be confident that northern fowl mite are not present might be substantially higher. For caged birds (traditional or enriched cages), automatic feed delivery, egg collection belts, or manure belts probably tend to spread mites within a row (Harris et al. 2000). Recognizing this, it might be especially desirable to check some birds in every row (stratified sampling). Mullens et al. (2000) tested the sequential sampling, sentinel hen sampling, and 'mites on eggs' (described below) methods on a large commercial caged laying-hen operation. They used three trained observers to detect and quantify northern fowl mite infestations of individual live chickens visually, followed by removal and digestion of all vent feathers to get an actual mite count. The observers failed to detect actual very low mite infestations of 1–10 mites over half the time but detected 11–50 mites over 80% of the time. Visual detection of northern fowl mite on eggs or the bird environment is probably easier in warmer weather because the mites move out to the feather tips to thermoregulate and thus move off or are dislodged from the host (De La Riva et al. 2015).

The first and most basic method for poultry red mite detection is searching the existing environment visually. This includes cage wires, water troughs or lines, manure surface, or litter. Attention can be placed on small crevices near nighttime bird roosting sites that provide dark hiding refugia for mites and are in the range of 1–3 mm thick. Zenner et al. (2009) noted that French cage-free facilities for laying hens mostly depended on farmers or their pest management advisors trying to examine the environment directly for mites

Fig. 1. The vent area of birds should be examined for northern fowl mite infestation. The birds should be held with the cloaca region facing away from the examiner (left). Uninfested birds have clean feathers and healthy skin (top right), while northern fowl mite-infested birds will have dirty mite-filled feathers (bottom right).

visually. Small clumps of dried feces near the birds, for example, were picked up and the bottoms examined for resting mites during the day. The resting mites tend to form clusters, at least partially under the influence of aggregation pheromones (Koenraadt and Dicke 2010). The relative sizes of mite clumps were scored as zero, low (1–20 mites), moderate (20–200 mites), or high (>200 mites; Zenner et al. 2009). But the researchers showed this method was much less sensitive than passively using mite traps placed into the chicken houses very near perches (described below). Cencek (2003) used sticky tape to collect the visualized mite clusters more or less in their entirety and classified them as small, medium or large based on their diameter. Mul and Koenraadt (2009) describe in detail the process of assessing risk points for mite introduction and the value of early detection and prevention of poultry red mite in poultry houses. The methods described could be adopted by any producer as she or he considers their own facility.

Good summaries of methods used for passive sampling for poultry red mite can be found in Mul et al. (2015) and Lammers et al. (2017). Both articles provided an assessment of the advantages and disadvantages of those methods. Several methods involve deploying a device designed to encourage resting mite occupation, which provides the possibility for subsequent mite counting. Factors influencing the choice of method(s) included speed, cost (including labor), ease of and time required for deployment, whether the method includes all mite life stages, susceptibility to moisture (absorptive materials change in weight if wetted and may become hostile places for mites to rest), ability to detect small populations and show relative density changes over time and space, degree of quantification, and finally whether the method has been evaluated experimentally (i.e., validated) using known numbers of mites.

It also is possible to collect environmental samples and hold them or bring them back to a laboratory for mite extraction, such as via Tullgren or Berlese funnels (Cencek 2003, Fiddes et al. 2005, Krantz and Walter 2009). This only works for living mites. Alternatively, a helpful and easy mite separation and recovery technique is to place poultry house debris in a sealed bag with one end of the bag placed on ice. Living mites will crawl away from the cold to the opposite side of the bag. Both techniques will also work for the collection of northern fowl mite, especially if infested feather material is used.

Another detection method often used by poultry producers is the presence of blood spots on eggs due to crushed, engorged poultry red mite. These are unsightly, may downgrade the prices paid for eggs, and their appearance may occur about the time poultry facility workers begin to complain about mites (see Odaka et al. 2017, Waap et al. 2019). Northern fowl mite may also be found on the surface of eggs, especially if densities are high (Mullens et al. 2000). For northern fowl mite detection, 4/100 mite-positive eggs (4%) in the egg rollouts is indicative of about 25% flock infestation prevalence for caged laying chickens (A.C.M., unpublished data). Treatments implemented at such an infestation level are more efficient and prevent or mitigate the economic damage expected from high mite infestations (Mullens et al. 2009).

Worker complaints, as mentioned above, are also used as a detection method for both northern fowl mite and poultry red mite, but likely are not particularly sensitive to low mite populations. In fact, Waap et al. (2019) noted that very few Portuguese farmers actually sampled routinely for poultry red mite, but that the threshold for farmer detection of poultry red mite (probably via blood spots or complaints) in their survey related to about 75 mites per poultry red mite sampling trap. In a long-term study on one commercial caged layer facility, based on farm worker complaints, the producer treated chemically for mites when egg infestations reached about 20% of eggs in rollouts (Mullens et al. 2000). So, for both mite species, there is a large discrepancy between systematic mite sampling (and early and more efficient treatment) and the much higher mite levels (and late and inefficient treatment) detected haphazardly via worker complaints.

Additionally, the detection of either mite species in a poultry house that has been empty for some time may warrant the use of a few sentinel birds to act as a 'trap crop' before moving a large, clean flock into a hopefully mite-free facility. This novel idea needs further study, as timing of bird placement and removal is critical, so sentinel birds do not end up becoming a bloodmeal source for the mite population to propagate significantly over a longer period. For poultry red mite the hens used for detection would probably be coupled with nearby sampling devices (mite traps; see below).

For northern fowl mite, designated sentinel birds in cage systems also may be sampled over time (e.g., weekly) within a flock. One concern with sentinels is the risk for people to spread mites from the sentinel birds throughout the flock, however. Mullens et al. (2009) used 50 evenly placed sentinels per house of 30,000 caged laying hens, taking care to check and clean hands and change disposable gloves between sentinels. On five dates, the sentinel mite infestations were compared with infestations from random hens three cages away from the sentinels, and the mite infestations were similar. With care it is possible not to significantly cross-contaminate sentinel hens. To be representative, it also is important that designated sentinels be held under equivalent conditions as the general flock (e.g., same cage density). Caged sentinel hens in groups such as in furnished cages can be identified by colored leg bands. The idea of repeatedly sampling the same sentinel hens is likely impossible or impractical in larger noncage systems, but to our knowledge it has not been tried. In such settings an individual is likely to sample any free-roaming birds that can be captured. Interestingly, such birds might tend to be the same unusually curious or calm individual hens in a flock, so they might essentially become similar to sentinels anyway. In smaller groups, such as backyard flocks, individual cage-free hens can be leg banded as sentinels for repeated capture if desired (Murillo and Mullens 2016a).

Quantification

Several northern fowl mite scoring systems or indexes have been developed (Furman and Coats 1957, Foulk and Matthysse 1963, DeVaney 1979, Collison et al. 1981, Lemke and Kissam 1986). In our extensive work at UC Riverside, we have used a scale that was developed by Arthur and Axtell in 1983 (Table 1). This scoring system has better resolution at lower infestation levels (useful in resolving an economic threshold mite density in the low to moderate range). It can also be modified; for example, Owen et al. (2009) added '–' and '+' to each score to indicate lower and upper 20th percentiles (Table 1). Visual estimates routinely underestimate population sizes (Lemke and Collison 1985) but can still be useful in following population trends over time. Lemke and Collison (1985) also found that mite-scoring experience did not influence counts and that, in general, individuals scoring the same birds were consistent. However, although in our experience different people will score similarly, visual scoring still is undeniably subjective. Consistency in the people used for scoring significantly reduces systematic interindividual error, so all our experimental northern fowl mite studies have used the same person scoring over time if possible.

Northern fowl mite scoring focuses on the vent region of the chicken where the majority of mites are found (Fig. 1). The counter should hold the bird with the cloaca pointing away from the body.

Table 1. Northern fowl mite visual scoring system categories to rate mite density in chicken vent feathers in columns 1 and 2 (Arthur and Axtell 1983). Columns 3 and 4 incorporate adding a plus or minus to the upper or lower 20th percentiles of each of categories 1–6 (Owen et al. 2009)

Northern fowl mite score	Raw mite number	Northern fowl mite score	Raw mite number
0	0	0	0
1	1–10	1–	1–2
2	11–50	1	3–7
3	51–100	1+	8–10
4	101–500	2–	11–19
5	501–1,000	2	20–30
6	1,001–10,000	2+	31–50
7	>10,000	3–	51–61
		3	62–89
		3+	90–100
		4–	101–181
		4	182–419
		4+	420–500
		5–	501–601
		5	602–899
		5+	900–1,000
		6–	1,001–2,801
		6	2,802–8,199
		6+	8,200–10,000
		7	>10,000

It helps to balance the bird upon a leg or knee, so that the bird stays calm. Starting at the posterior border of the keel bone (anterior edge of the vent region), gently lift the feathers up and examine them one-by-one using both hands. As one 'files' through the feathers, count (or estimate) the number of mites observed. The mites will appear as small dark moving dots on the feather and on the skin at the base of feathers (those are the mites). Larvae and unfed protonymphs are especially difficult to see and likely usually are missed, especially because the larvae do not move much. So, it is mostly larger and mobile adult northern fowl mite that are being detected. Small numbers of mites can be counted rather exactly, but numbers quickly become unmanageable as densities increase. When populations are high, individual feathers will be teeming with mites that may be several layers thick and partly obscured by mite feces, eggs, and cast skins. Here, estimates are more practical (there may be several thousand mites on a single feather; De La Riva et al. 2015). Continue to move through the feathers, being sure to include mite counts on the skin. The time required for the counting process should be less than 1–2 min per bird; otherwise, the possibility of 'herding' the mites from one area to another becomes a concern. Most of the mites will be anterior to the cloaca, but a few feathers posterior to the cloaca may harbor mites and should be examined.

If a more accurate mite count is desired, birds (alive or dead) may be washed with soapy water or treated with acaricide to remove ectoparasites (Murillo and Mullens 2016b). A light spritzing of pyrethrin, for example, will incapacitate ectoparasites, which then are easier to dislodge by gently disturbing the treated feathers manually above a white pan for recovery or counting. If washing is used, the soapy water can be run through a sieve and then backwashed into a clean pan for mite detection. These techniques are especially helpful when trying to detect very low levels of infestation that may be missed visually.

Several studies have addressed quantifying relative poultry red mite numbers. It has long been known that poultry red mite seek out dark, enclosed hiding places near the host nighttime roost, and Kirkwood (1965) utilized an attractive hollow trap perch to count mites inside carbaryl-treated or untreated trap perches for detection and control of mites. The idea for the use of cardboard as a substrate may have been derived from the Arends tube traps placed into the poultry environment for quantification of litter beetles, *Alphitobius diaperinus* (Panzer). They were initially developed by James Arends at North Carolina State University and consist of an outer protective 24-cm-long and 4-cm-diameter tube (e.g., PVC plastic), open at one or both ends and filled with a rolled-up piece of corrugated cardboard (Safrit and Axtell 1984). Litter beetles, like poultry red mite, seek out dark hiding places by day, and tubes placed in poultry litter become occupied by beetles. These tubes may be collected, frozen, and the beetles enumerated.

In an influential series of sampling and biological studies on poultry red mite, corrugated cardboard traps of varying sizes, but without external protective enclosures, were developed and tested by Nordenfors et al. at the National Veterinary Institute in Uppsala, Sweden (Nordenfors et al. 1999, Nordenfors and Höglund 2000, Nordenfors and Chirico 2001). Cardboard pieces could be fastened to wood structures in a poultry house. Sizes varied from an initial rather small unit, 10 or 14 cm long × 7 cm wide (Nordenfors et al. 1999, Nordenfors and Höglund 2000) to slightly larger units up to 20 cm × 14 cm (Nordenfors and Chirico 2001). Traps could be deployed for varying times, generally 24 or 48 h, retrieved and placed individually into sealed plastic bags, frozen, and opened to allow mites to be counted or sorted by stage, or possibly weighed for quantification. Nordenfors and Höglund (2000) successfully used nine traps per house, in stable locations, to track relative poultry red mite populations over time. From a sampling methodology standpoint, the Nordenfors and Chirico (2001) study looked closely at varying trap size and length of deployment (up to 10 d). They wanted to determine how many traps would be needed, at different field mite densities and with different coefficients of variation, to estimate populations. Larger traps did get more mites but were roughly comparable when corrected for size (10–80 mites per cm^2 per day). Denser populations, of course, required fewer traps to track successfully. They provided a table and suggested use of 11–19 traps per facility, with a 2-d deployment period.

Corrugated cardboard traps in varying configurations (including folded) have been the most commonly used monitoring devices for poultry red mite in Europe. Sometimes the cardboard has been protected by wood outside (Kilpinen et al. 2005), since the cardboard becomes essentially useless if it gets wet. A recent commercially available trap, the AVIVET trap, was tested and validated by Lammers et al. (2017). This tube trap (Fig. 2A) is basically a miniature version of the Arends trap that can be hung on perches. The plastic outer tube measures 50 mm long × 16 mm in diameter with rolled cardboard inside. Mites enter from the open ends. Traps are retrieved after 2 d of deployment, bagged, and frozen, and mites can be extracted for counting and stage determination or can be weighed (Fig. 2B). Traps require 7–10 min each to process, and 10 traps per house are recommended to track relative poultry red mite numbers. The researchers used controlled infestations of 50–5,000 mites per cage to validate the trap sensitivity, and 94% of the variability could be explained by known mite density.

Other traps without cardboard, but still exploiting the poultry red mite desire to hide, have been used successfully by some researchers. Odaka et al. (2017) used an all-wood trap with two pieces of cedar or Japanese cypress, 8.5 cm long, 4.5 cm wide, and 1 cm thick. A hinge on one side separates the wood pieces slightly on that side by 3 mm, but the opposite side allows the wood to touch. This

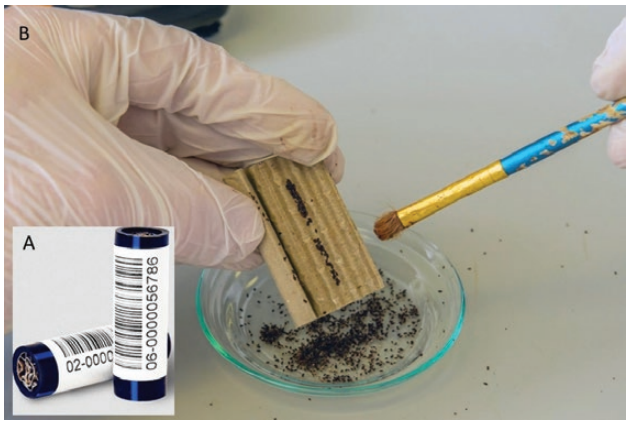

Fig. 2. The AVIVET trap (A) is a plastic tube with corrugated cardboard rolled inside. Poultry red mite will use the trap as harborage. The cardboard can be unfurled, and mites enumerated (B). Photographs courtesy of AviVet Veterinary Service, The Netherlands.

creates a range of gap size ≤ 3 mm, and poultry red mite find their own preferred zone related to their thigmotactic response. The traps were placed either in the egg rollout or on the floor. In this case they deployed 10 traps for 24 h and returned them in sealed bags to the lab, where they were refrigerated at 4°C (not frozen). They then used a digital camera and automatic counting software to count poultry red mite in the traps after exposure and picture taking.

An imaginative automated sampling and counting trap was developed and validated byMul et al. (2015). This small electronic tube unit can be placed under a perch where poultry red mite enter a 1- to 1.5-mm opening. A data logger counts mites as they pass a sensor, recording at 5-min intervals. Mites are retained against a small filter inside the tube. These were tested using releases of 50–5,000 mites per cage at a time. The researchers also looked at poultry red mite densities in the cage environment visually over time. The monitor tracked known mite densities over time, albeit with some significant variation among cages. The main benefit of this device is its ability to measure mites continuously and automatically.

Whether for detection or quantification, the use of pheromones (e.g., aggregation pheromone as per Koenraadt and Dicke 2010) or host-derived kairomones (as per attractive host skin lipids as per Zeman 1988) is an interesting possibility to improve sampling efficiency. As an example, aggregation/arrestment pheromones of bed bugs, *Cimex lectularius* L., have been examined and would potentially be useful in detecting lower level infestations, but the active materials have relatively low volatility and thus would have a limited range of attraction without supplementation (Olson et al. 2016). This option for improved sampling of both northern fowl mite and poultry red mite thus hinges on further work. To our knowledge, no specific compounds have been tested in this way for poultry mites to date.

Decision Making

Over the years, several different economic action thresholds have been suggested for northern fowl mite. Axtell and Arends (1990) suggested treatment as soon as northern fowl mite are detected. Harris et al. (2000) developed thresholds (based on 25–45% prevalence estimates) for varying infestation tolerance levels based on the percent of birds checked with northern fowl mite present (presence–absence sampling). This was more practical for farm personnel to use than an actual density-based scoring system, as researchers might use. It was based on the fact that the average infestation level (mites per bird) was strongly correlated with the proportion of chickens infested in the flock (r = 0.94). Below 15% infestation was considered noneconomic. A treatment decision in a flock might be reached rather quickly if all birds checked were either uninfested (negative) or all were infested. Intermediate infestation prevalence required continued sampling. Using the Harris sequential sampling method on a commercial farm, Mullens et al. (2000) set a sample size of 50 birds as a cutoff (default treatment decision). However, Harris et al. (2000) relied on statistical sampling that may underestimate the number of birds that needs to be examined to have high confidence a flock is not economically infested. These action thresholds do not necessarily reflect economic injury levels (pest level at which cost of damage exceeds the cost of control). Low to moderate northern fowl mite infestations (less than 100 mites per bird) may have detectable economic consequences (Arends et al. 1984), but Mullens et al. (2009) saw distinct economic effects in the form of reduced egg production or feed conversion efficiency with more than 100 mites per bird. Murillo and Mullens (2016a) used 100 northern fowl mite per bird as a density deserving control. All these northern fowl mite thresholds were developed for chickens in traditional (high-density) wire cages.

The most distinct difference between the existing body of work for northern fowl mite versus the body of work for poultry red mite is this area of decision making. To our knowledge, detailed and comprehensive published economic studies on actual producer facilities of the type described by Mullens et al. (2009) for northern fowl mite unfortunately are still lacking for poultry red mite. Similarly, the sequential sampling plan developed for northern fowl mite (Harris et al. 2000) has no parallel in the poultry red mite literature. The poultry red mite literature does indicate that extreme infestations in the range of 150,000–200,000 mites per bird can be fatal (e.g., Kilpinen et al. 2005).

A recent Japanese article by Odaka et al. (2017) provides a nice coupling of relative poultry red mite density to damage. Studies were done to compare poultry red mite numbers in the traps to the timing and intensity of egg staining (blood spots). Two farms were used. Trap counts below 60 poultry red mite/trap/day on one farm and below 130 poultry red mite/trap/d on the second farm were related to negligible staining, and the level of staining increased in a quantified and predictable way above those thresholds (segmented regression). So, it is possible to designate an action threshold to treat and prevent a designated level of economically-damaging egg staining for poultry red mite. It would be especially interesting and useful to link egg staining frequency to further poultry red mite economic damage, such as egg production or feed conversion efficiency.

Conclusions and Future Directions

The northern fowl mite and poultry red mite are equally formidable poultry pests with unique challenges related to detection, quantification, and decision making for on-farm control. In the United States, northern fowl mite has been the predominant poultry pest, but this may be changing as egg-production housing styles change. Even with the existence of a sequential sampling plan for northern fowl mite (Harris et al. 2000), we are not aware that many producers sample routinely for that pest, despite the knowledge that early treatment is far more effective. Importantly, the sampling methods developed for northern fowl mite have been developed and tested exclusively in wire hanging (traditional) cage systems. Changing housing greatly

affects both importance and sampling of pests like ectoparasites. There is an urgent need for information on northern fowl mite biology and sampling in alternative cage-free housing compared with traditional wire cage systems. For example, the dispersal pattern of northern fowl mite in cage-free housing is unknown. The behaviors performed by chickens in cage-free housing differ from birds in wire traditional cages (Lay et al. 2011) and may be one factor influencing northern fowl mite dispersal.

There is a particularly urgent need for development and training for methods of identification and detection of poultry red mite in the U.S. egg-layer industry. The European experience from the late 1990s to present shows that housing or other production changes, such as withdrawal of pesticides from the market, have profound influences on pest complexes, specifically poultry red mite. Those methods presumably would vary somewhat based on the system (e.g., enriched cages, aviary, free range). Presently, it is not clear how prevalent poultry red mite even is in the United States; amazingly, no surveys exist. Methods that optimize the detection of both mite species with minimal effort to producers will be highly desirable as these two species are likely to coexist in poultry flocks (A.C.M., personal observation).

The identification of mites is a time-consuming process that requires specialized tools and training. Easy availability of new diagnostic methods, such as those that use DNA (e.g., Fraser et al. 2018), could expedite the identification process especially for veterinary diagnostic labs that may not have the entomological training for mite identification.

Just as host antibodies may be used for the detection of internal parasites, it may be possible to test the presence of antibodies to mites, or even antigens from mites (e.g., mite salivary proteins), by examining chicken blood samples. Northern fowl mite elicit production of antibodies by the host, and these are likely specific enough for diagnosis, although more work is needed on that. Host immune responses to poultry red mite are under study, particularly in the United Kingdom (see Sparagano et al. 2014), but presently we know of no deterministic host responses that could be used in this way. Such tests have thus far been used only experimentally, often by scientists interested in determining host responses to mite blood feeding or feasibility of mite vaccines. So, mite antibody tests are not yet proven on a field scale for detection and are not available for general use by the public.

Finally, the Integrated Pest Management concept (Stern et al. 1959) entails much more than utilizing multiple techniques to achieve control. Its critical feature, in fact, is to link pest density to economic damage. To accomplish this, and to make appropriate control decisions, we must establish economic injury levels (pest level at which cost of damage exceeds the cost of control) and economic thresholds (pest level at which action must be taken to avoid the economic injury level being reached). We have some information on this for northern fowl mite in traditional cages, but we need better economic injury levels and action thresholds for northern fowl mite in systems beyond conventional wire cages. And we especially need better economic data for poultry red mite in all systems. This requires the careful tracking of flock-level feed consumption and egg production in both experimental and commercial settings. With northern fowl mite, the main economic impact is in feed conversion efficiency, which to our knowledge has not been well examined with poultry red mite. Measuring feed conversion exactly is a bit difficult in noncage systems but is not impossible. It is also important to understand how these two species coinfesting a flock may affect action thresholds. Decision making admittedly does not depend on these economic metrics alone. Increasingly animal welfare and comfort, as revealed by such things as chicken sleeping or grooming behavior (e.g., Kilpinen et al. 2005, Vezzoli et al. 2015), also enter into the picture and are harder to quantify. Preliminary work has shown no negative effect on welfare metrics when northern fowl mite infestations are under 100 mite per bird (A.C.M., unpublished data). Prevention of initial infestation (biosecurity) is of course paramount and the best option. But, given the widespread nature of northern fowl mite and poultry red mite infestations and the extreme difficulty in entirely eliminating them from a farm once they are there, it is likely that many producers will have to live with and manage mite infestations, making informed decisions regarding periodic control. Decision thresholds thus are, in our opinion, the top priority for research on both pests in the various types of production that are currently becoming more popular.

References Cited

Arends, J. J., S. H. Robertson, and C. S. Payne. 1984. Impact of northern fowl mite on broiler breeder flocks in North Carolina. Poult. Sci. 63: 1457–1461.

Arthur, F. H., and R. C. Axtell. 1983. Susceptibility of northern fowl mites in North Carolina to five acaricides. Poult. Sci. 62: 428–436.

Axtell, R. C., and J. J. Arends. 1990. Ecology and management of arthropod pests of poultry. Annu. Rev. Entomol. 35: 101–126.

Cencek, T. 2003. Prevalence of *Dermanyssus gallinae* in poultry farms in Silesia region in Poland. Bull. Vet. Inst. Pulway 47: 465–469.

Chen, B. L., and B. A. Mullens. 2008. Temperature and humidity effects on off-host survival of the Northern fowl mite (Acari: Macronyssidae) and the chicken body louse (Phthiraptera: Menoponidae). J. Econ. Entomol. 101: 637–646.

Collison, C. H., R. G. Danka, and D. R. Kennell. 1981. An evaluation of permethrin, carbaryl, and amitraz for the control of northern fowl mites on caged chickens. Poult. Sci. 60: 1812–1817.

De La Riva, D. G., D. Soto, and B. A. Mullens. 2015. Temperature governs on-host distribution of the northern fowl mite, *Ornithonyssus sylviarum* (Acari: Macronyssidae). J. Parasitol. 101: 18–23.

DeVaney, J. A. 1979. The effects of the northern fowl mite, *Ornithonyssus sylivarium* on egg production and body weight of caged White Leghorn hens. Poult. Sci. 58: 191–194.

Fiddes, M. D., S. Le Gresley, D. G. Parsons, C. Epe, G. C. Coles, and K. A. Stafford. 2005. Prevalence of the poultry red mite (*Dermanyssus gallinae*) in England. Vet. Rec. 157: 233–235.

Flocklay, A. S., E. Thomas, and O. Sparagano. 2017. Poultry red mite (*Dermanyssus gallinae*) infestation: a broad impact parasitological disease that still remains a significant challenge for the egg laying industry in Europe. Parasit. Vectors 10: 357.

Foulk, J. D., and J. G. Matthysse. 1963. Experiments on control of the northern fowl mite. J. Econ. Entomol. 56: 321–326.

Fraser, T. A., A. Martin, A. Polkinghorne, and S. Carver. 2018. Comparative diagnostics reveals PCR assays on skin scrapings is the most reliable method to detect *Sarcoptes scabiei* infestations. Vet. Parasitol. 251: 119–124.

Furman, D. P., and W. S. Coats. 1957. Northern fowl mite control with malathion. Poult. Sci. 36: 252–255.

George, D. R., R. D. Finn, K. M. Graham, M. F. Mul, V. Maurer, C. V. Moro, and O. A. Sparagano. 2015. Should the poultry red mite *Dermanyssus gallinae* be of wider concern for veterinary and medical science? Parasit. Vectors 8: 178.

Hall, R. D. 1979. The northern fowl mite...poultry's most damaging external parasite. Poult. Dig. 38: 430, 434, 438.

Harris, M. A., M. J. Brewer, and J. A. Meyer. 2000. Presence-absence sequential sampling plan for northern fowl mite, *Ornithonyssus sylviarum* (Acari: Macronyssidae), on caged-layer hens. J. Econ. Entomol. 93: 544–549.

Kells, S. A., and G. A. Surgeoner. 1996. Dispersion of northern fowl mites, *Ornithonyssus sylviarum*, between poultry facilities via infested eggs from layer and breeder flocks. J. Agric. Entomol. 13: 265–274.

Kilpinen, O., A. Roepstorff, A. Permin, G. Nørgaard-Nielsen, L. G. Lawson, and H. B. Simonsen. 2005. Influence of *Dermanyssus gallinae* and

Ascaridia galli infections on behaviour and health of laying hens (*Gallus gallus domesticus*). Br. Poult. Sci. 46: 26–34.

Kirkwood, A. C. 1965. A trap perch for the control of the poultry red mite (*Dermanyssus gallinae*). Br. Poult. Sci. 6: 73–78.

Knee, W., and H. Proctor. 2007. Host records for *Ornithonyssus sylviarum* (Mesostigmata: Macronyssidae) from birds of North America (Canada, United States, and Mexico). J. Med. Entomol. 44: 709–713.

Koenraadt, C. J. M., and M. Dicke. 2010. The role of volatiles in aggregation and host-seeking of the haematophagous poultry red mite *Dermanyssus gallinae* (Acari: Dermanyssidae). Exp. Appl. Acarol. 50: 191–199.

Krantz, G. W. and D. E. Walter (eds.). 2009. A manual of acarology, 3rd ed. Texas Tech University Press, Lubbock, TX.

Lammers, G. A., R. G. G. Bronneberg, J. C. M. Vernooij, and J. A. Stegeman. 2017. Experimental validation of the AVIVET trap, a tool to quantitatively monitor the dynamics of *Dermanyssus gallinae* populations in laying hens. Poult. Sci. 96: 1563–1572.

Lay, D. C., R. M. Fulton, P. Y. Hester, D. M. Karcher, J. B. Kjaer, J. A. Mench, B. A. Mullens, R. C. Newberry, C. J. Nicol, N. P. O'Sullivan, et al. 2011. Hen welfare in different housing systems. Poult. Sci. 90: 278–294.

Lemke, L. A., and C. H. Collison. 1985. Evaluation of a visual sampling method used to estimate northern fowl mite, *Ornithonyssus sylviarum* (Acari: Macronyssidae), populations on caged laying hens. J. Econ. Entomol. 78: 1079–1082.

Lemke, L. A., and J. B. Kissam. 1986. The status of northern fowl mite research: how far have we come? J. Agric. Entomol. 3: 255–264.

Lemke, L. A., C. H. Collison, and K. C. Kim. 1988. Host digestion to determine populations of the northern fowl mite, *Ornithonyssus sylviarum* (Acari: Macronyssidae), on mature chickens. J. Med. Entomol. 25: 183–190.

McCulloch, J. B., J. P. Owen, N. C. Hinkle, B. A. Mullens, and J. W. Busch. 2020. Genetic structure of Northern fowl mite (Mesostigmata: Macronyssidae) populations among layer chicken flocks and local house sparrows (Passeriformes: Passeridae). J. Med. Entomol. 57: 122–130.

Mul, M. F., and C. J. Koenraadt. 2009. Preventing introduction and spread of *Dermanyssus gallinae* in poultry facilities using the HACCP method. Exp. Appl. Acarol. 48: 167–181.

Mul, M. F., J. W. van Riel, B. G. Meerburg, M. Dicke, D. R. George, and P. W. Groot Koerkamp. 2015. Validation of an automated mite counter for *Dermanyssus gallinae* in experimental laying hen cages. Exp. Appl. Acarol. 66: 589–603.

Mullens, B. A., N. C. Hinkle, and C. E. Szijj. 2000. Monitoring northern fowl mites (Acari: Macronyssidae) in caged laying hens: feasibility of an egg-based sampling system. J. Econ. Entomol. 93: 1045–1054.

Mullens, B. A., J. P. Owen, D. R. Kuney, C. E. Szijj, and K. A. Klingler. 2009. Temporal changes in distribution, prevalence and intensity of northern fowl mite (*Ornithonyssus sylviarum*) parasitism in commercial caged laying hens, with a comprehensive economic analysis of parasite impact. Vet. Parasitol. 160: 116–133.

Murillo, A. C., and B. A. Mullens. 2016a. Timing diatomaceous earth-filled dustbox use for management of Northern fowl mites (Acari: Macronyssidae) in cage-free poultry systems. J. Econ. Entomol. 109: 2572–2579.

Murillo, A. C., and B. A. Mullens. 2016b. Diversity and prevalence of ectoparasites on backyard chicken flocks in California. J. Med. Entomol. 53: 707–711.

Murillo, A. C., and B. A. Mullens. 2017. A review of the biology, ecology, and control of the northern fowl mite, *Ornithonyssus sylviarum* (Acari: Macronyssidae). Vet. Parasitol. 246: 30–37.

Murillo, A. C., M. A. Chappell, J. P. Owen, and B. A. Mullens. 2016. Northern fowl mite (*Ornithonyssus sylviarum*) effects on metabolism, body temperatures, skin condition, and egg production as a function of hen MHC haplotype. Poult. Sci. 95: 2536–2546.

Nordenfors, H., and J. Chirico. 2001. Evaluation of a sampling trap for *Dermanyssus gallinae* (Acari: Dermanyssidae). J. Econ. Entomol. 94: 1617–1621.

Nordenfors, H., and J. Höglund. 2000. Long term dynamics of *Dermanyssus gallinae* in relation to mite control measures in aviary systems for layers. Br. Poult. Sci. 41: 533–540.

Nordenfors, H., J. Höglund, and A. Uggla. 1999. Effects of temperature and humidity on oviposition, molting, and longevity of *Dermanyssus gallinae* (Acari: Dermanyssidae). J. Med. Entomol. 36: 68–72.

Odaka, M., K. Ogino, M. Shikada, K. Asada, S. Kasa, T. Inoue, and K. Maeda. 2017. Correlation between the proportion of stained eggs and the number of mites (*Dermanyssus gallinae*) monitored using a 'non-parallel board trap'. Anim. Sci. J. 88: 2077–2083.

Olson, J. F., L. M. Ver Vers, R. D. Moon, and S. A. Kells. 2016. Two compounds in bedbug feces are sufficient to elicit off-host aggregation by bed bugs, *Cimex lectularius*. Pest Manag. Sci. 73: 198–205.

Owen, J. P., M. E. Delany, C. J. Cardona, A. A. Bickford, and B. A. Mullens. 2009. Host inflammatory response governs fitness in an avian ectoparasite, the northern fowl mite (*Ornithonyssus sylviarum*). Int. J. Parasitol. 39: 789–799.

Rutz, D. A. 1981. Integrated multipest management, a pilot program for poultry and livestock in North Carolina, pp. 148–159. *In* R. S. Patterson (ed.), Status of biological control of filth flies. USDA-SEA, Gainesville, FL.

Safrit, R. D., and R. C. Axtell. 1984. Evaluations of sampling methods for darkling beetles (*Alphitobius diaperinus*) in the litter of turkey and broiler houses. Poult. Sci. 63: 2368–2375.

Sikes, R. K., and R. W. Chamberlain. 1954. Laboratory observations on three species of bird mites. J. Parasitol. 40: 691–697.

Sparagano, O. A., D. R. George, D. W. Harrington, and A. Giangaspero. 2014. Significance and control of the poultry red mite, *Dermanyssus gallinae*. Annu. Rev. Entomol. 59: 447–466.

Stern, V. M. R. F., R. Smith, R. Van den Bosch, and K. Hagen. 1959. The integration of chemical and biological control of the spotted alfalfa aphid: the integrated control concept. Hilgardia 29: 81–101.

Vezzoli, G., B. A. Mullens, and J. A. Mench. 2015. Relationships between beak condition, preening behavior and ectoparasite infestation levels in laying hens. Poult. Sci. 94: 1997–2007.

Waap, H., T. Nunes, M. F. Mul, J. Gomes, and K. Bartley. 2019. Survey on the prevalence of *Dermanyssus gallinae* in commercial laying farms in Portugal. Avian Pathol. 48(Supp 1): S2–S9. doi:10.1080/03079457.2019.1606415

Zeman, P. 1988. Surface skin lipids of birds – a proper host kairomone and feeding inducer in the poultry red mite, Dermanyssus gallinae. Exp. Appl. Acarol. 5: 163–173.

Zenner, L., G. Bon, C. Chauve, C. Nemoz, and S. Lubac. 2009. Monitoring of *Dermanyssus gallinae* in free-range poultry farms. Exp. Appl. Acarol. 48: 157–166.