

Past, Present, and Future Contributions and Needs for Veterinary Entomology in the United States and Canada

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Nestled between the larger subdisciplines of medical entomology and crop protection, veterinary entomology occupies a unique position in economic entomology. It lies at the intersection of concerns for human pests and disease agent transmission, parasitology in wildlife and natural systems, and integrated pest management in agriculture. Many serious human nuisance pests and disease vectors overlap significantly with animal agriculture. Over the past decade, in fact, the concept of One Health has emerged globally (<http://www.onehealthinitiative.com/publications.php>). At the core of this concept is the idea that human, animal, and environmental health are linked, and thus should be considered as parts of a larger whole.

To that end, we must have scientists who recognize the connections, and this certainly includes veterinary entomologists. For example, cattle operations can produce and provide blood meals for lots of mosquitoes that may later bite people, and house flies developing on animal operations can effectively transfer dangerous bacteria such as *Escherichia coli* O157:H7 to nearby human populations. Wild birds are the main hosts for key zoonotic arboviruses such as West Nile, and wild rodents harbor the pathogens of plague and Lyme disease. So, the fields of medical and veterinary entomology truly are intimately connected, both operationally and conceptually. This is why they are often treated together in academic courses, and probably should be. Wildlife species themselves

suffer tremendously from arthropod pests, ranging from introduced parasitic *Philornis* spp. flies (Muscidae) now decimating endangered Darwin's finches (*Camarhynchus*, *Certhidea*, and *Geospiza* spp. [Koop et al. 2011]; Fig. 1A, B) to sarcoptic mange mites (*Sarcoptes scabiei* [L.]), which can be so virulent that they were once intentionally introduced for biological control of wolves in the American West (Jimenez et al. 2010, Almberg et al. 2012). Heavy infestations of winter tick, *Dermacentor albipictus* (Packard), possibly influenced by warming conditions and climate change, are killing moose and threatening other wild ruminants in the northern United States and Canada (Fig. 1C; Kutz et al. 2009, <https://tinyurl.com/nl4887n>).

Veterinary entomology also includes pests of pets and companion animals such as cats, dogs, and horses, and tremendous strides have been made in management of those pests. Good reviews exist covering the history, biology, and management of the cat flea, *Ctenocephalides felis* (Bouché), especially via fairly recent systemic and contact host pesticide treatments (Rust and Dryden 1997, Dryden 2009). In the traditional agriculture realm, which will be the focus of this paper, North American veterinary entomology has a rich history of accomplishments. It has saved billions of dollars for American animal agriculture, which exceeds the cumulative value of plant agriculture (<http://www.ers.usda.gov/topics/animal-products.aspx>).

The first goal of this paper is to highlight the immense progress that has been made in veterinary entomology.

We have essentially made some key pest problems “go away” in an economic sense, at least temporarily. But highlighting past accomplishments is not sufficient. Our second goal is to demonstrate that highly significant pest issues persist in animal agriculture. In fact, we are at a critical juncture. Animal welfare issues, global trade, and the organic food movement are combining to change the face of animal production and therefore pest complexes and their management (e.g., Wall 2007). As a third goal, looking forward, we need to point out that academic programs in veterinary entomology are in very serious trouble. We will discuss the reasons for this and try to convince readers that this is an unwise trajectory that needs to be changed, and soon. Our focus will be on veterinary entomology in the United States and Canada, but the basic issues, and even a lot of the pests, are most certainly global.

We are teachers, whether in the classroom or via extension forums, and teaching by example is a time-proven technique. So, as examples we will feature the stories of five arthropod pests affecting animals: (1) the primary screwworm, *Cochliomyia hominivorax* (Coquerel); (2) cattle fever ticks, *Rhipicephalus annulatus* (Say) and *R. microplus* (Canestrini); (3) cattle grubs, *Hypoderma bovis* (L.) and *H. lineatum* (Villers); (4) the stable fly,

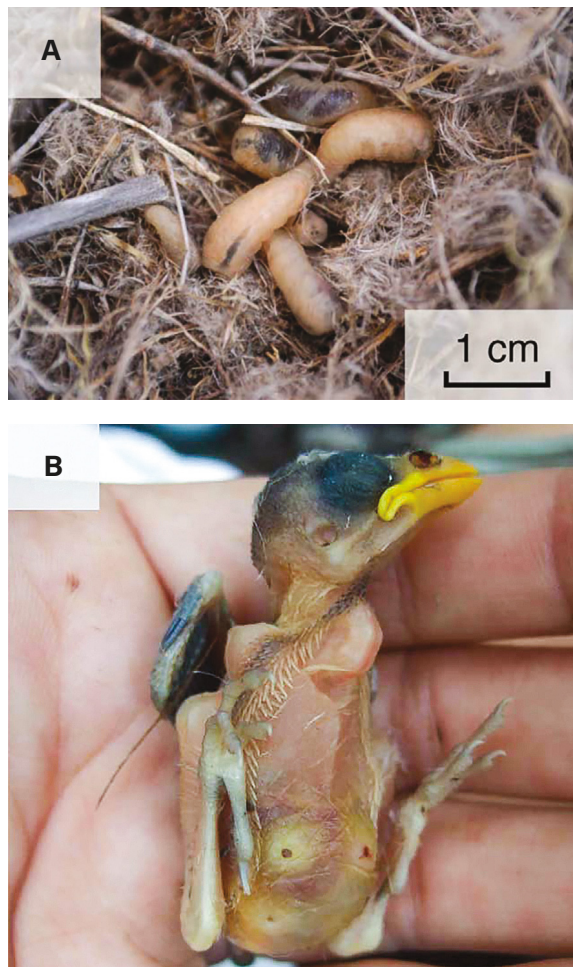


Fig. 1. One of Darwin's finches, *Geospiza fortis* (B), severely damaged by (A), the introduced parasitic muscid fly *Philornis downsi* Dodge and Aiken (photos courtesy of J. Koop, University of Massachusetts, Dartmouth, Massachusetts and PLOS ONE); (C) Moose killed by heavy infestation of the winter tick, *Dermacentor albipictus* (photo courtesy of M. Carstens, Minnesota Department of Natural Resources, Forest Lake, Minnesota).



Stomoxys calcitrans (L.); and (5) the chicken mite, *Dermatophagoides gallinae* (De Geer).

Knowledgeable readers may notice that among these groupings, only the ticks are famous as transmitters of disease agents. One, the chicken mite, is not even regarded as a major American production agriculture pest—yet. Our choice of examples is not accidental. In some parts of the world, domestic animals suffer damage from vector-borne disease in animal populations that probably exceeds losses from the direct impacts of the arthropods. Trypanosomes causing Nagana and transmitted by tsetse flies and *Theileria parva* (East Coast Fever) transmitted by ticks in Africa are great examples. Even in the United States, some animal vector-borne pathogens are quite damaging, either in terms of direct damage or in terms of real or potential losses in trade, a huge damage mechanism that is frequently overlooked. We also are at constant risk of importing new disease agents and perhaps their vectors, such as the tropical bont tick (*Amblyomma variegatum* F.) and heartwater disease (*Ehrlichia ruminantium*) from the Caribbean. Heartwater is a devastating and often fatal disease of livestock and native wild ruminants; introduction and establishment of it or other vector-borne diseases would seriously damage the \$64 billion beef cattle industry in the United States (<https://data.ers.usda.gov/reports.aspx?ID=17845>) and \$7.6 billion industry in Canada (<http://www.agr.gc.ca/eng/industry-markets-and-trade/market-information-by-sector/poultry-and-eggs/poultry-and-egg-market-information/industry-indicators/canadian-farm-cash-receipts/?id=1384971854412>) and the \$40 billion economic value generated by the hunting industry in the U.S. and Canada (Arnett and Southwick 2015). Therefore, we certainly don't want to overlook the major risk and ongoing damage of arthropod-transmitted animal diseases in North America.

However, most people, even many veterinarians, seem to be unaware that the majority of financial impact on animal agriculture in the United States and Canada probably is not the result of vector-borne disease. Rather, the arthropods themselves quietly do the damage, day in and day out, sapping host vitality and reducing weight gains or milk or egg yields, impairing feed utilization, etc. A recent estimate for stable flies assessed U.S. losses at \$2 billion per year (Taylor et al. 2012), and essentially all of those losses in weight gains or milk production are direct, and are not caused by pathogens. Direct pest losses often go unnoticed, even by producers. Just as important, consumers are entirely oblivious. While consumers heavily influence pest management in plant agriculture via demanding perfect produce at a supermarket, they see none of the pest losses to animal agriculture by buying a jug of milk or packaged meat in a grocery store. If we regard the “lack of well-being” as disease, the arthropods themselves are key, underappreciated “disease organisms” in most North American animal systems.

Screwworm: Banished but Not Gone

Arguably the greatest success story in all of economic entomology, the history of screwworm elimination from North and Central America (Wyss 2000) is known to

nearly all entomology graduate students. It is hard now to imagine that, in the rather recent past, screwworm flies invaded the southern and central United States every year from their overwintering sites in Mexico, southern Texas, and southern Florida. Cattlemen had to adjust their management activities such as castrating, dehorning, or calving to avoid the ravenous larvae hatching from egg masses laid near even small wounds. People occasionally were infested and even killed by this fly as well. Ranchers devoted a lot of their time and available labor to detecting and treating infestations before the cattle were literally eaten alive by marauding maggots. We even owe the large number of small whitetail deer now in parts of Texas partially to lack of screwworm, which once killed large proportions of newborn fawns and essentially functioned as their most important predator (R. Drummond, personal communication; Lindquist et al. 1992). A wonderful poem by Joel Nelson, a cowboy who knew of what he spoke, gives a great perspective on what screwworm control has meant to the cattle industry.

**We must continue to develop novel
techniques and training programs to
prevent resurgence of economic losses
due to pests and the pathogens they
transmit in livestock production systems.**

The sterile insect technique (SIT) was a radical concept when Edward Knippling first proposed it (see Knippling 1955). Could we eliminate a pest by flooding its habitat with reared, sterile individuals? It depended on lots of things: innate mating choice and frequency, field density, sterilization techniques that would not compromise the mating abilities of released flies, methods to reduce pre-release population levels, etc., not to mention the daunting challenge of rearing enough flies to allow releases over vast geographic areas. It was so radical that the USDA initially had some reservations about the idea, and cattlemen themselves helped to fund a lot of that early work. The leading scientists in 2016 received a posthumous Golden Goose Award, given to recognize groundbreaking research that seemed silly to some at the time (i.e., investigating the sex life of the screwworm fly) but which has paid dividends far larger than could be foreseen (<https://tinyurl.com/yazejxgq>). In our particular classes in medical and veterinary entomology, and hopefully most others, every student knows those intrepid, imaginative, and determined USDA researchers. Knippling and Bushland are immortalized now as namesakes of the USDA-ARS Knippling-Bushland Livestock Insects Laboratory in Kerrville, Texas. Science heroes deserve at least as much acclaim as those in sports or entertainment!

So, are we done with screwworm? Hardly. We are in an apparently long-term holding action at the Darien Gap in Panama, a narrow land bridge where continuing sterile fly releases fairly efficiently prevent the fly from entering again from South America. Someday maybe we will find the resolve, political climate, and financial means to

try to sweep this pest from South America. Meanwhile, any relaxation of the effort would mean reinvasion of this devastating pest. In fact, spot invasions have happened in the United States and North Africa. The North African example occurred in the form of 14,000 cases from 1989–1991 in Libya (Lindquist et al. 1992, Kouba 2004), which at the time had rather poor relations with the United States, to say the least. Joining forces to eradicate the pest from its African toehold helped to resolve a bit of that (<https://tinyurl.com/y79g655n>). All it takes is an undetected infestation coming in from an imported South American animal to set the stage for outbreaks. We are not sure of the source, but something like this may have happened in September–November 2016 in the Florida Keys. Screwworm infestations were detected in Key deer and dozens of them had to be euthanized (<https://tinyurl.com/ybcws3uj>). Authorities used a combination of control approaches, key among them quarantine and the release of an estimated 154 million sterile male flies. The pest was declared eradicated in April 2017, after killing an eighth of the existing Key deer (<https://tinyurl.com/yb8ynokg>). Clearly, this is not a problem of the past, but also the present. Wasn't it fortunate that we still had the USDA facility, trained personnel, and the ability to respond so quickly? We need trained veterinary entomologists even to handle the present holding action, and also to improve its efficiency and do the research to help in eventual efforts on further control.

Cattle Fever Ticks: A Quarantine Dam in Danger of Breaking

Like the screwworm, cattle fever ticks once were widespread throughout the southern United States. For many years, they were placed in the genus *Boophilus*, but now they are *Rhipicephalus*; *Boophilus* is a subgenus. Cattle that were exposed to the ticks as calves seemed to be mostly unharmed, but northern cattle transported to the South in the 1800s quickly succumbed to a mysterious disease named cattle fever or Texas cattle fever. Veterinary entomologists love reminding people of this fact: the really big breakthroughs in discovery of arthropod transmission of disease agents often originated in animal systems, not

The Screwworm

BY JOEL NELSON, 06 RANCH, ALPINE, TEXAS, 1987

The open range made cowboys
Who were tops at readin' sign
Wild cattle in rough country
Taught 'em how to use their twine.

The trail drives made good cowboys
When the night herd took a run
Those boys would have 'em gathered
By the coming of the sun.

But nothing made good cowboys
In all those days gone by
Like the ugly little larvae
Of the stinkin' screwworm fly.

Now the screwworm is disgusting
As its very name implies
It's carnivorously eating
'Ere its victim even dies.

From flies to eggs to larvae
And back to flies again
Their chain of life's unbroken
It's a cycle without end.

They'd work north every summer
And they'd stay till killing frost
The cowboy there to fight them
Rancher there to count his cost.

In rabbits, deer or livestock
Every wound and every scratch
Was an open invitation
For the screwworm eggs to hatch.

When two bulls would get to fightin'
And their heads was skint up some
You could bet before much time
had passed
Ma Screwworm fly would come.

When the cowboy came a ridin' by
There'd shore be worms to dope
And shore enuff he'd get 'er done
With one horse and one grass rope.

A favorite place for flies to lay
Was in a cankered eye
The calf's ear that was full of ticks
Was wormy by and by.

And each of these would soon have
screwworms
Workin' in his head
If they wasn't caught
by cowboys
Then they'd purty soon be dead.

Smear Sixty two, Blackwidow,
And E.Q. Three, Three, Five
Just anything to kill the worms
And keep the stock alive.

Was carried in an old boot top
Laced with a leather thong
You could smell a cowboy comin'
And still smell him when he'd
gone.

The dope would make his head hurt
And sometimes make him sick
But he knew those worms would
suffer worse
When 'ere they took a lick.

Those crawling bloody messy
sores
Would test a cowboy's grit
The ones with weaker stomachs
Better drift up north or quit.

A doctorin' wormy cattle
Was an everyday affair
One hundred eighty straight long days
The screwworms didn't care.

The cowboy ridin' fer the brand
Did what the job demanded
On a fifteen dollar saddle bronc,
Doctorin' cattle single handed.

Some days was fifty miles or more
Two horses—maybe three
Catch 'em, tie 'em, dope the worms,
Untie 'em, set 'em free.

Now usually gov'met programs
Are a minimal success
But the one that stopped the
screwworm
Has dang shore passed the test.

Cause it pushed the critter
southward
And I hope he's there to stay
Here's to the Mission Fly Lab
And the U.S. D. of A.

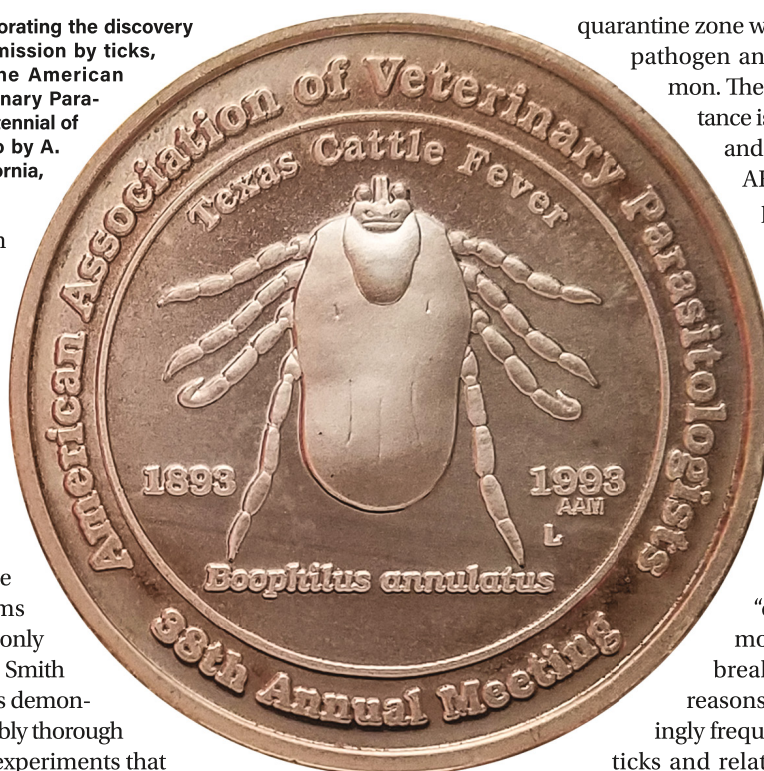
But let's drink a toast to
screwworms
And the hosses they have made
And to their moms the screwworm
flies
And all those eggs they've laid.

For they made some damn good
ropers
Of some cowboys long ago
But we've had enuff, By God,
Let's leave 'em down past Mexico.

Fig. 2. Coin commemorating the discovery of cattle fever transmission by ticks, commissioned by the American Association of Veterinary Parasitologists on the centennial of its publication (photo by A. Murillo, Univ. of California, Riverside).

in human ones. In this case, a bookish microbiologist with the fledgling Bureau of Animal Industry, Theobald Smith, truly plowed some new ground (Schultz 2008). In the early 1880s, when the knowledge that microorganisms caused disease was only a decade or two old, Smith and a few colleagues demonstrated in an admirably thorough and large series of experiments that the ticks harbored and transmitted the causal agent. Additionally, they had to (and did) pass the organism transovarially. This is because the ticks use a single cow as a host in their development; an individual tick feeds and molts on the same animal from the larva through the adult engorgement. It could only be the next generation (larvae hatching from eggs in the pasture) that could pass on the infective organism. What a breakthrough that was: the first unequivocal demonstration of vector involvement in disease transmission and the first proven case of transovarial transmission! As is evident in the 301-page monograph from 1893 (Bureau of Animal Industry Bulletin Number One; Schultz 2008), the scientific quality and quantity of those experiments absolutely puts later and more famous efforts by Ronald Ross (malaria and mosquitoes) to shame. This started what some call the “golden age” of medical and veterinary entomology, as one important disease agent after another was shown to be transmitted by arthropods (e.g., Walter Reed’s remarkable Yellow Fever Commission in the early 1900s). But somebody was first, and that was Smith, in an animal system. The centennial of publication of this momentous discovery was commemorated by a special coin commissioned by the American Society for Veterinary Parasitology (Fig. 2).

Armed with the knowledge of how the pathogen was transmitted, beginning in the first decade of the 1900s, the federal government of the United States embarked on a very long (several decades) and sometimes bloody struggle to eradicate the tick (*R. annulatus* was the target here) by means of treatments such as arsenical dips (Graham and Hourrigan 1977). Officials basically had to treat every cow in the South, a process forcibly resisted by some ranchers of the time. It is uncertain whether we could do that now, but for many decades we have had a



quarantine zone with Mexico, where the pathogen and ticks still are common. The front line in this resistance is the Rio Grande River, and the troops are USDA-ARS and USDA-APHIS personnel, from the cowboys looking for roaming tick-infested cattle crossing a shallow spot in the river to the researchers trying desperately to stay ahead of things such as tick resistance to acaricides.

A little-known fact is that the quarantine “dam” right now, at this moment, is in danger of breaking. For a variety of reasons, such as the surprisingly frequent use of deer by the ticks and relatively low water flow in the Rio Grande River (Perez de Leon et al. 2012), the ticks and the pathogen they carry are relentlessly finding the weak points in our national armor. Dozens of local outbreaks occur yearly in Texas counties near the border (Fig. 3). Without strenuous and continuing efforts, there is no doubt that the tick and

**We must foster training programs to provide
new arthropod control technologies to
address changing conditions and loss
of effectiveness of previous methods
in livestock production systems.**

the disease would again sweep through the South and probably extend farther north than they previously did. Climate change has been steadily moving tick ranges northward relative to a few decades ago (Dergousoff et al. 2013, Ogden et al. 2013). We need veterinary entomology training programs to supply the scientists to carry that fight forward.

Cattle Grubs: Back from the Dead?

The Livestock Insect Workers Conference is a group of entomologists who assemble yearly for exchange of research information, updates from industry, and extension discussions. Its first gathering, in 1956, was triggered by a momentous discovery in pest control: organophosphorus insecticides could work systemically and kill tiny cattle grub (*Hypoderma* spp.) larvae making their way through the bodies of cattle (the esophagus or spinal canal, depending on the species). In other words, they never showed up as larger larvae in the backs of cattle, where

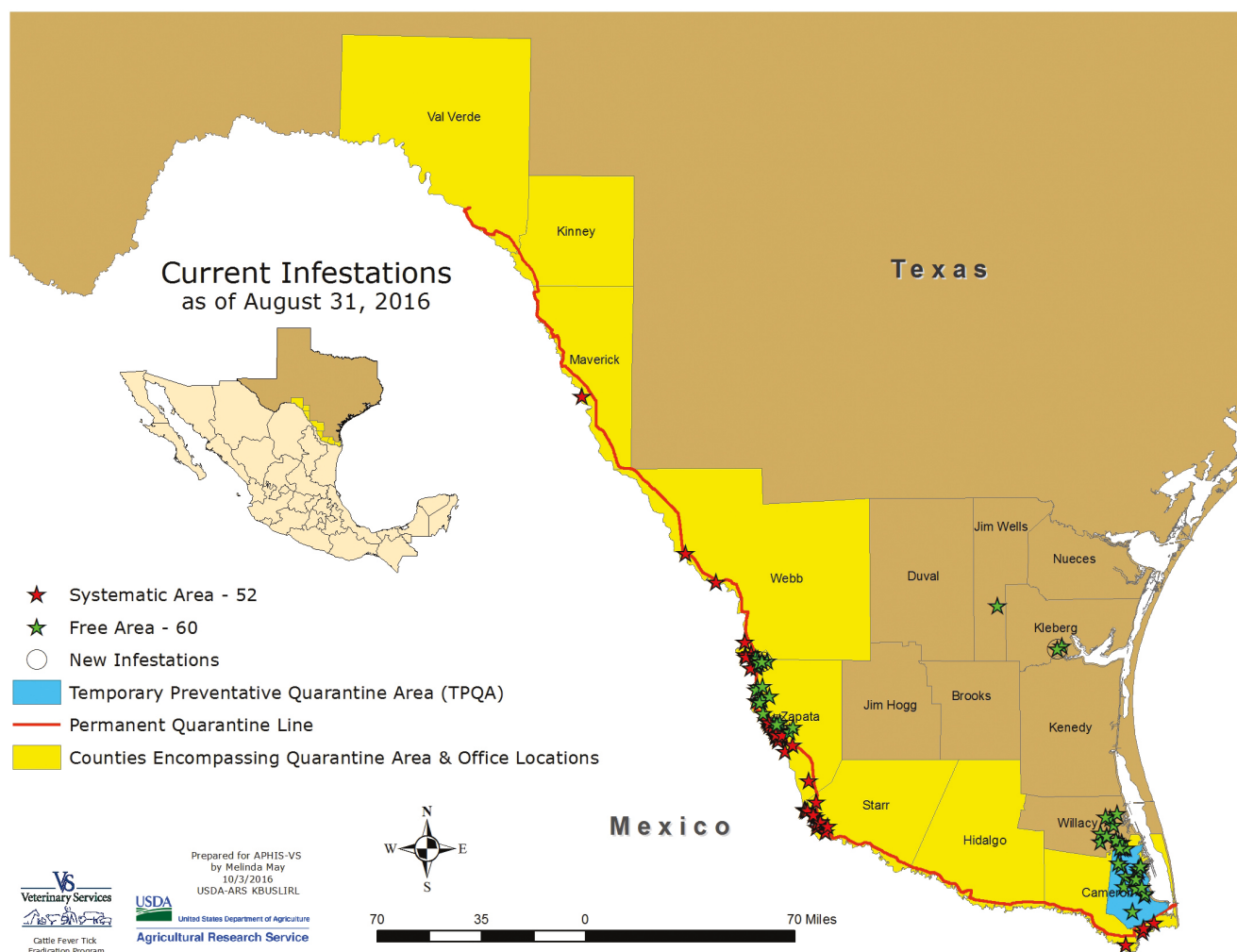


Fig. 3. Map of cattle fever tick (*Rhipicephalus annulatus* and *R. microplus*) infestations in Texas in late summer 2016 relative to the quarantine zone (figure courtesy of M. May and K. Lohmeyer, USDA Knipping-Bushland Livestock Insects Laboratory, Kerrville, Texas). Note the large number of incursions into and beyond the quarantine zone.

they caused significant damage to production, trim loss in the most valuable meat cuts damaged by grub activity, and leather damage to the thickest and most valuable part of the hide, caused by grubs chewing breathing holes (Fig. 4). A carefully timed treatment would free a herd from most infestation that year. Later, we would realize that even “microdoses” of the amazing parasiticide ivermectin would eliminate grubs, with less risk to cattle from adverse organophosphate reactions. Nowadays, it is difficult to locate clinical cases of mature cattle grubs in North American production herds, although the flies are remarkably adept at maintaining relict populations at relatively low field densities (Scholl 1993). Some European countries or regions apparently eradicated them while they had the chance, and perhaps a similar phenomenon has occurred in parts of North America.

However, cattle grubs are hanging on in scattered untreated herds in the United States and Canada, and they are still widespread in cattle in foreign countries such as the Indian subcontinent and eastern Europe (e.g., Gorcea et al. 2011). *Hypoderma* surveys in western Canadian yearling cattle from 2008–2010 showed 27–46%

seropositivity before their first treatment with macrocyclic lactones such as ivermectin, indicating natural exposure of those young cattle to cattle grubs (Colwell 2013). The ELISA values (enzyme-linked immunosorbent assay) were low, suggesting common but low-level exposure. Interestingly, clinical cases of cattle grubs seem to be absent in U.S. organic cattle, although quantitative survey data are lacking. In U.S. organic cattle, macrocyclic lactones such as ivermectin can be used on an emergency basis, but such treatment means the meat cannot ever be marketed as organic, and milk has a withdrawal period of 90 days (G. Jodarski, personal communication). All the same, we should be vigilant about a cattle grub resurgence and thinking ahead on how we could deal with it. Widespread and frequent use of the macrocyclic lactones for parasitic nematodes since the early 1980s, entertainingly called the “global worming” effect (Kaplan and Vidyashankar 2012), has led to widespread and serious resistance in damaging parasites such as *Ostertagia*, *Haemonchus*, and *Trichostrongylus*. This may lessen use of those materials in animal agriculture and perhaps encourage a cattle grub comeback.



Fig. 4. Cattle grub (*Hypoderma* spp.) damage to skin and meat in the back of a partially skinned steer (photo courtesy of D. Colwell, Agriculture and Agri-Foods Canada, Lethbridge, Alberta). *Hypoderma* larval photo by A. Murillo.

In the very old days, we used the natural plant product rotenone to kill grubs in cattle backs, and larvae indeed are somewhat accessible for treatment there with botanicals that might be used in operations such as organic systems. However, mature grubs in the back are big (2 cm). A dead, marble-sized piece of decaying insect body in its subcutaneous position is a recipe for some nasty infections. It also is possible to express larvae manually using the fingers, by placing a soda bottle atop the grub and giving it a sharp rap, or using a syringe to gently inject hydrogen peroxide into the space beneath the grub (Scholl and Barrett 1986). (In the latter case, the larva comes flying out of the animal's back as if shot from a cannon!) These techniques are a labor challenge and of dubious use on a commercial scale, however entertaining they might be in the short term.

There is a critical need for training programs and research on how to control pests in non-traditional animal production systems such as organic farms.

Ironically, at about the time ivermectin and similar materials hit the market, veterinary entomologists at Agriculture Canada and USDA had made substantial strides in developing a cattle grub vaccine (Scholl 1993). That was not commercially pursued due to its inability to compete with ivermectin, which must have been disappointing to the scientists, given all the work it had entailed over quite a few years. Maybe, however, we will see vaccines emerge as a treatment for grubs on organic facilities. Incidentally, in much of production animal agriculture, there are many other examples of arthropod pests under excellent control by macrocyclic lactones, such as scabies (*Sarcoptes scabiei* [L.]) or sucking lice (*Haematopinus suis* [L.]) in swine. Resistance by *Sarcoptes* to ivermectin has been known for over a decade (Currie et al. 2004) and resurgences are quite possible in untreated systems. Meanwhile, we have excellent research and control opportunities for veterinary entomologists, if we train them. Research on cattle grubs has been at a virtual standstill for decades, but they have potential to come back like the walking dead, and we need modern scientists to develop the new management methods that producers will need.

Stable Flies: Not Just a Confined Animal Pest Anymore

Stomoxys calcitrans has been a bad pest in North America and much of the rest of the world for many years. Both sexes bite the legs and lower body of livestock, approximately once daily, and cause much pain and suffering, which is reflected in reduced weight gains and/or milk production (Taylor et al. 2012). It is easy to spot a cattle herd under heavy attack. Cattle cluster together tightly, "dancing" madly (stamping their legs and throwing their heads) in an effort to dislodge the biting flies and



Fig. 5. Round bale in a Nebraska pasture. The hay debris is mixed into soil by cattle hooves and becomes a superior place for the stable fly, *Stomoxys calcitrans*, to develop (photo courtesy of D. Taylor, USDA-ARS, Lincoln, Nebraska). *Stomoxys* photo by B. Mullens.

jostling to get into the center of a cattle group to escape the worst fly attacks. These flies were introduced from Africa, and it seems a bit puzzling that we haven't at some time acquired one of the other 17 species in the genus. *Stomoxys nigra* Macquart, for example, is very damaging in Africa and would be an especially nasty addition to our North American fauna. Perhaps we should add that to the long list of potentially damaging exotic livestock pests (or associated diseases) we could get without the careful vigilance of entomologists who know what to expect and what to look for.

The larvae of stable flies inhabit moist organic substrates and especially like decaying vegetation if it is mixed with cattle urine or feces, which describes practically any confined livestock operation (e.g., beef cattle feedlots, confinement dairies in the Southwest). In northern locations such as Ontario, Canada, flies can persist in local refugia protected against extreme temperatures (Beresford and Sutcliffe 2009). Research has shown that stable flies may travel long distances on weather fronts (Jones et al. 1991, Showler and Osbrink 2015). This helps explain why they sometimes mysteriously appear by the thousands on beaches in the Florida panhandle and send beachgoers running in a panic from their otherwise beautiful surroundings. (Veterinary pests can also be human pests—it sometimes is a matter of circumstances.) Most of the flies probably originate well inland on livestock operations,



although rotting vegetation on beaches may produce a lot locally at times.

Traditionally, stable flies have not been a serious problem with pastured cattle; other muscoid Diptera such as the horn fly, *Haematobia irritans* (L.), or face fly, *Musca autumnalis* De Geer, develop in intact cattle dung pats and have filled that role. However, production methods change. Farmers seldom feed small, rectangular bales of hay to pasture cattle as a supplement anymore; they take a great deal of labor input relative to the much larger round bales. Round bales, 1.5 m or more in diameter, can be handled only by machinery; in fact, a single person probably can't even budge one without great effort. The huge bales are dropped into pastures or are sometimes placed within "feeder rings" that help confine the hay to some degree (Fig. 5). There is a lot of waste with the large bales, but they are still more affordable for farmers. As the surface hay layers are damaged by rain, sun,



Trained veterinary entomologists play a vital role in determining how integrated livestock-crop production and agroecosystems coming online may inadvertently contribute to animal pest populations, and how to minimize outbreaks.

and cattle feeding, loose hay falls to the ground. The hay eventually becomes one with the earth, after being trampled and liberally defecated and urinated on by the cattle. *Voilà*—the feeder rings thus become great sources of stable flies. In much of the Midwest and South, where significant natural rainfall occurs, pastured cattle now have bad issues with stable flies, whereas they did not before (Broce et al. 2005). In integrated plant agriculture, any changes in handling plant residues (e.g., composting or soil integration) can carry associated risks for exacerbating stable fly problems, as has recently been seen in Australia (Cook et al. 2011), and North America also is susceptible to that via changes in handling residues. This is another reason to call on trained veterinary entomologists for help, or better yet, consult them first and possibly avoid the problem.

Chicken Mite: Animal Welfare Creates a Niche

Our final example, chicken mite (*Dermanyssus gallinae*), called the poultry red mite in the European literature, is known to have been a bad chicken pest in the United States before World War II (Bishopp and Wood 1931; Fig. 6A). At that time, chicken and egg production looked a lot like scenes from Dorothy's family farm in the classic movie *The Wizard of Oz*. There were lots of hens running around on the ground, and they spent the night in roosts, where people came each day to collect the eggs by hand, one by one. There *Dermanyssus* joined a large number of other nasty chicken parasites—northern fowl mite, soft ticks in the genus *Argas*, sticktight and chicken fleas, and several species of biting lice—as a common pest in chicken roosts. In those days, several of the worst pests spent much of their time hiding in cracks and crevices near the roost areas. Legions of *Dermanyssus* and soft ticks came out at night to feed, then retreated to their hiding places, hiding from the daylight like Dracula in his crypt.

In the days after WWII, some enterprising California farmers led the way toward moving laying hens into cages (Fig. 6B). This provided major savings in labor and allowed fewer people to raise many more birds, greatly increasing profits. In the heady days of the early 1950s, the expected profit for a caged laying hen was an amazing \$5.00/year (Hartman 1953). Yet the absolute farm price of eggs (price per dozen) in the year 2000 was comparable to 1950, despite massive changes in the value of the U.S. dollar (Sumner et al. 2008). Profits per hen were far less in recent years. By scaling up production, eggs became relatively cheaper for consumers. Caged layer ranches began sprouting like pinfeathers over the California landscape

from Petaluma to Orange County, and other areas of the United States soon followed suit. As hens were crowded into cages, producers needed to invent and implement beak trimming methods, usually removing the beak tip using a hot blade when the birds were chicks. The beak eventually healed and resulted in a blunt beak tip that was a vastly inferior weapon with which caged hens would peck each other (they don't call it a "pecking order" for nothing), and there was less feed wastage.

While hen welfare aspects of the cages were (and are) open for serious debate (Lay et al. 2011), the cages have another unmistakable benefit overall—parasite control. Caged hens still have problems with some external parasites, such as northern fowl mite and lice, that complete their entire life cycle on the host. Crowded together and without proper beak tips for ectoparasite grooming (Chen et al. 2011), these birds are vulnerable to such external parasites, which spread well, reach high numbers, and cause a lot of economic damage or even become human pests for agricultural workers. However, lice have generally been pretty well controlled using pesticides, which can be readily applied using high-pressure sprays from underneath the suspended wire cages. Northern fowl mites can be readily treated that way, although they persist much better off-host than lice, and they move around and reinfest facilities via wild birds or moving equipment from one farm to another. Because caged hens are densely housed, accumulated feces and the subsequent fly issues (*Musca* and *Fannia* spp.) are also things farmers battle.

While cages have stimulated certain permanent ectoparasites or flies, they have given farmers an overall advantage in parasite control because they basically eliminate contact between hens and their feces. Feces fall directly away from hens onto a floor. The caged hens can no longer contact the ground either, so pests with a soil life stage, such as sticktight flea larvae (*Echidnophaga*) or soil-dwelling intermediate hosts of parasitic worms (such as beetles), have been entirely eliminated from caged flocks. Among arthropods, the soft ticks and *Dermanyssus* no longer have good hiding places near the hens, where they spend 99% of their time. Most importantly, perhaps, although they are not arthropods, many horrible parasitic nematode, tapeworm, and especially coccidian pests (*Eimeria* spp.) of chickens have been eliminated or greatly reduced in caged flocks by breaking the fecal-oral transmission cycle.

However, times and societal norms change. By the mid-1990s, western Europeans, led by the Scandinavians, began to eliminate conventional cages for animal welfare reasons and to substitute other designs, and some examples are described by Zhao et al. (2015). Crowded, bare wire conventional cages were viewed as cruel for the animals and legislatively were banned in the European Union by 2012 (see Sumner et al. 2008). Parasitically speaking, they didn't quite think this one through well enough. During that time, some of the traditional synthetic pesticide options used for ectoparasite control were also eliminated. In place of the conventional cages that once dominated western European egg production, hens are now housed



Fig. 6. (A) Chicken mites, *Dermanyssus gallinae*, have become serious problems in Europe since conventional cages (B) were banned for welfare reasons. This provides mites with necessary near-host harborage in alternative systems such as furnished cages (C), aviaries (D), or free range (E). The mite exists in the U.S. and Canada and is likely to become a problem in newer housing here as well. (Mite photos courtesy of M. Mul, Wageningen UR Livestock Research, Netherlands; conventional cage photo by B. Mullens; pasture photo by A. Murillo; furnished cage and aviary photos courtesy of J. Mench, Coalition for Sustainable Egg Supply Project [<http://www2.sustainableeggcoalition.org/>].)

in “furnished” cages (Fig. 6C), which have nestboxes, scratch pads, roosts, etc., that very effectively prevent efficient spraying with a pesticide. Alternatively, hens live in an array of cage-free options such as aviaries, culminating in free range or pasture systems (Fig. 6D, E). The newer housing gave chicken mites back their near-host harborage. As the conventional cages were eliminated, Europeans almost immediately began noticing that *Dermanyssus* had gotten worse—a lot worse. In fact, chicken mite vaulted to key pest status by the late 1990s. That

stimulated 20 years of research that still has not entirely solved the mite problem, although it is under better control (Sparagano et al. 2014).

Can this happen in North America? Of course it can; it is happening right now.

California’s Proposition 2, passed in 2008, banned cages at the usual densities by January 2015. Some California cage operations still exist, but hens are held at much lower densities. The long-term future of hen housing in North America pretty clearly is either in furnished cages or some kind of cage-free configuration. Consequently, we can expect egg costs for consumers to rise. Several other states and Canada now have set those poultry welfare wheels into motion, but on a longer time scale than we saw in California. Interestingly, the move toward cage-free eggs is being fueled almost entirely by demand by consumers who have never visited an actual farm but perceive hen welfare as better in cage-free conditions. Many huge egg suppliers, such as McDonald’s

and Walmart, subsequently have made pledges to use only cage-free eggs in the future. Whether customers are willing to pay for this remains to be seen, but the arthropods that need near-host shelter, *Dermanyssus* most certainly included, will eventually become much worse. Those parasites are already out there in North American backyard flocks (Murillo and Mullens 2016); the ectoparasite fauna on southern California backyard

Trained veterinary entomologists can determine how animal welfare and consumer concerns affect animal pest populations.

chickens is highly diverse and looks a lot like the fauna on feral chickens in Tanzania or Pakistan, but commercial birds and their producers haven't had to deal with this many parasite species in many, many years. Knowing this, veterinary entomologists have already been trying to develop a research base to provide pest control options for cage-free and organic systems. This is one of the ways that trained veterinary entomologists can help most. They know how changing systems, trends, and conditions can impact pest complexes and their management. Therefore, we need veterinary entomologists who can foresee these pest problems and help prepare our farmers and our general population to face them.

North American Veterinary Entomology Training Prospects

Going back to about 1980, most U.S. states with agricultural experiment station entomology programs had a person who dealt with pest control issues on agricultural animals. Canada had two entomology departments at the Universities of Alberta and Manitoba, an active veterinary entomology program at Guelph University, and one pest management program at Simon Fraser University. Canadian research on biting flies was particularly strong, with activities that stretched from Nova Scotia to British Columbia. Over the intervening time period, many changes have taken place. In general, a number of departments of entomology have been eliminated or merged into other units. As resources have been reduced, many veterinary entomology programs have died due to retirement or redirection. Medical entomology has a far greater glamour factor and lucrative NIH funding possibilities, and it has supplanted veterinary entomology research in several states.

A small bright spot in the veterinary entomology training arena is the fact that a number of USDA researchers do have adjunct appointments with departments of entomology in a few regions of the country. These scientists can have graduate students, providing some options for training more Ph.D.-level veterinary entomologists. It doesn't substitute for regular faculty in those departments, however.

Veterinary entomologists are well trained across the board in entomology as a science, but there is another important category of capable scientists and teachers

working in the area and coming from a parasitology perspective. Those faculty frequently teach from schools of veterinary medicine, and they do vital research on arthropod pests of animals and the associated pathogens they may transmit. Again, however, this doesn't entirely substitute for having scientists dedicated to and trained broadly in entomology. Aspiring veterinarians attending parasitology classes at the University of Tennessee or University of Georgia Schools of Veterinary Medicine, for example, receive only 1–2 weeks of classroom lecture on arthropods and ectoparasites, so a great deal of additional study is required for veterinarians to do research on them.

The recent loss of separate entomology departments in universities across the United States is well known, and only a single such department at the University of Manitoba now exists in Canada. By our rough estimate, relative to about 1980, dedicated veterinary entomology academic training faculty with an applied animal agriculture research emphasis have been lost in at least half the U.S. states where they once existed. The loss of veterinary entomology training capacity is unfortunate, and we hope that it can be reversed. As we have tried to show through the stories above, the need for veterinary entomologists persists and in fact is perhaps more urgent than at many points in the past. It is important we realize this and continue to train the next generation of veterinary entomologists within entomology departments.

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