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Surveys and Needs Assessments

Management of Plant and Arthropod Pests by Deer Farmers in Florida

Laura E. Harmon,[1] Katherine A. Sayler,[2] Nathan D. Burkett-Cadena,[3] Samantha M. Wisely,[2] and Emma N. I. Weeks[1,4]

[1]Entomology and Nematology Department, University of Florida, Gainesville, FL 32611, [2]Department of Wildlife Ecology and Conservation, University of Florida, Gainesville, FL 32611, [3]Florida Medical Entomology Laboratory, Entomology and Nematology Department, University of Florida, Vero Beach, FL 32962, and [4]Corresponding author, e-mail: eniweeks@ufl.edu

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Abstract

Deer farming is a growing livestock industry. As with established livestock farming, biting arthropod pest control is a challenge, but knowledge about pest control practices being utilized by deer farmers is limited. To fill this knowledge gap and to assess if recommended integrated pest management (IPM) programs were being used, we surveyed Florida deer farmers about their pest management programs via an online questionnaire. Of surveyed deer farmers in Florida, 94% reported using chemicals for plant and arthropod pest control. Deer farmers reported controlling biting midges, mosquitoes, horse flies, and deer flies as their target arthropods. The primary herbicide and arthropod-targeted pesticide reported were glyphosate and permethrin, respectively. Two thirds of deer farmers reported that they were concerned about pesticide resistance developing on their properties, and 72% reported utilizing resistance mitigation techniques such as alternating pesticides or using less pesticide at the start of a management routine. A majority, 66%, of deer farmers reported using a combination of control techniques. Future work should focus on best management practice development based on the study findings, as well as educational materials regarding IPM use for deer farmers. Together these tools should improve animal health and well-being on deer farms by facilitating safe and sustainable arthropod management.

Key words: deer farming, *Culicoides*, permethrin, best management practices, integrated pest management

Deer farming in the United States is a young and growing industry, with 7,828 deer farms in the country in 2007 (Anderson et al. 2007, DeVuyst 2013). A third of these farms (estimated at 2,639 farms) are hunting preserves, and the remainder are breeding operations, venison farmers (typically fallow and red deer, and elk), and scent collectors (Anderson et al. 2007). In Florida, there are approximately 400 deer farms (Anderson et al. 2007). Deer farming throughout the United States, especially in Florida, represents a lucrative industry as deer can be farmed on land that is not suitable for other forms of livestock or agriculture, can yield byproducts from animals such as venison, antlers, and hides, and can encourage tourism growth through guided tours and hunts (Brooks et al. 2015).

Arthropods that affect deer health include horse and deer flies, mosquitoes, ticks, and *Culicoides* biting midges (Diptera: Ceratopogonidae). Nuisance biting and vector-borne pathogen transmission by these arthropods can have economic impacts on the deer farming industry, just as they do in other livestock systems (Steelman 1976). Vector-borne diseases may lead to decreased fitness in livestock, which results in decreased productivity as well as morbidity and mortality (Steelman 1976). Some of these arthropods spread zoonotic pathogens, which also have impacts on public health, such as the pathogen that causes Lyme disease, which is transmitted by the tick, *Ixodes scapularis* (Say) (Ixodida: Ixodidae).

Horse and deer flies, or tabanids (Diptera: Tabanidae), represent serious deer pests, which could potentially result in economic losses through lowered livestock fitness (Perich et al. 1986), due to avoidance behavior, blood loss, localized skin reactions, secondary feeding in wounds, and myiasis as well as mechanical transmission of pathogens (Foil and Hogsette 1994). Tabanids are often associated with pathogens of bovids, such as *Bacillus anthracis* Cohn (Bacillales: Bacillaceae) and *Anaplasma marginale* Theiler (Rickettsiales: Anaplasmataceae) (Kraneveld and Djaenoedin 1940, Howell et al. 1941), and they likely also transmit these pathogens to and among deer. *Bacillus anthracis* is the causative agent of anthrax. Infection occurs when *B. anthracis* spores are ingested or inhaled during browsing or ingestion of soil, the spores germinate and replicate, the host dies, and then the blood of the host is exposed to oxygen resulting in contamination of surrounding vegetation and soil (Blackburn et al. 2014). Twenty-one tabanid species have been documented to mechanically transmit *B. anthracis* in a laboratory setting (Ganeva 2004), and tabanids have been directly implicated in the transmission of the bacteria during anthrax outbreaks (Mohiyudeen and Krishna Rao 1958). Tabinids also have been implicated in *A. marginale* transmission, an infectious agent of bovine anaplasmosis (Howell et al. 1941), which can infect other ruminants, such as deer (Morley and Hugh-Jones 1989, Keel et al. 1995). Infection with the pathogen is associated with losses in productivity in the cattle industry; however, deer are typically asymptomatic prior to death and can act as reservoirs (Keel et al. 1995).

Mosquitoes (Diptera: Culicidae) transmit various pathogens to humans and other animals. Eastern equine encephalitis (EEE) virus, which is a zoonotic pathogen transmitted by mosquitoes, has been detected in deer (Schmitt et al. 2007). EEE virus is transmitted by the *Culiseta* genus between birds and between birds and mammals by species in the genera *Aedes* and *Coquillettidia*. Mammals such as deer, humans, and horses are dead-end hosts; the disease caused by the virus is often fatal. In deer, symptoms include lethargy, confusion, poor coordination, tilted head, circling, blindness, paralysis, loss of fear, respiratory difficulties, emaciation, and death. Additionally, mosquitoes of the genus *Anopheles* transmit deer malaria, *Plasmodium odocoilei* (Haemosporida: Plasmodiidae), which reduces survival in fawns that become infected early in life (Guggisberg et al. 2018). Furthermore, blood feeding by female mosquitoes can be such a nuisance to other livestock that it drastically limits productivity (Steelman 1976).

Although research on the effect of ectoparasites on deer is limited, ectoparasites such as ticks are known to have effects on health and productivity of other livestock (Williams et al. 1977, 1978; Corrier et al. 1979; Riley et al. 1995). Bolte et al. (1970) found tick infestation to cause gross tissue damage in fawns, likely resulting in the death of four out of 11 tracked fawns. Ticks (Ixodida: Ixodidae) commonly found on white-tailed deer in the southeastern United States include *Amblyomma americanum* (Linnaeus), *Amblyomma maculatum* Koch, *Dermacentor albipictus* Packard, *Dermacentor variabilis* Say, *Ixodes affinis* Neumann, and *I. scapularis* (Kellogg et al. 1971). These tick species vector numerous pathogens to livestock and other animals. For example, ticks in the genus *Dermacentor* are vectors for *A. marginale*, the pathogen described earlier that also is transmitted by tabanids. In the United States, *A. americanum* is the major *Theileria cervi* (Bettencourt et al.) (Piroplasmorida: Theileriidae) vector, causative agent of theileriasis, to white-tailed deer (Cauvin et al. 2019). Theileriasis is a hemolytic disease, which, while relatively common in deer, mostly affects immunocompromised or translocated animals (Cauvin et al. 2019). In addition, deer may harbor zoonotic tick-borne pathogens, which as well as effects on deer themselves, have an impact on public health. *Ixodes scapularis* is known to vector *Borrelia burgdorferi* Johnson et al. (Spirochaetales: Spirochaetaceae), causative agent of Lyme borreliosis (Magnarelli et al. 1986). Although white-tailed deer are not reservoirs for the bacterium, in areas where deer density, human activity, and *I. scapularis* populations are high, risk of *B. burgdorferi* being transmitted to humans increases (Magnarelli et al. 1995, Kilpatrick et al. 2014).

Culicoides biting midges are common throughout the United States and transmit several important livestock diseases that makes their control vital in and around livestock facilities. For example, blue tongue virus (BTV) and epizootic hemorrhagic disease virus (EHDV) can impact fitness of infected animals, as well as result in mortality (Haigh et al. 2002). Mortality associated with BTV and EHDV ranges from 60 to 90% in previously unexposed animals (Prestwood et al. 1974, Roughton 1975, Hoff and Trainer 1978). *Culicoides* species that have been implicated in EHDV transmission include *C. variipennis* Coquillett, specifically *C. v. sonorensis* (Wirth & Jones), which also has been implicated in BTV transmission (Foster et al. 1977, Jones et al. 1977). *Culicoides insignis* Lutz is the other confirmed BTV vector in the United States (Tanya et al. 1992). Other *Culicoides* spp. are believed to act as vectors where the aforementioned vectors are not present or abundant. For example, in Florida, *C. stellifer* (Coquillett) and *C. venustus* Hoffman were implicated as EHDV vectors (McGregor et al. 2019). While these pathogens do not affect humans, BTV and EHDV in a region impacts not only cervids, but bovids as well, where bovids can have mild to severe clinical disease and potentially act as a reservoir (Hourrigan and Klingsporn 1975).

Best management practices (BMPs) are practices that protect the environment while also considering economic, availability, feasibility, and effectiveness factors. They are developed to provide protocols and information to stakeholders to enable management of property for target pest suppression while mitigating threat of resistance development and nontarget exposure. In cases where BMPs are being developed for pest control, integrated pest management (IPM) is frequently recommended as a tool to mitigate pesticide resistance. IPM involves use of monitoring and control to manage plant and arthropod pests in the most economical and effective manner possible (Kogan 1998). Control can include a combination of chemical, biological, mechanical, and cultural methods to reduce pest populations. It has been found that specially tailored IPM programs can be successful and cost-effective (Brenner et al. 2003). IPM use by deer farmers to control plant or arthropod pest populations in Florida has not been reported to date. With deer farming becoming an increasingly common industry in the United States, initial examination of the currently implemented management techniques of deer farmers is a crucial component in future development of management practices to effectively control pests while mitigating pesticide resistance development and protecting animal health on these facilities.

The purpose of this research was to: 1) assess deer farmer perception about pesticide use; 2) determine the type of pesticides used; 3) quantify the frequency with which pesticides are used; and 4) evaluate the current knowledge about pesticide resistance and incorporation of resistance mitigation tactics by deer farmers. This information was obtained through a Qualtrics survey delivered to deer farmers in Florida, and provided insight into behavior, attitudes, and knowledge of Florida deer farmers towards pesticides as well as allowed deer farmers to self-evaluate their pesticide usage level. Additional questions were focused on *Culicoides* biting midge management, as these small biting flies are important pathogen vectors in Florida and pose a significant threat to the industry (McGregor et al. 2019).

Materials and Methods

The survey was delivered to deer farmers, over 18 yr-old, in the state of Florida. Respondents were required to own deer in the state of Florida during the year surveyed. Gender, age, race, and ethnicity information about the deer farmers were not collected. The survey, which was submitted to the University of Florida Institutional Review Board (UF IRB) for consideration and approval, was declared exempt from full board review (IRB#201800055).

The survey was designed so that respondents only would be responsible for answering the questions that applied to them, based on their answers to previous questions. Due to this, the survey had a minimum of 10 and a maximum of 78 total questions. Questions addressed types of pesticides applied by deer farmers, as well as their application routines (Table 1). Pesticide

Table 1. List of questions in the survey distributed to deer farmers in Florida in 2018

Question	Type of answer	No. of responses	Response rate (%)
Approximately how many white-tailed deer do you have?	Text entry	32	100.0
Approximately how many acres are your white-tailed deer kept on?	Text entry	32	100.0
Do you have any of the following exotics on your property? Select all that apply:	Multiple choice	21	65.6
Do you have any of the following livestock on your property? Select all that apply:	Multiple choice	24	75.0
Do you have any of the following pets that are kept outdoors? Select all that apply:	Multiple choice	21	65.6
How do you house your white-tailed deer? Select all that apply:	Multiple choice	32	100.0
Do you apply chemicals to control unwanted pest insects/arthropods or to control growth of weeds?	Multiple choice	32	100.0
Do you use any of the following methods to control unwanted insects/arthropods?	Multiple choice	24	75.0
Do you use any of the following methods to control unwanted/undesirable plants?	Multiple choice	30	93.8
Have you observed pest insects/arthropods seeming to be less affected by pesticides on your property?	Yes/No	26	81.3
Do you use any of the following methods? Select all that apply:	Multiple choice	23	71.9
Are you concerned about pesticide resistance on your property?	Yes/No	27	84.4
Are you concerned about the health of your deer regarding pesticide exposure?	Yes/No	27	84.4
Which of these insect/arthropod pests do you attempt to control on your farm? Select all that apply:	Multiple choice	28	87.5
Please select the chemical product you apply to control unwanted pests:	Multiple choice	26	81.3
During what months do you treat for GENERAL insect/arthropod pest control. Select all that apply:	Multiple choice	28	87.5
Are you willing to provide detailed information on your pesticide usage on a month-by-month basis?	Yes/No	28	87.5
How much pesticide do you apply during the months you treat for GENERAL insect pest control	Slider scale	13	40.6
How often during the months you apply pesticide do you apply for GENERAL insect pest control?	Multiple choice	13	40.6
How much pesticide do you apply during the months you treat for GENERAL insect pest control?	Slider scale	13	40.6
How often during <Month> do you apply pesticide for GENERAL insect pest control?	Multiple choice	14	43.8
What method do you use to apply pesticide for indoor pens? Select all that apply:	Multiple choice	2	6.3
What method do you use to apply pesticide for outdoor pens? Select all that apply:	Multiple choice	27	84.4
What method do you use to apply pesticide on the preserve? Select all that apply:	Multiple choice	9	28.1
During what months do you apply pesticide to specifically control biting midges? Select all that apply:	Multiple choice	22	68.8
How much pesticide do you apply during the months you treat to specifically control biting midges?	Slider scale	10	31.3
How often during the months that you spray, do you apply pesticide for biting midge control?	Multiple choice	11	34.4
How much pesticide do you apply during the months you treat to specifically control biting midges?	Slider scale	9	28.1
How often during <Month> do you apply pesticide specifically for biting midge control?	Multiple choice	11	34.4
Do you know what herbicide(s) you use to control for unwanted/undesired plant growth?	Text entry	17	53.1
During which months do you apply herbicide to unwanted/undesired plants? Select all that apply:	Multiple choice	15	46.9
Are you willing to provide detailed information on your herbicide usage on a month-by-month basis?	Yes/No	15	46.9
How much herbicide do you put out during the months that you spray?	Slider scale	10	31.3
How often during the months that you spray do you apply herbicide on unwanted/undesired plants?	Multiple choice	11	34.4
If you would like more information about CHeRI, please include your e-mail address below.	Text entry	16	50.0

Questions abbreviated for brevity.

application methods provided in addition to a write in answer were misting system (sprinkler type usually around pens), pour-on (including spot-on, applied directly to the animal), rollers (i.e., 4-Poster Deer Treatment Device), ropes dipped in pesticide (similar to cattle backrubbers) and foggers (including ultra-low volume [ULV] sprayers). Housing type was defined as how deer were kept on the deer farm, and consisted of 'outdoor pens,' 'preserve/nonpenned,' and 'indoor pens.' A deer farm is a high-fenced property containing deer being bred or maintained as livestock. Within the farm there may be pens (indoor or outdoor) and/or a preserve. Pens are typically high-fenced areas with animals kept for breeding or other specialist uses. A preserve is a large high-fenced area within the farm with animals typically used for hunting purposes. Questions consisted of multiple choice, sliding scale, and brief text entry questions. Certain terms were used to avoid confusion. The term 'pesticide' was used to specifically refer to any chemical used to kill an arthropod, 'herbicide' was used for any chemical used to kill a plant pest, and 'dose' was used to refer to concentration. All scientific terms, including pesticide and herbicide, were defined for the respondent.

The survey was distributed to deer farmers through Qualtrics in 2018. Access to the survey was provided by asking deer farmer-oriented meeting attendees to take the survey in person, by providing an anonymous link to deer farmers who preferred to take the survey after meetings, and by distributing an anonymous link to the survey through the University of Florida, Institute of Food and Agricultural Sciences (UF/IFAS) Cervidae Health Research Initiative (CHeRI) listserv of approximately 50 deer farmers currently registered in the state of Florida. Respondents were expected to complete the survey immediately if taken in person. Deer farmers who were given anonymous links to the survey were given 3 wk to respond through Qualtrics, after which the associated survey was locked to additional entry. Deer farmers contacted through the CHeRI listserv were given 3 wk to respond to the e-mail, during which time they were reminded about the survey twice, before the survey was locked to additional entry. At each event those who had already taken the survey were requested not to complete it again.

Response rates were calculated for each survey event, of which there were five (Table 2). Four out of five survey events had responses, with the final survey having no additional responses. All surveys were delivered in person except for the final two survey events; event four was delivered via the April 2018 UF/IFAS CHeRI newsletter to deer farmers, and event five was delivered via e-mail.

All responses were combined in Qualtrics, and the percentage of respondents was reported for most questions. Minimum, maximum, and average were calculated for number of white-tailed deer kept on properties as well as property size. Average amount and frequency of pesticide application for general arthropod and *Culicoides* control was reported by month. Amounts were reported by each farmer on a scale from 1 to 5, with 1 being very little and 5 being very high. Utilization of an IPM strategy by a deer farmer was defined as using two or more listed strategies to control unwanted arthropods or plants.

When evaluating month by month control efforts for general arthropod and *Culicoides* management, substantial effort was considered for reports over a threshold of five (15% of deer farmers surveyed). Chi-square tests were conducted to evaluate if there were statistically significant differences ($\alpha = 0.05$) in each pesticide application method use between housing types.

Results

Response Rate for Each Survey Event

In total, 32 deer farmers were surveyed across all events out of a pool of 50, for a total response rate of 64%. The survey was given as separate events on field days, at meetings, and through newsletters and e-mails (Table 2) and took approximately 15–20 min to complete. Response rate varied from 0 to 30.5% (Table 2). Not all questions were answered by all participants as deer farmers had the option to stop the survey at any time (Table 1). Fourteen deer farmers replied to the more detailed version of the survey out of all respondents (43.8%) for general arthropod control and 11 (34.4%) for biting midge control. Only four deer farmers responded to the detailed version of the survey for unwanted/undesirable plant control, so these data have not been reported herein. Two potential respondents opened the survey but did not answer any questions.

Animals Reported on Deer Farms in Florida

Respondents reported variation in number and diversity of game and nongame animals located on farms, as well as in total farm acreage. On average, the white-tailed deer per farm was approximately 93 animals (2–700). Animals were kept on an average 151 acres (2–2,000 acres). Non-native ruminant species most often reported on farms included: axis deer (52.4%), black buck (38.1%), elk (33.3%), gemsbok (14.3%), fallow deer (14.3%), and Père David's deer (4.5%). Other exotic animals (23.8%) that deer farmers listed included: red deer, muntjacs, bongo, kudu, nilgai, sika deer, nyala, and eland. Horses were the most reported livestock (50.0%), with cattle, goats, and chickens each having the second highest percentages (all at 33.3%) followed by sheep (4.2%). Other livestock listed were guinea fowl, ducks, and turkeys (16.7%). Dogs made up the highest percentage of domesticated pets reported (71.4%), followed by cats (47.6%), and one bobcat (4.8%).

White-Tailed Deer Housing

Most respondents reported housing their deer in outdoor pens (96.9%), with other housing methods including on a preserve/

Table 2. Deer farmer survey response information for events in 2018

Event No.	Date	Description	Pool	Respondents	Response rate (%)
1	Jan. 27	UF/IFAS IPM Field Day	35	10	28.6
2	Apr. 14	SETDA Spring Fling	36	11	30.5
3	Apr. 20	UF/IFAS Deer Forage Field Day	12	2	16.7
4	May	UF/IFAS CHeRI newsletter	50	11	20.0
5	May	UF/IFAS CHeRI listserv e-mail	50	0	0.0

UF/IFAS = University of Florida Institute of Food and Agricultural Sciences, IPM = integrated pest management, SETDA = Southeast Trophy Deer Association, CHeRI = Cervidae Health Research Initiative.

nonpenned (37.5%), and indoor pens (9.4%). A combination of penned and nonpenned animals was reported by 11 respondents (34.4%). One report described fawns being housed in outdoor kennels before being moved to adult housing; adult housing type was not specified (3.1%).

Pesticide Application

Of 32 respondents, 93.8% reported using chemicals on their property. Approximately half the surveyed deer farmers (53.1%) reported using chemicals to control both plant and arthropod pests on their properties. Other respondents utilized only arthropod-targeted pesticides (37.5%), 3.1% utilized only herbicides, and 6.3% utilized no pesticides.

The primary herbicides utilized by respondents were glyphosate (81.8%), 2,4-dichlorophenoxyacetic acid (36.4%), a combination of metsulfuron methyl and nicosulfuron (18.2%). Lactofen, sodium bentazon, captan, clethodim, fluazifop-P-butyl, ammonium imazapic, and ammonium phosphate were reported once per chemical (9.1%).

Deer farmers were concerned with arthropod pests, in order of most concern to least concern: *Culicoides* biting midges, mosquitoes, horse flies and deer flies, ticks, stable flies (Diptera: Muscidae), horn flies, and fire ants (Hymenoptera: Formicidae) and house flies (Diptera: Muscidae) (Fig. 1). A majority (81.1%) of respondents said that they used pyrethrins or pyrethroids (permethrin 85.7%, bifenthrin 9.5%, and pyrethrins 9.5%) to control unwanted arthropods, with 3.8% of respondents relying on organophosphates, hydramethylnon, and a combination of hydramethylnon and *S*-methoprene, an insect growth regulator. A low percentage of deer farmers (19.2%) were uncertain what pesticide they were using at the time the survey was distributed.

Deer farmers were asked to report their main pesticide application method in their animal housing facilities. The pesticide application methods reported by two of the three farmers who used indoor pens were foggers, misting systems, ropes dipped in pesticide, rollers, and pour-on pesticide. Pesticide application methods reported for outdoor pens were (from most to least reported): foggers, misting systems, ropes dipped in pesticide and pour-on pesticide (two methods equally reported), and rollers (Table 3). Where deer were not kept in pens, pesticide application methods reported were (from most to least reported): foggers, misting systems, and ropes dipped in pesticide, pour-on pesticides, and rollers (last three methods equally reported; Table 3). There was no significant difference in pesticide application method use between housing types ($P > 0.05$).

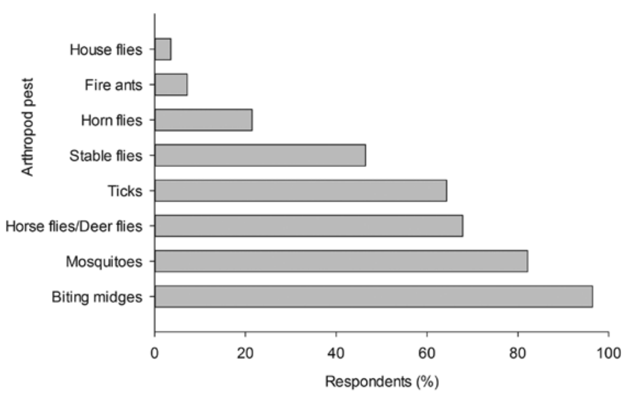

Fig. 1. Arthropods targeted for control on Florida deer farms in 2018. Percentage of respondents who listed the arthropod on the survey. Total number of respondents was 28.

General arthropod control (not targeting any specific arthropod pest) occurred beginning in March and lasting through October, with peak application beginning in July and lasting through September (Fig. 2). During this period, most deer farmers reported applying pesticide weekly (23.1%). On a scale of one to five, deer farmers on average reported using little pesticide in January, March–June, and November. In addition, deer farmers reported using moderate amounts of pesticides in February, July through October, and December (Table 4). Application frequency varied from 'daily' to 'when needed' in almost every month. Daily treatments began in March and continued through November (Table 4).

Biting midge control occurred beginning in April and continued through October. The largest peak for biting midge control began in July and continued through September (Fig. 2). Most deer farmers reported applying pesticide either weekly or every other week (27.3%) during the entire period they were treating for biting midge control. When asked for more detailed information on timing of control specifically for *Culicoides* biting midges, on a scale of one to five, deer farmers on average reported using moderate levels of pesticides from January to March, little pesticide from April to June and in October, and moderate levels of pesticides from June to September, and in November and December (Table 4). Application frequency varied from daily to when needed in almost every month. Daily treatments began in June and continued through September (Table 4).

The majority of deer farmers reported that they had not observed arthropod pests on their farms becoming more resistant to pesticides on their properties over time; however, most respondents were concerned about the possibility of pesticide resistance developing on their properties (Fig. 3). Farmers also expressed concern over the health of their deer or other animals on their property when encountering applied pesticides (Fig. 3). Respondents used the following resistance mitigation methods when applying pesticides: using lower doses of pesticides when possible (56.5%), using mixtures (43.5%), rotating pesticides (39.1%), using higher doses of pesticides if the first dose does not kill all target pests (30.4%), and providing pesticide-free refuge areas to maintain pesticide susceptible pest arthropods (4.3%).

Non-chemical Control Methods

Deer farmers reported using nonchemical control methods for plant pest reduction (93.7%). Combination of physical barriers and mowing was reported as the most common (63.3%) nonherbicidal method utilized to control plant pests. Physical removal (pulling plants) was the second most reported method (16.7%). Both reproduction prevention (e.g., removal of fruits; 10.0%) and natural predator use (e.g., herbivores; 10.0%) were the third most reported methods used for control of unwanted growth of weeds or undesirable plants. It also was determined that 50.0% of surveyed deer farmers were using an IPM program, i.e., more than one control strategy, in their weed management.

Unwanted arthropod control through nonpesticide methods was reported by 75% of farmers. Cultural control or prevention (e.g., removal of larval development sites; 29.2%) and biological control or natural predators, parasitoids, or parasites (29.2%) as the most utilized methods, with mechanical control methods such as trapping to reduce population density and physical control methods including barriers and screens (both at 20.8%) as the least utilized methods. When deer farmers who reported using biological controls for arthropod management were further questioned, it was found that

Table 3. Pesticide application on Florida deer farms in 2018 for nonpenned and outdoor pens (percentage of deer farmers who reported application technique)

Application techniques	Nonpenned (%)	Outdoor pens (%)
Foggers, including ULV fogging	66.7	81.5
Misting system	33.3	18.5
Ropes dipped in pesticide	11.1	14.8
Pour-on, including spot-on	11.1	14.8
Rollers, including 4-poster	11.1	3.7

Total number of respondents was 9 and 27 for nonpenned and outdoor pens, respectively. ULV = ultra-low volume.

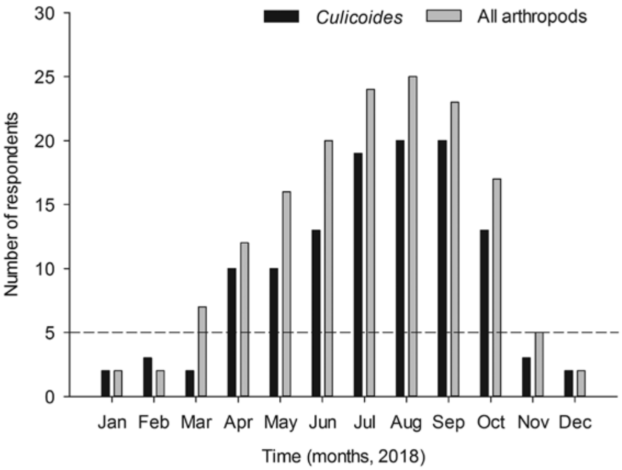

Fig. 2. Seasonality of *Culicoides* and general arthropod control on Florida deer farms in 2018. Number of respondents who reported pesticide application within a month for control of *Culicoides* and all arthropods on Florida deer farms. Pesticide application was considered high in months when reports exceeded five responses (dotted line). Total number of respondents were 28 and 22 for general arthropod and *Culicoides* management, respectively.

they were encouraging general predator presence (e.g., bats or birds) versus a specialized predator. It also was determined that 65.6% of surveyed deer farmers were using an IPM program, i.e., more than one control strategy, in their arthropod management.

Discussion

We were able to determine that the most utilized pesticide for arthropod management was permethrin and the most utilized herbicide was glyphosate. We found that deer farmers were managing for a wider variety of arthropod pests than was expected. We predicted that deer farmers would predominantly be managing for *Culicoides* biting midges, and, while 96.4% of deer farmers were managing *Culicoides*, deer farmers also were managing mosquitoes, horse flies/deer flies, and ticks.

Our finding that *Culicoides* biting midges were the most targeted arthropod was expected, but this has important implications for understanding pesticide resistance in this important vector group. Prior to this study, precise methods that Florida deer farmers were using to manage *Culicoides* biting midges had not been reported. Because deer farmers are targeting *Culicoides*, and using pyrethroids to control populations, recommendations can be developed to help mitigate pyrethroid resistance development in this genus. Methods reported elsewhere to control *Culicoides* biting midges have included: pesticide application to larval developmental sites; pesticide application to adult resting sites, including animal housing and hosts; using fine mesh screening barriers on livestock enclosures; placing livestock in midge-proof housing when adult *Culicoides* are active; and using repellents (Carpenter et al. 2008). We found that for Florida deer farmers, the primary method included application of pesticides to animal housing and directly to hosts, and the primary nonpesticide method was larval developmental site removal and attempts at biological control. Resistance development in this group would make it more difficult for deer famers to control *Culicoides* populations on their properties and could lead to greater EHDV and BTV outbreaks, which could lead to decreased production and increased losses for deer farmers.

Pesticide application in outdoor pens was reported as varying from 'daily' to 'when needed' in most months for both general arthropod and *Culicoides* control. This result implies that farmers are applying pesticide very frequently and perhaps could benefit from advice about surveillance, economic thresholds, rotating active ingredients with different modes of action, and how to target pesticide applications spatially and temporally. Frequent pesticide applications can greatly increase risk of pesticide resistance developing, which most deer farmers surveyed said that they were concerned with even if they had not, to their knowledge, seen it developing on their properties. A high percentage of deer farmers who reported using resistance mitigation techniques on their properties also were implementing more than one control method, in other words applying an IPM strategy. Concern with the potential for pesticide resistance on their properties, and willingness to utilize resistance mitigation techniques and combinations of techniques shows that introduction of BMPs is likely to be welcomed by deer farmers.

Resistance mitigation should help to prolong the life of the active ingredients available. There are only a few options for livestock farmers that wish to rotate active ingredients with different modes of action. On deer farms in Florida, approximately 75% of applications are made to the environment, and 25% indirectly and directly to the animals themselves. As deer farming is a relatively new industry, there are few products that are registered for use on deer. As it is a federal law to follow the label with regards to application of pesticides on species and sites, deer farmers have few viable options. Although, the 4-Poster Deer Treatment Device with 10% permethrin is registered for use to control ticks on deer, they are difficult to deploy on deer farms due to livestock density. To protect these high value animals, it seems pertinent that the industry pursues an exemption for application of effective active ingredients directly to animals through the U.S. Environmental Protection Agency Federal Insecticide, Fungicide, and Rodenticide Act (U.S. EPA FIFRA). Obtaining either a section 18 (emergency exemption) or a section 24c (special local need) could enable deer farmers access to more products, potentially permitting them to rotate active ingredients with different modes of action to slow resistance development and apply directly to animals to reduce waste and environmental contamination.

In addition to *Culicoides*, it is important to note that deer farmers are treating other arthropods with pesticides. These arthropods are known nuisances or pathogen vectors to white-tailed deer and pose a risk to the livestock industry and public health (Steelman 1976). Presence and treatment of multiple arthropod pests throughout much of the year affects pesticide application rates, as it means that deer farmers are using pesticides more frequently than they would be for a single pest. As deer farmers are targeting a wide arthropod pest variety, a single BMP that encompasses all arthropod pests would likely be the most effective approach; however, this would

Table 4. Pesticide application amount and frequency for general arthropod control versus *Culicoides*, specifically, by month

Month	Arthropod target	Average amount (Scale 1–5)	Daily	3–4 times per week	Twice per week	Weekly	Every other week	Once a month	When needed
Jan.	General arthropods	2.0				■		■	
	Culicoides	3.0				○		○	
Feb.	General arthropods	3.0				■		■	
	Culicoides	3.0				○		○	
Mar.	General arthropods	2.7	■		■			■	
	Culicoides	3.0				○		○	
Apr.	General arthropods	2.7	■		■		■	■	■
	Culicoides	2.3			○	○		○	○
May	General arthropods	2.9	■				■	■	■
	Culicoides	2.3			○	○		○	
Jun.	General arthropods	2.9	■		■	■	■	■	■
	Culicoides	2.8	○		○	○		○	○
Jul.	General arthropods	3.4	■	■	■	■	■	■	■
	Culicoides	2.9	○	○	○	○	○	○	○
Aug.	General arthropods	3.7	■		■	■	■	■	■
	Culicoides	3.1	○		○	○		○	○
Sep.	General arthropods	3.5	■		■	■	■	■	■
	Culicoides	3.3	○		○	○	○	○	○
Oct.	General arthropods	2.9	■	■	■	■		■	■
	Culicoides	2.7		○	○	○		○	○
Nov.	General arthropods	2.5	■			■		■	
	Culicoides	3.5				○		○	
Dec.	General arthropods	3.0				■		■	
	Culicoides	3.0				○		○	

Amount reported by each deer farmer was on a scale from 1 to 5, with 1 being very little and 5 being very high. Black squares (■) represent applications for general arthropods while open circles (○) represent applications for *Culicoides* reported in a month. Total number of respondents were 14 and 11 for general arthropod and *Culicoides* management, respectively.

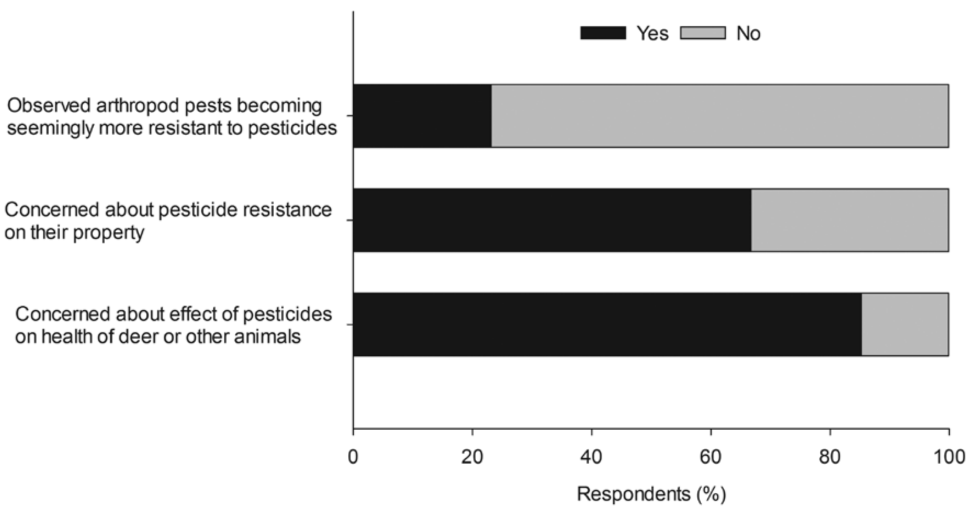

Fig. 3. Issues related to pesticide resistance and toxicity addressed by the survey, and percentage of deer farmers surveyed in 2018 who responded affirmative or negative. Total number of respondents were 26, 27, and 27 from top to bottom bars.

pose a substantial challenge, given the variation in biology, ecology, and phenology of the diverse pests and vector groups.

Through this survey, we found that deer farmers kept several different ruminant species along with their white-tailed deer. Among these animals were other cervids and bovids, which are likely affected by the same vector-borne pathogens for which white-tailed deer are hosts or reservoirs, such as *A. marginale*. Given that most deer farmers house animals in outside pens, most deer on deer farms in Florida are likely to encounter diverse pathogen vectors over their life. Deer on farms also are being held at higher densities than would be found in the wild (Cauvin et al. 2020), and high deer density is known to increase tick numbers, which likely increases disease exposure risk (Magnarelli et al. 1995). Now that we know which animals are present with deer on properties, as well as housing types being incorporated, we can focus BMPs to include these animals and housing types so that their utility is improved for Florida stakeholders.

Most respondents housed at least some of their animals in pens, while it was not a focus of this survey, Anderson et al. (2007) reported that on average deer farming facilities had 8–13 pens, which were 20–25 acres in size. Only a third of the farmers interviewed kept animals on a preserve, while not a question in our survey, previous surveys found these areas to be approximately 1,600 acres on average (Anderson et al. 2007). For both penned and nonpenned locations, pesticide application methods were reported in the same order of use. Foggers, misting systems, and ropes dipped in pesticide were the most utilized methods in both areas of the farm. Therefore, BMPs should focus on use of these tactics but consideration should also be given to if these methods should be used in the same frequency in both areas. For example, in penned areas fogging systems will result in much higher contact of deer with active ingredients than in nonpenned areas. As the majority of deer farmers are concerned about effects of pesticide exposure on their animals and previous studies have demonstrated negative health effects of permethrin, the most commonly used pesticide on deer farms, on other mammals (Imamura et al. 2002, Anadón et al. 2009, Wang et al. 2016), further research into how permethrin may be sequestering in animals on deer farms and potential health effects is warranted.

Response rates varied for each survey event. Response rates to in-person surveys were 16.7 to 30.5%. Response rates when delivered through electronic means varied from 20% to no responses, and often needed one or more reminders to complete the survey. As the survey period continued, fewer deer farmers responded to each survey instance. However, it is important to note that most survey events targeted the same potential participant pool. Response rates for each event are likely underestimated for two reasons. Firstly, there were multiple individuals from each farm present at an event making up the pool, but only one survey was taken per farm. Secondly, after each event the pool of people who had not yet completed the survey decreased. At the end of the survey period, 32 responses were obtained from approximately 50 deer farms registered in the CHeRI database, for a total response rate of 64.0%. For a survey consisting of more than 12 questions, that is being delivered to individuals not obligated to complete the survey, greater than 50.0% is a good response rate (Nulty 2008). We believe having multiple survey delivery methods contributed to having responses from over 60% of surveyed deer farmers.

There remains room for improvement to increase survey response rates, and future survey instances should seek to motivate respondents to respond either through a clearer explanation of what the data will be used for or by using incentives. Research has shown that use of predetermined incentives has the most impact on survey response rate (Saleh and Bista 2017). A study by Saleh and Bista (2017) showed that the highest response rate came when respondents were interested in the topic. The survey delivered to deer farmers was already highly targeted; however, there was no follow-up conducted to determine how deer farmers felt about the survey once they had completed it. A survey evaluation could be distributed to determine sections deer farmers felt should be improved upon in the survey and what could be done to encourage responses.

This survey was the first to assess deer farmers' views of pesticides and how and when they are using pesticides on their property. This information will be useful in the future to aid in BMP development for arthropod and weed management on deer farms within Florida. In the future, educational materials should be sent out to deer farmers to address gaps in knowledge identified during the survey. Educational material should consist of information on weed and arthropod management, specifically IPM and resistance development. BMP development, specifically for use on deer farms, should improve animal health and well-being on deer farms by facilitating safe and sustainable arthropod and plant pest management.

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