

# Use of Body-Mounted Cameras to Enhance Data Collection: An Evaluation of Two Arthropod Sampling Techniques

James R. Hagler,<sup>1,2</sup> Alison L. Thompson,<sup>1</sup> Melissa A. Stefanek,<sup>1</sup> and Scott A. Machtley<sup>1</sup>

<sup>1</sup>Arid-Land Agricultural Research Center, USDA-ARS, 21881 North Cardon Lane, Maricopa, AZ 85138 and <sup>2</sup>Corresponding author, e-mail: [james.hagler@ars.usda.gov](mailto:james.hagler@ars.usda.gov)

Subject Editor: Kris Godfrey

Received 3 January 2018; Editorial decision 15 March 2018

## Abstract

A study was conducted that compared the effectiveness of a sweepnet versus a vacuum suction device for collecting arthropods in cotton. The study differs from previous research in that body-mounted action cameras (B-MACs) were used to record the activity of the person conducting the arthropod collections. The videos produced by the B-MACs were then analyzed with behavioral event recording software to quantify various aspects of the sampling process. The sampler's speed and the number of sampling sweeps or vacuum suction taken over a fixed distance (12.2 m) of cotton were two of the more significant sampling characteristics quantified for each method. The arthropod counts obtained, combined with the analyses of the videos, enabled us to estimate arthropod sampling efficiency for each technique based on fixed distance, time, and sample unit measurements. Data revealed that the vacuuming was the most precise method for collecting arthropods in the relatively small cotton research plots. However, data also indicates that the sweepnet method would be more efficient for collecting most of the cotton-dwelling arthropod taxa, especially if the sampler could continuously sweep for at least 1 min or  $\geq 80$  m (e.g., in larger research plots). The B-MACs are inexpensive and non-cumbersome, the video images generated are outstanding, and they can be archived to provide permanent documentation of a research project. The methods described here could be useful for other types of field-based research to enhance data collection efficiency.

**Key words:** video tracking, arthropod sampling, cotton, Miridae, natural enemies

Body-mounted action cameras (B-MAC) have become increasingly popular for documenting sports events and other outdoor activities. This is due, in large part, to their small size, relatively low cost, durability, and exceptional video and audio quality. B-MACs have proven useful ideal for making self-videos of extreme sporting events (e.g., skiing, skydiving, surfing, etc.) and have been invaluable for quantifying various aspects of human behavior. For example, many police departments now require their officers to wear B-MACs. The videos produced by the B-MACs are useful for documenting evidence at a crime scene, training officers on proper police procedures, and increasing transparency and accountability to the public (Miller et al. 2014).

B-MACs have also been adapted for use in animal behavior studies. Specifically, B-MACs have been mounted onto various stationary (e.g., poles, trees, etc.) and non-stationary (e.g., high-speed trains) devices and used to monitor activities of vertebrates (aquatic and terrestrial) and invertebrates (Steen and Thorsdatter Orvedal Aase 2011, Letessier et al. 2013, Edwards et al. 2015,

Ferrari et al. 2015, Holding et al. 2016, Nakase and Suetsugu 2016, Garcia de la Morena et al. 2017, Gilpin et al. 2017). While B-MACs have been used to study animal behavior, they can also be used to monitor the behavior of researchers collecting data. Such recordings would provide permanent video documentation of scientific processes that could be used to: 1) acquire additional data for an experiment (as demonstrated in this study), 2) provide permanent documentation of a study (i.e., a video notebook), and 3) serve as a visual training aide for the next generation of students and employees.

We conducted a proof-of-concept study showing how B-MAC videos can be useful for documenting researcher activity and efficiency while collecting data in the field. We demonstrate how video surveillance data can be used to enhance and refine arthropod count data (i.e., choose the best sampling method) obtained by collections with a sweepnet and vacuum suction device. The techniques described here can be adopted to other types of field research to improve data acquisition.

Published by Oxford University Press on behalf of Entomological Society of America 2018.

This work is written by (a) US Government employee(s) and is in the public domain in the US.

This Open Access article contains public sector information licensed under the Open Government Licence v2.0 (<http://www.nationalarchives.gov.uk/doc/open-government-licence/version/2/>).

## Materials and Methods

### Arthropod Collection

#### Study Site

The study was conducted within a 0.87-ha upland cotton field (*Gossypium hirsutum* L.; cv DP1044B2RF) located at the University of Arizona Maricopa Agricultural Center, Maricopa, AZ (33.068°N, 11.971°W). The field was planted with approximately 7.6 cotton seeds/m on 1.02-m inter-row spacings on 18 May 2016 and grown using standard agronomic practices. The field was furrow irrigated as needed until 8 June 2016, after which it was drip irrigated as needed throughout the remainder of the study. Irrigation schedules were determined from a daily soil water balance model based on Food and Agricultural Organization-56 methods (Allen et al. 1998). The field was sprayed with pyriproxyfen (0.8 liter/ha), a *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) specific insect growth regulating insecticide on 22 July 2016.

#### Sampling Devices

The vacuum suction sampling device used was similar to the D-vac described by Dietrick (1961). The removable sample nets were made of nylon mesh. Each net measured  $\approx 52$  cm in diameter and  $\approx 42$  cm in length. The nets were attached to the end of the 35-cm diameter orifice of the vacuum hose with six 'Large, Hardened Steel' Binder Clips (Skilcraft, New Britain, CT) spaced equidistance apart. Suction air velocity of the D-vac was measured by a hand-held anemometer (CFM/CMM Thermo Anemometer, Model AN100, Extech Instruments, Melrose, MA) placed at the opening of the suction tube. The measurement was made at full throttle, with a collection bag in place. The vacuum collector achieved a sustained suction air velocity of  $6.1 \text{ m s}^{-1}$ . The sweepnet used was a standard 38-cm diameter 'net' that was constructed of durable canvas cloth (Catalog #7635HS, BioQuip Products Inc., Rancho Dominguez, CA). The net was attached to a 0.9-m wooden handle.

#### Arthropod Sampling Procedures

Arthropods were collected from six adjacent cotton plots that were embedded within the larger cotton field described above. Each plot was 12.2 m in length and contained 12 rows of cotton. Arthropods were collected with the sweepnet and vacuum devices on 9, 13, and 19 September 2016 between the hours of 0700 and 0900. The entire sampling process was video recorded with two B-MACs. It should be noted that these B-MACs are capable of continuously monitoring the sampler's GPS coordinates as they walk through the field. As

such, the plot plan and a typical path taken by the primary sampler, based on his GPS coordinates, is depicted in Fig. 1. The sweepnet and vacuum suction samples were always made from row 3 and row 10 of each of the six plots, respectively. The rationale for sampling the same rows on each sampling date with the same device was to give us the ability to assess the overall damage incurred by repeatedly sampling the same cotton plants each week using a field-based high-throughput phenotyping platform (in preparation). Our sampling protocol consisted of walking down the entire length (12.2 m) of each designated row in each plot at a constant (natural) speed with each device. We were not concerned about taking the same number of sweeps or vacuum suctions or sampling for the same length of time in each plot as we had planned to use the video recordings to standardize our data presentation of the arthropod counts.

After each vacuum sample was completed, the net was removed (with suction still being supplied by the vacuum) from the intake hose, and the entire net and its contents were immediately placed into a 3.8-liter zipper plastic bag. After each sweepnet sample was completed, the entire contents of each sample was dumped directly into a 3.8-liter plastic bag. The samples were placed into a chilled ice chest within a few minutes after each collection and frozen within an hour of the collection in a  $-20^\circ\text{C}$  freezer at the laboratory. The arthropod samples were stored in the freezer until they could be sorted and counted.

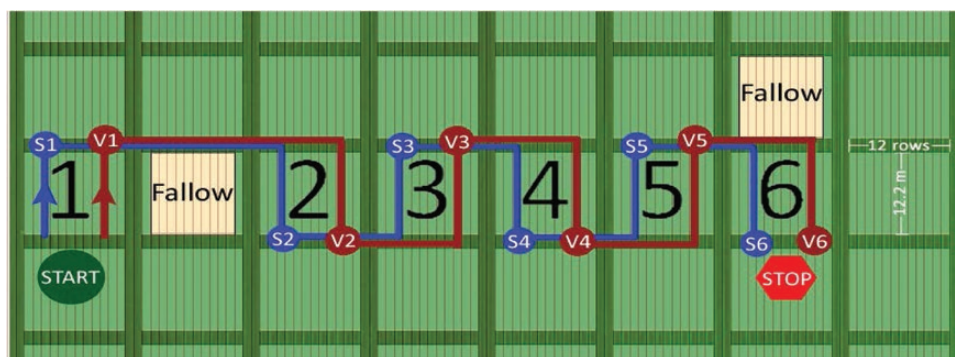
#### Video Surveillance of the Sampling Procedures

##### Body-Mounted Action Cameras

The sweepnet and vacuum suction sampling events were video recorded from start to finish on each of the three sample dates using two, body-mounted Garmin VIRB XE HD Action Cameras (Garmin International, Inc., Olathe, KS). The arthropod collections were always taken by the primary sampler (S. A. Machtley). A Garmin VIRB XE was attached to the forehead of the primary sampler using a Garmin forehead strap. A secondary sampler (J. R. Hagler) always assisted with the sample handling procedures (e.g., bagging, sealing, and carrying the samples). A Garmin VIRB XE was attached to the chest of the secondary sampler with a Garmin chest strap.

##### Measuring Sampling Behavior

It took  $\approx 30$  min to collect all six vacuum and sweepnet sample units from the six cotton plots on each sampling date. The two separate camera videos from the first collection date (9 September 2016) were merged (picture-in-picture) using Garmin's VIRB Edit



**Fig. 1.** Representation of the path where six 12.2-m cotton plots were sampled on 9, 13, and 19 September 2016. The sweep and vacuum sampler's paths are depicted by the blue and red lines, respectively. Sweep samples were always taken in row 3 and vacuum suction samples were always taken in row 10 of each plot. The blue and red circles indicate: 1) the zones where each sweep (S) and vacuum (V) sample was completed, 2) the contents of each respective sample was placed in the plastic bag for storage, and 3) the beginning point of the walk to the next sample plot. Note that the sampler's activity was continuously recorded by the body-mounted action cameras (B-MACs) from the start to finish points indicated on the figure.

software, converted to a single MP4 video, and then viewed using Windows Media Player the day after collection to identify distinct human behavioral events that occurred during the collection process. The various behaviors were then programmed into behavioral event logging software (The Observer Ver. 5.0, Noldus, [www.noldus.com](http://www.noldus.com), Wageningen, The Netherlands). The sampling behaviors that were timed with The Observer software included the period spent: 1) collecting arthropods in each row by sweepnet and vacuum, 2) handling the sweepnet and vacuum sample unit (e.g., placing the contents of each sample unit into a plastic bag), 3) time taken for each sweep and suction sample unit, and 4) walking between the various sampling points with the sweepnet or vacuum suction device. Also, the videos were viewed to tally (using The Observer software) the number of sweeps and vacuum suctions taken in each cotton plot.

### Statistical Analysis

The behaviors exhibited by the samplers during the sweepnet and vacuum suction procedures were pooled by plot (six plots) and date (three dates) for analysis ( $n = 15$  to 18 depending on the behavior observed). Descriptive statistics were calculated for each behavioral event and differences between the vacuum and sweepnet procedures were first analyzed by a two-tailed Student's *t*-test using SigmaPlot (SigmaPlot Ver. 13, Systat, San Jose, CA). However, these data never fulfilled the assumptions of a normal distribution or equal variance as determined by the statistical software. By default, the nonparametric Mann-Whitney Rank Sum Test was used to identify significant differences in behaviors between the two sampling treatments. Box-whisker plots (GraphPad Prism Ver. 7.03; GraphPad Software, Inc., La Jolla, CA) were constructed to depict the summary statistics for each of the behavioral events.

### Arthropod Counts

#### Data Collection, Analysis, and Presentation

Each sweepnet and vacuum suction sample was removed from the freezer and their contents were emptied onto a large piece of clean butcher paper. Thirty-three arthropod taxa were sorted and identified to the family, genus, or species level and tallied. Six focal arthropod families were selected for data presentation. The six focal families included: a family comprised of cotton pests (Miridae; most notably *Lygus* spp.); three families of predaceous true bugs (Geocoridae, Anthocoridae, and Reduviidae); and two families of predaceous spiders (Thomisidae and Salticidae). The raw data of counts and the summary statistics (e.g., sum total, mean, and standard error of the mean) obtained for all the cotton-dwelling arthropod taxa along with the summaries of the total number of sweeps or suctions taken per sample unit and the time spent in each plot are given in [Supplementary Appendix I](#). Each focal arthropod taxon was pooled over plots (six plots) and dates (three dates) for analyses ( $n = 18$ ). The Mann-Whitney Rank Sum Test was used to identify significant differences between arthropod counts obtained by the two sampling treatments.

The arthropod count data is displayed for the six focal species using three standardized procedures. First, box-whisker plots were constructed to depict the summary statistics yielded for the total number of individuals collected within a fixed distance (12.2 m) sample unit of cotton row by each sampling technique. Note that all box-whisker plots depict the first and third quartile, median (horizontal line across each box), mean (cross within each box), all the data points (red dots), and the minimum and maximum data values (whiskers). Second, the fixed distance (total) arthropod counts were converted to estimates of the number of individuals collected per 25 sweeps or suctions. This criterion was selected because it matches the sampling protocol used in

previous studies conducted at this research farm ([Naranjo et al. 2003, 2004](#)). Box-whisker plots were also constructed to depict the summary statistics yielded for the estimated number of individuals collected in a 25-sweep or suction sample unit. Finally, the total arthropod counts were converted to estimates of the number of individuals collected per minute of collection. This criterion was selected to provide a relative estimate of time and resources (labor) that would be needed to collect a given number of individuals of each taxon. Hence, box-whisker plots were constructed to depict the summary statistics yielded for the estimated number of individuals collected for every minute of sampling effort in a cotton row sampled by each technique. It should be noted that the number of sweeps or suctions per sample unit and the time unit estimates for the six focal arthropod taxa were determined by analysis of the B-MAC recordings obtained with the event recording software program. All the information needed to make sample and time conversions for all the cotton-dwelling arthropod taxa encountered in this study are given in [Supplementary Appendix I](#).

We also used two conventional indices to provide estimates of the relative sampling precision and efficiency between the sweepnet and vacuum suction collection treatments for every arthropod taxa, respectively. The first index, as described by [Buntin \(1994\)](#), calculates the relative precision of each sampling treatment. This index defines sampling precision as the relative variation (RV) of each scouting method (sampling treatment) as the percentage of the ratio of the standard error of the mean (SEM) to the mean ( $m$ ):

$$RV = (SEM / m) (100)$$

By definition, the smaller the RV the greater the precision of the collection method. The second index, as also described by [Buntin \(1994\)](#), calculates the relative efficiency of each sampling treatment. This index defines sampling efficiency as the relative net precision (RNP) of each treatment:

$$RNP = \left[ 1 / (RV_m)(c_p) \right] (100)$$

where,  $RV_m$  = mean relative variation calculated from the 18 sample units of each sampling treatment and  $c_p$  as the cost in human seconds of sampling effort (e.g., 23.1 s for the sweepnet samples and 103.2 s for the vacuum suction samples). By definition, the larger the RNP the greater the relative efficiency of the collection method.

In addition, we calculated a collection ratio (CR) index. The CR index simply provides a comparative measure of the effectiveness of the sampling methods as a function of the total number of individuals collected in each fixed-distance (12.2 m) plot:

$$CR = \text{total collected by vacuum} / \text{total collected by sweepnet}$$

By definition, any value less than 1.0 favors the sweepnet sampling method and every value greater than 1.0 favors the vacuum sampling method. Again, all the calculations of the relative sampling precisions and efficiencies between the sweepnet and vacuum suction collection treatments are given in [Supplementary Appendix I](#).

## Results

### Video Surveillance of the Sampler

Analysis of the B-MAC videos of data collection with the behavioral event recording software revealed that the sampler's natural walking speed with the sweepnet was about five times faster than with the backpack vacuum. Moreover, there was a lot less sample unit-to-sample unit variability in the time spent in each plot with the sweepnet. On average, the sweepnet and vacuum suction sample units took  $23.1 \pm 1.8$  (mean  $\pm$  SD) and  $103.2 \pm 18.0$  s per row;

respectively (Fig. 2A). Also, there were only about half as many sweeps ( $30.9 \pm 2.1$ ) as vacuum suction (52.5 ± 11.3) taken in the designated sampling rows (Fig. 2B). An individual sweep or vacuum suction took  $0.7 \pm 0.04$  and  $2.0 \pm 0.2$  s, respectively (Fig. 2C). As expected, it took significantly less time to handle (i.e., remove the sample from each apparatus and place in the plastic baggie) a sweepnet sample unit ( $23.5 \pm 9.5$  s) than a vacuum sample unit ( $54.6 \pm 7.1$  s; Fig. 2D). The behavioral analysis also revealed that it took a longer amount of time to walk between the plots with the lightweight sweepnet (0.63 kg) than it did with the heavy (18.5 kg) and cumbersome backpack vacuum device (Fig. 2E). This outcome was unexpected; however, the reason for this discrepancy in these data was identified by reexamination of the video recordings and is discussed below.

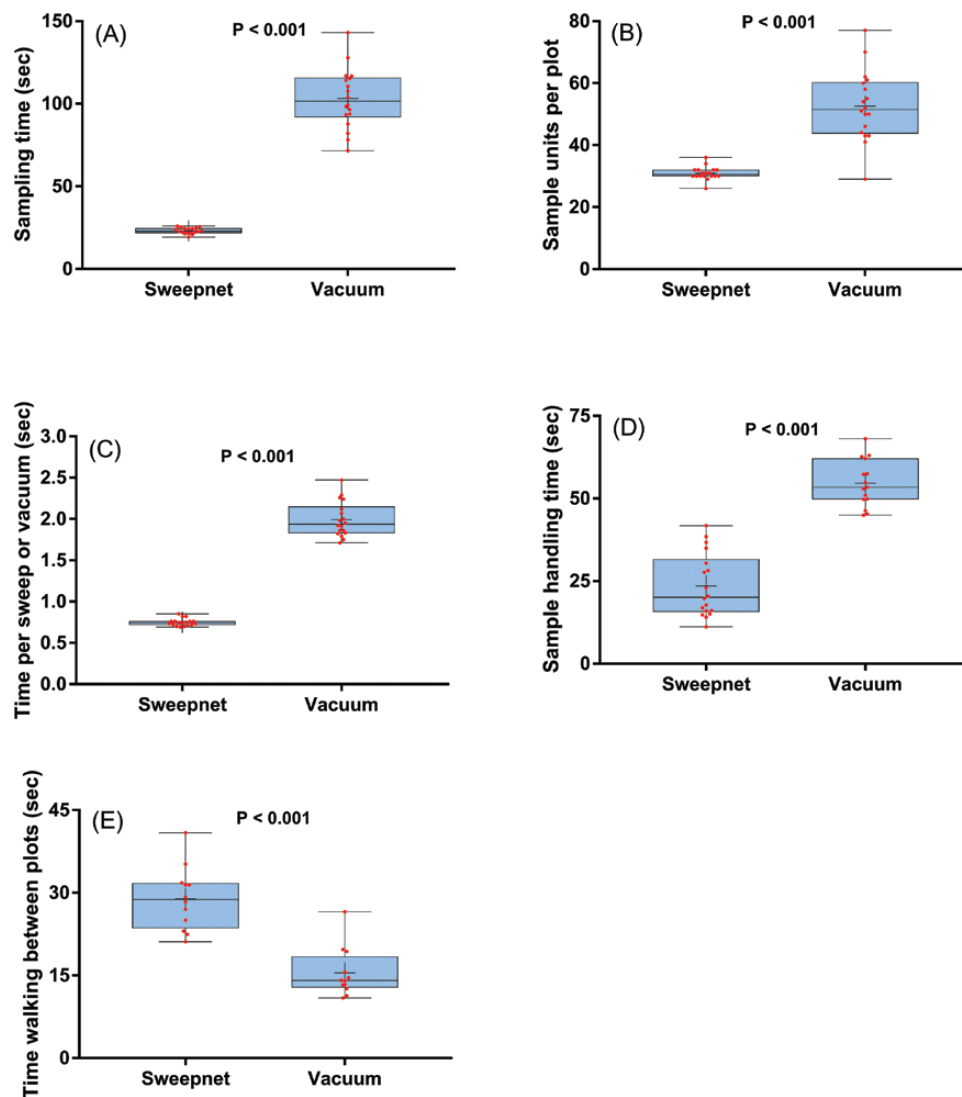
### Arthropod Counts Yielded Within Sample Units

The raw arthropod count data, summary statistics, RV RNP, and CR calculations for all the arthropod counts are provided in [Supplementary Appendix I](#). The number of individuals collected within the sample unit (fixed distance of cotton row) for the six focal

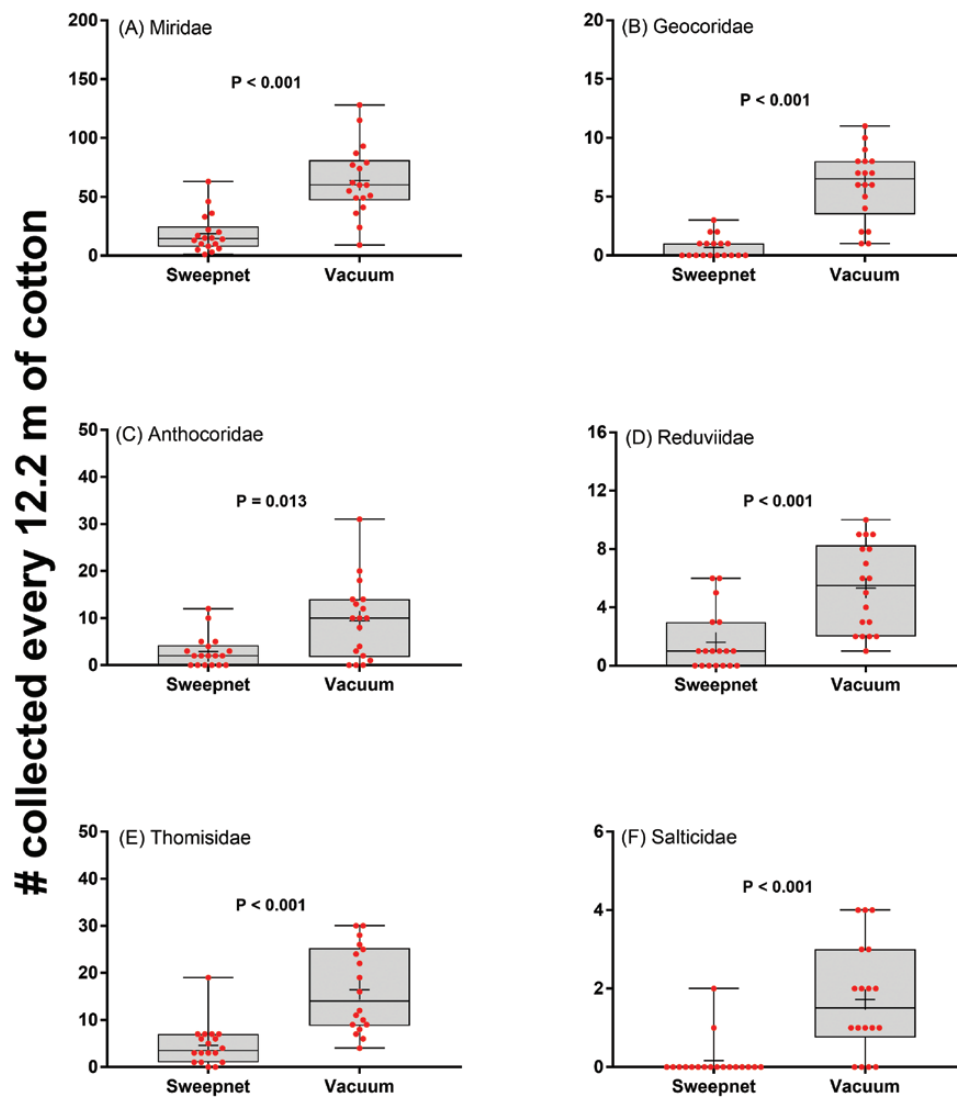
arthropod taxa are given in Fig. 3. Data revealed (for the six focal taxa) that three to 10 times more arthropods were captured in the vacuum samples. It should be noted though that the behavioral analysis revealed that there were only 1.7 times more vacuum suction taken than sweeps in each plot (Fig. 3B).

### Arthropod Counts Yielded From a Fixed Number of Sweeps or Suctions

The raw data for estimating capture rates for all the arthropod taxa on a fixed number of sweeps and vacuums are given in [Supplementary Appendix I](#). The estimated number of individuals collected in every 25 sweeps or vacuum suction for the six focal arthropod taxa are given in Fig. 4. Except for the Anthocoridae taxon (*Orius tristicolor* [White] [Heteroptera: Anthocoridae];  $P = 0.07$ ), our analysis predicts that significantly more specimens of the other focal taxa will be captured in a standardized 25-vacuum suction unit than in a 25-sweep unit. In general, the vacuum method produced about three times more arthropods than the sweepnet method based on the 25-sweep or suction sample unit (Fig. 4 and [Supplementary Appendix I](#)).



**Fig. 2.** Behaviors exhibited by a person sampling arthropods in 12.2-m rows of cotton using a sweepnet or a vacuum sampling device. (A) time expended in each 12.2-m plot ( $n = 18$ ); (B) number of sweeps or vacuum suction taken in each plot ( $n = 18$ ); (C) time needed for an individual sweep or suction unit; ( $n = 18$ ); (D) time spent handling each sample for storage ( $n = 18$ ); and (E) time spent walking from plot to plot ( $n = 15$ ).  $P$ -values represent the significant differences between the sweepnet and vacuum treatments (Mann-Whitney Rank Sum Test).



**Fig. 3.** Box-whisker plots depicting the summary statistics ( $n = 18$ ) for the number of arthropods (adults and juvenile stages combined for each taxon) collected by sweepnet and vacuum within a 12.2-m row of cotton.  $P$ -values represent the significant differences between the sampling treatments (Mann-Whitney Rank Sum Test). Raw arthropod count data sets and summary statistics for these taxa and 27 other taxa are provided in [Supplementary Appendix I](#).

### Arthropod Counts Yielded From a Fixed Amount of Sampling Time

The raw data for estimating capture rates for all the arthropod taxa on a time unit measurement are given in [Supplementary Appendix I](#). The estimated number of individuals collected for every minute spent sampling (sweeping or vacuuming) for the six focal taxa are given in [Fig. 5](#). In general, there were fewer differences between arthropod capture rates between the two sampling methods when data were converted to the time unit measurement. For example, there were significant differences in the number of Geocoridae and Salticidae collected per minute of vacuuming, but there were not any differences in the number of Miridae, Anthocoridae, Reduviidae, and Thomisidae captured ([Fig. 5](#)).

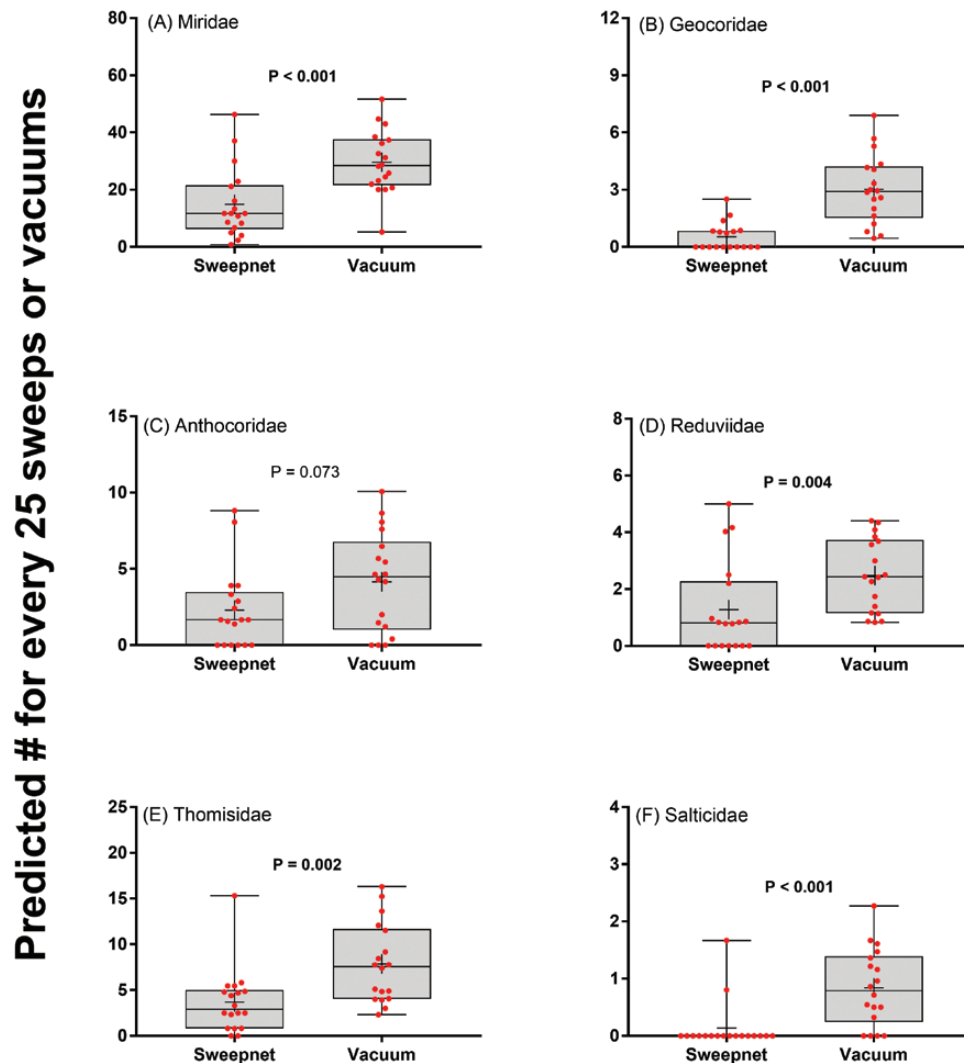
### Discussion

There are a wide variety of methods (e.g., sweepnet, vacuum, sticky trap, pitfall trap, beat bucket, etc.) available for collecting arthropods in the environment (see [Southwood 1978](#) and [McEwen 1997](#) for reviews). The choice of the sampling technique used for any

given study will depend largely on the arthropod's habitat (arboreal, ground dwelling, etc.), arthropod's morphology and phenology (small, large, life stage, etc.), plant's morphology and phenology (architecture and stage of growth), and host plant preference (row crop, grass, etc.). The sampling method of choice will also be largely dependent on the size of the area that needs to be examined and, based on the size of the area, which procedure is the most precise coupled with the easiest to employ. Sweepnet and vacuum suction devices (hand-held and backpack, respectively) are among the two most commonly cited methods for collecting foliar arthropods in cotton and most other agro-ecosystems ([Morris 1960](#)). Sweepnet sampling is usually preferred because the nets are light and the sweeping procedure is a lot less labor intensive than vacuuming (personal observation). Moreover, vacuums are relatively expensive, cumbersome, loud, and require mechanical maintenance.

Several studies have directly compared the efficiency of sweepnet and vacuum suction sampling techniques for collecting canopy dwelling arthropods ([Byerly et al. 1978](#), [Buffington and Redak 1998](#), [Doxon et al. 2011](#)). The data generated from those studies have been one dimensional in that they evaluated collection efficacy based on a



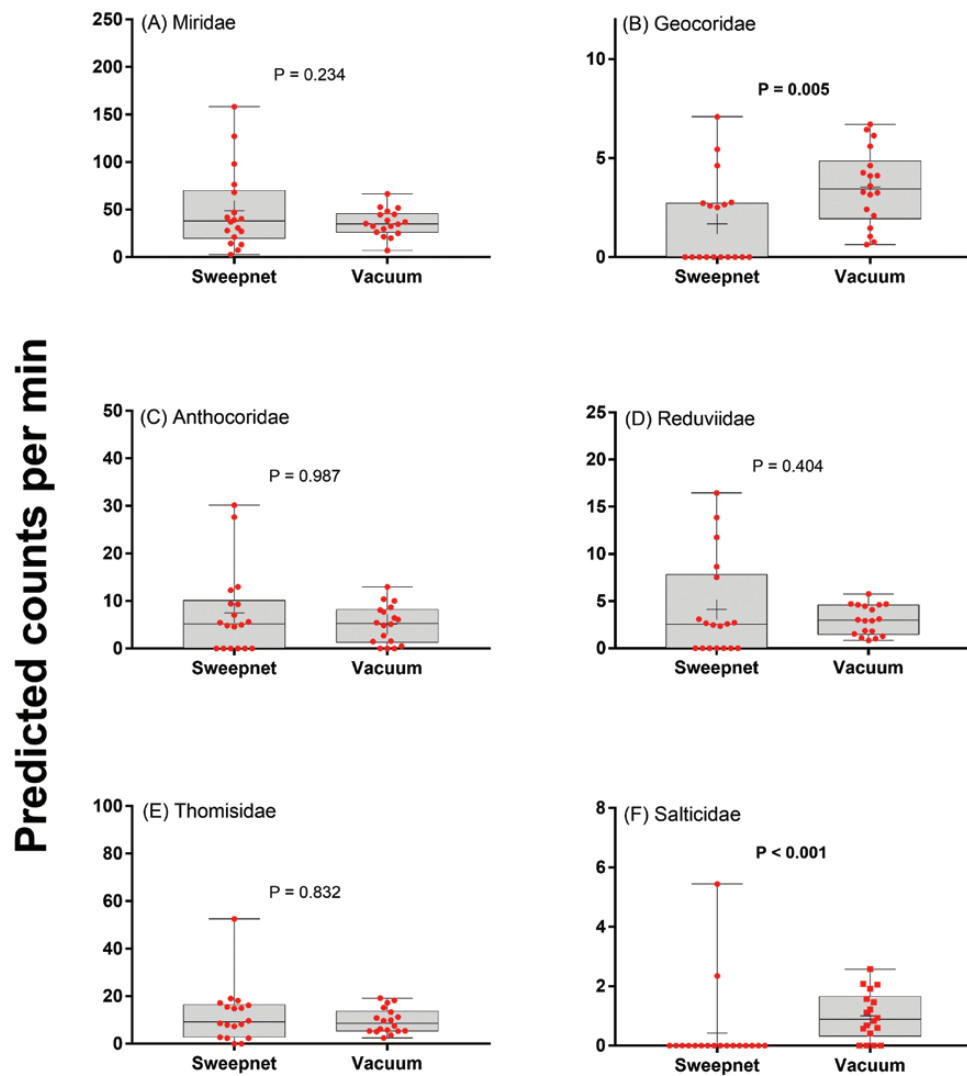


**Fig. 4.** Box-whisker plots depicting the summary statistics ( $n = 18$ ) for the estimated number of arthropods (adults and juvenile stages combined for each taxon) collected with 25 sweeps and 25 vacuum suction.  $P$ -values represent the significant differences between the sampling treatments (Mann-Whitney Rank Sum Test). Raw arthropod count data and summary statistics for these taxa and 27 other taxa are provided in [Supplementary Appendix I](#).

single criterion of either a fixed distance or a fixed number of sweeps and vacuums per sample unit. This study first evaluates sweepnet and vacuum collection efficiency of arthropods within a relatively short (12.2 m) distance of cotton. In general, the patterns of arthropod counts obtained from the 12.2 m fixed distance were similar to those obtained by [Byerly et al. \(1978\)](#) and [Buffington and Redak \(1998\)](#). That is, the vacuum suction device regularly captured more arthropods than the sweepnet. Moreover, it proved to be more precise (less variation) than the sweepnet as indicated by the consistently lower values yielded by the RV index ([Supplementary Appendix I](#)).

Our study differs from previous studies in that the B-MAC recordings along with the behavioral event recording analysis software then allowed us to enhance our data collection efforts. Specifically, we were able to quantify various aspects of the sampler's behavior during the experiment. Most notably, the behavioral analysis revealed that it took about five times longer to sample a 12.2-m row of cotton with a vacuum than with a sweepnet. This 'cost' in efficiency was not unexpected given that the vacuum sampler was about 30 times heavier and required more physical handling of the device. Moreover, the behavioral analysis revealed that almost twice as many vacuum suction were taken per 12.2 m of cotton than sweeps while walking

at a natural pace with each device. In turn, the video surveillance data also gave us a means to enhance our data collection effort by converting arthropod counts from a fixed distance of cotton to estimates of arthropod counts collected from both a fixed sample unit criteria (e.g., a 25-sweep or suction unit) and fixed time unit criteria (e.g., 1 min) of measurement. Such knowledge of sampling efficiency on multiple scales (e.g., distance, sample unit, and time) can be invaluable for choosing the most precise and efficient (e.g., cost effective) sampling tool for an experiment. For instance, our original data, based on fixed distance estimates, revealed that the vacuum device was more precise (e.g., fewer zero counts) at capturing the wide variety of arthropod taxa inhabiting the relatively small cotton plots ([Fig. 3](#); [Supplementary Appendix I](#)). Also, data indicate that the vacuum device would be more precise if relatively few sample units are taken (e.g., <25 sweeps or vacuums within a plot) within the boundaries of a small plot. However, if sampling speed (cost) is accounted for (remember that sweepnetting is almost five times more time efficient than vacuuming; [Fig. 2A](#); [Supplementary Appendix I](#)), then sweepnetting would yield about as many catches of Miridae, Anthocoridae, Reduviidae, and Thomsidae (and many of the other non-focal arthropods given in [Supplementary Appendix I](#); [Fig. 5](#)).



**Fig. 5.** Box-whisker plots depicting the summary statistics ( $n = 18$ ) for the estimated number of arthropods (adults and juvenile stages combined for each taxon) collected after 1 min of continuous sweeping and vacuuming.  $P$ -values represent the significant differences between the sampling treatments (Mann-Whitney Rank Sum Test). Raw arthropod count data and summary statistics for these taxa and 27 other taxa are provided in [Supplementary Appendix I](#).

However, the research plots for such an experiment would need to be long enough so that the sampler could continuously sweep for at least 1 min. If so, the walking speed data generated from the video analysis reveal that a sampler would require approximately 200 sweeps and 80 m of the continuous cotton row to reach an equilibrium of arthropod catches for 1 min of sampling effort for each technique, respectively. In short, for small plot sampling, the vacuum device would yield more captures (and less zero counts), but the less cumbersome sweepnet method would be a more practical approach for collecting arthropods in cotton if the research plots are relatively large.

The B-MAC videos can also be useful for identifying a posteriori discrepancies or errors in a set of data in that they provide permanent video documentation of an experiment. For instance, the behavioral analysis showed that it took twice as much time for the two samplers (the primary and secondary sampler) to walk between the plots with the sweepnet device. This outcome did not seem reasonable because we expected that our walking speed would be much faster with the light and nimble sweepnet. However, upon further examination of the B-MAC videos, the data revealed some interesting differences in our social behaviors during the data collection process. Specifically,

the gas-powered vacuum device generated a lot of noise. Hence, the two samplers wore ear plugs for hearing protection. As such, the vacuum sampling handling process (note that it still took longer than the sweepnet handling process) and the trek to the next vacuum sample plot was very focused on movement. Conversely, the samplers often paused for personal discussions (chat) between the sweepnet sampling sites. Ultimately, this chatting behavior did not hamper the sweepnet sampling efficiency, but it slowed the overall sampling process for a few minutes. However, this provides an example of how B-MAC video documentation can be used decipher unexpected research results.

In summary, we demonstrate how B-MAC video recordings in combination with behavioral event recording software can be used to enhance the data collection effort for field research. Using this research approach we were able to, without any additional labor or time effort in the field, determine the efficiency of collecting cotton-dwelling arthropods with vacuum and sweepnet devices at fixed distance, sample, and time unit measurements. The conventional estimators of relative precision (RV) and relative cost efficiency (RNP) support our findings. In addition to augmenting data acquisition, the B-MAC recordings can be useful for identifying inconsistencies in

data, reviewing research procedures after the completion of a study (i.e., a video archive), and serve as a training aid for students and employees.

## Supplementary Material

Supplementary data is available at *Journal of Insect Science* online.

## Acknowledgments

We thank Sarah Casey for her technical assistance and Steve Naranjo for providing valuable suggestions on the penultimate version of this manuscript. This project was supported by USDA CRIS projects 2020-22620-022-00D and 2020-21410-006-00D and, in part, by Cotton Incorporated Research Grant 13-738. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

## References Cited

- Allen, R. G., L. S. Pereira, D. Raes, and M. Smith. 1998. Crop evapotranspiration—guidelines for computing crop water requirements. FAO irrigation and drainage paper 56. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Buffington, M. L., and R. A. Redak. 1998. A comparison of vacuum sampling versus sweep-netting for arthropod biodiversity measurements in California coastal sage scrub. *J. Insect Conserv.* 2: 99–106.
- Buntin, G. D. 1994. Developing a primary sampling program, pp. 99–115. *In* L. P. Pedigo and G. D. Buntin (eds.), *Handbook of sampling methods for arthropods in agriculture*. CRC Press, Boca Raton, FL.
- Byerly, K. F., A. P. Guitierrez, R. E. Jones, and R. F. Luck. 1978. A comparison of sampling methods for some arthropod populations in cotton. *Hilgardia* 46: 257–282.
- Dietrick, E. J. 1961. An improved backpack motor fan for suction sampling of insect populations. *J. Econ. Entomol.* 54: 394–395.
- Doxon, E. D., C. A. Davis, and S. D. Fuhlendorf. 2011. Comparison of two methods for sampling invertebrates: vacuum and sweep-net sampling. *J. Field Ornithol.* 82: 60–67.
- Edwards, J., G. P. Smith, and M. H. F. McEntee. 2015. Long-term time-lapse video provides near complete records of floral visitation. *J. Pollination Ecol.* 16: 91–100.
- Ferrari, E. J., Z. A. Schakner, C. A. Villafana, L. S. Enriquez, and D. D. Lawson. 2015. Pilot study of underwater observations of interactions between harbor seals, California sea lions, and cormorants with halibut trawl fisheries in southern California. *Aquat. Mamm.* 41: 333–340.
- García de la Morena, E. L., J. E. Malo, I. Hervás, C. Mata, S. González, R. Morales, and J. Herranz. 2017. On-board video recording unravels bird behavior and mortality produced by high-speed trains. *Front. Ecol. Evol.* 5: 117.
- Gilpin, A. M., A. J. Denham, and D. J. Ayre. 2017. The use of digital video recorders in pollination biology. *Ecol. Entomol.* 42: 383–388.
- Holding, M. L., E. H. Kern, R. D. Denton, and H. L. Gibbs. 2016. Fixed prey cue preferences among dusky pigmy rattlesnakes (*Sistrurus miliarius barbouri*) raised on different long-term diets. *Evol. Ecol.* 30: 1–7.
- Letessier, T. B., J. J. Meeuwig, M. Gollock, L. Groves, P. J. Bouchet, L. Chapuis, G. M. S. Vianna, K. Kemp, and H. J. Koldewey. 2013. Assessing pelagic fish populations: the application of demersal video techniques to the mid-water environment. *Methods in Oceanography*. 8: 41–55.
- McEwen, P. 1997. Sampling, handling and rearing insects, pp. 5–26. *In* D. R. Dent and M. P. Walton (eds.), *Methods in ecology & agricultural entomology*. CAB International, Wallingford, UK.
- Miller, L., J. Toliver, and Police Executive Research Forum. 2014. Implementing a body-worn camera program: recommendations and lessons learned. Office of Community Oriented Policing Services, Washington, DC.
- Morris, R. F. 1960. Sampling insect populations. *Ann. Rev. Entomol.* 5: 243–264.
- Nakase, Y., and K. Suetsugu. 2016. Techniques to detect flower-visiting insects in video monitoring and time-lapse photography data. *Plant Species Biol.* 31: 148–152.
- Naranjo, S. E., J. R. Hagler, and P. C. Ellsworth. 2003. Improved conservation of natural enemies with selective management systems for *Bemisia tabaci* (Homoptera: Aleyrodidae) in cotton. *Biocontrol Sci. Tech.* 13: 571–587.
- Naranjo, S. E., P. C. Ellsworth, and J. R. Hagler. 2004. Conservation of natural enemies in cotton: role of insect growth regulators in management of *Bemisia tabaci*. *Biol. Control* 30: 52–72.
- Steen, R., and A. L. Thorsdatter Orvedal Aase. 2011. Portable digital video surveillance system for monitoring flower-visiting bumblebees. *J. Pollination Ecol.* 5: 90–94.
- Southwood, T. R. E. 1978. *Ecological methods*, 2nd ed. Chapman & Hall, New York, NY.