Notes

Evaluation of the AHDriFT Camera Trap System to Survey for Small Mammals and Herpetofauna

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Abstract

Traditional surveys for small mammals and herpetofauna require intensive field effort because these taxa are often difficult to detect. Dynamic environmental conditions and dense vegetative cover, both of which are attributes of biodiverse wet meadow ecosystems, further hamper field surveys. Camera traps may be a solution, but commonly used passive infrared game cameras face difficulties photographing herpetofauna and small mammals. The adapted-Hunt drift fence technique (AHDriFT) is a camera trap and drift fence system designed to overcome traditional limitations, but has not been extensively evaluated. We deployed 15 Y-shaped AHDriFT arrays (three cameras per array) in northern Ohio wet meadows from March 10 to October 5, 2019. Equipment for each array cost approximately US$1,570. Construction and deployment of each array took approximately 3 h, with field servicing requiring 15 min per array. Arrays proved durable under wind, ice, snow, flooding, and heat. Processing 2 wk of images of 45 cameras averaged about 13 person-hours. We obtained 9,018 unique-capture events of 41 vertebrate species comprised of 5 amphibians, 13 reptiles (11 snakes), 16 mammals, and 7 birds. We imaged differing animal size classes ranging from invertebrates to weasels. We assessed detection efficacy by using expected biodiversity baselines. We determined snake communities from 3 y of traditional surveys and possible small mammal and amphibian biodiversity from prior observations and species ranges and habitat requirements. We cumulatively detected all amphibians and 92% of snakes and small mammals that we expected to be present. We also imaged four mammal and two snake species where they were not previously observed. However, capture consistency was variable by taxa and species, and low-mobility species or species in low densities may not be detected. In its current design, AHDriFT proved to be effective for terrestrial vertebrate biodiversity surveying.

Keywords: adapted-Hunt drift fence technique; camera trap; wet meadow; presence–absence research; survey

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Introduction

Biological surveys often focus on select taxa due to species-specific activity and behavioral patterns, detection (the probability of documenting a present organism), and established sampling methods. Broad biodiversity surveys thus necessitate researchers or teams with a multitude of skills and can consume considerable time and resources (Garden et al. 2007). Camera trapping is increasingly popular in conservation research and monitoring to reduce field effort. Camera traps are remotely operated cameras that photograph an area either on a trigger or timer to document passing wildlife. They are typically used to image species that are difficult to visually observe (Swann et al. 2004).

Researchers have several options when considering camera trap deployment (Rovero et al. 2013). Laser active trigger camera traps record an image when a constant laser is interrupted. Environmental conditions such as vegetation or mud splashes from precipitation can block the laser and trigger the camera trap without animals present (Guyer et al. 1997; Hobbs and Brehme 2017). Time-lapse camera traps are set to record at or over predetermined time intervals regardless of animal presence (Geller 2012). These cameras can consume substantial battery power and need to be frequently serviced (Glen et al. 2013; Rovero et al. 2013; Meek et al. 2014). Passive infrared (PIR) camera traps ideally only trigger when the sensor detects a thermal infrared differential caused by a passing animal. This property limits PIR camera battery use and generally minimizes the number of images without animals (Swann et al. 2004). They also outperform some other passive triggers, such as microwave sensors (Glen et al. 2013). These properties have established PIR camera traps as the most commonly used commercial game cameras (Swann et al. 2004; Rovero et al. 2013; Meek et al. 2014).

Passive infrared sensors are often misunderstood to detect body temperature, core temperature, ambient temperature, or heat in motion. Rather, they detect an infrared discrepancy caused by an object surface that is sufficiently hotter or colder than the background surfaces (Welbourne et al. 2016). This issue is not typically a problem for large-bodied endotherms. However, ectothermic and small-bodied animals (i.e., herpetofauna, mice, voles, shrews) can have surface temperatures too similar to background surfaces to trigger PIR sensors (Welbourne 2014). Passive infrared camera sensitivity (propensity to trigger when an animal is under the camera sensor) is thus a challenge when applied to these taxa (Glen et al. 2013; Merchant et al. 2013; Welbourne 2014). As such, researchers may choose active laser (Hobbs and Brehme 2017) or time-lapse (Geller 2012) cameras or rely on traditional methods, especially for ectotherms. Indeed, reptile surveys rarely apply camera traps and instead typically use traditional visual encounter, artificial cover, or live-trapping (pitfall or funnel) methods (Dorcas and Willson 2009; McDiarmid et al. 2012). Still, PIR camera traps compare favorably to traditional small mammal snap or live trapping (De Bondi et al. 2010).

Researchers have also needed to compromise between the area of camera coverage vs. the detail of the images for species identification (DeSa et al. 2012; Glen et al. 2013). Most camera traps are set in open environments with a wide detection zone (Swann et al. 2004). This type of detection zone can result in images wherein it is difficult to identify small-bodied animals to the species level. Narrow detection zones are better for acquiring photos capable of identifying small-bodied species, but may miss more animals (Glen et al. 2013).

There have been recent attempts to solve the PIR sensitivity and detection zone issues when camera trapping small mammals and herpetofauna. Drift fences combined with traps are a favored method to capture species of herpetofauna (Campbell and Christman 1982; Greenberg et al. 1994; Ryan et al. 2002; McDiarmid et al. 2012) and small mammals (Williams and Braun 1983; Mitchell et al. 1993) that are otherwise difficult to observe. The camera overhead augmented temperature (COAT) system uses drift fences to concentrate animals into a central gap (Welbourne 2013). Thermally homogeneous background surfaces are necessary for ideal PIR sensitivity (Welbourne et al. 2016). The COAT camera is therefore aimed downward at a corkboard, thereby providing a somewhat thermally homogeneous background surface. This setup increases PIR sensitivity compared with cameras aimed at the ground or into open space (Welbourne 2013; Welbourne et al. 2016). Even so, the COAT system has limited sensitivity, operates best only during certain hours, and does not capture animals moving outward along the fence (Welbourne 2014). Meanwhile, the Hunt trap places a PIR camera inside of an inverted bucket housing unit equipped with bait (McCleery et al. 2014). The bucket results in a narrow detection zone, and the lid is thermally homogeneous. Buckets also provide cameras with consistent shade, protection, and stable environmental conditions relative to the open air. This setup should remove or alleviate PIR camera problems at high ambient temperatures seen in conventional deployment (Swann et al. 2004). Overall, these factors allow Hunt trap cameras to be durable, sensitive, and able to obtain clear pictures for species identification. Yet, the system omits species not attracted to the bait and can capture many images of an individual (McCleery et al. 2014).

The adapted-Hunt drift fence technique (AHDriFT) combines the strengths of the COAT and Hunt trap methods (Martin et al. 2017). Drift fences funnel animals under PIR cameras inside of modified Hunt traps. This system encompasses the biodiversity sampling benefits of traditional drift fences (McDiarmid et al. 2012), enhances PIR sensitivity (Welbourne at al. 2016), and allows for detailed images (McCleery et al. 2014). Martin et al. (2017) photographed 32 vertebrate species and identified species in 98% of AHDriFT images. As with Hunt traps, ambient temperatures due to night, sunny, or cloudy conditions should not strongly influence camera durability or sensitivity. Camera batteries and secure digital (SD) cards can also be easily changed in the field without deconstructing equipment. Martin et al. (2017) assert that AHDriFT reduced their field time by 95% compared with drift fences and traps. Camera traps are also noninvasive, which removes the ethical issue of animal trapping mortality (De Bondi et al. 2010; Edwards and Jones 2014) as well as permit restrictions for listed or venomous species.

Taken together, these traits make AHDriFT a potential alternative to traditional drift fence and trapping. Although conceptual testing has produced promising results, the method has not been extensively evaluated. For example, the original design was for Florida sand dunes, which may experience static and fair environmental conditions relative to some other ecosystems. Even so, the original cameras only operated 84% of deployment time (Martin et al. 2017). Whether the method is durable enough for widespread application under more strenuous environmental conditions is unresolved. Furthermore, the method's ability to adequately capture biodiversity remains untested.

Northern Ohio wet meadows are open-canopy systems characterized by organic-rich mineral soils, high and fluctuating water tables, and herbaceous vegetation (Sears 1926). Unlike Florida sand dunes, they experience a range of environmental conditions over a typical biological field season (March–October), such as strong winds, snow, ice, rain, flooding, heat, fast vegetative growth, and dynamic water tables. Wet meadows also have greater biodiversity than sand dunes, including rare and imperiled species in Ohio (ODNR 2020), but dense vegetation hampers traditional detection of many species (Slaughter and Kost 2010). Burrowing species present an additional potential challenge for AHDriFT maintenance and efficiency. Holes or tunnels under the drift fences or buckets reduce the likelihood that animals are coaxed into the camera traps. These characteristics make northern Ohio wet meadows ideal for camera trap deployment and for testing AHDriFT in strenuous and biodiverse environments.

We modified AHDriFT for wet meadow conditions and assessed its durability and required effort. We compared our small mammal and herpetofauna detections to biodiversity baselines, including established snake community data. We then generally compared our species capture efficiency with that of other traditional and PIR camera trap methods. We also provide detailed methodological instructions, practical information, and recommendations for researchers and managers.

Methods

We selected 15 wet meadow fields across northern Ohio in Wyandot, Huron, and Ashtabula counties. We chose fields with known snake communities to assess detection efficacy against an established biodiversity baseline because snakes are traditionally difficult to detect (Steen 2010; Durso and Seigel 2015), and their biodiversity can be challenging to capture without using multiple methods or long-term studies (Kéry 2002; Dorcas and Willson 2009; McDiarmid et al. 2012). We determined snake communities in each field from at least 3 y of traditional visual encounter and artificial cover (tin) surveys (unpublished data). We did not have field-level amphibian and small mammal community information from prior surveys. Instead, we used previous opportunistic observations (unpublished data), Ohio range maps, and species habitat requirements (Bokman et al. 2016; Parsons et al. 2019) to determine species that could potentially occur in our fields.

We modified AHDriFT from the original design (Martin et al. 2017) to an omni-directional Y-shape configuration, with an "array" defined as three camera traps connected by drift fences (Figure 1A). We considered an entire array as one sampling unit (i.e., the three cameras as nonindependent). We used 1.27-cm-thick oriented strand board for the drift fences and metal fence posts for support. Each array arm measured 4.88 m in length. Construction materials and detailed deployment instructions are available as supplemental material (Text S1, *Supplemental Material*) and as an open-source online publication (Amber et al. 2020). We deployed one array at the geometric center of each field (15 arrays; 3 cameras per array, 45 total cameras) from March 10 to October 5, 2019. We used Reconyx Hyperfire 2 Professional PIR camera traps (model HP2X Gen3) with custom flash and 28-cm focal lengths modified by the manufacturer. These adjustments increased image clarity by focusing the cameras and flash to the distance to the bucket lid. We selected camera settings of highest sensitivity and three-image burst per trigger event. We used rechargeable nickel metal hydride AA batteries (EBL 1.2V HR 6; 2,800 mAh) and 32-GB SD cards to allow the cameras to operate continuously. We examined arrays every 7–14 d for damage and gaps under the fences, buckets, guide boards, and fence joints. We changed camera SD cards and batteries every 2 wk.

We broadly defined a camera "false-trigger" as any image that did not capture an animal or animal part. We manually processed raw images by removing false-triggered images and assigning species images into designated folders. We used the R package 'camtrapR' (Niedballa et al. 2017 [version 1.1]; R Core Team 2019 [version 3.6.1]) to compute a species "unique-capture" record table. We determined species unique-captures using a 60-min interval between images of the same species at a given array. This framework ensured that the dataset was not inflated by an individual rapidly moving around a camera or an array (Martin et al. 2017).

Results

Deployment, operation, and servicing

The equipment cost of each array was about US$1,570 (Table 1). Our arrays withstood all environmental fluctuations, including wind, ice, flooding, freezing, and heat (daily temperatures ranged from −10 to 36°C). The only operational maintenance required was minor fence back-filling of gaps with mud in the first weeks following deployment. After the water tables settled, we did not need to conduct repairs. Arrays remained operational despite vegetative growth, and we did not observe any holes or tunnels created by burrowing species. Paper wasps *Polistes* spp. and mud daubers *Sceliphron caementarium* sometimes built nests in the buckets or on the cameras. New vegetation also occasionally grew into the buckets. Although these factors resulted in more false-triggers, they were easily removed and did not impair array operation. The 45 cameras operated 9,198 of the 9,204 trap-nights (one camera malfunctioned for 6 d). The malfunction appeared to be due to a hardware issue. We did not observe camera problems or changes in their

Figure 1. (**A**) Y-shaped adapted-Hunt drift fence technique array in a recently mowed wet meadow field in mid-March, 2019, in Ashtabula County, northern Ohio. An "array" consisted of three passive infrared (PIR) camera traps each set inside of a modified inverted bucket housing unit and placed at the ends of three 4.88-m-long drift fences; (**B**) the entrance of the modified inverted bucket housing unit that connects to the drift fence, with external wooden guide boards; and (**C**) a downward-facing PIR camera trap attached to a white acrylic sheet over the internal wooden guide boards inside of a bucket housing unit.

efficiency due to overheating or general environmental conditions.

We constructed each camera trap housing unit in about 1 h and deployed each array in about 2 h (Table 2). When checking the cameras, batteries typically read "full" charge, with only one occasion showing 50%. The 32-GB SD cards usually read 0% full, although two unusual occasions each used 16% of capacity (~22,500 and 28,000 images). Those occasions were due to false-triggers by one camera. We resolved the problem by lowering that camera's sensitivity setting by one level. We suspect that the camera's oversensitivity was caused by a preexisting mechanical issue. Swapping SD cards and batteries averaged 13.96 min (standard deviation, ±3.21) per array for one researcher, typically faster in warm and dry weather. Two weeks' worth of images of all 45 cameras required 6–19 person-hours to process (mean, 13.08; standard deviation, ±3.84). The shortest processing times were in the spring (March–May) when animals were less active. The longest processing times resulted from when there were unusually large amounts of false-triggers.

Species captures

We recorded 190,851 false-triggered images (52.57 GB). The primary causes of false-triggering were flooding and daylight shifts, influenced by bucket orientation on the landscape. We obtained 75,477 species images (18.4 GB) with a per camera mean of 1,679 (±830) species images. Discounting the two unusual false-trigger occasions by one camera, we had approximately two false-trigger images per species image. This rate compares to an upwards of 50:1 false-trigger-to-species image ratio during original AHDriFT testing (S. Martin, The Ohio State University, personal communication). We obtained excellent image quality (Figure 2) and identi-

Table 1. Estimated material cost breakdown for constructing and servicing one Y-shaped adapted-Hunt drift fence technique array in northern Ohio wet meadows from March 10 to October 5, 2019. An "array" consisted of three passive infrared (PIR) camera traps each set inside of a modified inverted bucket housing unit and placed at the ends of three 4.88-m-long drift fences. We built drift fences from 1.27-cm-thick oriented strand board and used metal fence posts for support. Camera traps were customized by the manufacturer to a focal length of 28 cm. We include double the secure digital (SD) cards and batteries needed to set the cameras so that they can be swapped and allow for continuous camera operation. The total number of units needed of each piece of equipment is provided (in parentheses). Estimated costs represent the approximate total sum needed to purchase all the units needed of each piece of equipment.

Equipment	Estimated cost ($US)
Camera trap supplies	
Reconyx PIR custom cameras (3)	1,200
Rechargeable AA batteries (72)	90
SD cards (6)	60
Total	1,350
Camera trap housing unit supplies	
5-gal (19-L) buckets and lids (3)	20
Acrylic sheets (3)	40
Spray paint (1)	4
L-brackets (9)	4
Machine screws, hex nuts (39)	10
Washers (12)	2
Wing nuts (9)	3
Drywall screws (24)	4
Metal rods (3)	8
Wood studs (2)	5
Total	100
Drift fence supplies	
Oriented strand boards (3)	60
Metal fence posts (13)	45
Zip-ties, screws, nuts	15
Total	120
Total	1,570

fied all vertebrate images to the species level. We recorded a total of 9,018 unique-captures from 41 species (Data S1, *Supplemental Material*), including 5 amphibian, 13 reptile (11 snake), 16 mammal, and 7 avian species (Table 3). We imaged an average of 21 species per array, with a range of 16–24. We also recorded the total number of invertebrate detections that included ants, bees, wasps, beetles, flies, moths, mantids, and spiders. Mammals had the most unique-captures (4,595), followed by reptiles (2,495), invertebrates (987), birds (889), and amphibians (52). Our captures per unit effort (array trap nights) were comparable to or sometimes greater than traditional methods (Table 4).

Discussion

Our AHDriFT design (Figure 1) has some potential limitations. The biggest obstacle is the upfront cost of the equipment per array (Table 1). Camera trapping

Table 2. We deployed 15 Y-shaped adapted-Hunt drift fence technique (AHDriFT) arrays in northern Ohio wet meadow fields (one array per field) from March 10 to October 5, 2019, to evaluate the method as a survey tool. An "array" consisted of three passive infrared (PIR) camera traps each set inside of a modified inverted bucket housing unit and placed at the ends of three 4.88-m-long drift fences. We provide the typical effort breakdown for constructing and servicing arrays, and the image processing time for all three cameras used in an array. Time range (minutes) minimums and maximums are approximated for array construction and for the final record table. Time range (minutes) minimums and maximums are exact for data acquisition and processing effort (mean ± standard deviation).

Task per array	Time (min)
AHDriFT array construction	
Build three camera trap housing units	135–180
Deploy one array (one person)	90–120
Deploy one array (two people)	60–90
Deploy one array (three people)	30–50
Deploy one array (four people)	30–45
Data acquisition and processing	
Change batteries and secure digital cards	9–25 (13.96 ± 3.21)
Process 2 wk of images	24–76 (52.32 ± 12.84)
Final record table ('camtrapR')	5–10

generally requires more initial investment than traditional survey methods (Garden et al. 2007). Nonetheless, AHDriFT is substantially less expensive than some other camera trap systems for small mammals and ectotherms (Hobbs and Brehme 2017). There are also some areas where costs can be reduced or minimized. Equipment costs can be reduced by a third by deploying a two-camera linear array in narrow areas where the drift fence will effectively intercept moving animals. Researchers can also purchase SD cards with smaller memory than we used. Although some material costs can be lowered, we do recommend investing in high-quality cameras. Our professional-grade cameras operated continuously except for one camera for 6 d, outperforming the consumer-grade cameras used by Martin et al. (2017). We recognize that our enhanced camera performance may also be attributed in part to our modified design. For example, we attached the cameras to opaque acrylic rather than to transparent plexiglass (Martin et al. 2017), which may have better prevented overheating. We also achieved much lower false-trigger rates compared with the original design, but this is likely due to using professional-grade cameras (Glen et al. 2013). We recommend field research comparing different camera trap models in both our designs and the original AHDriFT designs. For the drift fences, sturdy materials allowed them to endure dynamic conditions and remain suitable for a second field season. We also note that cameras can be a long-term investment. Multiseason studies can therefore benefit by investing in quality materials despite upfront costs.

Furthermore, in some cases AHDriFT may be a more cost-efficient method than traditional methods because it minimizes field effort (Table 2). Traditional methods may need low upfront investment, but their field requirements can ultimately lead to higher costs than

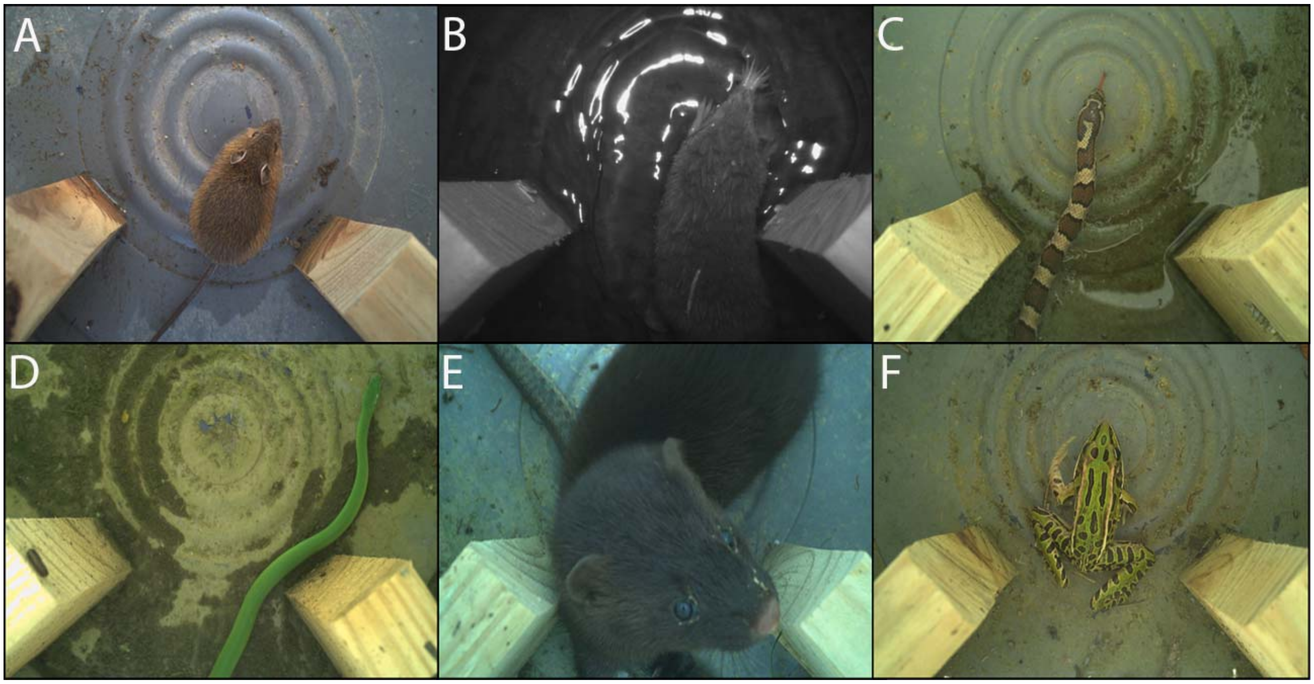

Figure 2. Sample species-level camera trap images captured using the adapted-Hunt drift fence technique in northern Ohio wet meadows from March 10 to October 5, 2019. (**A**) Woodland jumping mouse *Napaeozapus insignis*. (**B**) Star-nosed mole *Condylura cristata*. (**C**) Eastern milksnake *Lampropeltis triangulum*. (**D**) Smooth greensnake *Opheodrys vernalis*. (**E**) American mink *Neovision vision* consuming an eastern gartersnake *Thamnophis sirtalis*. (**F**) Northern leopard frog *Lithobates pipiens*.

camera trapping (Garden et al. 2007). Although we changed SD cards and batteries every 2 wk, arrays likely only need to be serviced every 4–8 wk. Reducing field person-hours may be particularly cost-effective for labor-intensive surveys for diverse taxa or research in dynamic ecosystems. As such, research targeting multiple species may particularly benefit by using AHDriFT to simultaneously survey for numerous species. Image processing effort can also be reduced if researchers are interested only in certain species. Much of our processing time was spent sorting every species image, particularly of common species such as deer mice *Peromyscus* spp., common five-lined skinks *Plestiodon fasciatus*, and song sparrows *Melospiza melodia*.

A second obstacle of our array design is transporting and deploying materials. The oriented strand board drift fences are heavy, especially after soaking up water. Erecting arrays also entailed strenuous physical effort. Using lightweight corrugated plastic for fences may reduce physical strain, and its durability is currently being tested. Silt fencing, metal flashing, or wildlife exclusion fencing may be viable options as well. We also dug trenches by hand using a mattock, but fences may be installed quicker and easier using a powered trencher. This limitation is not inherent of AHDriFT and is equivalent to traditional drift fence deployment.

Third, researchers interested in a particular species or taxa should consider life-history traits to select the most appropriate survey method. Although we imaged seven avian species, AHDriFT is designed for ground-dwelling species and does not adequately capture avian biodiversity. Of our avian unique-captures, 75% were song sparrows and 21% were northern house wrens *Troglodytes aedon*. Drift fences also rely on animals encountering and moving along them. Thus, AHDriFT is most effective at imaging highly mobile species or species present in dense populations. For example, eastern gartersnakes *Thamnophis sirtalis* and masked shrews *Sorex cinereus* had the most detections, and we frequently imaged mice and meadow voles *Microtus pennsylvanicus* (Table 3). All of these species are numerous in our fields and actively forage for food (Bokman et al. 2016; Gibbons 2017). Meanwhile, species in low densities or low-mobility species likely have reduced probability of encountering the drift fences. For example, we observed 7 of the 12 possible snake species in all fields where they are known to occur (Table 3). Snake species not imaged in a field typically had only one, and no more than five, prior observations in that field over 3 y of traditional surveys (unpublished data). The exception is Kirtland's snakes *Clonophis kirtlandii*, which are abundant in two of our fields. Kirtland's snakes have fossorial life histories, low mobility, and tend to move through or under the vegetative thatch (Gibbons 2017). These traits likely reduce the probability that they move along drift fences or under the camera traps. Taken together, AHDriFT can miss low-mobility species or species in low densities. Nonetheless, we contend that this limitation is generally applicable to camera trapping (De Bondi et al. 2010) and traditional drift fence and trapping (Steen 2010). We also note that we did not test camera sensitivity of all species in all environmental circumstances. For example, we suspect that amphibians moving during rain events may not have been consis-

Table 3. We deployed Y-shaped adapted-Hunt drift fence technique arrays in 15 wet meadow fields (one array per field) from March 10 to October 5, 2019, in northern Ohio. An "array" consisted of three passive infrared camera traps each set inside of a modified inverted bucket housing unit and placed at the ends of three 4.88-m-long drift fences. Unique-capture events (captures) are defined as detections greater than or equal to 60 min apart of a species at a given array, with all three cameras considered as one sampling unit. The number of fields that a species was imaged in (fields) is followed by the total number of possible fields in which the species is known or expected to occur (in parentheses). For amphibians, lizards, and mammals, total possible fields are based on prior opportunistic observations or inferred from species ranges and habitat requirements. For snakes, total possible fields are known from 3 y of prior visual encounter and artificial cover object (tin) surveys. Field values marked with an asterisk (*) indicate imaged species that are not known or expected to be in our fields, but have been observed in or could potentially inhabit adjacent areas. Listed species have superscript designations after their common names (see abbreviations footnote).

Species	Common name	Captures	Fields
Amphibians			
Ambystoma texanum	Small-mouthed salamander	1	1 (2)
Anaxyrus americanus	American toad	11	6 (15)
Lithobates catesbeianus	American bullfrog	1	1*
Lithobates clamitans	Green frog	15	9 (15)
Lithobates pipiens	Northern leopard frog	24	9 (15)
Reptiles			
Chrysemys p. marginata	Midland painted turtle	3	3*
Clonophis kirtlandii	Kirtland's snake	0	0 (2)
Lampropeltis triangulum	Eastern milksnake	10	5 (8)
Nerodia s. sipedon	Northern watersnake	9	8 (8)
Opheodrys vernalis	Smooth greensnake[E]	15	2 (2)
Pantherophis spiloides	Gray (black) ratsnake	8	5 (1)
Plestiodon fasciatus	Common five-lined skink	490	10 (12)
Sistrurus catenatus	Eastern Massasauga rattlesnake[E,LT]	72	12 (13)
Storeia dekayi	Dekay's brownsnake	69	12 (15)
Storeia occipitomaculata	Northern red-bellied snake	3	2 (4)
Thamnophis butleri	Butler's gartersnake	24	1 (1)
Thamnophis radix	Plains gartersnake[E]	26	2 (2)
Thamnophis sauritus	Eastern ribbonsnake	21	6 (1)
Thamnophis sirtalis	Eastern gartersnake	1,745	15 (15)
Mammals			
Blarina brevicauda	Northern short-tailed shrew	152	15 (15)
Condylura cristata	Star-nosed mole[SC]	16	9 (12)
Cryptotis parva	Least shrew[R]	0	0 (15)
Didelphis virginiana	Virginia opossum	58	13 (15)
Marmota monax	Groundhog	7	5*
Mephitis	Striped skunk	7	4*
Microtus pennsylvanicus	Meadow vole	1,390	15 (15)
Mustela frenata	Long-tailed Weasel	97	12 (15)
Napaeozapus insignis	Woodland jumping mouse[SC]	396	13 (13)
Neovision vision	American mink	11	4 (12)
Peromyscus spp.	Deer mice	1,031	15(15)
Procyon lotor	Raccoon	8	5*
Rattus norvegicus	Brown rat	1	1*
Sorex cinereus	Masked shrew	1,135	14 (15)
Sylvilagus floridanus	Eastern cottontail	212	11 (15)
Tamias striatus	Eastern chipmunk	32	7 (10)
Zapus hudsonius	Meadow jumping mouse[R]	41	3 (3)
Birds and invertebrates			
Dumetella carolinensis	Gray catbird	5	2
Geothlypis trichas	Common yellowthroat	58	12
Melospiza melodia	Song sparrow	633	14
Passerina cyanea	Indigo bunting	5	1
Porzana carolina	Sora[SC]	1	1
Siala sialis	Eastern bluebird	1	1
Troglodytes aedon	Northern house wren	186	12
Invertebrate spp.	Invertebrates	987	15

E = Ohio endangered; SC = Ohio species of concern; R = rare in Ohio; LT = federally threatened.

Table 4. Comparison of catch per unit effort (CPUE) of traditional survey techniques and passive infrared (PIR) camera trapping for common taxa across published studies. Camera trap methods include the adapted-Hunt drift fence technique (AHDriFT) and PIR game cameras conventionally deployed without drift fences. We deployed Y-shaped AHDriFT arrays in 15 wet meadow fields (one array per field) from March 10 to October 5, 2019, in northern Ohio. An "array" consisted of three PIR camera traps each set inside of a modified inverted bucket housing unit and placed at the ends of three 4.88-m-long drift fences. Sherman live-trap method refers to deployment without drift fences. Drift fence and live-trap combinations (DF + live trap) for small mammals use either Sherman, Elliot, or cage live traps. Drift fence and live-trap combinations (DF + live trap) for snakes use pitfall or funnel traps. We estimated CPUE from total captures divided by total trap nights of all sampling units or independent surveys. A single array or traditional drift fence and trap plot, regardless of the number of cameras or traps, is considered as one sampling unit for the purpose of generalizing data. Snake visual and artificial cover surveys categories define each survey of a site as one unit of effort, regardless of walking transect or cover object densities.

Species	Method	CPUE	Ecosystem	Reference
Mouse	AHDriFT	0.47	Wet prairie	This study
		0.42	Sand dune	Martin et al. (2017)
	PIR game cameras	0.02	Tidal salt marsh	DeSa et al. (2012)
	Snap-trap	2.20	Forest	Williams and Braun (1983)
	Sherman live trap	0.25	Forest	Williams and Braun (1983)
		0.13	Forest	Bruseo and Barry (1995)
	DF + live trap	0.70	Forest	Williams and Braun (1983)
		0.05	Ephemeral pool	Edwards and Jones (2014)
Vole	AHDriFT	0.44	Wet prairie	This study
	PIR game cameras	0.00	Tidal salt marsh	DeSa et al. (2012)
	Snap-trap	0.00	Forest	Williams and Braun (1983)
	Sherman live trap	0.00	Forest	Williams and Braun (1983)
	DF + live trap	0.25	Forest	Williams and Braun (1983)
		<0.01	Ephemeral pool	Edwards and Jones (2014)
Shrew	AHDriFT	0.41	Wet prairie	This study
		0.02	Sand dune	Martin et al. (2017)
	Snap-trap	0.05	Forest	Williams and Braun (1983)
	Sherman live trap	0.00	Forest	Williams and Braun (1983)
	DF + live trap	3.25	Forest	Williams and Braun (1983)
		0.16	Ephemeral pool	Edwards and Jones (2014)
Snake	AHDriFT	0.64	Wet prairie	This study
		0.16	Sand dune	Martin et al. (2017)
	PIR game cameras	0.01	Cliff, beach	Welbourne (2014)
	Visual survey	0.22–0.74	Variable	Kéry (2002)
	Artificial cover	0.37	Grass, scrub	Kjoss and Litvaitis (2001)
	DF + live trap	0.05	Grass, scrub	Kjoss and Litvaitis (2001)
		0.02	Sand pine scrub	Greenberg et al. (1994)

tently captured (Martin et al. 2017) and may explain why we did not detect amphibians in all expected fields and their generally low counts, despite that the arrays cumulatively captured their biodiversity (Table 3). Of course, no single survey method is without flaws or biases toward specific taxa. We encourage research into AHDriFT detection of specific target species.

And fourth, data derived from a single array in a field are likely best used for presence–absence research. Species occupancy modeling can be a potential application of camera trap data and combined with environmental, climatic, and spatial covariates (Tobler et al. 2015). However, we obtained too few unique-captures per field for population-level analyses of some species. Researchers seeking to infer species abundance or activity should carefully consider potential limitations to detection when designing a study. Ongoing research is investigating the cost efficiency of deploying multiple arrays per field to increase detections.

The use of AHDriFT images for capture–mark–recapture studies would also present a challenge due to the variability in how animals entered the buckets or the physical condition inside of the buckets (leaves, water, etc.). These conditions sometimes made unique patterns difficult to discern, especially at night. Automated identification software also needs a degree of image standardization and much larger datasets (Schneider et al. 2019). Furthermore, although passive integrated transponder tags are commonly used in capture–mark–recapture studies (Gibbons and Andrews 2004), readers placed in the camera trap buckets may not be effective because animals did not always fully enter the buckets, and so may not activate the passive integrated transponder reader. The efficacy of passive integrated transponder readers combined with AHDriFT can nonetheless be a valuable route for future research. As of this writing, we recommend traditional survey methods such as trapping to identify individuals.

Despite limitations, we found that AHDriFT is an effective new method in general small mammal and herpetofauna surveying. Traditional survey methods can vary in the biodiversity observed of small mammals (Sealander and James 1958) and herpetofauna (Dorcas and Willson 2009). Meanwhile, we detected a wide range of multitaxa biodiversity and 92% of expected snakes and small mammals (Table 3). Importantly, this biodiversity included species of different size classes, ranging from invertebrates and mice to weasels and minks. We also imaged many species that are traditionally difficult to detect, such as moles and snakes. These images included four mammal and two snake species in fields where they were not previously observed or expected (Table 3). Although we did not image least shrews *Cryptotis parva*, we note that they are rare in Ohio (Bokman et al. 2016), and whether the species truly occurs in our fields is unknown. Using camera traps also removed the serious issues of animal mortality and small mammal bait bias associated with traditional trapping (Beer 1964; De Bondi et al. 2010; Edwards and Jones 2014). Furthermore, traditional survey methods often have few or highly variable captures per unit effort (Table 4). We found that AHDriFT was generally equitable in this metric compared with traditional techniques. In addition, we could have decreased the frequency of our field visits, which would have increased our captures per unit effort. However, we caution against stringent interpretation of capture rates across studies of different ecosystems, populations, and species. More research is needed to better quantitatively compare detection rates of different methods in the same geographic and temporal settings.

Nonetheless, AHDriFT generally performed well compared with other PIR camera trap systems for small mammals and herpetofauna. Although the Hunt trap is bait biased (McCleery et al. 2014), we captured diverse species and size classes (Table 3). Still, our array design is not suitable for the tidal environments for which the Hunt trap was designed (McCleery et al. 2014). In addition, in 300 d the COAT system imaged 118 reptiles (Welbourne 2014), whereas in just 210 d we averaged 166 reptile unique-captures per array. This difference may be in part because the COAT camera primarily worked during the day after the cork was sufficiently warmed (Welbourne 2014) and more thermally homogeneous (Welbourne et al. 2016). Our arrays operated continuously and were extremely sensitive, even capturing small invertebrates. The distance of the COAT camera to the ground (70 cm) and size of the detection zone also limited its image quality (Welbourne et al. 2015). We obtained superb species-level images by using custom focal-length cameras (Figure 2).

Overall, we recommend using AHDriFT to establish site terrestrial vertebrate biodiversity or to target multiple species concurrently. Surveyors seeking to limit person-hours can camera trap numerous sites that would traditionally require intensive field effort. These applications can be especially beneficial to land trusts, permitting agencies, wildlife managers, developers, and environmental consultants. There is also the possibility of incorporating the method into citizen science programs, which could reduce the time required by researchers to verify species identifications (McShea et al. 2016; Schuttler et al. 2019). We conclude that AHDriFT can be a powerful research, management, and conservation tool for small mammals and herpetofauna.

Supplemental Material

Please note: The *Journal of Fish and Wildlife Management* is not responsible for the content or functionality of any supplemental material. Queries should be directed to the corresponding author for the article.

Text S1. Construction and deployment instructions with required materials and step-by-step photographs for a Y-shaped adapted-Hunt drift fence technique (AHDriFT) array. Arrays consist of 4.88-m-long drift fences made of 1.27-cm-thick oriented strand board and metal fence posts for support. A passive infrared (PIR) camera trap is placed at the end of each drift fence in a modified inverted bucket housing unit (three cameras and buckets per array). Instructions are to build arrays designed to withstand the environmental conditions of northern Ohio wet meadows from March to October.

Found at DOI: https://doi.org/10.3996/JFWM-20-016.S1 (3.73 MB PDF).

Data S1. Data archive (comma separate value spreadsheet) of the unique-capture record table of the species imaged using the 15 adapted-Hunt drift fence technique (AHDriFT) arrays in this study. We deployed one array per wet meadow field from March 10 to October 5, 2019, in northern Ohio. Unique-captures are defined as detections greater than or equal to 60 min apart of a species at a given AHDriFT array, with all cameras at an array considered as one sampling unit. Location information is provided only to the county level to protect listed species.

Found at DOI: https://doi.org/10.3996/JFWM-20-016.S2 (285 KB CSV).

Reference S1. Bokman H, Emmert J, Dennison J, McCormac J, Norris J, Parsons K, Rhodedeck A. 2016. Mammals of Ohio: field guide. Ohio Department of Natural Resources, Division of Wildlife publication 5344 R0216. Ohio Department of Natural Resources, Columbus, Ohio.

Found at DOI: https://doi.org/10.3996/JFWM-20-016.S3 (10.3 MB PDF); also available at https://ohiodnr.gov/wps/portal/gov/odnr/discover-and-learn/safety-conservation/about-ODNR/wildlife/documents-publications/backyard-wildlife-documents.

Reference S2. Parsons K, Davis J, Lipps G, Pfingsten R, Mann A, Denny G. 2019. Amphibians of Ohio: field guide. Ohio Department of Natural Resources, Division of Wildlife publication 5348-0019. Ohio Department of Natural Resources, Columbus, Ohio.

Found at DOI: https://doi.org/10.3996/JFWM-20-016.S4 (10.47 MB PDF); also available at https://ohiodnr.gov/wps/portal/gov/odnr/discover-and-learn/safety-conservation/about-ODNR/wildlife/documents-publications/backyard-wildlife-documents.

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Found at DOI: https://doi.org/10.3996/JFWM-20-016.S6 (3.89 MB PDF); also available at https://www.researchgate.net/publication/273946087_Natural_Community_Abstract_for_Wet_Prairie/link/5510d23e0cf2ba84484002e3/download.

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