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# TAXONOMIC BIASES OF SEVEN METHODS USED TO SURVEY A DIVERSE HERPETOFAUNAL COMMUNITY

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***Abstract*.—We conducted a survey of a diverse herpetological community in southeastern Oklahoma from 2012–2013, with the goals of examining its composition and comparing the results of several commonly used survey methods. We used pitfall traps and funnel traps positioned along drift fences, funnel traps placed along logs, various aquatic turtle traps (hoop nets, crawfish traps, and minnow traps), artificial cover objects, and automated recording systems. We also recorded all incidental encounters. We documented 53 reptile and amphibian species. Incidental encounters, funnel traps along drift fences, and pitfall traps documented more species than any of the other methods. Incidental encounters, funnel traps along drift fences, and turtle traps were the only methods that captured unique species (i.e., species that were undetected using other methods), and the combination of those three methods documented representatives of every species found at the site. Funnel traps along drift fences had significantly higher capture rates than funnel traps along logs, and crawfish traps captured more species and had higher capture rates than minnow traps.**

*Key Words*.—automated recording system; cover board; drift fence; funnel trap; hoop net; pitfall trap

## INTRODUCTION

Amphibian and reptile declines are topics of increasing concern (Alford and Richards 1999; Gibbons et al. 2000). To minimize further declines, it is vital to have a comprehensive understanding of the composition and distribution of herpetological communities, especially communities with high species richness and communities that harbor rare and endangered species (Vieites et al. 2009). It is also important to know which survey methods will most effectively and reliably document species of interest so that surveys can be conducted efficiently (Ryan et al. 2002; Sung et al. 2011).

Many survey methods papers either test just a few methods or focus on only a few taxa (Bury and Corn 1987; Engelstoft and Ovaska 2000; Enge 2001; Scheffers et al. 2009). Such studies are useful because they allow statistical comparisons of trap efficiency among the methods, but these studies often fail to discuss the full range of species found at a site. Comparatively few papers have incorporated a wide range of methods and considered an entire herpetological community. This community-level approach has the disadvantage of largely precluding statistical inference regarding trap efficiency. It would not, for example, be valid to compare the effectiveness of funnel traps and turtle traps because each trap type targets a different suite of taxa.

Nevertheless, surveys that employ a diverse array of methods across an entire community can provide a wealth of information regarding the taxa captured by various methods. For example, a researcher who is interested in only one taxon can use such a survey to determine which methods are best suited for maximizing the number of captures while minimizing cost and effort. Similarly, when conducting a comprehensive survey, it is important to know which methods are suitable for documenting an entire community as well as which methods are nonessential, and studies that compare a wide range of methods allow future researchers to see which methods captured unique species (i.e., species that were only captured by one method) and which methods only captured species that were also captured by other methods. Therefore, in this paper we present the results of a two-year herpetological survey in which we used seven methods at a site with over 50 species of reptiles and amphibians.

## MATERIALS AND METHODS

***Study site*.**—Boehler Seeps and Sandhills Preserve is a 196 ha preserve in Atoka County, Oklahoma, USA (34°10'0"N, 95°53'21"W). It is composed of a mixture of habitats that are common in Gulf Coast states such as Texas and Louisiana but are unusual for Oklahoma. A central feature of this site is its two shallow (< 1.0 m deep) beaver-formed lakes: Hassell Lake (surface area = 2.05 ha) and Boehler Lake (surface area = 2.82 ha; Fig. 1). Both lakes are fed by a series of acidic seeps, resulting in water that has low turbidity but is dark with

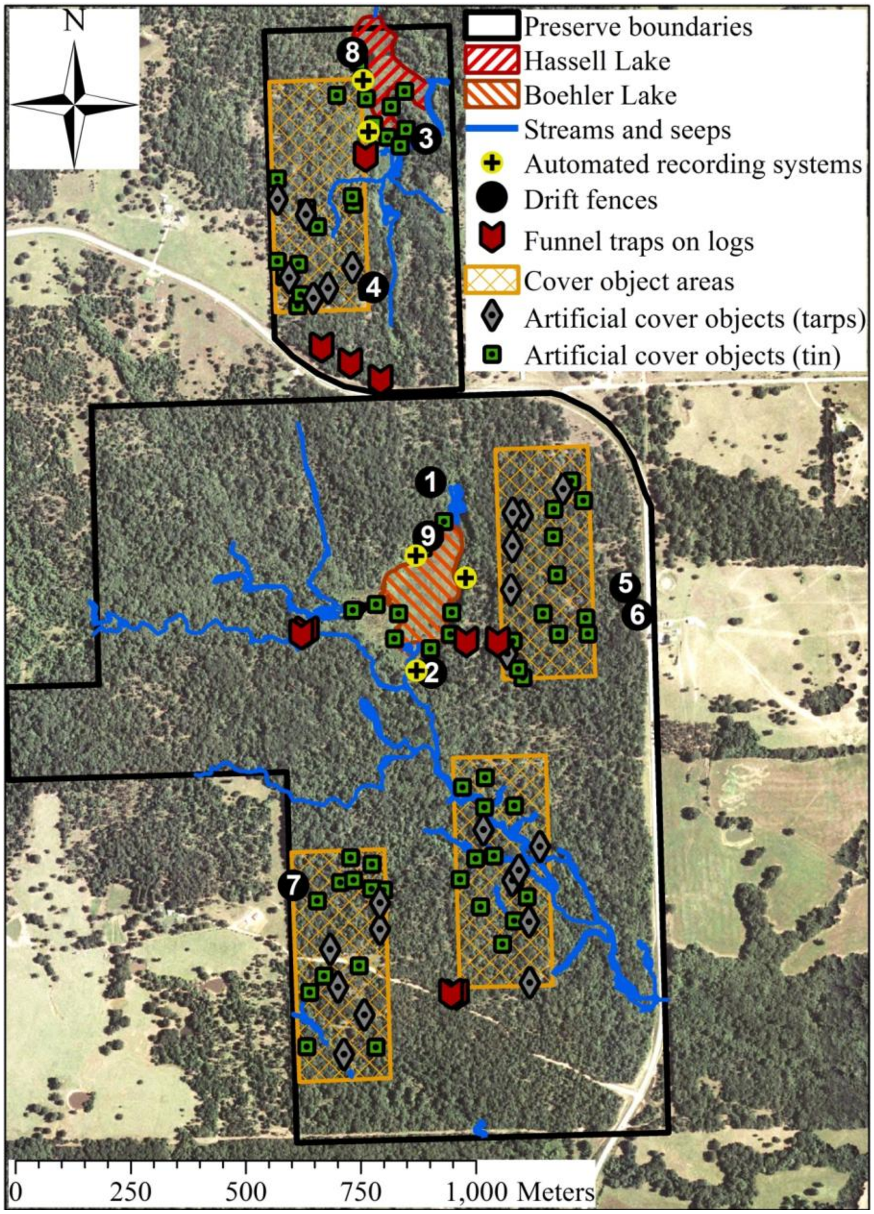


**FIGURE 1.** The study site in Atoka County, Oklahoma, USA, showing the locations where each of our survey methods were employed. Drift fence numbers correspond to the fence descriptions in Table 1.

tannin. Seeps also feed multiple small intermittent streams that typically flow in the spring but are mostly dry by summer, leaving only a few small pools of water. Most sections of the lakes are thick with emergent vegetation (predominantly Common Rush, *Juncus effusus*, Giant Cutgrass, *Zizaniopsis miliacea*, and Broadleaf Cattail, *Typha latifolia*). Yellow Pond-Lilies (*Nuphar lutea*) and several species of submerged aquatic vegetation are also abundant. The lakes and streams are bordered by a dense layer of Greenbrier (*Smilax rotundifolia*) and other hydrophilic plants, but the habitat away from the water rapidly transitions into upland Bluejack Oak (*Quercus incana*) forest. The soil in this forest is dry, sandy, and virtually free of rocks.

The unusual combination of habitats at this site has resulted in high biological diversity, including many taxa that are rare both locally and globally. A herpetological survey was conducted in 2008 and documented 41 species of reptiles and amphibians, including two species listed as Species of Greatest Conservation Need (Oklahoma Department of Wildlife Conservation. 2005. Oklahoma's Comprehensive Wildlife Conservation Strategy. Available from http://www.wildlifedepartment.com/CWCS.htm [Accessed 27 June 2015]; Patton and

**TABLE 1**. Descriptions of the drift fences used to study a herpetofaunal community in Atoka County, Oklahoma, USA. Number (#) = the designation of each fence (see Fig. 1 for fence locations), PT = pitfall traps, and SEFT = single-ended funnel traps, DEFT = double-ended funnel traps.

| # | Years used | Shape | Material | Height (m) | Length (m) | No. of PT | No. SEFT | No. DEFT |
|---|---|---|---|---|---|---|---|---|
| 1 | 2012– 2013 | straight | aluminum | 0.6 | 15.2 | 4 | 4 | 2 |
| 2 | 2012 | Y | vinyl fabric | 0.9 | 30.5 per arm | 6 per arm | 2 per arm | 2 per arm |
| 3 | 2013 | straight | vinyl fabric | 0.5 | 30.5 | 6 | 4 | 2 |
| 4 | 2013 | straight | vinyl fabric | 0.7 | 5.5 | 0 | 4 | 0 |
| 5 | 2013 | straight | vinyl fabric | 0.5 | 15.0 | 4 | 4 | 0 |
| 6 | 2013 | straight | vinyl fabric | 0.5 | 9.1 | 2 | 0 | 2 |
| 7 | 2013 | straight | vinyl fabric | 0.5 | 30.5 | 6 | 4 | 2 |
| 8 | 2012 | straight | aluminum | 0.5 | 3.0 | 0 | 2 | 0 |
| 9 | 2012– 2013 | straight | aluminum | 0.5 | 3.0 | 0 | 2 | 0 |

Wood 2009). This previous survey provided important baseline data and made it clear that the herpetological community of this site merited further study.

***Survey methods***.—We conducted continuous surveys from May to early July in 2012 and 2013 (excluding automated recording units, we used all of the methods described below for the entirety of these two periods). To increase the total amount of sampling time and document species that are only active seasonally, we conducted shorter surveys of varying duration and intensity in other months. We included the data from these shorter surveys in the general data set, but excluded them from some of the statistical analyses (see Statistical analysis). To thoroughly sample the herpetological community, we used seven different survey methods: (1) pitfall traps positioned along drift fences, (2) funnel traps along drift fences, (3) funnel traps along logs, (4) turtle traps, (5) artificial cover objects, (6) automated recording systems, and (7) incidental encounters.

We used nine drift fences of various designs during the study (Jones 1986; Enge 2001, 2005; Table 1). The locations of the fences were deliberately chosen to ensure that all habitat types were sampled (Fig. 1). We used 18.9 L buckets for pitfall traps and placed them such that the fences bisected them, allowing animals to enter the trap from either side of a fence. We used aluminum window screen to construct both single-ended (i.e., an opening on only one end) and double-ended (i.e., an opening on both ends) funnel traps with 25 cm diameters (Greenberg et al. 1994; Crosswhite et al. 1999). It has been demonstrated that traps with two funnels in series capture over twice as many reptiles and amphibians as traps with only one funnel per end (Yantis 2005; Farallo et al. 2010); therefore, we installed two funnels on single-ended traps and four funnels on double-ended traps. We installed single-ended funnel traps on the ends of drift fences and placed double-ended funnel traps in the middle of the fences. Additionally, we positioned several single-ended funnel traps along logs (seven in 2012 and five in 2013; only two traps were in the same location both years). We placed a tarp over each funnel trap to shade it, and we placed wet sponges in the pitfall traps and funnel traps to prevent animals from desiccating (Gibbons and Semlitsch 1981; Todd et al. 2007). During 2012, we used aluminum wings to increase the capture rate of pitfall traps on drift fence #2 (we placed four 0.6 m wings around each pitfall trap to increase its effective trap area), and in 2013, we used them sporadically on the funnel traps on drift fences #1, 3, 5, and 7 (one wing was placed at each opening of the funnel traps; McKnight et al. 2013). We checked all of the traps every morning and moved animals at least 50 m from the fences before releasing them.

In February 2012, we placed 72 artificial cover objects (48 pieces of roofing tin and 24 vinyl fabric tarps) at random locations in the preserve (Engelstoft and Ovaska 2000; Fig. 1). To select locations for these objects, we used aerial maps to identify four 500 × 200 m sections of the preserve that appeared to cover all habitat types at the site. Next, we used a random number generator to select GPS coordinates for 12 pieces of tin and six tarps within each area. We placed 10 additional pieces of tin along the edges of both lakes (using a random number generator was not possible for positioning these pieces). During 2012 we randomly selected half of the pieces of tin and half of the tarps within each area and checked them every 8 d. We checked the remaining cover objects every 4 d. Because of low capture rates in 2012, we checked the cover objects sporadically in 2013 rather than following a fixed schedule. We monitored the boards around each lake sporadically in both years.

From February to April 2012, we used automated recording systems (two at Hassell Lake and three at Boehler Lake; Wildlife Acoustics, Concord, Maine, USA) to monitor the anuran community (Peterson and Dorcas 1992, 1994). From 5 February to 24 March, they recorded every evening for 3 min intervals at 1900, 2100, and 2300, and from 25 March to 30 April they recorded at 2000, 2200, and 0000. The shift was made to compensate for increasing day length. These time ranges cover the peak calling times for most North American anuran species (Shirose et al. 1997; Bridges and Dorcas 2000; de Solla et al. 2005). To increase the accuracy of the results, we listened to recordings manually rather than using call recognition software (Waddle et al. 2009). We only recorded the presence or absence of anuran species rather than estimating the number of individuals.

We used a variety of traps to assess the aquatic turtle community (Cagle and Chaney 1950; Gibbons 1990; Ream and Ream 1996; Adams et al. 1999; Klemish et al. 2013). We used hoop nets (2.54 × 2.54-cm mesh) from Memphis Net and Twine Co. (Memphis, Tennessee) of the following diameters: 0.91 m (six traps), 0.76 m (two traps), 0.61 m (two traps), 0.51 m (two traps). We also used 12 collapsible crawfish traps (1.0 × 1.0-cm mesh) with a 0.3 m diameter and an opening on both ends (#TR-503; American Maple Inc., Gardena, California, USA), eight steel minnow traps (0.6 × 0.6-cm screen) with a 0.2 m diameter and an opening on both ends (Plano Molding Company, St. Plano, Illinois, USA), and two basking traps (Memphis Net and Twine Co., Memphis, Tennessee, USA). We attached 6 m leads to several of the hoop nets and used a combination of baited and unbaited traps (Vogt 1980; Smith et al. 2006). We used sardines as bait in 2012, and we used both sardines and dried krill in 2013 (the change was made in an attempt to increase capture rates for a target species for other, simultaneous projects). Within each lake, we only baited half of the crawfish traps and minnow traps in 2012, and in both years we did not bait one of the hoop nets on a lead. We placed half of each trap type in each lake and checked all of the turtle traps every other day. Minnow traps and basking traps were only used in 2012 while all other traps were used in both years. Additional traps were used sporadically in streams and seeps.

In addition to the animals detected using our various trapping methods, we recorded all encounters with reptiles and amphibians outside of traps and grouped them into an Incidental Encounter category. Incidental encounters included: hearing anurans, finding animals while moving between trap sites, finding animals under logs, and finding animals on the road adjacent to the preserve. Because of the extraordinary number of incidental encounters of some species, we did not record exact counts of anurans or larval salamanders. Also, because most incidental encounters occurred haphazardly while performing other tasks, we could not justify any method of quantifying our search effort. For the purposes of this study, we did not mark any animals that we captured/encountered. Therefore, the data are presented as the number of captures, not the number of individuals, and they may not reflect true species abundances because some individuals may have been captured more than once.

***Statistical analysis***.—We used a chi-square test of independence to compare taxonomic biases among the seven survey methods. For this analysis we used the total number of captures in each order/suborder (e.g., Caudata, Lacertillia, Serpentes, etc.). We assigned n = 225 for each species that was not actually counted (e.g., anurans in incidental encounters and ARS recordings). We chose this value because it was the highest tabulated number of incidental encounters for any other species. This was a conservative estimate, but increasing this estimate resulted in lower *P*-values and increased the risk of committing a Type I Error. Sample sizes for all other groups are listed in Table 2. We used additional chi-square tests (21 total) to make post-hoc comparisons between every possible combination of two methods. We used a sequential Bonferroni correction (minimum $\alpha = 0.0024$) to control the family-wise error rate of these tests (Holm 1979). Because these chi-square tests used the taxonomic distribution within each method, we think the comparisons were valid even though the number of traps used in each method varied.

We used a Mann-Whitney U test to compare trap efficiency (# of captures/trap/day) for funnel traps on drift fences and funnel traps on logs (n = 107 days for each method). Because there were more funnel traps on fences than on logs and having a small number of traps increases the probability of a catch rate of zero for a given day, we only used the data from seven randomly selected funnel traps on fences for 2012 and five for 2013 (there were seven funnel traps on logs in 2012 and five in 2013). We randomly selected a new set of traps for each day. Because all of the funnel traps on logs were single-ended, we did not include the double-ended funnel traps on drift fences in the analysis.

We used Kruskal-Wallis tests to compare trap efficiency (# of captures/trap/day) among crawfish traps, minnow traps, and hoop nets (all sizes of hoop net were combined into a single category; n = 36 days for each method). We conducted separate tests for the capture rates of turtles, snakes, and anurans. Because there were only eight minnow traps, we randomly selected eight crawfish traps and eight hoop nets and only used the data from those traps. We randomly selected a new set of traps for each day. We used the Nemenyi-Damico-Wolfe-Dunn method to make post-hoc pair-wise comparisons (Siegel and Castellan 1988). Additionally, we used a chi-square test of independence with Yate's correction to compare the relative number of adult/juvenile anurans and tadpoles that were captured by crawfish traps and minnow traps. We used a second chi-square test of independence with Yate's correction to compare the relative number of large tadpoles

**TABLE 2**. Summary of all of the reptile and amphibian species that were documented in a study a study of a herpetofaunal community in Atoka County, Oklahoma, USA. Individuals were not marked; therefore these numbers represent captures, not individuals. Abbreviations are IE = incidental encounters (any encounters not included in the other methods), ACO = artificial cover objects, PT = pitfall traps, FT (DF) = funnel traps on drift fences, FT (logs) = funnel traps on logs, TT = turtle traps, ARS = automated recording systems, All = the total number documented for each species, and #M = the number of methods that detected each species. For Anurans exact counts were not recorded for incidental encounters or ARS recordings because of the high frequency with which most anuran species were encountered and detected. This is reflected by a > sign in the sum column and rows.

| Species | IE | ACO | PT | FT (DF) | FT (logs) | TT | ARS | All | #M |
|---|---|---|---|---|---|---|---|---|---|
| Anura | | | | | | | | | |
| *Acris blanchardi* | many | 0 | 17 | 154 | 0 | 9 | many | > 180 | 5 |
| *Anaxyrus americanus charlesmithi* | many | 0 | 40 | 7 | 1 | 1 | many | > 49 | 6 |
| *Anaxyrus woodhousii woodhousii* | many | 0 | 4 | 3 | 0 | 0 | 0 | > 7 | 3 |
| *Gastrophryne carolinensis* | many | 0 | 344 | 57 | 1 | 0 | many | > 402 | 5 |
| *Hyla cinerea* | many | 0 | 1 | 6 | 0 | 9 | many | > 16 | 5 |
| *Hyla versicolor* | many | 0 | 5 | 12 | 0 | 2 | many | > 19 | 5 |
| *Lithobates areolatus areolatus* | 1 | 0 | 6 | 0 | 0 | 0 | many | > 7 | 3 |
| *Lithobates catesbeianus* | many | 0 | 0 | 2 | 0 | 79 | many | > 81 | 4 |
| *Lithobates clamitans* | many | 0 | 97 | 44 | 0 | 25 | many | > 166 | 5 |
| *Lithobates palustris* | many | 0 | 291 | 104 | 5 | 16 | many | > 416 | 6 |
| *Lithobates sphenocephala utricularia* | many | 1 | 786 | 462 | 11 | 28 | many | > 1288 | 7 |
| *Pseudacris crucifer* | many | 0 | 1 | 1 | 0 | 0 | many | > 2 | 4 |
| *Pseudacris fouquettei* | many | 0 | 0 | 3 | 0 | 0 | many | > 3 | 3 |
| *Pseudacris strekeri* | many | 0 | 21 | 7 | 0 | 0 | many | > 28 | 4 |
| *Scaphiopus hurterii* | many | 1 | 994 | 230 | 83 | 0 | many | > 1308 | 6 |
| Unidentified tadpoles | many | 0 | 0 | 0 | 0 | 222 | 0 | > 222 | 2 |
| Caudata | | | | | | | | | |
| *Ambystoma opacum* | 17 | 0 | 14 | 3 | 0 | 0 | 0 | 34 | 3 |
| *Ambystoma texanum* | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 2 |
| *Notophthalmus viridescens lousianensis*[a] | > 12 | 0 | 239 | 93 | 8 | 5 | 0 | > 357 | 5 |
| *Siren intermedia nettingi* | 1 | 0 | 0 | 0 | 0 | 17 | 0 | 18 | 2 |
| Squamata (Lacertilia) | | | | | | | | | |
| *Anolis carolinensis carolinensis* | 16 | 1 | 1 | 0 | 0 | 0 | 0 | 18 | 3 |
| *Aspidoscelis sexlineata viridis* | 160 | 0 | 10 | 3 | 0 | 0 | 0 | 173 | 3 |
| *Plestiodon anthracinus pluvialis* | 6 | 5 | 3 | 3 | 0 | 0 | 0 | 17 | 4 |
| *Plestiodon fasciatus* | 15 | 18 | 13 | 10 | 4 | 0 | 0 | 60 | 5 |
| *Plestiodon laticeps* | 2 | 1 | 2 | 5 | 1 | 0 | 0 | 11 | 5 |
| *Sceloporus consobrinus* | 225 | 9 | 48 | 29 | 2 | 0 | 0 | 313 | 5 |
| *Scincella lateralis* | 122 | 16 | 26 | 60 | 2 | 0 | 0 | 226 | 5 |
| Unidentified *Plestiodon*[b] | 14 | 22 | 1 | 1 | 0 | 0 | 0 | 38 | 4 |
| Squamata (Serpentes) | | | | | | | | | |
| *Agkistrodon contortrix contortrix* | 8 | 2 | 1 | 15 | 5 | 0 | 0 | 31 | 5 |
| *Agkistrodon piscivorus leucostoma* | 82 | 0 | 0 | 17 | 0 | 61 | 0 | 160 | 3 |
| *Carphophis vermis* | 1 | 0 | 5 | 0 | 0 | 0 | 0 | 6 | 2 |
| *Cemophora coccinea copei* | 0 | 0 | 2 | 8 | 1 | 0 | 0 | 11 | 3 |
| *Coluber constrictor*[c] | 15 | 3 | 0 | 19 | 2 | 0 | 0 | 39 | 4 |
| *Coluber flagellum flagellum* | 3 | 2 | 0 | 5 | 1 | 0 | 0 | 11 | 4 |
| *Crotalus horridus* | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1 |
| *Farancia abacura reinwardtii* | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 |
| *Heterodon platirhinos* | 1 | 0 | 0 | 2 | 0 | 0 | 0 | 3 | 2 |
| *Lampropeltis holbrooki* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 |
| *Nerodia erythrogaster* | 3 | 0 | 0 | 4 | 0 | 5 | 0 | 10 | 5 |
| *Nerodia fasciata confluens* | 7 | 0 | 0 | 0 | 0 | 23 | 0 | 30 | 2 |
| *Nerodia rhombifer rhombifer* | 2 | 0 | 0 | 1 | 0 | 7 | 0 | 10 | 3 |
| *Opheodrys aestivus aestivus* | 37 | 0 | 1 | 1 | 0 | 0 | 0 | 39 | 3 |
| *Pantherophis obsoletus* | 10 | 2 | 0 | 8 | 0 | 0 | 0 | 20 | 3 |

**TABLE 2**. cont.

| Species | IE | ACO | PT | FT (DF) | FT (logs) | TT | ARS | All | #M |
|---|---|---|---|---|---|---|---|---|---|
| *Sistrurus miliarius streckeri* | 2 | 0 | 0 | 2 | 3 | 0 | 0 | 7 | 3 |
| *Storeria dekayi texana* | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 5 | 3 |
| *Storeria occipitomaculata occipitomaculata* | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 2 |
| *Tantilla gracilis* | 4 | 1 | 3 | 0 | 0 | 0 | 0 | 8 | 3 |
| *Thamnophis proximus proximus* | 48 | 9 | 1 | 16 | 0 | 1 | 0 | 75 | 5 |
| Testudines | | | | | | | | | |
| *Chelydra serpentina* | 2 | 0 | 0 | 0 | 0 | 18 | 0 | 20 | 2 |
| *Deirochelys reticularia miaria* | 2 | 0 | 0 | 1 | 0 | 75 | 0 | 78 | 3 |
| *Kinosternon subrubrum hippocrepis* | 5 | 0 | 0 | 0 | 0 | 518 | 0 | 523 | 2 |
| *Pseudemys concinna concinna* | 0 | 0 | 0 | 0 | 0 | 72 | 0 | 72 | 1 |
| *Sternotherus odoratus* | 2 | 0 | 0 | 0 | 0 | 269 | 0 | 271 | 2 |
| *Terrapene carolina triunguis*[d] | 28 | 1 | 0 | 0 | 0 | 0 | 0 | 29 | 2 |
| *Trachemys scripta elegans* | 8 | 0 | 1 | 0 | 0 | 812 | 0 | 821 | 3 |
| Total number of encounters | | | | | | | | | |
| Anura | many | 2 | 2607 | 1092 | 101 | 391 | many | > 4194 | 7 |
| Caudata[a] | > 30 | 0 | 254 | 97 | 8 | 22 | 0 | > 411 | 5 |
| Squamata (Lacertilia) | 560 | 72 | 104 | 111 | 9 | 0 | 0 | 856 | 5 |
| Squamata (Serpentes) | 229 | 19 | 16 | 101 | 12 | 99 | 0 | 476 | 6 |
| Testudines | 47 | 1 | 1 | 1 | 0 | 1764 | 0 | 1814 | 5 |
| All species | > 867 | 94 | 2982 | 1402 | 130 | 2276 | many | > 7751 | 7 |

[a]Twelve efts were found under logs, but many larvae were found in a drying pool. This is reflected by a > sign in the sum column and row.

[b]Skinks occasionally escaped before they could be identified to species

[c]The Eastern Yellow-bellied Racer subspecies (*C. c. flaviventris*), Southern Black Racer subspecies (*C. c. priapus*), and possible hybrids were found

[d]One specimen was likely a hybrid between *T. c. triunguis* and *T. ornata*

(*Lithobates* spp.) and small tadpoles (*Hyla* spp. and Blanchard's Cricket Frogs, *Acris blanchardi*) captured by crawfish traps and minnow traps. Because minnow traps were only used in 2012, we only used the data from the lakes for the summer of 2012 for all turtle trap comparisons.

We performed all tests in the program R (version 3.0.2; R Development Core Team, Vienna, Austria) using a significance value of $\alpha = 0.05$ unless otherwise noted. For most of our sub-methods (e.g., baited vs. unbaited turtle traps and single-ended vs. double-ended funnel traps), we were not confident that they had been sufficiently controlled or randomized to make accurate comparisons between the sub-methods. Therefore, these sub-methods were combined for all analyses unless otherwise noted (see Discussion).

## RESULTS

We documented 7,751 reptiles and amphibians representing 53 species (Table 2). Additionally, we found two subspecies and possible hybrids of the racer (Eastern Yellow-bellied Racer, *Coluber constrictor flaviventris* and Southern Black Racer, *C. c. priapus)* and an atypical Three-toed Box Turtle (*Terrapene carolina triunguis*) that matches a published description of a Three-toed Box Turtle/Ornate Box Turtle hybrid (*T. ornate*; Cureton et al. 2011). Skinks escaped before they could be identified to the species level on several occasions; therefore, we recorded these as unidentified *Plestiodon*. Twelve of the species found in our survey had not been documented at this site in the 2008 survey (Patton and Wood 2009). We documented more species (48 total) by recording incidental encounters than by any other method (Fig. 2; Table 3). Funnel traps on drift fences and pitfall traps recorded the second and third greatest number of species (38 and 35, respectively).

In 2012, only three methods captured unique species (i.e., species that were not documented by other methods). Those methods were incidental encounters (three), funnel traps on drift fences (two), and turtle traps (one; the numbers in parentheses are the numbers of unique species). In 2013, incidental encounters (five), funnel traps on drift fences (one), pitfall traps (one), and turtle traps (five) were the only methods that captured unique species. When the data from both years are combined, only incidental encounters (one), funnel traps on drift fences (one), and turtle traps (two) captured unique species, and the combination of those methods

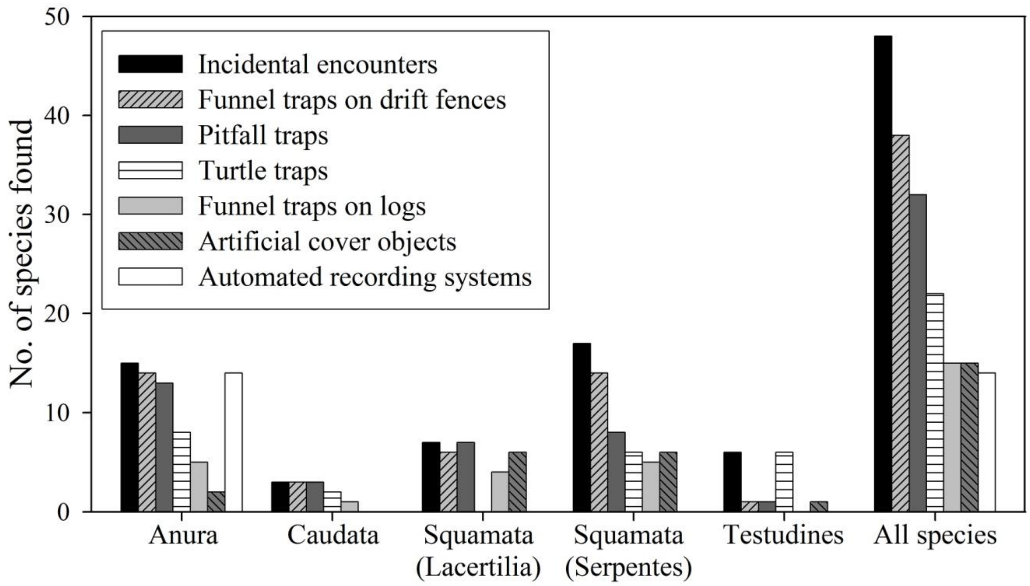


**FIGURE 2**. The number of species in each taxonomic group found by each survey method during a study a herpetofaunal community in Atoka County, Oklahoma, USA. The percentage of all documented species that were found by each method is also shown.

would have been sufficient to document all of the species found in this study.

Artificial cover objects, automated recording systems, and funnel traps on logs all had relatively low capture rates (Fig. 2). Funnel traps on logs had a mean of 0.19 captures/trap/day; whereas, funnel traps on drift fences had a mean of 0.5 captures/trap/day. The median ranks of their capture rates were significantly different ($U$ = 7339.5, $P < 0.001$). There were no obvious differences between the capture rates of tin and tarp cover objects. Among the 48 pieces of tin and 24 pieces of tarp that were randomly placed in the forest, 53 captures were made by tin, and 26 were made by tarps. However, this comparison is severely limited by the low capture rates.

**TABLE 3**. The number of species found by the method listed on the column headings but not found by the method listed in the left-hand column. Larger numbers indicate that the method in the top row was better relative to the method listed in the left column. IE = incidental encounters (any encounters not included in the other methods), ACO = artificial cover objects, PT = pitfall traps, FT (DF) = funnel traps on drift fences, FT (logs) = funnel traps on logs, TT = turtle traps, ARS = automated recording systems. Numbers in brackets are the total number of species captured by each method.

| | IE | ACO | PT | FT (DF) | FT (logs) | TT | ARS |
|---|---|---|---|---|---|---|---|
| | [48] | [15] | [32] | [38] | [15] | [22] | [14] |
| IE | | 0 | 2 | 3 | 1 | 2 | 0 |
| ACO | 33 | | 21 | 24 | 6 | 20 | 12 |
| PT | 18 | 4 | | 12 | 3 | 12 | 2 |
| FT (DF) | 13 | 3 | 6 | | 0 | 8 | 1 |
| FT (logs) | 34 | 6 | 20 | 23 | | 18 | 9 |
| TT | 28 | 13 | 22 | 24 | 11 | | 6 |
| ARS | 34 | 13 | 21 | 25 | 9 | 14 | |
| Mean | 26.7 | 6.5 | 15.3 | 18.5 | 5.0 | 12.3 | 5.0 |

There were different taxonomic biases among the methods ($\chi^2$ = 12647.8, df = 24, $P < 0.001$; Fig. 3). Post-hoc tests showed that there were no significant differences in the distribution of taxa between either incidental encounters and funnel traps on logs ($\chi^2$= 8.82, df = 4, $P$ = 0.066) or funnel traps on drift fences and funnel traps on logs ($\chi^2$ = 1.01, df = 4, $P$ = 0.909). All of the other methods were significantly different from each other ($\chi^2 \geq 47.15$, df = 4, $P < 0.001$; Fig. 3a).

Taxonomic biases were also evident in the different turtle trapping methods. The median ranks of the capture rates of hoop nets, crawfish traps, and minnow traps differed significantly for turtles ($H$ = 80.48, df = 2, $P < 0.001$), snakes ($H$ = 15.20, df = 2, $P < 0.001$), and anurans ($H$ = 14.38, df = 2, $P < 0.001$). Post-hoc comparisons (minimum significant difference in mean ranks = 17.67) showed that the median rank of turtle capture rates was significantly higher for hoop nets than crawfish traps (difference in mean ranks [DMR] = 39.14), and it was significantly higher for crawfish traps than minnow traps (DMR = 25.35). The median rank of anuran capture rates was significantly higher for crawfish traps than hoop nets (DMR = 21.40), but there was not a significant difference between the median ranks of anuran capture rates for crawfish traps and minnow traps (DMR = 5.36) or minnow traps and hoop nets (DMR = 16.03). We did not conduct post-hoc tests

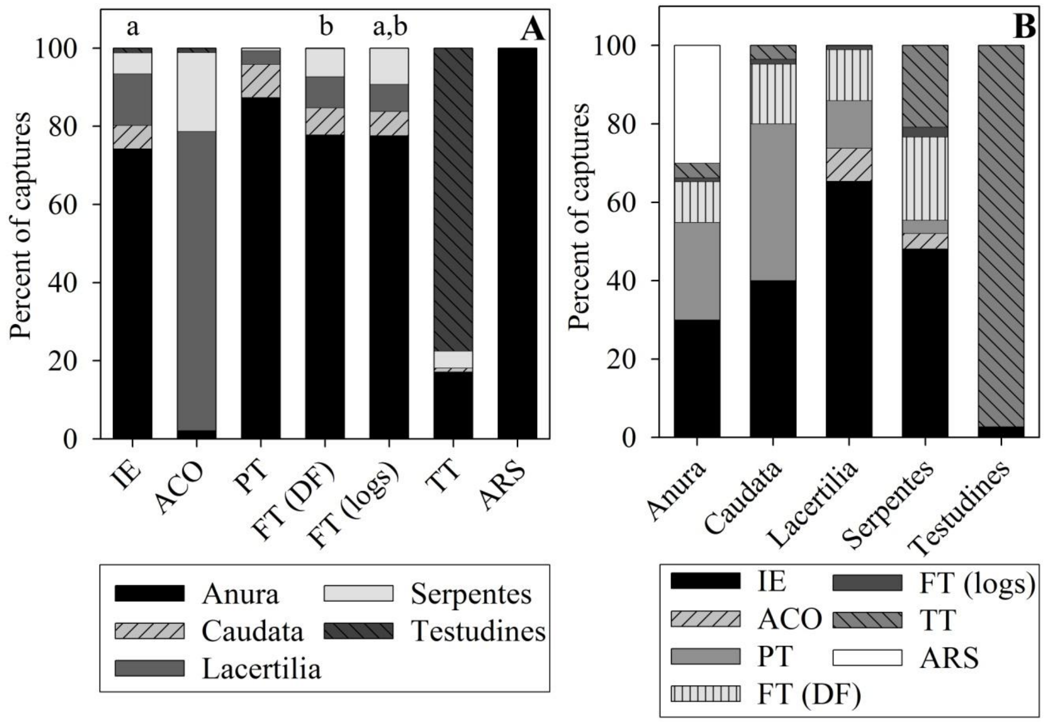


**FIGURE 3**. (A) The percentage of captures in each taxonomic group is shown for each survey method during a study a herpetofaunal community in Atoka County, Oklahoma, USA. Methods with the same letter designation did not differ significantly. (B) For each taxonomic group, the percentage of captures made by each method is shown. The value 225 was used for any species for which exact counts were not recorded (e.g., anurans in incidental encounters). IE = incidental encounters (any encounters not included in the other methods), ACO = artificial cover objects, PT = pitfall traps, FT (DF) = funnel traps on drift fences, FT (logs) = funnel traps on logs, TT = turtle traps, ARS = automated recording systems.

on snakes because hoop nets and minnow traps had equal mean ranks with only one snake capture each. Although not compared statistically, basking traps appeared to do very poorly, with only 14 captures (two species) during 70 trap days (35 d per trap).

In the summer of 2012, crawfish traps captured 27 adult/juvenile anurans and 17 tadpoles. Minnow traps captured three adult/juvenile anurans and 17 tadpoles, and the proportions of adults/juveniles and tadpoles were significantly different ($\chi^2$ = 10.08, df = 1, $P$ = 0.001) between crawfish traps and minnow traps. Among the tadpoles captured by crawfish traps, 13 were large (*Lithobates* spp.) and four were small (*Hyla* spp. and *A. blanchardi*). Among the tadpoles captured by minnow traps, four were large and 13 were small. The proportions of large and small tadpoles were significantly different ($\chi^2$ = 7.53, df = 1, $P$ = 0.006) between crawfish traps and minnow traps.

## DISCUSSION

***Survey methods***.—The number of different methods that we used and confounding factors, such as different numbers of traps, limited our ability to statistically compare trap efficiency. Nevertheless, some tentative conclusions are still warranted, especially regarding the taxonomic biases of different methods. First, recording incidental encounters proved to be an important part of the study. This method documented more species than any of the other methods, and it was the only method that documented Timber Rattlesnakes (*Crotalus horridus*). Also, this method resulted in more lizard and snake captures than any of the other methods.

Both pitfall traps and funnel traps along drift fences documented roughly the same number of species for every taxon except snakes, but the relative number of captures in each taxon differed between the two methods. Pitfall traps were biased towards anurans and salamanders, and the funnel traps along drift fences were biased towards snakes and lizards. These taxonomic biases are generally consistent with the results of other studies; however, lizards have often been reported to be more readily captured using pitfall traps than funnel traps (Bury and Corn 1987; Greenberg et al. 1994; Crosswhite et al. 1999).

Funnel traps placed along logs did not appear to be a viable alternative to using drift fences. Funnel traps on logs captured fewer species and had a significantly lower

**TABLE 4.** The average number of captures per trap per day for turtle traps in the lakes at Atoka County, Oklahoma, USA. Because only a few of each diameter were used, all hoop nets were grouped for this comparison. Only the data from the summer months of 2012 and 2013 when trapping efforts were consistent were included; data from streams and seeps were excluded because of the sporadic nature of our sampling effort in these habitats (minnow traps were only used in 2012). These data included the results from all of the traps of each category rather than the random subset that was used in our statistical analysis.

| Species/Group | Minnow trap | Crawfish trap | Hoop net |
|---|---|---|---|
| *Trachemys scripta elegans* | 0.000 | 0.084 | 1.002 |
| *Kinosternon subrubrum hippocrepis* | 0.035 | 0.315 | 0.304 |
| *Sternotherus odoratus* | 0.000 | 0.026 | 0.330 |
| *Deirochelys reticularia miaria* | 0.000 | 0.005 | 0.084 |
| *Chelydra serpentina* | 0.000 | 0.004 | 0.019 |
| *Pseudemys concinna concinna* | 0.000 | 0.002 | 0.102 |
| Anura (adults and subadults) | 0.004 | 0.047 | 0.013 |
| Anura (tadpoles) | 0.067 | 0.100 | 0.003 |
| Caudata | 0.000 | 0.007 | 0.000 |
| Squamata (serpentes) | 0.004 | 0.091 | 0.011 |

median catch rate than funnel traps placed along drift fences. This result suggests that many reptiles and amphibians can readily cross logs rather than being compelled to move along them.

The usefulness of automated recording systems in surveys depends on the purpose of the survey and the habitat being surveyed (Corn et al. 2000). They have the advantage of being able to collect data without a researcher being present, and they can collect detailed data on the timing and magnitude of choruses (Saenz et al. 2006; Steelman and Dorcas 2010). The recordings are, however, very time consuming to analyze manually. In our study, they documented 14 species of anuran at each lake, but all of these species were also found by at least two other survey methods. Therefore, at sites like ours that have only a few discrete wetlands, they do not appear to be necessary for herpetological surveys if other methods such as funnel traps and pitfall traps are used, and if the primary objective is simply to document the presence or absence of species. However, their usefulness may increase at sites that have multiple types of wetlands distributed across a large area.

Artificial cover objects were not effective at our site, and they were strongly biased towards lizards. They resulted in fewer captures than any other method that we employed, and they only documented 15 species. This differs from the results of other studies for which artificial cover objects have been very successful, especially at capturing snakes (Grant et al. 1992; Kjoss and Litvaitis 2001; Seigel et al. 2002; Scheffers et al. 2009). One possible explanation is that it was too hot for most species to use the cover objects (Parmelee and Fitch 1995; Joppa et al. 2009). This is supported by the observation that the capture rate and species richness were higher in the spring than in the summer. Time of day and the amount of time the boards had been in place are also potential factors, but the cover objects were checked at various times of day during both years of the study, and there was no obvious difference between the capture rates of 2012 and 2013.

Several differences are apparent among the various types of turtle traps that we used. The capture rate of turtles was significantly higher for hoop nets than either crawfish traps or minnow traps, and the catch rate for crawfish traps was significantly higher than the catch rate for minnow traps. Also, hoop nets had the highest number of captures for every species of turtle except Mississippi Mud Turtles (*Kinosternon subrubrum hippocrepis*), which were captured most frequently by crawfish traps. This may be because this species prefers shallow heavily vegetated water, and the crawfish traps can be placed in shallower areas with more vegetation than the larger hoop nets (Ernst and Lovich 2009). This result demonstrates the importance of using a variety of traps that can sample a wide range of available habitats if a community survey is the objective.

Although hoop nets had more captures for most species of turtle, crawfish traps still captured representatives of every turtle species, whereas minnow traps only captured *K. s. hippocrepis*. Additionally, crawfish traps captured hatchlings of five of the six species of turtle, all of which were too small to be captured by the hoop nets. Therefore, these traps not only increased the number of captures, but they also expanded the size range of individuals that could be captured.

Turtle traps also frequently captured species other than turtles (Table 4). This is especially true of the crawfish traps, which were the only traps that documented Western Lesser Sirens (*Siren intermedia nettingi*) and had a higher capture rate for snakes than either minnow traps or hoop nets. Although there was not a significant difference in the overall capture rate of anurans between crawfish traps and minnow traps, there were significant differences in the species composition of the anurans captured. First, minnow traps captured primarily tadpoles (17/20); whereas, crawfish traps captured mostly adults and juveniles (27/44). Second, the species of tadpoles that were captured differed between the traps, with minnow traps capturing mostly small species

(*Hyla* spp. and *A. blanchardi*) and crawfish traps capturing mostly larger *Lithobates* species. This was most likely because the mesh size of the minnow traps was smaller. Based on these results, it appears that crawfish traps are more effective than minnow traps for every taxon except the smaller anuran species.

Despite the high catch rates we obtained using crawfish traps, they should be implemented cautiously. Klemish et al. (2013) used these traps to survey amphibians and reported that frogs can get their legs stuck between the wire coil and the mesh. Although we never recorded such an incident, we did have several problems with snakes. Large snakes were safely captured in these traps, but some smaller snakes had a tendency to tangle themselves in the mesh, sometimes resulting in drowning. For most species this was a rare occurrence and would likely not prevent the use of these traps; however, for Western Mud Snakes (*Farancia abacura reinwardtii*), the mortality rate was 100%. Using the crawfish traps, we captured one individual in this survey and four more at other sites. All five tangled themselves and drowned. It appears that their morphology allows their heads to pass through the mesh easily but makes it difficult for them to pull their heads back out. Also, their aquatic burrowing tendencies resulted in them consistently attempting to pass through the bottom of the trap; whereas, other snakes often tangled themselves near the surface where they could still breathe. This problem will likely exist for other species, such as Rainbow Snakes (*Farancia erytrogramma*), that have similar morphology and behavior. Therefore, we do not recommend using these traps in habitats that contain these species or if a species of conservation concern is being targeted.

***Species distributions and notes***.—Most species were either not captured frequently enough to discern a distribution pattern, or they were captured frequently across all habitat types. Nevertheless, there are a few species that merit discussion. First, while all of the aquatic species were documented in both lakes, only a few of the species ventured into the streams and seeps. For example, Western Cottonmouths (*Agkistrodon piscivorus leucostoma*) were frequently seen throughout the streams and seeps, and even in the summer, they could be found concentrated around the remaining pools in the stream bed (Hill and Beaupre 2008; McKnight et al. 2014). In contrast, the *Nerodia* species were infrequently found in the streams or seeps. Similarly, *K. s. hippocrepis* was the only aquatic turtle species that was commonly found away from the lakes (a single Red-eared Slider, *Trachemys scripta elegans*, was the only additional testudine; Strecker, 1926; Gibbons et al. 1983).

The distribution of Northern Scarlet Snakes (*Cemophora coccinea copei*) was also of interest. They have generally been reported from sandy areas with oak trees, pine trees, or both (often with wire grass) but can be found in fields and grassy ecotones (Williams and Wilson 1967; Palmer and Tregembo 1970; Nelson and Gibbons 1972). The *C. c. copei* in our study were limited to drift fences #2 and #3, and the funnel trap on a log on the southwest side of Hassell Lake. All three of these locations were in oak forest with sandy soil, but only the funnel trap on the log was in an area with grass (this trap was open for both years but only caught one *C. c. copei*). All three locations were within 60 m of a lake. Nelson and Gibbons (1972) also reported high numbers of scarlet snakes near ponds, but the scarlet snakes in their study were not exclusively near the water.

***Conclusions and suggestions for future studies***.—Our study demonstrates the importance of using multiple survey methods over multiple years. By expanding the number of methods used and the duration of the survey, we were able to document 12 species that were not documented in a previous survey (Patton and Wood 2009), and both years of our survey were necessary to document all 53 species. Only 50 species were documented in 2012, and 51 were documented in 2013. Based on our results, the combination of turtle traps, funnel traps along drift fences, and recording incidental encounters is probably sufficient for documenting the majority of the species at a site with similar habitat features. Pitfall traps did, however, have more captures than funnel traps, and in 2012 they documented one species that was not found by other methods, so their inclusion is recommended. Although recording incidental encounters was an important part of this survey, it should be stressed that most of the encounters were made while monitoring traps. Therefore, it is unlikely that relying solely on incidental encounters would result in an adequate survey of a site.

Automated recording systems, artificial cover objects, and funnel traps on logs were neither necessary nor efficient components of our general herpetological survey. However, artificial cover objects have been frequently reported to be effective at other sites; therefore, we recommend evaluating their use on a case-by-case basis. Also, while our method of randomly selecting the locations for cover objects resulted in adequate coverage across all major habitat types, the cover objects were widely dispersed and very time consuming to monitor. Therefore, placing cover objects along transects is probably a better method in many circumstances.

Cawfish traps returned significantly higher capture rates than minnow traps for every taxonomic group except anurans, and within anurans, minnow traps captured almost exclusively tadpoles of small species; whereas, the crawfish traps captured mostly larger species, including both tadpoles and adults/juveniles.

Therefore, the crawfish traps appear to be superior to the minnow traps in most respects, but they should be used cautiously because of their tendency to drown some snake species.

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