ESTIMATES AND EFFECTS OF VERTEBRATE PREDATION ON DRIFT FENCE

ASSOCIATED PITFALL TRAPS

THESIS

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by

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The following work is dedicated to Leonard and Carol Ferguson, two wonderful parents.

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ABSTRACT

ESTIMATES AND EFFECTS OF VERTEBRATE PREDATION ON DRIFT FENCE ASSOCIATED PITFALL TRAPS

by

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Drift fence sampling with associated pitfall traps is a technique used to assess small vertebrate communities among a variety of taxa. Researchers using this trapping technique have analyzed a number of factors from drift fence design to associated problems. One potential problem often overlooked is the effect foraging vertebrate predators might have on animals captured in pitfall traps. Removal of animals from pitfalls by vertebrate predators might lead researchers to inaccurate conclusions regarding the composition of small vertebrate animal communities and their populations. Motion-sensitive cameras and track monitoring stations were used to estimate the amount and variety of vertebrate predators attending a series of 18 pitfall arrays monitoring the endangered Houston toad (*Bufo houstonensis*) on the Griffith League Ranch in Bastrop County, Texas. Ten potential vertebrate predators were documented visiting pitfall arrays with the northern raccoon (*Procyon lotor*) being the most frequently recorded visitor for both the motion-sensitive cameras (41.8% of total photographs) and track monitoring stations (64.5% of total tracks recorded). Proportions of pitfalls with tracks and animals present were compared to the proportion of pitfall traps without tracks and animals using a 95% confidence interval of two proportions and nominal logistic regression analyses. No statistical difference was detected in number of animals captured in pitfalls visited by predators verse number of animals captured in pitfalls without predator activity (95% CI $= -0.026 < P_1 - P_2 < 0.035$; $r^2 = 0.0012$, $p = 0.2712$). Although the presence of predators did not seem to affect the overall capture success of pitfall traps, the frequency of predator visits to pitfalls indicated risks still existed for confined animals. This risk increases when dealing with rare or endangered taxa, which could potentially be exposed to higher levels of predation when confined to pitfall traps. The generally low capture success of 18 pitfall arrays during my study and the difficulty in addressing direct predation might have limited my ability to detect the true effects of predators on drift fence sampling. Future studies should focus on different monitoring techniques such as infrared video camera systems and other ways to estimate the loss of individual animals from pitfall traps. Additionally, precautionary measures should be encouraged for researchers using pitfall sampling to survey rare or endangered taxa.

CHAPTER 1

ESTIMATES AND EFFECTS OF VERTEBRATE PREDATION ON THE GRIFFITH LEAGUE RANCH, BASTROP COUNTY, TEXAS

Introduction

Pitfall traps with or without associated terrestrial drift fences remain a commonly applied technique in sampling small vertebrate animals (Shoop 1965, Stenhouse 1985, Sutton et al. 1999, Jenkins et al. 2003). This field technique is widely used and several studies have evaluated effectiveness and reported problems with the method (Brown 1997, Crosswhite et al. 1999), such as escape of captured animals (Mazerolle 2003), pitfall avoidance by certain species such as terrestrial turtles (Christiansen and Vandewalle 2000), and the ability of animals to trespass or circumvent fences (Dodd 1991). Another important potential problem with drift fence arrays is mortality of trapped animals (Yunger et al. 1992, Enge 2001).

Mortality factors associated with pitfall trapping include desiccation (Jenkins et al. 2003), drowning (Aubry and Stringer 2000), starvation (Yunger et al. 1992), exposure (Padget-Flohr and Jennings 2001), and predation within pitfall traps (Dodd and Scott 1994). However, predation upon animals caught in drift fence arrays by foraging vertebrate predators is rarely mentioned, and most researchers have attempted to correct or calculate the effects of only the aforementioned suite of problems. To my knowledge no study has directly addressed the effects potential vertebrate predators might have on drift fence sampling. Most direct predation events mentioned in the literature are anecdotal and address predation within pitfall traps by trapped mammals such as shrews (Jenkins et al. 2003) or minor disturbances to pitfall covers by meso-carnivores such as the northern raccoon (*Procyon lotor*) (Sutton et al. 1999). Predation of drift fence arrays by larger carnivores or other potential vertebrate predators is rarely discussed and has not been studied quantitatively.

However, researchers using other trapping techniques, such as live trapping small mammals with Sherman traps have reported predation by spotted skunks (*Spilogale putorius*) (Hooven et al. 1979) and mink (*Mustela vison*) (Platt 1968). Such studies in conjunction with literature anecdotes lend support to the idea that predation of captured animals in pitfall arrays with drift fences is possible (Gibbons and Semlitsch 1981, Heyer et al. 1994, Walls 1995).

Detecting predation on traplines can be unusually difficult to document. In fact, Hooven et. al. 1979 and Platt 1968 used indirect evidence to draw conclusions about which carnivore consumed their trapped animals. In addition, most predators are elusive and often nocturnal, making direct observation of predation along traplines challenging.

Several techniques have been used to overcome such obstacles and allow researchers to document predation in their absence. One such approach is the use of automated photography or infrared camera systems (Carthew and Slater 1991, Kucera and Barrett 1993). The use of infrared camera systems has increased in the past 10 years with broad applications in field studies such as identification of predators at songbird nests (Thompson et al. 1999), estimates of grizzly bear (*Ursus arctos*) populations (Mace et al. 1994), and identification of predators of ground nesting birds (Hernandez et al. 1997). Camera systems enable biologists to monitor predatory behavior at both artificial (Savidge and Seibert 1988) and natural (Van Schaik and Griffiths 1996) sites.

Although not typically used to record predation, carnivore track monitoring stations can document the presence, amount, and variety of predators in a given area (Roughton and Sweeny 1982, Conner et al. 1983, Diefenbach et al. 1994). Consisting of a cleared circle approximately 1 m in diameter, these stations record tracks of predators in the circle's media (e.g. sand, lime dust) after elimination of all previous tracks. In doing so, track monitoring stations allow researchers to monitor activities of elusive and difficult to study predators.

Even with motion-sensitive camera monitoring and scent station indices, difficulties still arise when studying predation, including the inability to accurately assess diagnostic sign at predation sites (Lariviere 1999), underestimation of a particular predator using motion-sensitive cameras (Thompson et al. 1999), interspecific variation and intraspecific overlap in depredations (Staller et al. 2005), and confounding effects of scavengers and multi-predator visits (Hartman et al. 1997, Lariviere 1999). Despite such difficulties, studies examining predation are ecologically important, especially when predators pose a threat to other organisms. Based upon problems with other trapping techniques (Platt 1968, Hooven et al. 1979) and anecdotal information gleaned from the literature, this could be the case with drift fence associated pitfall traps.

In the case of pitfall traps, predation of captured animals may pose a serious threat to the integrity of data, calling into question the reliability of information on the vertebrate fauna. Losses of captured animals to foraging vertebrate predators could bias population estimates and limit the possibility of detecting rare or elusive species typically underrepresented in traps. The problem becomes more serious when using pitfall traps to monitor rare, threatened, or endangered species. In such instances, as is the case with the endangered Houston toad (*Bufo houstonensis*) in Bastrop County, Texas, the loss of individuals to predation on traplines can be extremely detrimental. In an ecological sense, losses in a population plagued by low numbers in fragmented habitats and limited movement among patches, could increase the probability of extinction.

Using a combination of techniques, I tested the effects vertebrate predators might pose to all vertebrate animals captured in pitfall traps and how data obtained from terrestrial drift fence studies might be biased by the removal of animals. In particular, I attempted to document the effects of predation on terrestrial drift fences with pitfall traps used in a study of an ecologically sensitive species, the endangered Houston toad.

The objectives of my study were to quantify activities of vertebrate predators along pre-established drift fence arrays using pitfall traps to highlight potential threats to captured animals, and to elucidate potential bias in data collection on vertebrate communities.

Materials and Methods

Study Site

My study was conducted on the Boy Scouts of America's Griffith League Ranch – a 2012-ha ranch located in north-central Bastrop County within the Lost Pines Ecological Region of Texas (Fig. 1). Plant communities consist of mixed conifer hardwoods of loblolly pine (*Pinus taeda*), blackjack oak (*Quercus marilandica*) and post oak (*Quercus stellata*), mature stands of loblolly pines, several open pastures and mixed deciduous hardwoods of oaks (*Quercus spp.*) with an under story of yaupon (*Ilex vomitoria*), American beauty berry (*Callicarpa americana*), and farkleberry (*Vaccinium arboreum*). Soils are 91% sandy loam.

Eighteen drift fence arrays were constructed to monitor the local herpetofauna including the endangered Houston toad over a two-year period beginning in fall 2001. Five groups of drift fence arrays were installed (Fig. 2). Group one consisted of four Y-shaped drift fence arrays that surrounded a known Houston toad breeding pond. Three other Y-shaped drift fence arrays were located in a deciduous-evergreen mixed forest to intercept Houston toads from another known breeding pond. These three arrays were designated group two. Group three, in a similar habitat as treatment group two but dominated more by loblolly pines, had three Y-shaped drift fence arrays. These arrays were positioned to intercept toads from a third known breeding pond. Group four contained three Y-shaped arrays set in a line that began near a 2-ha lake and extended outward east to west through a mixed deciduous-evergreen forest. Five straight-line drift fence arrays, two with four pitfall traps and three with five pitfall traps, made up group

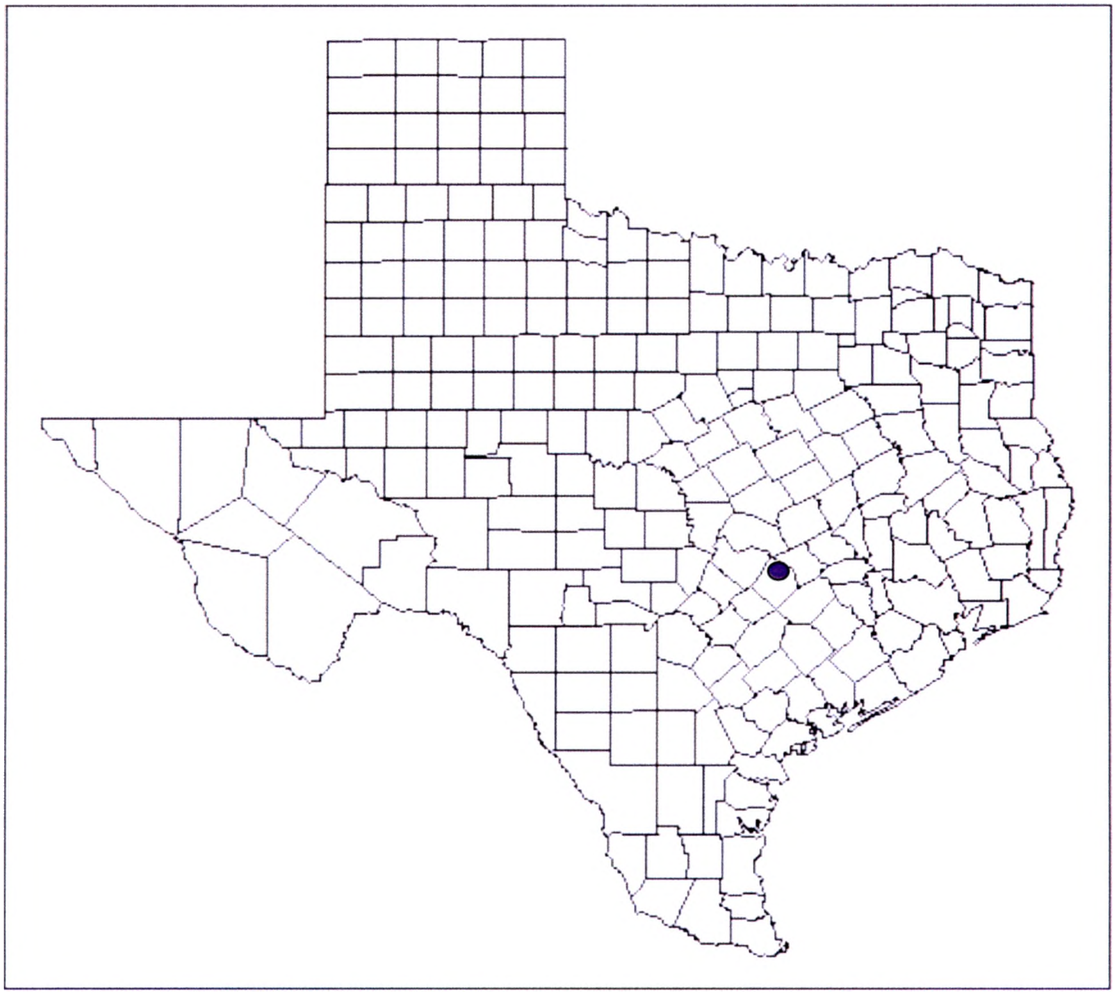


FIGURE 1. State of Texas with counties delineated indicating the location of the study site, the Griffith League Ranch (highlighted in blue), in north-central Bastrop County.

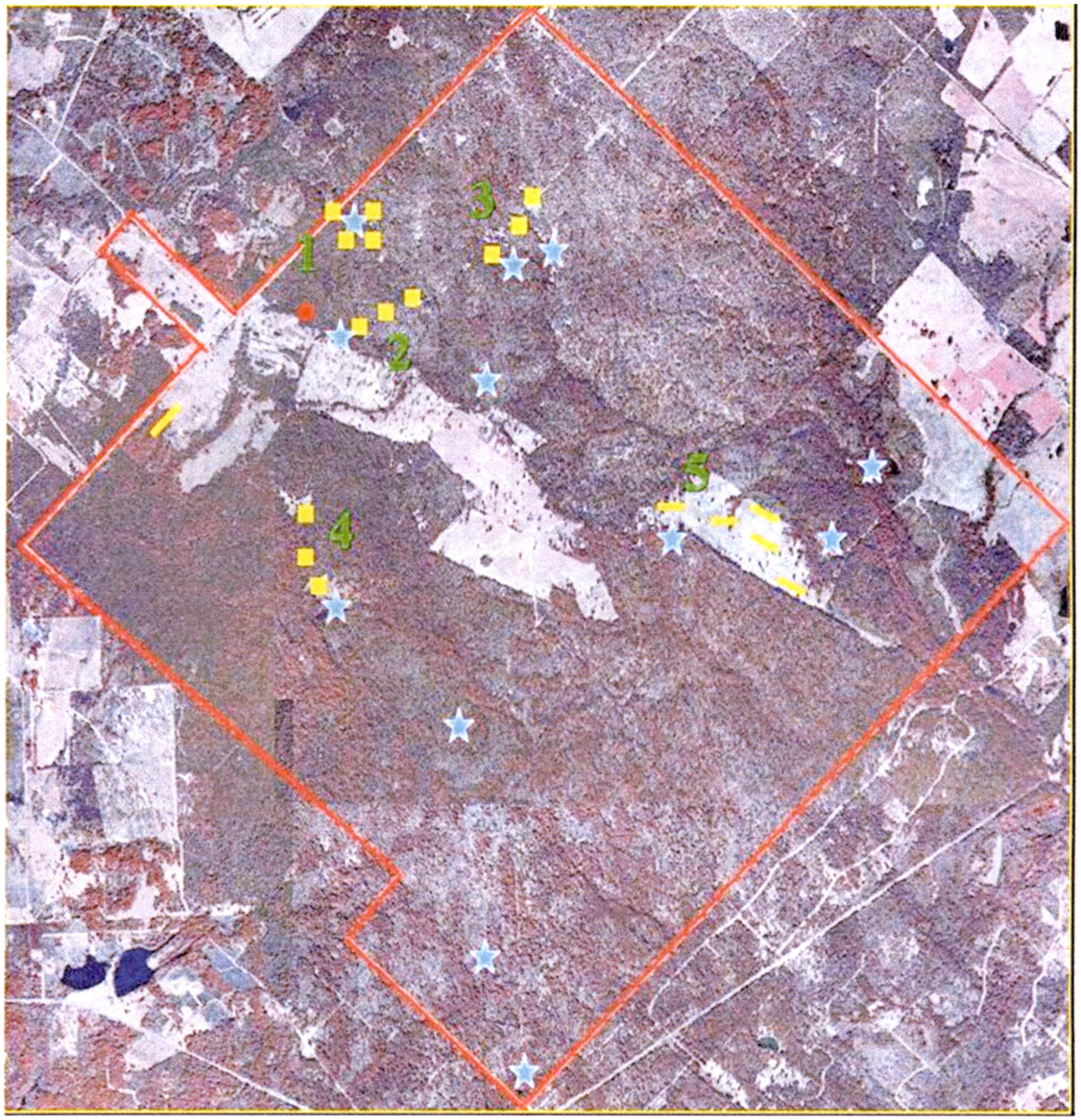


Figure 2. Aerial photograph of the Griffith League Ranch in north-central Bastrop County, Texas indicating the locations of the drift fence arrays used for the study of Houston toad ecology and predator effects on pitfall sampling.

1 = Group 1
2 = Group 2
3 = Group 3
4 = Group 4
5 = Group 5

= Y-shaped arrays
= Straight line arrays
= Ponds

five (Fig. 2). Y-shaped arrays had three radiating arms of 18 cm by 15 m aluminum flashing buried 5 cm into the ground with four pitfall traps; three terminal and one central. Straight-line drift fences were built of the same aluminum flashing in the same manner as the Y-shaped arrays (Bury and Corn 1987).

Each Y-shaped array had six funnel traps (two on each arm) supplementing the pitfall traps. Traps were checked daily for captured animals between March 2001 – August 2004. Captured animals were measured, marked either by toe clippings, PIT tags, or ventral scale clips, gender determined, and released greater than twenty meters from the array.

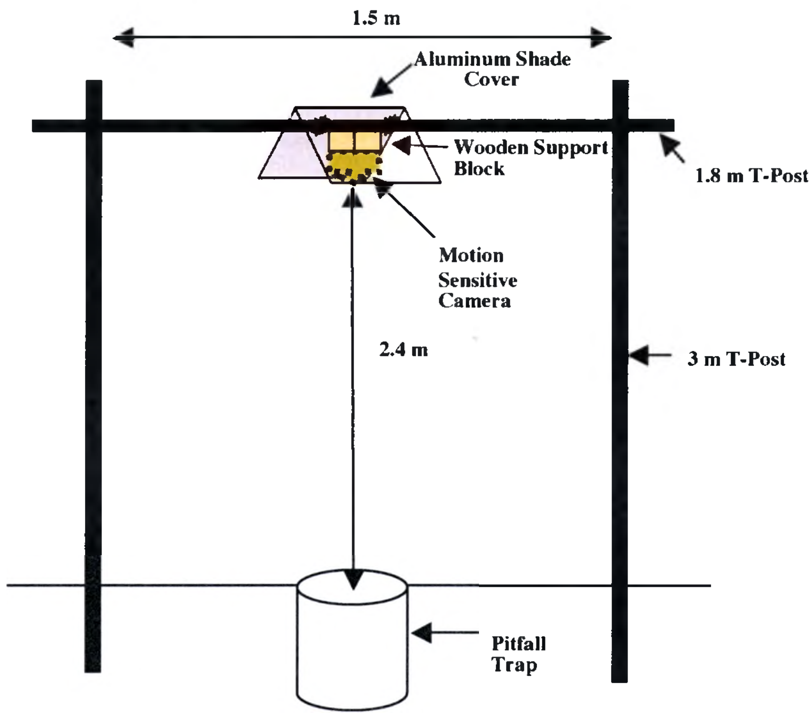
The predation study was initiated in 2003 in response to a perceived increase in potential predator activity around arrays (scat, tracks, disturbances, etc.). The study involved a two-pronged approach using motion-sensitive cameras and track monitoring stations to document predator activity around arrays.

Camera Stations

Ten Deer Cam® Model DC-100 cameras (DeerCam®, Park Falls, WI) were installed at 10 of the 18 drift fence arrays across the study site. Traplines and pitfall traps with cameras were chosen randomly. Two cameras were assigned to each group. A "central camera" was placed at a pitfall trap in the interior of a drift fence and a "terminal camera" was placed at a pitfall trap at the end of a drift fence. Central cameras were supported 2.4 m over the central pitfall trap by a 1.8-m t-post vertically attached to two 3-m t-posts placed 1.5 m apart (Fig. 3a). Cameras were secured to t-posts using a wooden block, bungee cords, and a large hose clamp. Centrally located cameras were fitted with an aluminum flashing shade and rain cover to minimize weather-induced damages to the equipment. Terminal cameras were attached to a 1.8-m t-post via bungee cords and a wooden block that were cinched to the t-post with a large hose clamp (Fig. 3b). Terminal cameras were located 3 m from the center of a pitfall trap and 0.6 m from the ground. Cameras were set to record the date and time for each photograph in order to distinguish the capture of multiple visitors versus repeat visitors. The camera settings were adjusted to high sensitivity and to take photographs at 30-second intervals after disruption of the motion sensor. All cameras were operational for 24 hours a day and checked periodically (~ once a week) for proper functioning. Once film was exposed, it was replaced and the developed photographs labeled with camera location and date.

Track Monitoring Stations

Track monitoring stations consisted of a 2-m diameter circle of cleared earth with the pitfall trap as the center. Y-shaped arrays had two pitfall traps, one central and one randomly chosen terminal pitfall trap, surrounded by the 2-m diameter circles of sand from the ranch. The pasture traplines in group five had alternating pitfall traps fitted with track monitoring stations. To prevent vegetation re-growth, a 13-cm deep hole 2-m in diameter was dug around the pitfall trap, lined with artificial pond liner, and filled with sand substrate. A total of 38 track monitoring stations were set in place in addition to five controls of 2-m circles placed greater than one hundred meters from the nearest track monitoring station in each group for a total of 43 track monitoring stations. Control plots were installed for comparison of visitation rates between monitoring stations with and without pitfall traps. This allowed me to determine whether visitation rates were in a)



b)

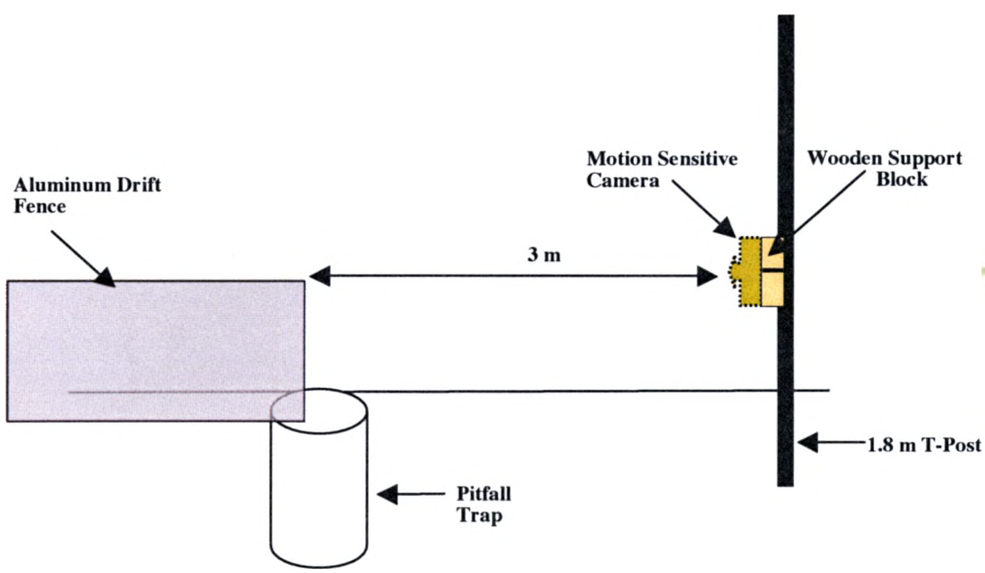


Figure 3. Detailed image of the structural design used to suspend motion-sensitive cameras over centrally located pitfall traps (a) and the design used to support cameras placed to monitor terminally located pitfall traps (b).

response to disturbances at the monitoring stations or if pitfall traps functioned as an attractant to predators attending the stations.

Each track monitoring station was raked four times a month to clear any previous tracks and prepare the sand for new track detection during the period of the study in which the pitfall traps were operational (21 October 2003 – 17 June 2004). After 17 June 2004, all pitfall traps were permanently closed and rakings reduced to twice a month to detect whether predators continued visiting stations after the pitfall traps were shut down. After raking, each station was checked the following morning for occurrence, pattern, and kinds of animal tracks present. Tracks were identified to species when possible and recorded as unknowns when that was not possible. The presence or absence of animals in pitfall traps was also recorded. Track monitoring stations were used as an index of predator abundance and to document differences in the variety, rate of visitation, and trap affinity of vertebrate predators.

Predator Exclusion Devices

I constructed predator exclusion devices (PEDs) out of 1.27 cm plywood. The PEDs consisted of 40.64 cm x 40.64 cm squares with four holes drilled in the corners by a Forstner bit (Fig. 4). Two 7.62 cm x 40.64 cm strips with two holes drilled in the terminal ends of the strips were made for each 40.64 x 40.64 square. Four pieces of 0.61 m rebar were hammered into the ground 10.16 cm from the pitfall trap's edge. The two strips were attached lengthwise (parallel to the drift fence) 10.16 cm from the pitfall trap lip with 27.94 cm cable ties. The squared 40.64 x 40.64 piece was set upon the strips and secured using two large binder clips for easy removal and access to pitfall traps (Fig. 4)

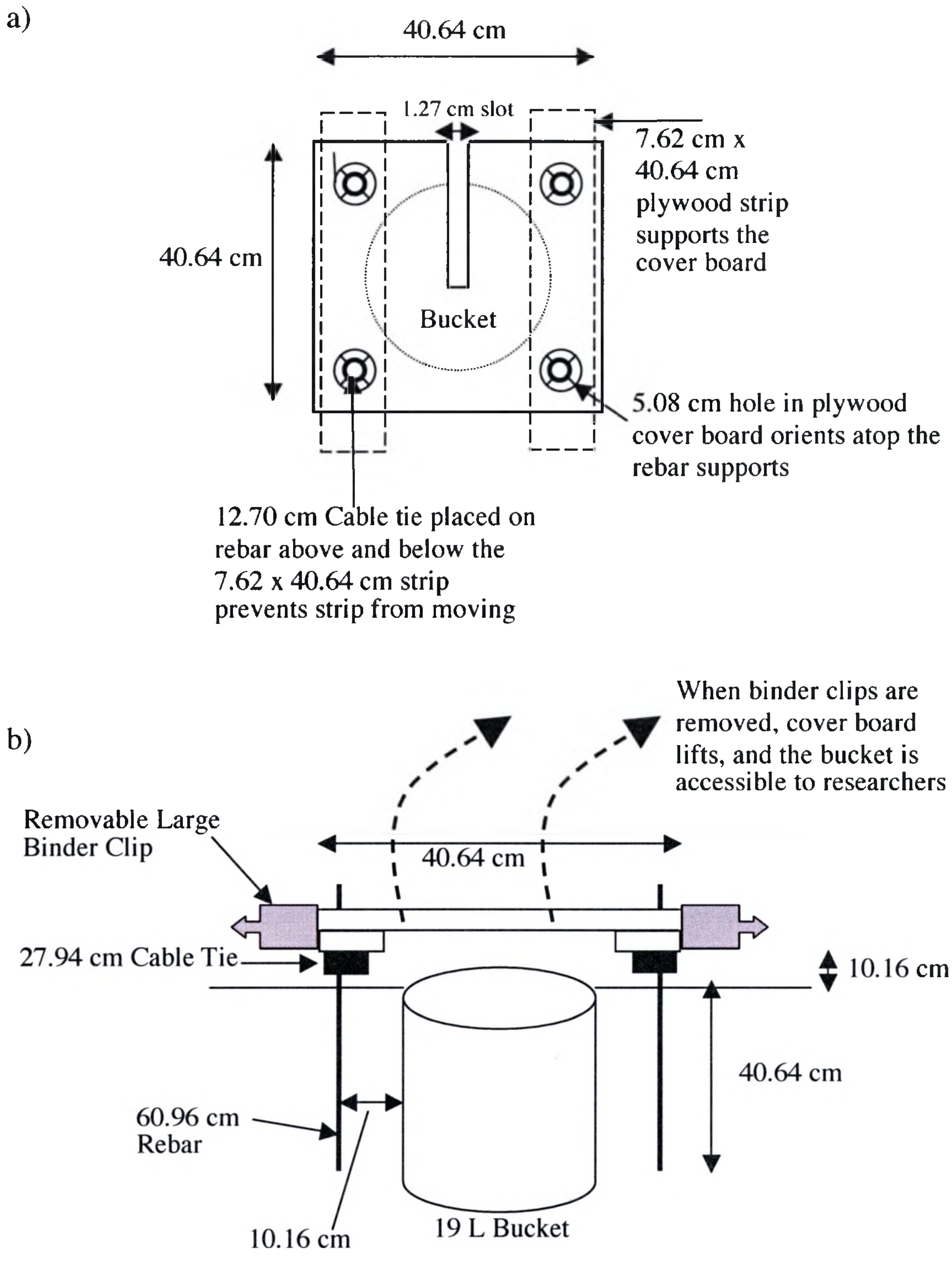


Figure 4. Detailed drawing of a Predator Exclusion Device illustrating its general operation and an aerial view (a) plus a lateral view (b) of the PED with pitfall trap.

I placed PEDs on individual pitfall traps at arrays where adult Houston toads had been captured in past years. According to previous capture data, 11 of 18 arrays had captured at least one Houston toad over the past two years. PEDs were only placed upon terminal pitfall traps, leaving central pitfall traps open. A total of 29 PEDs were installed across 10 arrays. PEDs were installed prior to intense toad activity in 2004.

Analyses

A variety of statistical analyses were used in an attempt to directly address the question of how the detection of a predator at a station or pitfall trap influenced the probability of capturing an animal in pitfall traps. I first calculated a 95% confidence interval of two proportions. The first proportion was the number of vertebrate animals caught verse the number of pitfall trap nights with predator tracks present. The second proportion was the number of vertebrate animals caught verse the number of pitfall trap nights with no tracks of any animal present. In doing so, these two values could be directly compared to one another to determine whether the proportion of animals caught in pitfall traps was directly affected by the presence or absence of predator tracks in the track monitoring stations.

A nominal logistic regression was performed using JMP (v. 5.0.1a, SAS Institute, Inc., Cary, NC). I treated tracks as a categorical variable and presence or absence of animals in pitfall traps as a numerical variable. Only information obtained when pitfall traps were physically opened and operational was included in analyses.

A Chi Square test of independence was performed using the program S-PLUS (v 6.1, Insightful Corporation, Seattle, WA) to test for an association between visitation rates and presence or absence of a pitfall trap.

Results

Camera Stations

Ten Deer Cam® Model DC-100 cameras were installed on 11 February 2004 and remained operational until 1 September 2004 for a total of 210 camera-days. A total of 455 photographs documented 15 different species of animals (Table 1). The most frequently photographed species was the northern raccoon with 190 photographs (41.8% of total photographs) followed by researchers (81 photographs; 17.8%) and empty frames (71 photographs; 15.6%). Cameras documented prolonged visitation of specific predators and illustrated activities of predators at pitfall traps. Thirty-two photographs showed predators either physically in pitfall traps or looking into or investigating the contents of pitfall traps. These animals included the northern raccoon, gray fox (*Urocyon cinereoargentius*), fox squirrel (*Sciurus niger*), striped skunk (*Mephitis mephitis*), Virginia opossum (*Didelphis virginiana*), bobcat (*Lynx rufus*), and coyote (*Canis latrans*).

Track Monitoring Stations

Track monitoring stations were in place and operational from the 21 October 2003 until the 20 December 2004. During this time, 563 (36.5%) of 1541 rakings had tracks present. This period was split into two phases based on the number of raking events per month. From 21 October 2003 – 17 June 2004, raking occurred four times per month. There were 443 rakings (35.8%) of 1236 with tracks present. During this period, the most frequent visitor was the northern raccoon with 292 track recordings followed by the American Crow (*Corvus brachyrhynchos*) (n=53) and then unknown or unidentifiable

Table 1. Details of variety and frequency of animals documented at pitfall traps on the Griffith League Ranch in Bastrop County, Texas using 10 Deer Cam® Model DC-100 motion-sensitive cameras from 8 February 2004 –20 December 2004.

Species	# of Photographs	% Photographs
Northern raccoon (*Procyon lotor*)	190	41.8%
Empty frames (blank)	71	15.6%
American crow (*Corvus brachyrhynchos*)	35	7.69%
Wild turkey (*Meleagris gallopavo*)	14	3.08%
White-tailed deer (*Odocoileus virginianus*)	14	3.08%
Gray fox (*Urocyon cinereoargentius*)	7	1.54%
Bobcat (*Lynx rufus*)	7	1.54%
Greater roadrunner (*Geococcyx californianus*)	6	1.32%
Nine-banded armadillo (*Dasypus novemcinctus*)	5	1.10%
Coyote (*Canis latrans*)	5	1.10%
Great-crested Flycatcher (*Myiarchus crinitus*)	3	0.66%
Striped skunk (*Mephitis mephitis*)	2	0.44%
Virginia opossum (*Didelphis virginiana*)	2	0.44%
Three-toed box turtle (*Terrapene carolina*)	2	0.44%
Mourning dove (*Zenaida macroura*)	1	0.22%

tracks (n=31). Other predator species documented included the gray fox, Virginia opossum, coyote, snake, and the striped skunk (Fig. 5). From 18 June 2004 – 20 December 2004, raking occurred two times per month and all pitfall traps were closed. One hundred-twenty (39.3%), of 305 rakings had tracks present. Again, the most frequent visitor was the northern raccoon with 71 recorded visits followed by unidentifiable tracks (n=15) and the American Crow and snake with seven recordings each. Track monitoring stations recorded the same species during the second phase as the first except for the addition of the bobcat in the second phase (Fig. 6).

Predator Exclusion Devices

A total of 29 PEDs were installed across 10 of 18 drift fence arrays on the Griffith League Ranch. Only one straight-line drift fence array captured Houston toads, and had two PEDs placed at both terminal pitfall traps. All other arrays, which were the standard Y-shape, had three PEDs per line: one at each terminal pitfall and none on the central pitfall trap. Pitfall traps with PEDs caught animals 5 times verses 63 on pitfall traps without PEDs. Thirty-five pitfalls did not have PEDs present.

Six incidences of predation upon toads occurred near unprotected pitfall traps. Five of these involved predation upon Hurter's spadefoot toads (*Scaphiopus hurteri*), which were partially consumed up to the pectoral region. Northern raccoon tracks occurred at all five sites. The sixth incidence of predation was upon a Gulf Coast toad (*Bufo valliceps*), whose carcass was found alongside an unprotected pitfall trap with its rear hind limbs chewed off. Northern raccoon tracks were also recorded at this site. This type of predation, in which the rear portion of toads are consumed, leaving behind the

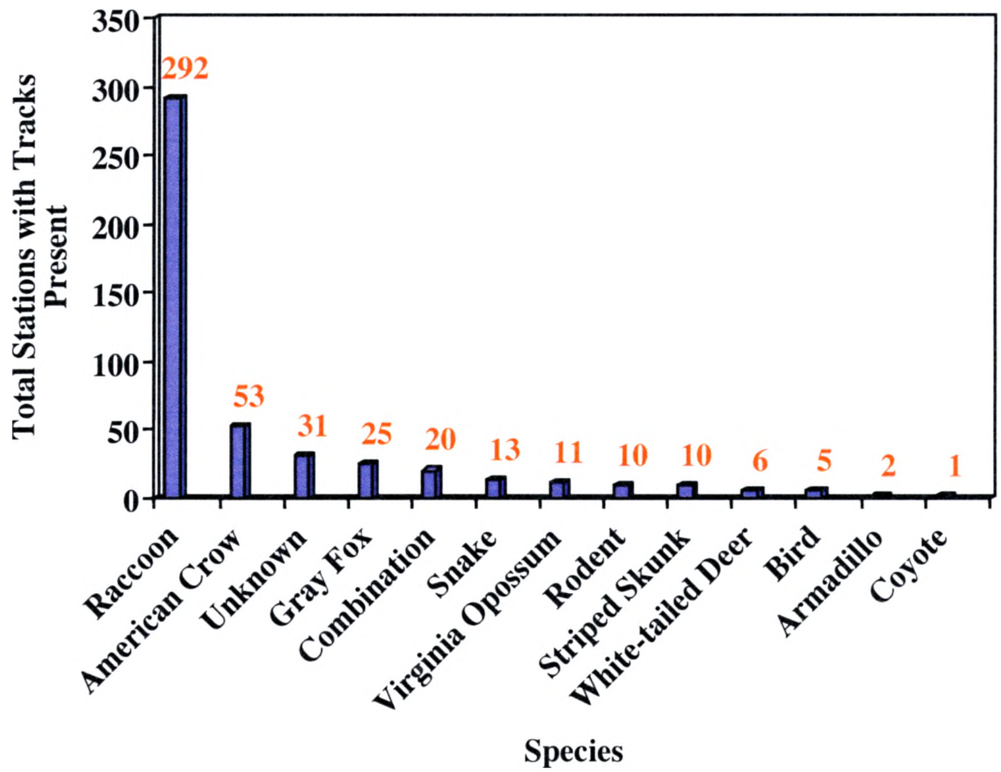


Figure 5. Total number of vertebrate tracks represented by individual species or groups recorded in the track monitoring stations installed on the Griffith League Ranch, Bastrop County, Texas from 21 October 2003 –17 June 2004.

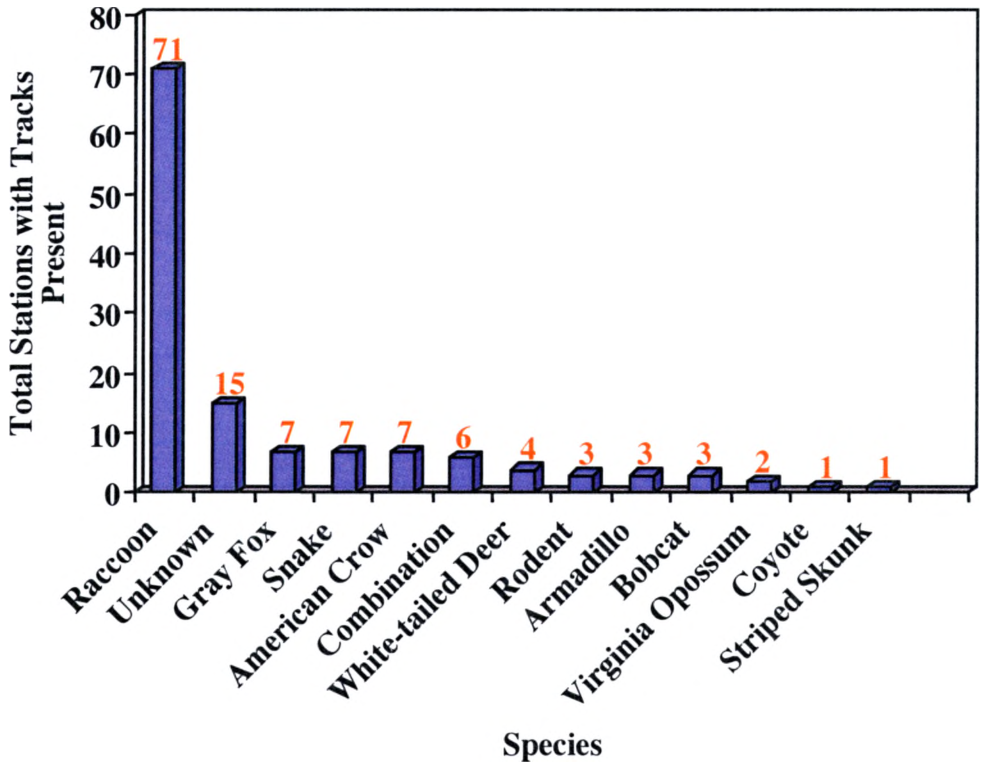


Figure 6. Total number of vertebrate tracks represented by individual species or groups recorded in the track monitoring stations installed on the Griffith League Ranch, Bastrop County, Texas from 18 June 2004 –20 December 2004; raking twice a month with all pitfall traps closed.

head and neck, has been documented in both the striped skunk and the northern raccoon (Schaaf and Garton 1970, Groves 1980)

In general, the overall capture success at track monitoring stations for the period traps were operational (21 October 2003 until 17 June 2004 for a total of 55 days) was low. A total of only 113 captures occurred across all arrays and pitfalls, with 116 animals caught in pitfalls and 19 animals captured in funnel traps. When related to pitfalls with track monitoring stations, only 68 instances occurred where pitfalls had animals present representing 80 individuals.

Analyses

All statistical analyses comparing the effects of tracks on the presence or absence of animals in pitfall traps showed no significant difference. The 95% confidence interval calculated for the proportion of pitfalls with tracks and animals (n = 24) and with tracks and no animals (n = 328) verse the proportion of pitfalls with no tracks and animals (n = 39) to no tracks and no animals (n = 611) contained zero ($-0.024 < P_1 - P_2 < 0.040$). The two proportions', $P_1 = 0.068$; $P_2 = 0.060$ 95% confidence interval was $-0.024 < P_1 - P_2 < 0.040$ indicating that there was no difference between the proportion of pitfalls with tracks that caught animals to the proportion of pitfall traps without tracks that caught animals.

The nominal logistic regression produced an r^2 value of 0.0012 with an associated $P = 0.2712$. A total of 745 observations were used to calculate the nominal logistic regression analysis.

During the two months in which both the track monitoring stations and control plots were operational on the Griffith League Ranch, no significant differences occurred in visitation rates at track monitoring stations and control plots ($\chi^2 = 0.3667$, $P = 0.5448$), indicating that patterned foraging was not occurring.

Discussion

In this study, I attempted to document the effects of predators on animals captured in pitfall traps using both direct and indirect indices of predator activity at arrays. Interestingly, the two methods produced somewhat conflicting results. Based on direct measurements of predator activity at pitfall arrays, predators posed a serious threat to animals confined to pitfall traps. This was clearly seen in the data obtained using motion-sensitive cameras, where predators, such as northern raccoons, were seen physically entering or investigating pitfall traps on multiple occasions. The amount of visitation by predators indirectly documented at track monitoring stations also indicated a serious threat to captured animals. The consistent visitations at pitfalls by predators theoretically would increase the potential for fatal interactions between predators and prey confined to pitfalls. Despite these obvious threats, statistical analyses failed to detect a significant correlation between the presence of predators and the absence of animals in pitfall traps. However, this lack of statistical significance does not mean that vertebrate predators do not affect the data collected in studies using pitfall arrays.

In general, overall capture success during the nine months of the study (21 October 2003 –17 June 2004) was low. As with other trapping techniques, the ability of pitfall traps to capture animals was dependent upon many factors. Factors known to biaspitfall trapping results include variation in morphology, ecology, and behavior of species (Gibbons and Semlitsch 1981), length and intensity of trapping (Bury and Corn 1987), and weather conditions (Crosswhite et al. 1999). Often these biases translate into variations in capture rates of certain species and can lead to inaccurate estimates of diversity and abundance of target animals. This fluctuation and variation in capture success may have compounded the ability of statistical tests to detect the factor responsible for the discrepancies in capture success at individual pitfalls.

Additional factors making it difficult to directly address the effects of predators at pitfalls included temporal discrepancies. That is, the animal detected or captured in the pitfall might have been caught prior to or post to the time at which the predator was recorded visiting the pitfall trap.

Despite the low statistical resolution among the analyses, evidence obtained from motion-sensitive cameras and track monitoring stations indicated a high level of predator activity occurred in and around pitfall traps. This consistent presence of vertebrate predators could still prove potentially problematic for researchers using this trapping technique. This is especially true when dealing with endangered or rare taxa. Agencies such as the United States Fish and Wildlife Service and Institutional Animal Care and Use Committees are typically reluctant to issue permits for studies using methods in which animals will be exposed to potential pain, suffering, or mortality (Karraker 2001). The amount of predation documented along drift fences in my study highlighted the potential risks facing animals confined in traps. Exposing an endangered animal that is already threatened by low numbers to increased risks of predation defeats the purpose of studying the animal. The amount of predator activity at pitfall arrays should encourage researchers to use some type of preventive measure, such as a PED, to reduce the unnecessary risks of exposure to predators.

Predators might influence the data obtained in pitfall array studies by the removal of ecologically rare taxa caught in pitfalls. Only five individuals of the six-lined racerunner (*Cnemidophorus sexlineatus*) were caught over a 3-year sampling period in Georgia (Gibbons and Semlitsch 1981). Such low numbers of an animal in a pitfall study reduces the detection of this species if individuals are lost to predation. If an individual happens to be captured on a day a predator visits the pitfall trap, the species might not be detected at the study site.

Although predator activity along drift fence arrays in north-central Bastrop County appeared to have no effect on the number of animals captured in pitfalls, the amount of predator activity should cause researchers to use caution in drift fence studies with associated pitfall traps. My study provides the first quantitative analysis of predation effects on pitfall trapping and highlights some of the major predators that may pose a threat to captured animals. Additional studies on the direct effect of predator activity on drift fence sample data should continue. In particular, a variety of methods should be used to document whether predators significantly influence capture success at pitfall traps.

CHAPTER 2

TEMPORAL ASPECTS OF VERTEBRATE PREDATION AND EFFECTIVENESS OF PREDATOR EXCLUSION DEVICES ON A NOVEL STUDY SITE IN GUADALUPE COUNTY, TEXAS

Introduction

Although the Griffith League Ranch in Bastrop County, Texas provided an ideal study location for an estimation of the effects vertebrate predators had on drift fence associated pitfall trapping (Chapter 1), there were several drawbacks to this site. One drawback stemmed from the fact that the predation study was not initiated until two years after drift fence sampling with pitfalls began. This limited my ability to address the question of initial predator patterns and activity levels in relation to drift fence operations. How quickly do vertebrate predators begin visiting or investigating the pitfall arrays would be difficult to address under the conditions found on the Griffith League Ranch. Knowledge about the initial and subsequent activities of predators in relation to drift fence operational schedules could prove useful to researchers using drift fence sampling with pitfall traps. The time required for predators to recognize pitfall traps as potential food sources and begin active visitation might also determine the necessity for introducing predator preventive techniques with initiation of a pitfall study. Do preventive measures need to be implemented from the beginning of a pitfall study, or is there a lag in predator activity until predators recognize the presence of animals in pitfalls? Such questions would require a novel study site in which predator activity was monitored from the first day of operation of pitfalls with drift fences.

Additional problems associated with this study site were directly related to the Houston toad. Ethical issues involving increased risks to captured toads would be problematic for the testing of predation using artificial or natural baits in pitfalls. Placement of animals or animal remains in pitfall traps would allow physical detection of active predation. Baiting pitfalls would also allow for a direct test of the PEDs ability to keep predators out and captured animals in.

The need to answer such questions led me to initiate a second study on the effects of vertebrate predators on pitfall trapping at a new study site located in Guadalupe County, Texas. The major objectives of this secondary study were to highlight how quickly vertebrate predators begin visiting pitfall arrays, how temporal operations of pitfall traps affect visitation rates, and how efficient PEDs are at keeping predators out and animals in pitfall traps. In conjunction with the data collected at the Griffith League Ranch, this study would provide the first comprehensive assessment of vertebrate predator effects on drift fence sampling with associated pitfall traps.

Materials and Methods

Study Site

The study was conducted on private property located in northern Guadalupe County, Texas (Fig. 7). The 9-ha parcel was surrounded on all sides by similar or larger-sized privately owned parcels of land used for both hunting and ranching operations. The primary vegetation was characteristic of the ecotone between the blackland prairie and the hill country. The majority of the property is open pasture with scattered mesquite trees (*Prosopis glandulosa*). Five permanent ponds are on the property. Vegetation typical of pond edges include large stands of mesquite and black willow (*Salix nigra*). Texas persimmon (*Diospyros texana*), hackberry (*Celtis laevigata*), agarito (*Berberis trifoliolata*), bumelia (*Bumelia lanuginosa*) and mountain laurel (*Sophora segundiflora*) grow along a creek and drainage that crosses the property. Prickly pear (*Opuntia lindheimeri*) and tasajillo (*Opuntia leptocaulis*) are also found along these riparian corridors. Arrays of seasonal herbaceous plants are present including species of sunflower (Asteraceae) in spring and summer. Soils are hard black clay with associate cobble.

Six straight-line drift fence arrays with two pitfall traps per array were constructed to test the initial response of predators to drift fence operations and to monitor the herpetofauna and small mammal communities of the ranch. The drift fence arrays were set in pairs along the outer portion of the property's boundaries to minimize the amount of fencing material needed to exclude horses that freely grazed the property. Each array within a pair was separated by about 100 m and pairs were separated by at least 300 m.

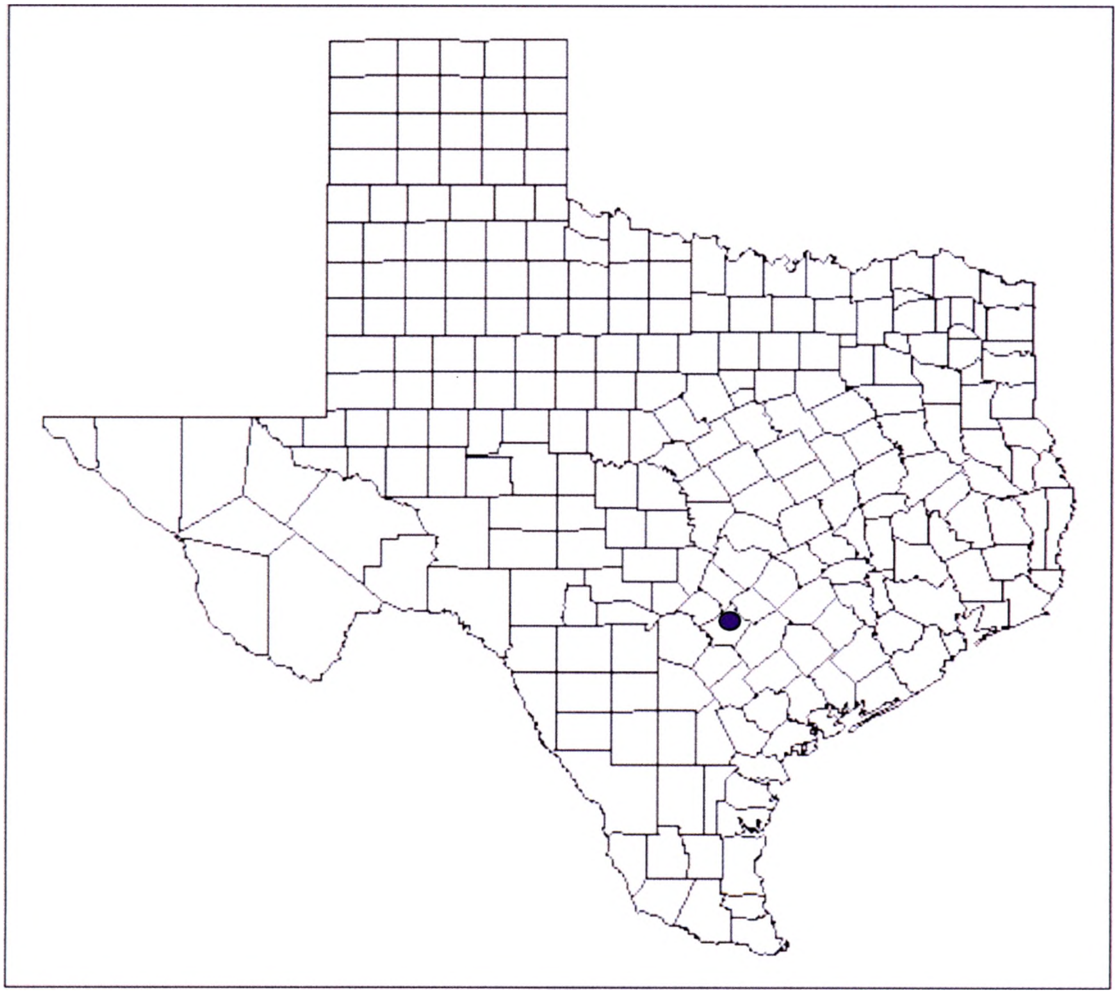


Figure 7. State of Texas with counties delineated indicating the location of the study site, a private ranch (highlighted in blue) in northern Guadalupe County, Texas.

Drift fence lines were constructed out of aluminum flashing 18 cm high by 15 m long and two 19-L buckets were placed on opposite terminal ends of the flashing. The flashing was buried 5 cm and pitfall traps flush with the ground. Each array was surrounded by welded wire livestock panels with 15.24 cm squares by 6.99 cm gauge rods 0.635 cm in diameter supported by1.8-m t-posts to minimize risks to livestock. Each fence was affixed with a gate for access to arrays. The protective fencing was placed 1.2 m from the flashing or drift fence. Holes, 3.5 cm x 3.5 cm, were cut in the livestock paneling to allow predators free movement within the protective fencing, and hence access to pitfalls and drift fence arrays.

Camera Stations

One Deer Cam® Model DC-100 camera was installed on each of the six drift fence arrays. Cameras were assigned to individual pitfall traps randomly. Four of six cameras were suspended 2.4 m over pitfall traps by a 1.8-m t-post vertically attached to 3-m tall t-posts placed 1.5 m apart. Cameras were secured to the t-post using a wooden block, bungee cords, and a large hose clamp. Centrally located cameras were additionally fitted with an aluminum flashing shade and rain cover to minimize weather-induced damages to the equipment (Chapter 1- Fig. 3a). The two terminal cameras were attached to a 1.8-m t-post via bungee cords and a wooden block cinched to the t-post with a large hose clamp. Terminal cameras were located 3 m from the center of the pitfall trap and placed 0.6 m from the ground (Chapter 1- Fig. 3b). Cameras were set to record the date and time of each photograph to distinguish the capture of multiple visitors versus repeat visitors. The camera settings were adjusted to high sensitivity and to take photographs at

30-second intervals after disruption of the motion sensor. All cameras were operational for 24 hours a day and checked periodically (~ once a week) for proper functioning. Once the film was exposed, it was replaced, developed, and photographs labeled with camera location and date.

Track Monitoring Stations

Track monitoring stations consisted of a 1-m diameter circle of cleared earth with pitfall traps at the center. All 12 pitfall traps on all six drift fence arrays had track monitoring stations installed. Sand was used as the tracking media. A 2.3-cm deep hole, 1-m in diameter, was excavated around pitfall traps and filled with sand. In addition to the 12 track monitoring stations found on arrays, four control stations were installed in order to compare the rates of visitation at monitoring stations with and without pitfall traps. Track monitoring control stations were placed between the two-paired traplines (~50 m from the nearest array) and consisted of the same 1-m diameter circle of sand media. In total, 16 track monitoring stations were installed on the property; 12 located on pitfall traps within traplines and four control stations.

Each track monitoring station was raked four times a month to clear the trap of any previous tracks and prepare the sand for new track detection. Each station was checked the following morning for the occurrence, pattern, and kinds of animal tracks present. Tracks were identified to species or recorded as unknowns. The presence or absence of animals in pitfall traps was also recorded. Track monitoring stations were used as an index of predator abundance and to document differences in the variety, rate of visitation, and trap affinity by vertebrate predators.

Predator Exclusion Devices

PEDs were constructed of 1.27 cm plywood and consisted of 40.64 cm x 40.64 cm squares cut using a circular saw with four holes drilled in the corners with a Forstner bit (Chapter 1- Fig. 4). Two 7.62 cm x 40.64 cm strips with two holes drilled in the terminal ends of the strips were also made for each 40.64 x 40.64 square. Four pieces of rebar were hammered into the ground 10.16 cm away from the pitfall traps edge. The two strips were attached lengthwise (parallel to the drift fence) 10.16 cm from the pitfall trap lip with 27.94 cm cable ties. The squared 40.64 x 40.64 piece was set upon the strips and secured using two large binder clips for easy removal and access to pitfall traps.

PEDs were randomly placed on pitfall traps on three of the six traplines, thus creating a situation where each pair maintained a protected trapline with PEDs and an unprotected trapline without PEDs. Doing so allowed traplines with and without PEDs to be compared in their overall capture success, thus illustrating the overall usefulness of PEDs. PEDs were installed at the initiation of the study.

Baited Pitfall Trap Tests

The design of the baited pitfall trap test was to directly test the capability of PEDs to prevent vertebrate predators from removing animals from pitfall traps. Additionally, the baited pitfall trap tests helped highlight which predators posed a primary threat to animals confined in pitfall traps. The baited pitfall trap tests were initiated eight months after the initial operation of drift fence arrays and track monitoring had begun. This allowed for any patterning of predators to arrays to be disrupted and hence enabled testing under semi-novel conditions.

Three individual trials or tests were conducted using common dwarf hamsters (*Phodopus campbelli*) as bait. The hamsters were frozen, but were allowed to thaw at room temperature prior to baiting pitfall traps. Each trial consisted of a four-day period of baiting and monitoring via track monitoring stations and motion-sensitive cameras. Six fresh hamsters were used each day for a total of 24 hamsters per trial. To prevent bias from permanent placement of PEDs, traplines were randomly selected to receive PEDs at the start of each day's trial. This insured that traplines with PEDs were randomly chosen throughout the four day trial, thus allowing for random PED rotations. Hamsters were placed randomly in one of two pitfall traps on a single trapline by flipping a coin at each line. Track monitoring stations were checked every 12 hours during the trial for the presence or absence of tracks and whether the hamster had been removed or remained in the pitfall trap. Traplines were closed and unoperational between each of the four-day periods.

Analyses

Several statistical tests similar to those used to analyze the data in the Griffith League Ranch study were conducted. Again, the major objective was to determine whether or not the presence of predator activity (e.g. tracks and photographs) influenced capture success at pitfall traps. Additional analyses conducted on the second dataset included a Chi Square test of independence on the influence the presence or absence of a PED had on the removal of bait from a pitfall trap.

The data were first analyzed by calculating a 95% confidence interval of two proportions. The first proportion was the number of vertebrate animals caught verse the number of pitfall trap nights with predator tracks present. The second proportion was the number of vertebrate animals caught verse the number of pitfall trap nights with no tracks of any animal present. In this manner, the direct effects of predator activity on pitfall capture success could be analyzed.

A paired T-test was used to analyze the effects of PEDs on capture success of pitfall traps. Paired arrays with protected and unprotected pitfall traps were compared to one another to determine whether the number of animals caught in protected pitfall traps was greater than the number captured in unprotected traps.

Chi Square analysis was conducted on baited pitfall data to test whether or not PEDs were associated with removal rates of hamsters. An additional Chi Square test of independence was performed using the program S-PLUS (v 6.1, Insightful Corporation, Seattle, WA) to test for an association between visitation rates and the presence or absence of a pitfall trap.

Results

Camera Stations

Six Deer Cam® Model DC-100 cameras were installed on 23 June 2004 and remained in operation until 5 October 2004 for a total of 105 days per camera. Cameras were removed between trials to minimize damage and reduce the risks of loss while traps were not checked. Cameras were re-installed for the baited pitfall trap tests on 9 May 2005. Cameras were operational for four days during each of three trials (Trial 1: 9 May 2005 – 13 May 2005; Trial 2: 8 June 2005 – 11 June 2005; Trial 3: 4 July 2005 – 7 July 2005) for a total of 12 days per camera. During 117 days per camera operation, 256 photographs were taken with 199 empty frames or no animal present. The most frequent predator documented using the cameras was the northern raccoon with nine photographs followed by the domestic cat (*Felis domesticus*) with six photographs. Five individual domestic cats attended track monitoring stations and their associated pitfall traps. The unique morphologies of these cats made identifying individuals easy. Only one other potential vertebrate predator was documented on film; the striped skunk appeared in a single photograph. Other animals documented by the motion-sensitive cameras included the Northern Mockingbird (*Mimus polyglottos*), Eastern cottontail (*Sylvilagus floridanus*), and nutria (*Myocastor coypus*). Each occurred in a single photograph.

Overall photographic documentation was low compared to track monitoring data. Dysfunctional cameras may have caused the low documentation of animals at camera stations. Some cameras were inoperable more often than other cameras.

Track Monitoring Stations

Track monitoring stations were in place and operational from 23 June 2004 – 5 October 2004. During this period, 65 (34.4%) of 189 rakings had tracks. Tracks occurred in monitoring stations on the first day of operation. A single Virginia opossum was recorded at a track monitoring station on 23 June 2004. Seven sets of tracks were recorded at four different stations on the following day with tracks of a passerine bird, northern raccoon, Virginia opossum, and domestic cat. Three sets of northern raccoon tracks were recorded at three different stations. Visitation rates increased in frequency with a peak activity of 24 track recordings in July. August had 16 track sets and September had 18.

After closing the traps for eight months, the first predator at track monitoring stations during baited pitfall trap tests, when traps were reopened, was the northern raccoon. Tracks occurred at three track monitoring stations on two separate lines on 10 May 2005. After having the lines closed for eight months, within two days of re-opening the lines potential predators were already attending pitfall arrays. Visitations occurred throughout all three trials with 14 tracks recorded in May, nine in June, and eight in July. Of these 31 tracks, 20 (65%) were northern raccoon, Virginia opossum, domestic cat, or snake.

The most frequent visitor during the first sampling period was the domestic cat with 22 visits followed by the northern raccoon with 11 visits (Fig. 8). Other predators documented at track monitoring stations included the striped skunk with eight visits and the Virginia opossum with seven visits. Other species included the nine-banded armadillo (*Dasypus novemcinctus*), nutria and a bird (Fig. 8).

During the baited pitfall trap tests, 8 May 2005 – 7 July 2005, track monitoring stations had both am and pm rakings and were operational for 12 days. Of 252 rakings, 31 (12.3%) had tracks present. Species composition at track monitoring stations was similar to the first part of this study.

Predator Exclusion Devices

A total of six PEDs were installed across the six drift fence arrays on the ranch in Guadalupe County, Texas. Each line had two pitfall traps permanently affixed with a PED during 23 June 2004 – 5 October 2004. The number of pitfall traps with PEDs equaled the number of pitfall traps without PEDs. During raking, pitfall traps without PEDs (six pitfall traps) caught animals 14 times with 33 individuals of four species [Gulf Coast toad, Great Plains narrow mouth toad (*Gastrophryne olivacea*), bullfrog (*Rana catesbeiana*), and Texas spiny lizard (*Sceloporus olivaceus*)]. Pitfall traps with PEDs caught animals 11 times with 18 individuals of the same four taxa. Captures in pitfalls with and without PEDs were dominated by anurans, which represented 96.1% of all animals captured in pitfall traps during rakings.

Total captures during my study (23 June 2004 – 5 October 2004; 9 May 2005 – 13 May 2005; 8 June 2005 – 11 June 2005; 4 July 2005 – 7 July 2005) from both funnel and pitfall traps resulted in 563 captures of 629 individuals of 20 species. Six of these 20 species were anurans, 12 reptiles, and two mammals. Two hundred fifty-seven (40.9%) individuals were captured in funnel traps. The remaining captures occurred in pitfall traps. The two mammal species captured in traps were the hispid cotton rat (*Sigmodon hispidus*) and the least shrew (*Cryptotis parva*). All hispid cotton rats, except one

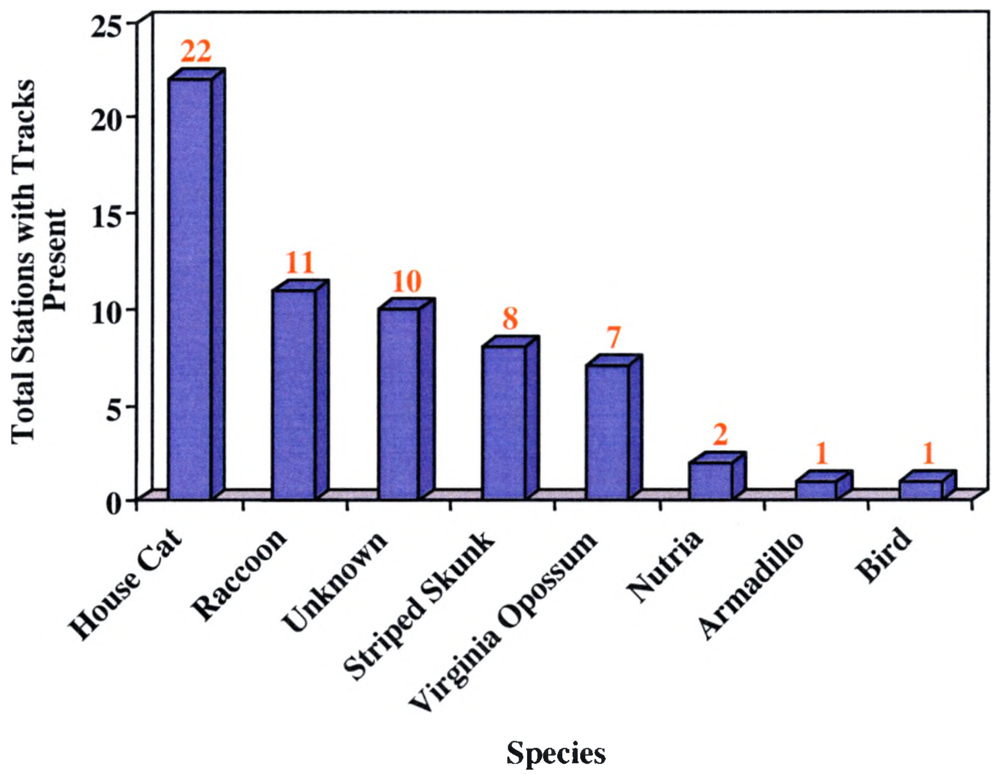


Figure 8. Total number of vertebrate tracks recorded in the track monitoring stations installed on a private ranch in northern Guadalupe County, Texas from 23 June 2004 –5 October 2004 by individual.

individual, were caught in funnel traps placed along drift fence arrays. One least shrew was captured on 1 September 2004. Anurans were the most dominant group captured on the ranch with 445 captures (70.7%), followed by squamates (23.8%), and mammals (5.4%). The most frequently caught animal was the bullfrog with 298 captures. This high number of bullfrog captures probably resulted from high levels of juvenile dispersal from waterways located near traplines. Other species incidentally encountered on the property included the yellow-bellied mud turtle (*Kinosternon flavescens*), common snapping turtle (*Chelydra serpentina*), green tree frog (*Hyla cinerea*), and the green anole (*Anolis carolinensis*).

During the 12 days of baited pitfall trap tests, 25 captures of 25 individuals occurred. A majority of these captures (80%), were in funnel traps with only 5 pitfall trap captures. Seventeen snakes were caught in funnel traps. Two species undetected in the first period were caught over the three four-day trials. These were the Texas brown snake (*Storeria dekayi*) and the prairie kingsnake (*Lampropeltis calligaster*) (Table 2). Each was represented by a single specimen. The smaller semi-fossorial Texas brown snake was caught in a pitfall.

Baited Pitfall Trap Tests

I conducted three independent baited pitfall trap trials: 9 May 2005 – 13 May 2005; 8 June 2005 – 11 June 2005; 4 July 2005 – 7 July 2005. Seventy-two (24/ trial) dwarf hamsters were used during the test. During a trial, an equal number of randomly selected pitfall traps with and without PEDs received a hamster. During the three trials, six hamsters were removed from pitfall traps by predators. Five of six removals of

Table 2. Total number of individual species caught using drift fence arrays and associated pitfall traps during four sampling periods (23 June 2004 – 5 October 2004; 9 May 2005 – 13 May 2005; 8 June 2005 – 11 June 2005; 4 July 2005 – 7 July 2005) totaling 112 sampling days on a private ranch in Guadalupe County, Texas.

	Sampling Period				
Species	First	Second	Third	Fourth	Total
Anura					
Rana berlandieri	1				1
Rana catesbeiana	298				298
Rana sphenocephala	4				4
Acris creptians	1				1
Gastrophryne olivacea	73	1			74
Bufo valliceps	66	1			67
Lacertillia					
Sceloporus olivaceus	7	1			8
Sceloporus undulatus	2				2

Table 2 continued.

Species	First	Second	Third	Fourth	Total
	Sampling Period				
Serpentes					
Crotalus atrox	1				1
Coluber c. flaviventris	12	2	1		15
Elaphe o. lindheimeri	3	2	1		6
Nerodia e. transversa	7	1	3	1	12
Nerodia r. rhombifer	2	1			3
Thamnophis p. rubrilineatus	9	2	3	1	15
Thamnophis m. marcianus	1				1
Virginia striatula	1	1			2
Storeria dekayi				1	1
Lampropeltis c. calligaster				1	1

Table 2 continued.

Species	First	Second	Third	Fourth	Total
	Sampling Period				
Mammalia					
Sigmodon hispidus	32		1		33
Cryptotis parva	1				1

hamsters were accompanied by predator tracks in the track monitoring stations. Two instances in which hamsters were gone, northern raccoon tracks occurred to the edge of the pitfall trap. Two times house cat tracks were in the sand at the stations. One time the sand station showed a large snake drag into and out of a pitfall trap protected by a PED. A large (~168 cm) Texas rat snake (*Elaphe obsoleta lindheimeri*) was captured in a funnel trap on the same side as the snake drag. The Texas rat snake had a large bulge in its midsection indicating it had recently fed. In total, pitfall traps without PEDs lost four hamsters and pitfall traps with PEDs lost two hamsters. One pitfall trap unprotected by a PED with probable predation of a hamster did not have any visible tracks of a predator in the sand. A lightweight, medium-sized snake might not have been heavy enough to leave a drag in the dry sand. Two hamsters taken from PED protected pitfall traps had clear northern raccoon and house cat tracks up to and around the pitfall trap and PED device. A third hamster was clearly removed by a large rat snake with a distinct drag mark. The hamster removed from the PED by the northern raccoon was most likely the result of researcher error. In moving PEDs, the re-bar pieces had to be re-driven into the ground and the entire apparatus re-installed. In post investigations, the height of the PED from the pitfall trap lip was 10.67 cm, higher than the recommended 8.89 cm level suggested for optimum functionality (Ferguson and Forstner, In review). As to the loss to cats, the PED appeared intact and undisturbed. Several photographs of domestic cats indicated that the cats were relatively young in age and small in size. The overall curious nature, agility, and general lack of fear of humans by feral or domestic cats might make PEDs less efficient in deterring domestic cats. This raises concern for other similarly built and agile predators, such as members of the mustelid family, which preyed upon animals trapped in

Sherman box traps (Platt 1968). Researchers should pay special attention when using devices similar in build to the PEDs used in my study in areas with a high diversity of such species (e.g., the Pacific Northwest and Boreal forest regions).

Analyses

All statistical tests yielded non-significant results. The proportion of pitfall traps with tracks that caught animals was not different from the proportion of pitfall traps without tracks that caught animals (95% CI: $-0.074 < P_1 - P_2 < 0.136$), indicating that the presence of predators did not influence the capture success of animals in pitfalls.

The presence or absence of PEDs appeared to have no influence on whether or not pitfalls captured and retained animals ($t = -1.0104$, $df = 2$, $P = 0.7907$). In fact, the total number of animals captured in pitfall traps without PEDs (221) was higher than the total number (132) captured in pitfall traps protected by PEDs. However, 132 of 221 captures in unprotected buckets occurred in a single trapline located next to a creek, and of those 132 captures, 107 (81.1%) were juvenile bullfrogs.

The results of the baited pitfall trap tests analysis indicated that the presence or absence of PEDs did not influence the removal of hamsters from a pitfall trap ($\chi^2 = 0.0193$, $P = 0.8895$, $df = 1$). The limited number of hamsters removed (6 of 72) may have limited the analysis' ability to detect differences in the efficiency of PEDs at excluding predators. Additionally, there were only five instances where tracks occurred in the track monitoring stations.

Although all tests had non-significant results, experimental design (e.g. length of sampling period) and inadequate sample sizes may have limited the detection of any relationships that existed among the factors being tested. Such is the case when dealing with the efficiency of PEDs in protecting animals in pitfall traps. Other factors, such as using a non-native, dead prey item to bait pitfall traps may have added to the confounding factors of my analysis.

No difference existed for visitation rates at control plots and track monitoring stations at the Guadalupe County study site ($\chi^2 = 0.0079$, $P = 0.9291$).

Discussion

Despite the lack of statistical significance for a relationship between predator activity at drift fence array traplines and the pitfall's ability to capture animals, several intriguing facts regarding predation on drift fence arrays are highlighted by the results of this additional study. First and foremost, is how quickly predators began to visit pitfall traps at a novel site. Traplines on the Griffith League Ranch had been established for two years prior to monitoring of predator activity, however, traplines on the Guadalupe County site were entirely new. Despite this novelty, predators initiated investigations on the first day traps were opened and continued to visit the pitfalls throughout the study.

Other differences were illustrated by comparison of the two study sites. The composition of predators that consistently visited traplines differed dramatically. Although northern raccoons were present at both sites (GLR-Chapter 1 and current site), the northern raccoon was the most common visitor at the Griffith League Ranch; whereas, on the Guadalupe study site, the domestic cat was the most frequent predator at track monitoring stations. Another major difference was the lack of larger, more human-wary carnivores documented on the Guadalupe study site. Its proximity to small-parcel housings and much smaller size than the Griffith League Ranch seemed to support a wider array of predators acclimated to human habituation, such as striped skunks and the Virginia opossum. No larger mesopredators, such as the coyote or bobcat were documented on the Guadalupe study site; whereas, both of these species and others, such as the gray fox, were documented on multiple occasions at the Griffith League Ranch. Of course vegetation and environmental conditions varied among the sites, which might explain the differences in carnivore community dynamics seen at track monitoring stations. This difference in sites is important when weighing the potential risks posed to drift fence arrays by predators under differing circumstances. In more urban sites, predators that should concern researchers are the more urban adapted species, such as the Virginia opossum; whereas, in more remote sites all predators known to inhabit the site should be considered potential threats to animals confined in pitfalls. This information highlights the need to custom design a trapping regime based on the risks and costs associated with target animals being collected and predators occupying the study area to minimize the loss of captured animals to predators.

Despite heavy predator activity at both study sites (GLR- Chapter 1 and current site), there was no significant effect on the overall capture success of pitfalls. Protecting a pitfall trap with an exclusion device failed to provide significant effects on capture success, and few pitfall traps with baited carcasses had active removal by known predators. The lack of statistical significant effects on trap success seems contradictory based on activity levels at both sites (GLR- Chapter 1 and current site). One would expect that high levels of predator activity along drift fence arrays would be associated with foraging. That is, predators are not just happening upon traps but actively tending pitfalls and fences in their foraging schedules. At this particular site, predators had to enter a fenced enclosure just to reach the drift fence arrays and pitfall traps. Patterned visitation would indicate that predators are successful in obtaining prey from within pitfalls at a consistent level- a level high enough to encourage repeated attendance at pitfall traps. However, during the two months in which both the track monitoring stations and control plots were operational on the Griffith League Ranch, no significant differences occurred in visitation rates at track monitoring stations and control plots, indicating that patterned foraging was not occurring. There were however, individual treatment groups, such as group 1 where track monitoring stations had greater activity levels than control plots. Comparing control plots to track monitoring stations at the Guadalupe County study site also yielded no significant difference between visitations at the two kinds of stations. At both study sites (GLR- Chapter 1 and current site) traps had some predator activity occurring, > 30%of the time. That is, 30% of all days at a track monitoring station predators were found to be actively visiting them. This relatively high level of visitation indicates predators were consistently appearing at pitfall traps and supports the idea that they were actively removing animals, but analyses showed animal removal was non-significant. Why the discrepancy?

There appears to be a number of confounding factors influencing the overall capture success of pitfalls and interactions of captured animals with predators. First, the timing of predator visits to a pitfall trap is crucial. If a predator arrives and leaves prior to an animal being captured in the array, the data would show a situation with tracks and prey present, lending support to the idea that prey are not actively being removed from traps. Additionally, certain predators may show preferential selection for prey, such as bobcats feeding on small mammals and lagomorphs (Thornton et al. 2004). This preference might limit the amount of time a predator spends searching an array for food, especially, as was the case at the Guadalupe site, where small mammals rarely, if ever were captured in pitfall arrays. Prey availability and preference might limit predator visitation, and hence, the frequency of animal removal from pitfall traps, thus limiting the detectability of predator influence on overall capture success. Saturation of prey items in a pitfall trap might also limit the ability to detect problems with animal removal. On the Guadalupe study site during juvenile bullfrog emergence in later summer and early fall, it was not uncommon to catch >15 bullfrog juveniles in a single pitfall trap on a night. This overabundance of prey items might have prevented the detection of losses of individuals from a pitfall.

By using artificial baits, I attempted to reduce the factors that might have influenced detection of significant levels of prey removal from pitfalls. However, several factors related to the baited pitfall trap tests may have prevented that detection capability from the very beginning. The use of a non-native dead prey item might have been problematic. The lack of movement and noise by dead animals contrasted with the activities made by a live animal confined to a pitfall trap. This lack of attractant cues might have created an artificial bias in the loss of bait. But the most likely explanation for the lack of removal of hamster bait stemmed from the short duration of the tests and the lack of predator activity and low capture rates of live animals during these periods. When compared to the 30% levels of activity documented in the longer first two studies, the 12.3% activity level of predators is relatively low. In addition, only five total captures occurred in pitfalls during the baited pitfall trap trials. The low activity levels and lack of capture success by pitfalls, as well as the non-native recently thawed prey item, probably restricted the active removal rates of prey items from pitfall traps.

Although the statistical analysis showed that the overall effect of predator activity at drift fence arrays with associated pitfall traps is negligible, the amount of activity quantified during both studies (Chapter 1 and current) indicates that interactions between predators and captured animals might be more problematic and less random than previously thought. The risks facing animals of special concern being studied might be enough to convince agencies to withhold permission for using this common and effective trapping technique. The amount and variety of predators documented shows a need to think critically about using this technique when concerns about artificial mortality are of importance. Future studies should focus on ways to minimize the noise surrounding capture success of pitfalls to truly tease out how much of an effect these frequent visitors are having on the captured fauna. The use of automated film recordings might help provide direct evidence of removal of animals by specific predators, thus illustrating areas such as preferential removal and or consumption of retained animals by certain predators (Thompson et al. 1999).

Appendix 1. Total capture frequency of vertebrates by species and individual pitfall arrays from dates that track monitoring stations were operational at the Griffith League Ranch, Bastrop County, Texas 21 October 2004 –17 June 2004.

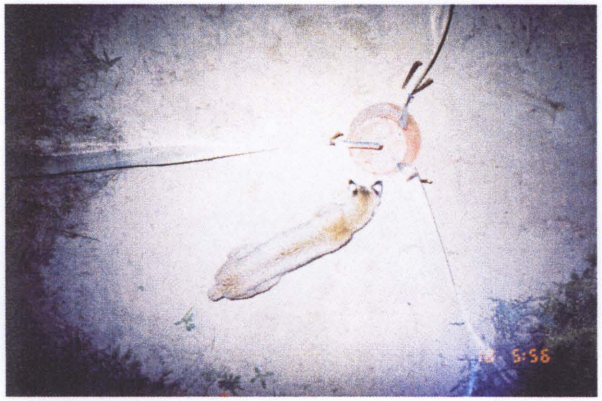
	Pitfall Array																	
Species	A	B	C	1	2	3	4	5	6	7	10	11	12	13	14	15	16	17
Caudates																		
Ambystoma tigrinum				1		1	1											
Anura																		
Acris crepitans	1		2	3	12	2	1											
Bufo valliceps		1			1	1									1			
Scaphiopus hurteri		1							1					1				
Hyla cinerea	1	1																
Gastrophryne olivacea	1			2	2						1							
Rana sphenocephala		8			3			1								1		
Rana catesbeiana											1							
Lacertillia																		
Scincella lateralis							1	2								1		

Appendix 1 continued.

	Pitfall Array																	
Species	A	B	C	1	2	3	4	5	6	7	10	11	12	13	14	15	16	17
Lacertillia																		
Sceloporus undulatus	1						1		1	1		3				1		1
Cnemidophorus sexlineatus							1			1			1					
Mammalia																		
Baiomys taylori		1	1			2	3	2	2	1		4	3	8	4	2	1	1
Cryptotis parva		1	1				1				1	2	1	1	1			1
Geomys attwateri														1				
Total	4	13	4	6	18	6	9	5	4	3	3	9	5	10	6	5	1	3

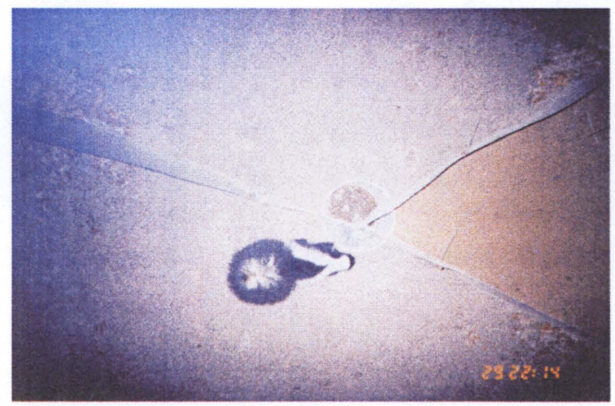
Appendix 2. Example images of vertebrates taken by the motion-sensitive cameras installed on the Griffith League Ranch.

Bobcat (*Lynx rufus*); Line 7-1; 9/18/04



Common raccoon (*Procyon lotor*); Line 5-S; 3/1/04

Gray fox (*Urocyon cinereoargentius*); Line 16-1; 8/1/04



Striped skunk (*Mephitis mephitis*); Line A-1; 5/29/04

Appendix 2 cont.

Virginia opossum (*Didelphis virginiana*), Line 5-S; 6/9/04

American Crow (*Corvus brachyrhynchos*); Line B-W; 4/1/04

Coyote (*Canis latrans*); Line 5-S; 7/25/04

Fox squirrel (*Sciurus niger*); Line C-1; 5/16/04

WORKS CITED

AUBRY, K. B., and A. B. STRINGER. 2000. Field test of the SMED, a small mammal escape device for pitfall trapping amphibians. Northwest. Nat. 81:69.

BROWN, L. J. 1997. An evaluation of some marking and trapping techniques currently used in the study of anuran population dynamics. J. Herpetol. 31:410–419.

BURY, B. R., and P. S. CORN. 1987. Evaluation of pitfall trapping in northwestern forests: trap arrays with drift fences. J. Wildl. Manage. 51:112–119.

CARTHEW, S. M., and E. SLATER. 1991. Monitoring animal activity with automated photography. J. Wildl. Manage. 55:689–692.

CHRISTIANSEN, J. L., and T. VANDEWALLE. 2000. Effectiveness of three trap types in drift fence surveys. Herpetol. Rev. 31:158–160.

CONNER, M. C., R. F. LABISKY, and D. R. PROGULSKE. 1983. Scent–station indicies as measures of population abundance for bobcats, raccoons, gray foxes, and opossums. Wildl. Soc. Bull. 11:146–152.

CROSSWHITE, D. L., S. F. FOX, and R. E. THILL. 1999. Comparison of methods for monitoring reptiles and amphibians in upland forest of the Ouachita mountains. Proc. Okla. Acad. Sci. 79:45–50.

DIEFENBACH, D. R., M. J. CONROY, R. J. WARREN, W. E. JAMES, L. A. BAKER, and T. HON. 1994. A test of the scent-station survey technique for bobcats. J. Wildl. Manage. 58:10–17.

DODD, K. C., JR. 1991. Drift fence-associated sampling bias of amphibians at a Florida sandhills temporary pond. J. Herpetol. 25:296–301.

DODD, K. C., JR., and D. E. SCOTT. 1994. Drift fences encircling breeding sites, p. 125–130. *In:* Measuring and Monitoring Biological Diversity Standard Methods for Amphibians. R. W. Heyer, M. A. Donnelly, R. W. McDiarmid, L.-A. C. Hayek, and M. S. Foster (eds.). Smithsonian Institution Press, Washington and London.

ENGE, K. M. 2001. The pitfalls of pitfall traps. J. Herpetol. 35:467–478.

FERGUSON, A. W., AND M .R .J. FORSTNER. 2005. Design and implementation of a predatory exclusion device for pitfall traps. Herpetol. Rev. (In review).

GIBBONS, J. W., and R. D. SEMLITSCH. 1981. Terrestrial drift fences with pitfall traps: an effective technique for quantitative sampling of animal populations. Brimleyana. 7:1–16.

GROVES, J. D. 1980. Mass predation on a population of the American toad, *Bufo americanus*. Am. Midl. Nat. 103:202–203.

HARTMAN, L. H., A. J. GASTON, and D. S. EASTMAN. 1997. Raccoon predation on ancient murrelets on East Limestone Island, British Columbia. J. Wildl. Manage. 61:377–388.

HERNANDEZ, F., D. ROLLINS, and R. CANTU. 1997. An evaluation of Trailmaster® camera systems for identifying ground-nest predators. Wildl. Soc. Bull. 25:848–853.

HEYER, R. W., M. A. DONNELLY, R. W. MCDIARMID, and L.-A. C. HAYEK. 1994. Measuring and monitoring biological diversity: standard methods for amphibians. Smithsonian Institution, Washington, DC.

HOOVEN, E. F., H. C. BLACK, and J. C. LOWRIE. 1979. Disturbance of small mammal live traps by spotted skunks. Northwest Sci. 53:79–81.

JENKINS, C. L., K. MCGARIGAL, and L. R. GAMBLE. 2003. Comparative effectiveness of two trapping techniques for surveying the abundance and diversity of reptiles and amphibians along drift fence arrays. Herpetol. Rev. 34:39–42.

KARRAKER, N. E. 2001. String theory: reducing mortality of mammals in pitfall traps. Wildl. Soc. Bull. 29:1158–1162.

KUCERA, T. E., and R. H. BARRETT. 1993. The Trailmaster® camera system for detecting wildlife. Wildl. Soc. Bull. 21:505–508.

LARIVIERE, S. 1999. Reasons why predators cannot be inferred from nest remains. Condor. 101:718–721.

MACE, R. D., S. C. MINTA, T. L. MANLEY, and K. E. AUNE. 1994. Estimating grizzly bear population size using camera sightings. Wildl. Soc. Bull. 22:74–83.

MAZEROLLE, M. J. 2003. Using rims to hinder amphibian escape from pitfall traps. Herpetol. Rev. 34:213–215.

PADGET-FLOHR, G. E., and M. R. JENNINGS. 2001. An economical safe-house for small mammals in pitfall traps. Calif. Fish Game. 7:72–74.

PLATT, A. P. 1968. Selective predation by a mink on woodland jumping mice confined in live traps. Am. Midl. Nat. 79:539–540.

ROUGHTON, R. D., and M. W. SWEENY. 1982. Refinements in scent-station methodology for assessing trends in carnivore populations. J. Wildl. Manage. 46:217–229.

SAVIDGE, J. A., and SEIBERT, THOMAS F. 1988. An infrared trigger and camera to identify predators at artificial nests. J. Wildl. Manage. 52:291–294.

SCHAAF, R. T., and J. S. GARTON. 1970. Raccoon predation on the American toad, *Bufo americanus*. Herpetologica. 26:334–335.

SHOOP, R. C. 1965. Orientation of *Ambystoma maculatum*: movements to and from breeding ponds. Science. 149:558–559.

STALLER, E. L., W. E. PALMER, J. P. CARROLL, R. P. THORNTON, and C. D. SISSON. 2005. Identifying predators at northern bobwhite nests. J. Wildl. Manage. 69:124–132.

STENHOUSE, S. L. 1985. Migratory orientation and homing in *Ambystoma maculatum* and *Ambystoma opacum*. Copeia. 3:631–637.

SUTTON, P. E., H. R. MUSHINSKY, and E. D. MCCOY. 1999. Comparing the use of pitfall drift fences and cover boards for sampling the threatened sand skink (*Neoseps reynoldsi*). Herpetol. Rev. 30:149–151.

THOMPSON, F. R., III, W. DIJAK, and D. E. BURHAMS. 1999. Video identification of predators at songbird nests in old fields. Auk. 116:259–264.

THORNTON, D. H., M. E. SUNQUIST, and M. B. MAIN. 2004. Ecological separation within newly sympatric populations of coyotes and bobcats in south–central Florida. J. Mammal. 85:973–982.

VAN SCHAIK, C. P., and M. GRIFFITHS. 1996. Activity periods of Indonesian rain forest mammals. Biotropica. 28:105–112.

WALLS, J. G. 1995. George Johnson, commercial collector, p. 84–87. *In:* Reptile Hobbyist. Vol. 1.

YUNGER, J. A., R. BREWER, and R. SNOOK. 1992. A method for decreasing trap mortality of *Sorex*. Can. Field-Nat. 106:249–251.

VITA

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