

Differential Responses of Postmetamorphic Amphibians to Cattle Grazing in Wetlands

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ABSTRACT Global amphibian declines have been linked to various anthropogenic land uses. Recent studies have documented negative impacts of cropland agriculture and deforestation on amphibians; however, few have examined potential impacts of cattle grazing in wetlands on resident amphibians. Therefore, we measured differences in number of captures and body size of postmetamorphic amphibians, egg mass abundance, and shoreline vegetation structure and composition between 4 wetlands with direct cattle access and 4 wetlands from which cattle were excluded on the Cumberland Plateau in Tennessee, USA. We captured amphibians at wetlands from March to August 2005 and 2006 using pitfall traps. Number of green frog (*Rana clamitans*) metamorphs captured at nonaccess wetlands was 2.5 times and 9.8 times greater than at wetlands with cattle access in 2005 and 2006, respectively. However, number of American toads (*Bufo americanus*) captured was 68 times and 76 times greater at cattle-access wetlands in 2005 and 2006, respectively. In general, metamorph body size was negatively correlated with species-specific capture rate. We detected no differences in egg mass abundance between cattle land-use types. Height, percent horizontal cover, and percent vertical cover of shoreline vegetation were 74%, 25%, and 84% greater, respectively, in nonaccess wetlands in 2005; vegetation trends were similar in 2006. Our results suggest that cattle impact amphibian populations but effects vary by species. Differences in postmetamorphic capture rate may be related to less emergent vegetation at cattle-access wetlands. Although body size differed between land uses for metamorphs, these trends probably were short-lived, because we did not detect differences in juvenile and adult body size between land uses for most species. Based on our findings, we suggest that fencing cattle from wetlands may be a prudent conservation strategy for some amphibian species (e.g., ranids), whereas other species (e.g., bufonids) may benefit from controlled grazing. (JOURNAL OF WILDLIFE MANAGEMENT 73(2):269–277; 2009)

DOI: 10.2193/2007-562

KEY WORDS agriculture, amphibian declines, anthropogenic stressors, body size, capture rate, grazing, vegetation.

Amphibian populations have been declining for several decades (Collins and Storer 2003, Stuart et al. 2004). In 2004, the Global Amphibian Assessment (GAA) classified 32% of amphibian species in decline and in threat of extinction (GAA 2004). It is commonly agreed that the most widespread and influential human impact on amphibian populations is direct loss and alteration of aquatic and terrestrial habitat (GAA 2004). Agriculture, silviculture, and urbanization are human land uses frequently cited as negatively impacting amphibians (Collins and Storer 2003). Most studies investigating impacts of agriculture on amphibians have focused on cropland production (e.g., Knutson et al. 1999, Gray et al. 2004a). Destruction of terrestrial habitat, decreases in habitat connectivity, and application of pesticides and fertilizers are possible mechanisms negatively affecting amphibians inhabiting wetlands surrounded by cropland agriculture (Bonin et al. 1997, Hecnar and McCloskey 1998, Gray et al. 2004b, Relyea 2005).

Another common agricultural land use is cattle grazing. Currently, there are 1.1 million cattle farms in the conterminous United States, with approximately 98 million head (U.S. Department of Agriculture 2007). Many of these farms contain wetlands that cattle use to acquire water and

graze vegetation (Belsky et al. 1999). Farm ponds also are used by amphibians and often represent the only wetland habitat available for breeding and larval development in an agriculturally dominated landscape (Knutson et al. 2004). Cattle may negatively impact amphibians by affecting aquatic and terrestrial environments. Grazing of shoreline vegetation could negatively affect postmetamorphic amphibians by reducing breeding and foraging sites and escape cover (Healey et al. 1997, Jansen and Healey 2002). Cattle also reduce water quality through deposition of nitrogenous waste (Line 2003), which could negatively influence postmetamorphic recruitment.

Most studies measuring impacts of cattle on postmetamorphic amphibians have been correlative in nature (e.g., Healey et al. 1997, Bull and Hayes 2000, Pyke and Marty 2005). Knutson et al. (2004) reported that wetlands with cattle access had lower amphibian species richness and lower larval and egg mass abundance of gray treefrogs (*Hyla versicolor*) and spring peepers (*Pseudacris crucifer*) than did wetlands without cattle. Healey et al. (1997) and Jansen and Healey (2002) reported that cattle may negatively impact amphibian abundance indirectly by reducing vegetation in Australian wetlands. Schmutzer et al. (2008) found that species diversity and richness of larval amphibians were lower in farm ponds with cattle, which could negatively affect postmetamorphic recruitment. In contrast, Bull and

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Hayes (2000) and Bull et al. (2001) reported no differences were detected in abundance of amphibian eggs and larvae between grazed and ungrazed ponds. Pyke and Marty (2005) also reported that cattle grazing in natural vernal pools may benefit salamander communities by maintaining suitable habitat conditions for reproduction. Inconsistencies in effects of cattle on amphibians may be a consequence of species-specific sensitivities, differences in grazing intensity, and potentially the spurious nature of correlative studies. These inconsistencies emphasize the importance of improving our understanding of impacts of cattle grazing in wetlands on resident amphibians.

Our objective was to compare species-specific capture rate of postmetamorphic amphibians inhabiting farm ponds exposed to and excluded from cattle grazing. We also measured postmetamorphic body size because it often is positively correlated with survival, reproduction, and recruitment in amphibian populations (Wilbur 1984, Semlitsch et al. 1988, Gray and Smith 2005). Shoreline vegetation structure and composition associated with ponds was measured due to its importance in amphibian survival and reproduction in temperate regions (Wells 2007).

STUDY AREA

We conducted our study at the University of Tennessee Plateau Research and Education Center on the Cumberland Plateau in Crossville, Tennessee, USA (36°00'50.64"N, 85°07'56.31"W). We used 8 farm ponds (hereafter wetlands) as experimental units for our study; 4 wetlands had been exposed to grazing for >10 years. The remaining 4 wetlands were surrounded by fence, preventing direct access by cattle for >10 years. Landscape composition was similar between land-use types (Burton 2007); thus, land-use type in our study represented presence or absence of direct cattle access in wetlands. Mean density around our cattle-access wetlands was 132 cattle/wetland ha per month (SE = 34.7), with access allowed all 12 months. Wetlands were 0.14–1.04 ha (\bar{x} = 0.32, SE = 0.10) and in proximity to each other (<2 km total separation). Pastures associated with access wetlands were 4.8–8.7 ha (\bar{x} = 6.8, SE = 0.8, n = 4), and average distance from nonaccess wetlands to grazing cattle was 110 m (SE = 58 m). Our wetlands were typical of farm ponds in the United States, having emergent nonpersistent and persistent herbaceous shoreline vegetation and permanently flooded unconsolidated bottoms in the center (Burton 2007). Species composition of herbaceous plants was predominately cattail (*Typha latifolia*), rushes (Juncaceae), and sedges (Cyperaceae; Burton 2007). Fish were present in all wetlands, but species-specific abundance was similar between cattle land-use types (Schmutzer 2007).

METHODS

Field Sampling

Using pitfall traps, we measured relative capture rate of postmetamorphic amphibians. We partially enclosed (50% of the circumference) all study wetlands with a 60-cm-high

continuous drift fence (Fig. 1). We did not completely encircle wetlands by drift fence to reduce processing time and thereby increase the number of independent wetlands that we could sample. We placed the drift fence parallel to and approximately 10 m upslope from the shoreline of the wetland. We placed pitfall traps (19-L buckets) on alternate sides and adjacent to the fence flush with the ground (Dodd and Scott 1994). Pitfall spacing was 5 m for half the drift fence length and 10 m for the remaining portion, which we did to quantify differences in capture rates for an ancillary study. An electrical fence surrounded the drift fence and pitfall traps at wetlands with cattle access to prevent cattle from destroying the fence or injuring themselves by stepping in the pitfalls (Fig. 1). We opened pitfalls twice per week (Mondays and Thursdays) for 24 hours from 28 March to 26 August 2005 and from 27 March to 25 August 2006. After biological processing of captures, we closed pitfalls.

We identified captured individuals by species, age, and sex, and we toe-clipped them uniquely using scissors sterilized in 0.01% chlorhexidine diacetate (Camper and Dixon 1988). We measured body mass and snout-vent length (SVL) for 5 random individuals caught per species per wetland per sampling event. After processing, we rehydrated individuals (i.e., placed them temporarily in a bucket of water) and released them on the opposite side of the fence from which we captured them (Dodd and Scott 1994). All sampling and marking techniques followed approved University of Tennessee Institutional Animal Care and Use Committee protocol number 1425. Amphibian capture was approved under Tennessee Wildlife Resources Agency scientific collection permit number 1990.

We visually estimated relative egg mass abundance once per week at each wetland. We divided wetlands into the 4 cardinal quadrants and randomly selected one quadrant at the beginning of the study for egg mass surveys (Fig. 1). We also surveyed the opposing quadrant for egg masses. Within each surveyed quadrant, we randomly selected one of the 2 cardinal azimuths forming the quadrant. We placed a permanent transect (10 m long) 1 m from the random cardinal azimuth so that it extended into the selected quadrant. We oriented the transect 2 m from and parallel to the shoreline (Fig. 1). We counted all egg masses we observed along the transect and identified them to one of the following taxonomic groups: 1) American bullfrog (*Rana catesbeiana*) and green frog (*Rana clamitans*), 2) pickerel frog (*Rana palustris*) and southern leopard frog (*Rana sphenoccephala*), 3) American toad (*Bufo americanus*) and Fowler's toad (*Bufo fowleri*), and 4) Cope's gray treefrog (*Hyla chrysoscelis*). We combined amphibian species in these groups because we were unable to confidently distinguish between these species within groups in the field.

We measured emergent shoreline vegetation once per month at each wetland. We measured vegetation in a 1-m² plot that we placed along a randomly selected azimuth in the 2 quadrants not used for egg mass surveys (Fig. 1). We randomly generated a new azimuth each month per wetland. We placed the plot at the midpoint of the emergent

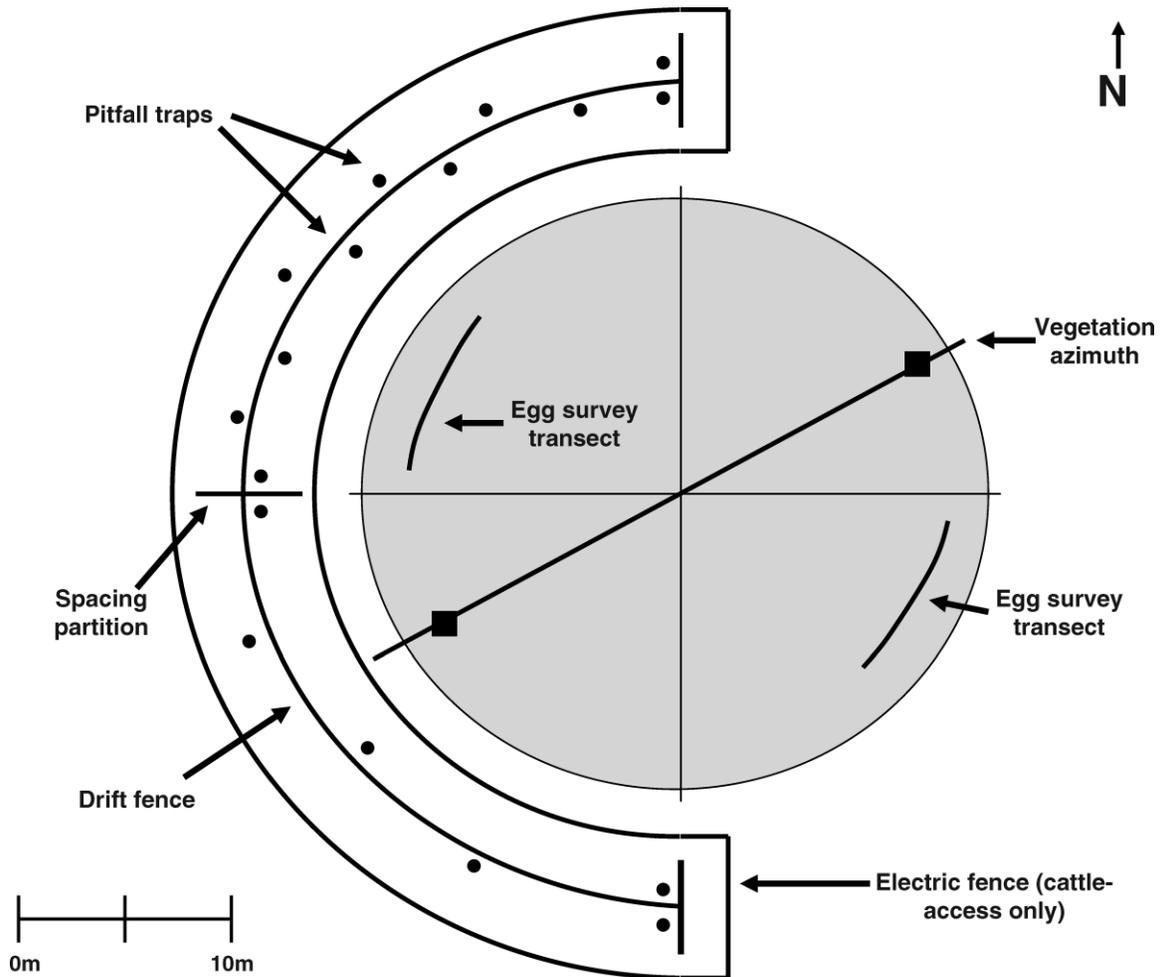


Figure 1. Schematic of pitfall, amphibian egg mass transect, and vegetation plot placement at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA 2005–2006.

vegetation zone along the azimuth in each quadrant. We measured vegetation height and percent vertical structure using a graduated profile board placed at the center of each plot (Higgins et al. 2005). We recorded and averaged maximum and minimum height of the shoreline vegetation covering the profile board for mean vegetation height per sampling location. In the 1-m² plot, we visually estimated percent horizontal cover of vegetation and water and we enumerated plant species richness (Higgins et al. 2005). For each vegetation response variable, we averaged all measurements among sampling locations within wetlands, so there was one value per variable per wetland per sampling event.

Statistical Analyses

Amphibian response variables included species-specific capture rate from pitfalls; body mass and SVL by species, age, and sex class; and egg mass abundance for the taxonomic groups. We used total daily capture of new individuals (i.e., recaptures not included) per wetland as an index of relative abundance. We did not estimate abundance using mark–recapture methods (e.g., Jolly–Seber) because recapture rate was <2% for all species (Williams et al. 2002, Burton 2007). We standardized daily capture by dividing by

the number of pitfall traps at each wetland because circumference, hence number of traps, differed among wetlands. Given that wetlands were experimental units, daily captures represented subsamples. Therefore, we quantified monthly trends by averaging captures across days within months for each wetland, which resulted in an 8 × 6 response matrix corresponding to 8 wetlands and 6 months for each amphibian species. We similarly averaged egg mass abundance per taxonomic group for each month. We measured vegetation once per month, thus averaging across days within months was not necessary.

We used a 2-factor repeated-measures analysis of variance with Hunyh–Feldt correction to test for differences between cattle land uses and among months (Montgomery 2000). When an interaction between land-use and month effects occurred, we separated analyses by month for land-use tests. For body size estimates, we used an analysis of covariance, with capture date as the covariate, to test for differences in SVL and mass between cattle land uses (Montgomery 2000). We used capture date as the covariate to partition possible variation associated with postmetamorphic growth. We performed all statistical analyses using the SAS[®] system

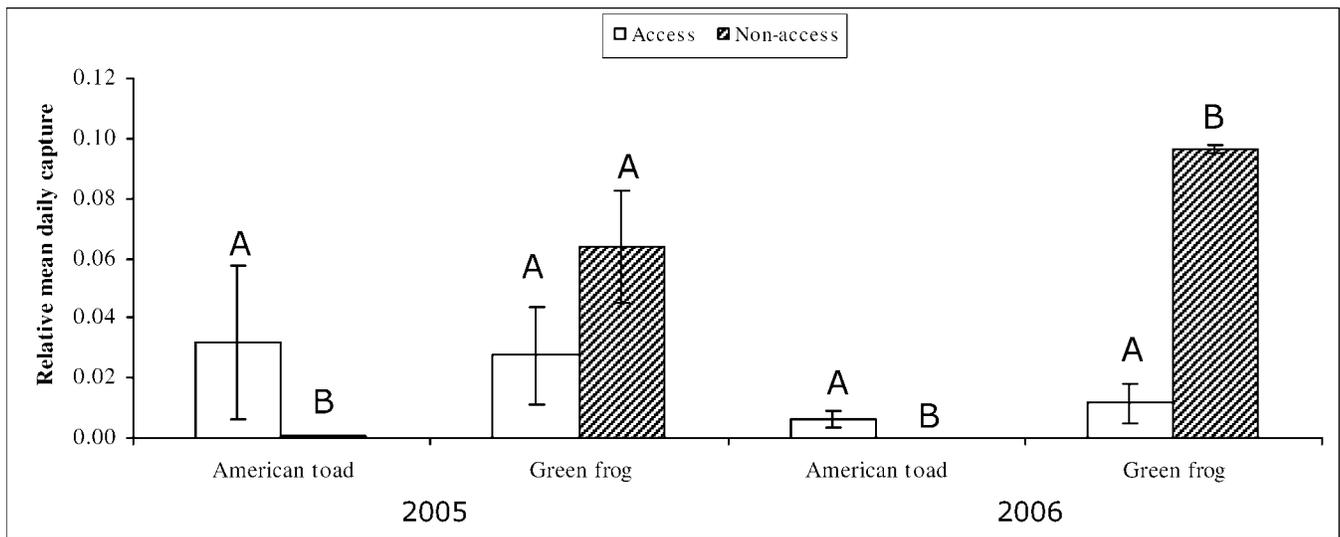


Figure 2. Relative mean daily capture of postmetamorphic amphibians that differed significantly between cattle land uses at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2005 and 2006. Unlike letters over adjacent bars within species indicate statistical significance.

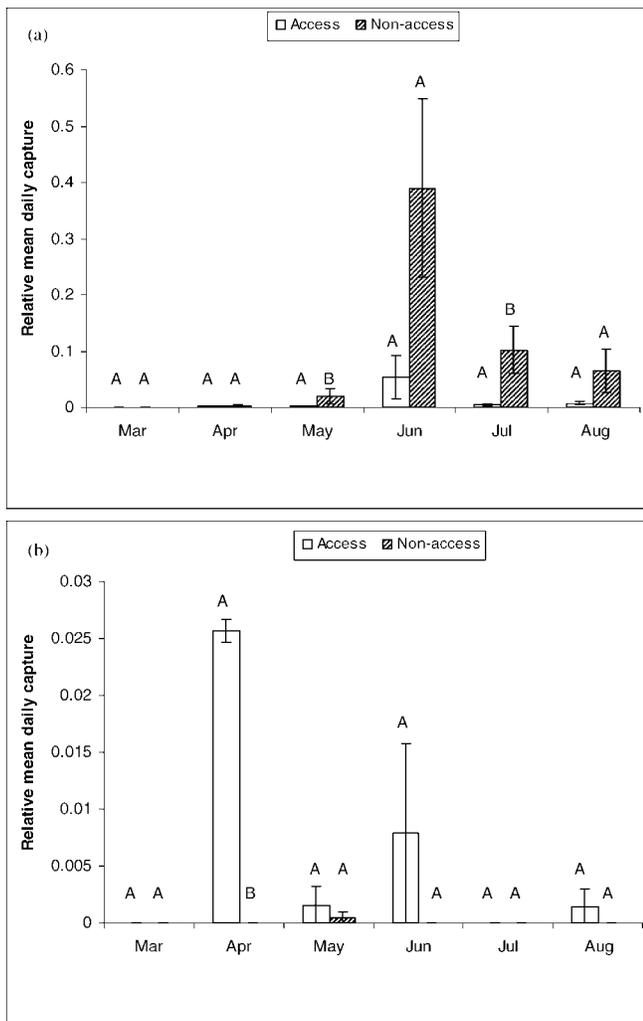


Figure 3. Relative mean daily capture of postmetamorphic green frogs (a) and American toads (b) between cattle land uses among months at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2006. Unlike letters over adjacent bars within months indicate statistical significance.

(SAS Institute, Cary, NC) at $\alpha = 0.10$ (Tacha et al. 1982, Littell et al. 1991, Stokes et al. 2003).

RESULTS

Mean daily capture of green frogs at nonaccess wetlands was 8.7 times greater than at cattle-access wetlands in 2006 ($F_{1,6} = 2.5$, $P = 0.07$; Fig. 2). However, land-use and month effects interacted ($F_{5,30} = 2.4$, $P = 0.07$); thus, we analyzed land-use tests by month. Monthly tests revealed that number of green frogs captured at nonaccess wetlands was 16 times and 21 times greater than at access wetlands in May and July 2006, respectively ($F_{1,6} \geq 3.0$, $P \leq 0.05$), with similar trends apparent during other months (Fig. 3a). Although differences were not significant ($F_{1,6} = 1.2$, $P = 0.19$), mean number of green frog captures was 2.3 times greater at nonaccess than at access wetlands in 2005 (Fig. 2). Age–sex class tests revealed that green frog metamorphs were the demographic group driving these trends. Mean daily capture of green frog metamorphs at nonaccess wetlands was 9.8 times greater than at access wetlands in 2006 ($F_{1,6} = 2.7$, $P = 0.06$; Fig. 4b). In 2005, green frog metamorphs were 2.5 times more abundant at nonaccess than at access wetlands, although we did not detect statistical differences ($F_{1,6} = 1.3$, $P = 0.18$; Fig. 4a).

Mean daily capture of American toads at cattle-access wetlands was 68 times and 76 times greater than at nonaccess wetlands in 2005 and 2006, respectively ($F_{1,6} \geq 4.1$, $P \leq 0.03$; Fig. 2). Land-use and month effects interacted in 2006 ($F_{5,30} = 3.1$, $P = 0.03$). Monthly tests revealed that American toads were more abundant at cattle-access wetlands in April 2006 ($F_{1,6} = 4.7$, $P = 0.02$; Fig. 3b); similar trends existed during other months. This trend was driven by all age–sex classes, but only mean capture of adult female and male American toads at access wetlands was significantly greater than at nonaccess wetlands in 2005 and 2006, respectively ($F_{1,6} \geq 4.6$, $P \leq 0.02$; Fig. 4a, b). For 12 other species that were captured, we detected no differences

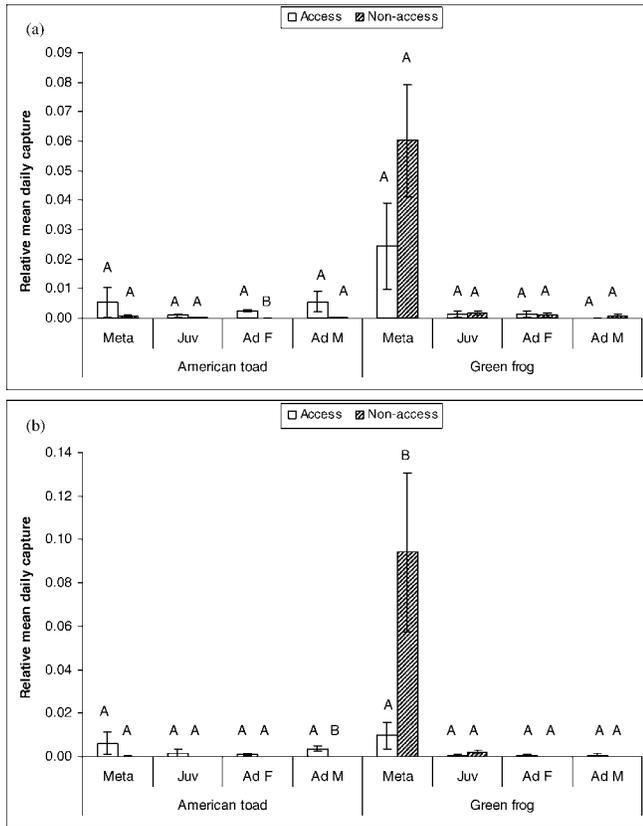


Figure 4. Relative mean daily capture for each age and sex class of postmetamorphic amphibians that differed significantly in mean daily capture between cattle land uses (see Fig. 2) at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2005 (a) and 2006 (b). Unlike letters over adjacent bars within age–sex classes indicate statistical significance. Meta indicates metamorph.

Table 1. Mass (g) of postmetamorphic amphibians between cattle land uses at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2005 and 2006.

Species ^a	Age and sex class ^{b,c}	Land-use type					
		<i>n</i>	Access		Nonaccess		
	\bar{x} ^d		SE	<i>n</i>	\bar{x}	SE	
BUAM	Juv	13	3.02 A	0.98	2	4.75 A	2.0
	Ad M	33	26.31 A	1.45	2	19.50 A	3.25
BUFO	Metamorph	56	0.85 A	0.44	3	2.42 B	1.80
	Juv	10	2.45 A	0.67	9	5.19 B	0.73
	Ad F	6	30.75 A	3.75	2	31.0 A	25.0
	Ad M	28	19.75 A	0.94	3	22.53 A	2.73
PSCR	Ad F	2	1.75 A	1.0	3	3.42 A	0.08
RACA	Metamorph	33	5.03 A	0.56	88	4.38 A	0.25
	Juv	5	12.45 A	0.67	4	12.50 A	2.43
	Ad F	7	29.0 A	6.60	6	20.88 A	3.86
RACL	Metamorph	105	3.79 A	0.17	422	2.78 B	0.06
	Juv	8	8.49 A	1.49	23	8.15 A	0.62
	Ad F	7	27.96 A	4.34	6	27.08 A	3.01
RAPA	Metamorph	28	1.78 A	0.09	32	1.44 B	0.09
	Ad F	6	15.67 A	0.42	2	22.50 A	11.0
RASP	Metamorph	57	1.73 A	0.07	68	1.38 B	0.06

^a BUAM = American toad, BUFO = Fowler’s toad, PSCR = spring peeper, RACA = American bullfrog, RACL = green frog, RAP A = pickerel frog, RASP = southern leopard frog.

^b Metamorph is <1 yr old, juv is >1 yr but not displaying secondary sexual characteristics, ad F is >1 yr and possessing female reproductive characteristics such as eggs, ad M is >1 yr and possessing male reproductive characteristics such as vocal sacs.

^c If an age–sex class is missing, we did not perform analyses due to insufficient data.

^d Means within rows followed by unlike letters are different by analysis of covariance with date of capture as the covariate.

in mean daily capture between cattle-access and nonaccess wetlands ($F_{1,6} \leq 1.7$, $P \geq 0.12$). Also, we detected no differences between land uses in relative abundance of egg masses ($F_{1,6} \leq 1.1$, $P \geq 0.19$).

Mass and SVL at nonaccess wetlands were 20–185% greater than at cattle-access wetlands for metamorph and juvenile Fowler’s toad ($F_{1,56} \geq 2.8$, $P < 0.10$; Tables 1, 2). Snout–vent length at nonaccess wetlands also was 11% greater than at access wetlands for adult male Fowler’s toad ($F_{1,28} = 12.5$, $P < 0.001$). In contrast, mass and SVL at cattle-access wetlands were 7–36% greater than at non-access wetlands for green frog, southern leopard frog, and pickerel frog metamorphs ($F_{1,57} \geq 4.2$, $P \leq 0.05$). Snout–vent length at access wetlands also was 14% greater than at nonaccess wetlands for adult male American toad ($F_{1,32} = 20.6$, $P < 0.001$). We detected no other differences ($F_{1,7} < 3.1$, $P \geq 0.14$), although there was a trend toward greater body size in cattle-access wetlands for ranids (Tables 1, 2).

Height, percent horizontal cover, and percent vertical structure of vegetation at nonaccess wetlands were 74%, 25%, and 84% greater, respectively, than at cattle-access wetlands in 2005 ($F_{1,6} \geq 2.6$, $P \leq 0.07$; Table 3). Percent vertical structure also was 41% greater at nonaccess wetlands in 2006 ($F_{1,6} = 4.0$, $P = 0.03$). We detected no additional differences ($F_{1,6} \leq 1.9$, $P \geq 0.11$; Table 3).

DISCUSSION

We found that capture rate of green frog metamorphs at wetlands without cattle was greater than at wetlands with cattle access; however, the opposite relationship existed for American toads. In general, postmetamorphic body size was

Table 2. Snout–vent length (mm) of postmetamorphic amphibians between cattle land uses at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2005 and 2006.

Species ^a	Age and sex class ^{b,c}	Land-use type					
		Access			Nonaccess		
		<i>n</i>	\bar{x} ^d	SE	<i>n</i>	\bar{x}	SE
BUAM	Juv	13	26.78 A	2.83	2	34.39 A	4.49
	Ad M	33	60.93 A	0.96	2	53.24 B	0.64
BUFO	Metamorph	56	12.75 A	0.40	3	17.5 B	1.48
	Juv	10	28.73 A	1.92	9	34.42 B	1.75
	Ad F	6	62.42 A	2.84	2	55.66 A	16.37
	Ad M	28	53.82 A	0.79	3	59.96 B	1.27
PSCR	Ad F	2	25.31 A	3.11	3	30.37 A	0.18
RACA	Metamorph	33	37.36 A	1.26	88	35.02 A	0.63
	Juv	5	50.13 A	0.85	4	50.91 A	2.97
	Ad F	7	63.82 A	5.21	6	59.47 A	3.80
RACL	Metamorph	105	32.47 A	0.39	422	29.78 B	0.23
	Juv	8	42.89 A	1.88	23	44.07 A	1.03
	Ad F	7	64.56 A	3.47	6	63.56 A	2.35
RAPA	Metamorph	28	27.38 A	0.68	32	25.55 B	0.63
	Ad F	6	58.75 A	0.87	2	60.51 A	12.30
RASP	Metamorph	57	26.36 A	0.27	68	24.59 B	0.35

^a BUAM = American toad, BUFO = Fowler's toad, PSCR = spring peeper, RACA = American bullfrog, RACL = green frog, RAPA = pickerel frog, RASP = southern leopard frog.

^b Metamorph is <1 yr old, juv is >1 yr but not displaying secondary sexual characteristics, ad F is >1 yr and possessing female reproductive characteristics such as eggs, ad M is >1 yr and possessing male reproductive characteristics such as vocal sacs.

^c If an age–sex class is missing, we did not perform analyses due to insufficient data.

^d Means within rows followed by unlike letters are different by analysis of covariance with date of capture as the covariate.

negatively correlated with capture rate. Height and structure of shoreline vegetation was less at cattle-access wetlands compared with nonaccess wetlands. These results suggest that impacts of cattle on postmetamorphic amphibians may be species-specific and mediated by changes to microhabitat at breeding sites.

Number of green frog metamorphs captured may have been negatively impacted at cattle-access wetlands by a reduction in emergent shoreline vegetation. Height, percent horizontal cover, and percent vertical structure of vegetation in nonaccess wetlands were greater than in cattle-access

wetlands both years. Many amphibians benefit from emergent shoreline vegetation because it affords cover from predators and inclement weather, provides protection from desiccation, and serves as sites for amplexus, oviposition, and foraging (Duellman and Trueb 1986, Hazell et al. 2001, Dodd 2004). Previous studies reported high abundance of green frogs associated with shoreline vegetation (Woodford and Meyer 2003, Lichtenberg et al. 2006). Although green frogs are habitat generalists (Hecnar 1997), adults and presumably metamorphs typically spend most of their time during the growing season near the shoreline of wetlands in areas with emergent vegetation (Minton 1972). Green frog tadpoles also are positively associated with shoreline emergent vegetation (Warkentin 1992). Schmutzer et al. (2008) documented that green frog tadpoles were 1.4–5 times more abundant at wetlands without cattle.

In contrast, we captured more American toads at cattle-access wetlands. American toads also are considered habitat generalists and are common in terrestrial environments that are modified by humans (Kolozsvary and Swihart 1999, Lehtinen et al. 1999, Waldick et al. 1999, Semlitsch and Bodie 2003). True toads (*Bufo*) commonly inhabit xeric environments with less vegetation and are able to withstand a greater loss of body water than ranids (Thorson 1955, Schmid 1965, Duellman and Trueb 1986, Conant and Collins 1998). Although we did not measure differences in light intensity or ground temperature, it is reasonable to assume that these abiotic factors were greater along shorelines at cattle-access wetlands due to increased exposure to solar radiation associated with less vegetation. Thus, the terrestrial microclimate at cattle-access wetlands

Table 3. Emergent shoreline vegetation characteristics between cattle land uses at 8 agricultural wetlands on the University of Tennessee Plateau Research and Education Center, Crossville, Tennessee, USA, March–August 2005 and 2006.

Metric ^a	Yr	Land-use type			
		Access		Nonaccess	
		\bar{x} ^b	SE	\bar{x}	SE
Ht (m)	2005	0.42 A	0.08	0.73 B	0.08
	2006	0.60 A	0.11	0.86 A	0.03
HC	2005	47.48 A	4.33	59.42 B	3.31
	2006	59.93 A	6.69	73.56 A	3.54
VS	2005	24.48 A	4.40	44.94 B	6.14
	2006	29.65 A	5.79	41.92 B	0.92
Richness	2005	4.23 A	0.98	4.03 A	0.38
	2006	4.31 A	0.46	5.18 A	0.36

^a Ht = mean plant ht, HC = % horizontal cover, VS = % vertical structure, Richness = plant species richness/m².

^b Means within rows followed by unlike letters are different by repeated measures analysis of variance.

may have been less hospitable for green frogs than for American toads.

Greater capture of toads at cattle-access wetlands also could have been related to differential predation rates. Adult toads have numerous granular glands that produce toxins making them unpalatable to most vertebrate predators (Duellman and Trueb 1986, Wright and Whitaker 2001). In addition, toad tadpoles are unpalatable to fish predators (Kats et al. 1988). Thus, reduction in shoreline vegetation may not have impacted toad predation rates. Conversely, ranids have fewer granular glands as adults, and green frog tadpoles frequently use shoreline vegetation to avoid predation (Warkentin 1992).

Differences in water quality between cattle-access and nonaccess wetlands also may have contributed to observed amphibian trends by impacting larval populations and postmetamorphic recruitment. Schmutzer et al. (2008) reported that specific conductivity, turbidity, ammonia, and nitrate were greater and dissolved oxygen was lower at cattle-access wetlands. Moreover, ammonia concentrations in cattle-access wetlands have been reported to reach levels that are lethal to green frog embryos (i.e., >0.6 mg/L; Jofre and Karasov 1999, Schmutzer et al. 2008). Alternatively, American toad embryos were found to tolerate higher ammonia levels (>0.9 mg/L) than were green frogs (Jofre and Karasov 1999). Thus, high ammonia levels at cattle-access wetlands may have reduced hatching of green frog embryos and negatively impacted postmetamorphic recruitment. Schmutzer et al. (2008) noted that other water quality variables that differed between cattle land-use types (e.g., dissolved oxygen, specific conductivity) did not reach levels known to negatively impact amphibian embryos or larvae. Green frogs may be especially sensitive to changes in the aquatic environment because they often overwinter in sediment at the bottom of wetlands; thus, they are potentially exposed to water quality stressors for longer duration (Houlahan and Findlay 2003, Dodd 2004).

We did not detect differences in egg mass abundance and number of adult captures for most amphibian species between cattle land uses. We caution against inferring that these results suggest cattle do not impact larval and adult age classes. A lack of detectable trends may have been a consequence of sampling design and method. We sampled egg masses in fixed plots in standardized locations. Stratified sampling within shoreline vegetation may have been a more ideal design, because these are common areas for temperate amphibians to oviposit. Also, we used pitfall sampling to index postmetamorphic abundance. Although pitfall traps are effective at capturing metamorphs, we recently completed a study that demonstrated escape rate of adult ranid and plethodontid amphibians from 19-L buckets was $>95\%$ (M. Foster and M. Gray, University of Tennessee, unpublished data). Indeed, Schmutzer et al. (2008) detected differences in richness and abundance of amphibian larvae between cattle-access and nonaccess wetlands, providing circumstantial evidence that differences may exist in egg mass and adult abundance between these land uses.

In general, postmetamorphic body size was greater for individuals captured at cattle-access wetlands for all species, except Fowler's and American toads. This trend was especially noticeable for metamorphs and was negatively related to capture rate of postmetamorphic amphibians at our study wetlands. These results echo previous studies on postmetamorphic body size at agricultural wetlands, which reported negative density-dependent relationships with body size (Oldham 1985, Gray and Smith 2005). Density dependence builds on the premise that fewer individuals imply greater per capita resources for each individual, thus lower competition (Wilbur 1976, 1977; Collins 1979). It has been reported that density of conspecifics in the terrestrial and aquatic environments is negatively related to postmetamorphic body size and survival (Wilbur 1977, Goater 1994, Morey and Reznick 2001, Relyea and Hoverman 2003), which can negatively impact evolutionary fitness (Werner 1986, Semlitsch et al. 1988, Berven 1990, Vonesh and De la Cruz 2002). Recapture rates were low ($<2\%$) at our wetlands (Burton 2007); thus, we cannot make any conclusions on whether body size differences conferred evolutionary fitness at our wetlands. We caution against concluding that the apparent positive effect of cattle grazing on metamorph body size will lead to greater postmetamorphic fitness. Fitness benefits of larger metamorph size will depend on condition of the terrestrial environment surrounding cattle impacted wetlands, which we did not evaluate. However, potential body-size effects in metamorphs probably were short-lived at our study site, because we detected few differences in juvenile and adult body size between land uses.

The only species that did not follow a postmetamorphic density-dependent trend were pickerel and southern leopard frogs. Mean capture rate of these species was greater at cattle-access wetlands as was body size of metamorphs. Body size of metamorphs may have been influenced by larval density (Berven 1990, Morey and Reznick 2001). Schmutzer et al. (2008) studied the same wetlands and years, and found that abundance of pickerel and southern leopard frog tadpoles was lower at cattle-access wetlands compared with nonaccess wetlands. In general, larval abundance of other species that Schmutzer et al. (2008) captured was negatively related with postmetamorphic body size.

Our results suggest that potential effects of direct cattle access in wetlands on amphibians are species-specific. In general, American toads may be impacted less by environmental changes associated with cattle grazing in wetlands, whereas green frogs (and perhaps other ranids) may be heavily impacted by cattle. We captured 12 additional species during our study (Burton 2007); however, capture rate of these species was low, which reduced our ability to document additional trends between cattle land uses. Small sample size ($n = 4$ wetlands/land use) probably contributed to our inability to detect additional statistical differences. Although species that we detected differences in capture rate between land uses are not currently declining, their responses may be representative of less common species

with similar life history (e.g., mountain yellow-legged frog [*Rana muscosa*] and Wyoming toad [*Bufo baxteri*]).

Environmental cofactors of cattle land use responsible for green frog and American toad trends are unknown but probably include a combination of reduced shoreline vegetation and lower water quality in cattle-access wetlands. Differences in shoreline vegetation may have served as proximate cues for habitat selection or caused increased mortality of ranids at cattle-access wetlands through accelerated water loss and increased predation. Differences in species-specific tolerances to water quality also may have influenced ranid larval survival and thus postmetamorphic recruitment and abundance (Schmutzer et al. 2008). In general, controlled studies (e.g., Jofre and Karasov 1999) suggest that toad tadpoles are influenced less by lower water quality, perhaps contributing to their greater capture rate at cattle-access wetlands. In addition, Gray et al. (2007) documented that green frog tadpoles inhabiting our cattle-access wetlands were 4 times more likely to be infected with *Ranavirus* than those in nonaccess wetlands. Thus, ranaviral disease may have played a role in green frog postmetamorphic capture rate. Indeed, the importance of vegetation reduction, lower water quality, and emergence of pathogens in amphibians inhabiting cattle-access wetlands needs further investigation.

MANAGEMENT IMPLICATIONS

Allowing cattle access in wetlands may have positive and negative effects on amphibians. Knutson et al. (2004) reported that cattle ponds are frequently used by amphibians, and they may be the only remnant breeding habitat in an agricultural landscape. Species sensitive to reduced shoreline vegetation and water quality associated with cattle grazing may benefit from cattle exclusion. Partially fencing cattle from portions of a wetland or limiting cattle density in space or time may minimize impacts on amphibians and be a viable conservation alternative. Future research directions need to quantify benefits of partial enclosures, regulating cattle density, and rotational grazing on amphibians. We quantified impacts of direct cattle access in wetlands on postmetamorphic amphibians. However, several studies (e.g., Gibbs 1998, Gray et al. 2004b, Todd and Rothermel 2006) have documented the importance of terrestrial habitat on amphibian movements and survival. Possible effects of vegetation reduction by cattle on amphibians in the terrestrial landscape need to be examined.

ACKNOWLEDGMENTS

Our study was funded by the University of Tennessee Institute of Agriculture, the University of Georgia Veterinary Diagnostic and Investigational Laboratory in Tifton, Georgia, and the Tennessee Wildlife Resources Agency. We especially thank J. Hitch and the Plateau Research and Education Center staff for access to the study wetlands and for providing housing. We also thank the following individuals for field assistance or reviewing initial drafts of our manuscripts: K. Carpenter, M. Foster, J. Hoverman, J.

Laux, J. McCurry, A. Moodhart, J. Mulhouse, D. Varble, and 4 anonymous referees.

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Associate Editor: Maerz.