nent transport in runoff to groundwater recharge or nearby ace water bodies. Because trace elements might exceed the EPA standards prematurely in a BMP detention basin, it is ntial to monitor the amounts of trace elements within these ns further and act to replenish the filtering media or modify the cture of the basin to assure the best water quality.

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SURVEY OF AQUATIC MACROINVERTEBRATES OF A NATIONAL WETLAND AREA IN BASTROP COUNTY, TEXAS

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Abstract.–The Lost Pines Ecoregion in East Central Texas is an ecologically unique area composed of a diverse set of terrestrial and aquatic organisms, many of which are on the western edge of their ranges within Texas. We assessed the diversity, abundance, and occurrence of aquatic invertebrates in small wetland ponds located on the Griffith League Ranch, a relatively intact remnant area of the Lost Pines. Seventeen ponds were sampled for aquatic invertebrates and abiotic wetland pond characteristics (e.g., wetland pond size and hydroperiod) from February 2006 to January of 2007. The most common taxa found in all ponds were in the family Chironomidae (Diptera) and the most diverse invertebrate group in the area was the family Dytiscidae (Coleoptera), which was composed of 20 genera. Differences in species composition between small ponds and large ponds were noted, such that many of the taxa present in smaller more ephemeral ponds were in general not present in larger and more permanent ponds. The difference in species composition between small and large ponds highlights the need for different conservation strategies for managing ephemeral systems within a landscape to maintain regional diversity. In addition, this information will serve as critically important baseline data to assess the potential effects of the intense and widespread 2011 Bastrop Complex Fire on the wetland communities in this region.

The Lost Pines ecoregion is an ecologically distinct region which exhibits a unique mixture of geological characteristics, flora, and fauna. Today, fragments of this system remain in portions of five counties in East Central Texas with the largest remnant in Bastrop County. During the Pleistocene Epoch, cooler and wetter conditions in Central Texas led to an expansion of the flora and fauna of the eastern US into this region (Toomey et al. 1993). As a consequence, this area became a 'suture zone' for organisms of diverse biogeographic origins, including the boreal, temperate, and subtropical zones (Remington 1968). Episodic climate fluctuations during the Pleistocene led to the loss of most of the boreal- and eastern-associated taxa and the isolation of remnant populations, creating the unique organismal diversity and floral composition of this region (Al-Rabab'ah & Williams 2004). One example is the relict disjunct population of loblolly pine (*Pineus taeda*) representing the westernmost extension of southern pine forest in the US. This area is often called the "Lost Pines" and once covered several thousand hectares. The Lost Pines region is also located along the 98th Meridian, which currently represents a zone of general transition in the state between western-associated and eastern-associated taxa (Blair 1950). Indeed, vertebrate and terrestrial insect communities in this region contain a relatively large proportion of taxa of eastern origin, indicating a unique faunal assemblage that is loosely sympatric within this remnant loblolly pine forest (Raun 1959; Taber 2008). In addition to its geographically unique floral and faunal assemblages, the Lost Pines contains one of the largest remaining populations of the endangered Houston toad, *Bufo* (*Anaxyrus*) *houstonensis* (Hillis et al. 1984; Duarte et al. 2011). Houston toad populations overall are in decline (McHenry & Forstner 2009; Forstner & Dixon 2011) and this decline is thought to be a consequence of a restriction in their range due to habitat loss from human development and changes in land use (Brown 1971; Brown 1975; Brown & Mesrobian 2005; Gaston et al. 2010). Within the Lost Pines ecoregion, the Griffith League Ranch (GLR) represents a large, relatively undisturbed tract of mixed post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*) and loblolly pine forest interspersed with post oak savannah habitat. Historically, this region was subject to periodic wildfires that maintained forest structure, but the presence of two state parks and a growing human population in the area have led to fire suppression and a build-up of understory fuel.

The GLR encompasses 1,962 ha and is located ~8 km north of Bastrop State Park. Within GLR, there are nineteen known ephemeral, semi-permanent, and permanent wetland ponds that serve as potential Houston toad habitat (Jackson et al. 2006). Thirteen ponds are designated as wetlands as part of the National Wetlands Inventory (U.S. Fish and Wildlife Service 1993a, 1993b). Wetlands ponds within GLR range in origin, size and hydroperiod (Table 1).

Some ponds on GLR are naturally-formed depressions within the landscape, while others are man-made livestock ponds ≤80 years old. These wetland systems are the relatively drier upland counterparts to the wetter dwarf palmetto (*Sabal minor*) and ash (*Fraxinus* spp.)-associated Ottine Wetlands located approximately 60 km away in Gonzalez County, Texas. Like the upland Lost Pines wetlands, the lowland Ottine Wetlands are remnant swamp and marsh ecosystems from the Pleistocene Epoch; however, the fauna of the Ottine Wetlands have received comparatively greater attention (e.g., Taber & Fleenor 2005). Although previous studies have addressed the composition and occurrence of amphibians, terrestrial invertebrates, and flightless vertebrates in the Lost Pines and GLR (Raun 1959; Gaston et al. 2001; Taber 2008; Ferguson et al. 2008), there is very little published information on the occurrence and composition of aquatic invertebrates in the wetland ponds of this area. Given the conservation status of some of the aquatic-associated organisms of the Lost Pines (e.g., Houston toads), the conservation priority of wetland habitats in general (Ormerod et al. 2009), and the functional importance of invertebrates in many wetland food webs (e.g., Chase & Knight 2003), a survey of the aquatic invertebrate fauna of the wetland ponds of GLR represents critically important information.

METHODS

The survey of the aquatic invertebrate fauna associated with the GLR wetland ponds was performed from February 2006 to January 2007. Sampling for aquatic invertebrates occurred once a month during this period, but was not conducted in July 2006 so as to not interfere with Houston toad juvenile emergence and in December 2006 due to logistical reasons. Thus, ponds were sampled for invertebrates ten times over the study period. On each date wetland invertebrates were sampled and measurements of the area for each pond were made. In order to estimate pond surface area, various measurements were taken and the pond surface area was calculated using the closest geometric shape. In addition, we estimated the hydroperiod of each pond during the study period. Hydroperiod of

Table 1. General morphometric aspects and taxonomic richness of wetland ponds on Griffith League Ranch, Bastrop, TX during the study period. The table displays the mean surface area, the proportional hydroperiod, and the number of genera/species recorded at each pond (taxon richness, *S*).

	Area (m^2)	Hydroperiod	Richness
1	477.97	1	66
2	815.89	1	55
3	15.83	0.4	5
5A	69.94	0.4	36
5B	309.28	1	51
6	23.35	0.5	18
7	46.78	NA	30
8	43.51	0.2	18
9	212.23	0.9	55
10	212.65	1	41
11	356.97	1	49
12	2321.2	1	43
13	19.64	0.7	11
14	24.15	0.8	15
15	67.15	0.7	23
16	1334.88	1	46
17	0.51	NA	7

each pond is expressed as the proportion of sampling dates ($n = 10$ dates) which the pond contained water. Invertebrate sampling was performed with a 500 µm mesh dip net. Each pond was actively sampled for a 15 minute time period, ensuring all available mesohabitats were sampled. Collected invertebrates were preserved in the field with 95% ethanol and returned to the lab for processing and identification. Invertebrates were identified using taxonomic keys to the lowest practical level, typically to genus (Merrit & Cummins 1996, Thorp & Covich 2001).

RESULTS

From February 2006 to January 2007, there was a pronounced period of drought in the region and only seventeen of the nineteen ponds contained water and were subsequently sampled for invertebrates. During the study period, the mean water surface area of ponds ranged from 0.51 to 1334 m^2 (Table 1). Of the seventeen ponds examined during this study, seven held water for the entire survey period (proportional hydroperiod = 1; Table 1). All other ponds exhibited less permanence and held water for only a portion of the survey period (range of proportional hydroperiods = 0.2 – 0.9). Ponds 7 and 17 were not located until fairly late in the survey (June and December respectively); therefore hydroperiod could not be calculated for these ponds.

During the survey, we collected a total of 25,233 individual aquatic invertebrates comprised of 19 orders, 57 families and 114 genera (Table 2). The most diverse family across all GLR wetland ponds was Dytiscidae (Coleoptera), which was represented by 20 genera, followed by the family Libellulidae (Odonata) with 14 genera. Aquatic invertebrates found at the GLR consisted mainly of lentic taxa, as indicated by genera such as *Hydrometra* (Hemiptera: Hydrometridae), *Curicta* (Hemiptera: Nepidae), *Pelocoris* (Hemiptera: Naucoridae), *Orthemis* (Odonata: Libellulidae), *Erythemis* (Odonata: Libellulidae), and *Celina* (Coleoptera: Dytiscidae). These genera are largely associated with non-flowing lentic systems (Merritt et al. 2008). Among the GLR wetland ponds, Pond 1 had the highest richness ($S = 66$), with Ponds 2 and 9 having the second highest richness ($S = 55$) (Table 1). The most ubiquitous family found in GLR wetland ponds was Chironomidae (Diptera), which was present in sixteen ponds. Other widely distributed taxa included the mosquito genus *Aedes* (Diptera: Culicidae) and the mayfly *Callibaetis* (Ephemeroptera: Baetidae), which were both present in thirteen ponds.

Discussion

Several aquatic invertebrate taxa found at GLR exhibited occurrence and distribution patterns in GLR wetland ponds that have implications for conservation and management of the Lost Pine wetlands. The fairy shrimp *Streptocephalus*, (Branchiopoda: Anostraca) was found in three wetland ponds (Ponds 5A, 8, and 13) in October and November 2006 and January 2007. Although

Table 2. Aquatic invertebrates captured during the survey of wetland ponds on Griffith League Ranch, in Bastrop, Texas. Wetland ponds (designated by specific Pond ID numbers) are listed across the top row and an 'X' designates if a taxon was present in that pond.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Collembola																		
Poduridae							X							X		X		
Smithuridae					X				X									
Entomobryidae		X			X	X	X		X							X	X	
Ephemeroptera																		
Caenidae	*Caenis*	X	X			X						X	X				X	
Baetidae	*Callibaetis*	X	X		X	X	X	X		X	X	X	X			X	X	X
Baetidae	*Camelobaetidius*		X															
Odonata																		
Coenagrionidae	*Argia*	X											X				X	
Coenagrionidae	*Ischnura*	X	X			X		X		X	X	X					X	
Coenagrionidae	*Enallagema*	X	X			X		X				X	X				X	
Libellulidae	*Ladona deplanata*					X						X						
Libellulidae	*Plethimis lydia*	X	X			X		X		X	X	X	X				X	
Libellulidae	*Pachydiplax longipennis*	X				X				X		X					X	
Libellulidae	*Libellula*	X	X			X		X		X	X	X	X		X		X	
Libellulidae	*Leucorrhinia*												X				X	
Libellulidae	*Erythemis*	X	X			X						X						
Libellulidae	*Micrathyria hageni*	X	X			X						X						
Libellulidae	*Tramea*	X	X			X		X				X	X					
Libellulidae	*Erythrodiplax*					X		X		X								
Libellulidae	*Pantala*					X		X		X								

Libellulidae	*Plethimis lydia*	X	X			X		X		X	X	X	X				X	
Libellulidae	*Pachydiplax longipennis*	X				X				X		X					X	
Libellulidae	*Libellula*	X	X			X		X		X	X	X	X		X		X	
Libellulidae	*Leucorrhinia*												X				X	
Libellulidae	*Erythemis*	X	X			X						X						
Libellulidae	*Micrathyria hageni*	X	X			X						X						
Libellulidae	*Tramea*	X	X			X		X				X	X					
Libellulidae	*Erythrodiplax*					X		X		X								
Libellulidae	*Pantala*					X		X		X								

Table 2. Cont.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Libellulidae	*Orthemis*	X	X			X				X	X	X	X					
Libellulidae	*Sympetrum*	X								X								
Cordulidae	*Epicordulia*	X	X			X						X	X				X	X
Lestidae	*Lestes*	X			X	X		X			X							
Aeshnidae	*Aeshna*													X				
Aeshnidae	*Anax*		X		X	X		X		X	X	X						
Aeshnidae	*Boyeria*						X							X				
Gomphidae	*Gomphus*	X									X	X	X				X	
Hemiptera																		
Hebridae	*Merragata*									X								
Gerridae	*Trepobates*	X	X					X				X	X				X	
Gerridae	*Aquarius*	X	X							X	X	X			X	X	X	
Gerridae	*Limnogonus*	X																
Gerridae	*Limnoporus*		X														X	
Pleidae	*Neoplea*	X	X			X				X	X	X				X		
Hydrometridae	*Hydrometra*															X		
Nepidae	*Rantra*	X	X									X	X				X	
Nepidae	*Curicta*	X				X						X						
Corixidae	*Graptocorixa*		X								X							
Corixidae	*Hesperocorixa*					X				X								
Corixidae	*Centrocorisa*		X			X				X		X						
Corixidae	*Trichocorixa*	X			X	X			X	X	X	X	X				X	
Corixidae	*Ramphocorixa*									X								
Corixidae	*Sigara*					X				X						X		
Corixidae	*Palmacorixa*												X					

Table 2. Cont.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Corixidae	*Corisella*					X				X	X							
Belastomatidae	*Belostoma*	X	X		X			X		X		X	X					
Belastomatidae	*Lethocerus*		X															
Naucoridae	*Pelocoris*	X	X			X				X		X	X					
Notonectidae	*Notonecta*		X		X	X	X	X		X	X							
Notonectidae	*Buenoa*		X		X	X		X		X	X	X		X			X	
Veliidae	*Microvelia*	X	X												X			
Mesoveliidae	*Mesovelia*	X				X	X	X		X	X		X			X		
Orthoptera																		
Gryllotalpidae			X							X								
Trichoptera																		
Leptoceridae	*Oecetis*	X	X			X				X		X	X				X	
Hydroptilidae	*Orthotrichia*	X	X									X					X	
Hydroptilidae	*Oxyethira*	X																
Lepidoptera																		
Crambidae	*Nymphalini*	X						X			X							
Crambidae	*Crambus*										X				X			
Megaloptera																		
Corydalidae	*Chauliodes*													X			X	
Coleoptera																		
Curculionidae		X				X	X		X			X			X			
Melyridae															X			
Scirtidae	*Scirtes*				X												X	
Haliplidae	*Peltodytes*		X							X		X	X				X	
Haliplidae	*Haliplus*		X			X	X	X			X	X	X		X		X	

		1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Lepidoptera																		
Crambidae	*Nymphalini*	X						X			X							
Crambidae	*Crambus*										X				X			
Megaloptera																		
Corydalidae	*Chauliodes*													X			X	
Coleoptera																		
Curculionidae		X				X	X		X			X			X			
Melyridae															X			
Scirtidae	*Scirtes*				X												X	
Haliplidae	*Peltodytes*		X							X		X	X				X	
Haliplidae	*Haliplus*		X			X	X	X			X	X	X		X		X	

Table 2. Cont.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Dytiscidae	*Anodocheilus*	X				X												
Dytiscidae	*Neobidessus*												X					
Dytiscidae	*Neoporus undulatus*	X							X	X	X	X	X		X	X	X	
Dytiscidae	*Neoporus dimidiatus*					X						X	X				X	
Dytiscidae	*Neoporus C*				X													
Dytiscidae	*Liodessus*									X	X							
Dytiscidae	*Laccophilus*	X	X		X	X	X			X	X	X	X		X		X	
Dytiscidae	*Celina*	X														X		
Dytiscidae	*Bidessonotus*	X											X					
Dytiscidae	*Rhantus calidus*									X						X		
Dytiscidae	*Thermonectus basilaris*		X			X				X								
Dytiscidae	*Thermonectus nigrofasciatus*		X			X		X	X	X	X							
Dytiscidae	*Hydrovatus*		X									X						
Dytiscidae	*Cybister*		X		X					X	X							
Dytiscidae	*Copelatus*										X							
Dytiscidae	*Coptotomus*		X								X		X				X	
Dytiscidae	*Agabus*		X		X		X	X		X	X			X	X	X		
Dytiscidae	*Desmoprachia deflocatta*							X										
Dytiscidae	*Hygrotus nubilis*		X							X								
Dytiscidae	*Uvarus*									X								
Noteridae	*Hydrocanthus*	X										X						
Noteridae	*Notomicrus*															X		
Hydrophilidae	*Heloporus*					X					X							
Hydrophilidae	*Helocharus*	X									X							
Hydrophilidae	*Hydrobius*									X								

Table 2. Cont.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Hydrophilidae	*Tropisternus collaris*	X	X		X	X				X	X		X		X			
Hydrophilidae	*Tropisternus lateralis*	X	X		X	X		X	X	X	X		X					
Hydrophilidae	*Laccobius*														X			
Hydrophilidae	*Hydrophilus*				X							X						
Hydrophilidae	*Cymbiodyta*	X											X					
Hydrophilidae	*Enochrus*			X														
Hydrophilidae	*Berosus*	X			X	X				X			X					
Hydrophilidae	*Paracymus*	X	X		X	X	X		X	X							X	
Hydrochidae	*Hydrochus*												X					
Gyrinidae	*Dinetus*		X							X								
Gyrinidae	*Gyrinus*												X				X	
Limnichidae	*Limnichus*									X								
Elmidae	*Dubiraphia*																X	
Diptera																		
Chironomidae		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceratopogonidae		X	X			X				X	X	X	X				X	
Tabanidae	*Chlorotabanus*	X																
Tabanidae	*Leucotabanus*	X																
Tabanidae	*Chrysops*	X							X	X		X						
Ephyridae		X			X				X		X	X				X		X
Sciomyzidae					X													
Empididae		X																
Choaboridae	*Choaborus*				X		X			X						X		
Culicidae	*Anophelus*	X	X		X	X	X	X	X	X		X	X				X	
Culicidae	*Aedes*	X		X	X	X	X	X	X		X	X		X		X	X	X

		1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Chironomidae		X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
Ceratopogonidae		X	X			X				X	X	X	X				X	
Tabanidae	*Chlorotabanus*	X																
Tabanidae	*Leucotabanus*	X																
Tabanidae	*Chrysops*	X							X	X		X						
Ephyridae		X			X				X		X	X				X		X
Sciomyzidae					X													
Empididae		X																
Choaboridae	*Choaborus*				X		X			X						X		
Culicidae	*Anophelus*	X	X		X	X	X	X	X	X		X	X				X	
Culicidae	*Aedes*	X		X	X	X	X	X	X		X	X		X		X	X	X

Table 2. Cont.

Order/Family	Species	1	2	3	5A	5B	6	7	8	9	10	11	12	13	14	15	16	17
Culicidae	*Culiseta*	X				X	X		X							X	X	X
Culicidae	*Culex*	X	X		X				X	X	X						X	X
Tipulidae		X	X		X								X				X	
Stratiomyidae	*Odontomyia*	X																
Amphipoda																		
Hyalellidae	*Hyalella*	X	X							X							X	
Crangonyctidae	*Synurella*			X	X										X	X		
Cladocera																		
Daphnidae	*Simocephalus*	X	X		X	X	X	X	X	X	X	X	X	X		X	X	
Daphnidae	*Daphnia*			X												X		
Anostraca																		
Streptocephalidae	*Streptocephalus seali*				X				X					X				
Limnophila																		
Planorbidae	*Helisoma*							X										
Planorbidae	*Menetus*	X	X		X							X	X				X	
Physidae	*Physa*	X	X	X	X	X		X			X	X	X		X		X	
Ancylidae	*Hebetancylus*	X	X		X			X				X	X				X	
Veneroida																		
Corbiculidae	*Corbicula*									X								
Calanoid		X			X		X	X		X	X	X		X			X	
Cyclopoid		X	X		X	X				X	X	X	X			X	X	
Podocopida		X	X		X	X		X	X		X	X	X			X	X	

anostracans commonly occur in temporary pond communities, these animals require periods of habitat desiccation in order to complete their life cycle; the ponds in which they were found on GLR all exhibited a period of drying during the study. Indeed, it appears that wetland pond size and hydroperiod play important roles in the occurrence of a suite of other invertebrate taxa on GLR. For example, Ponds 3, 5A, 8, and 13, 14, and 15 are relatively small ponds with shorter hydroperiods (Table 2). These ponds contained invertebrate taxa that differed from the larger, more permanent ponds. Genera only found in these smaller ephemeral ponds include *Enochrus* (Coleoptera: Hydrophilidae), *Neoporus* (Coleoptera: Dytiscidae), *Notomicrus* (Coleoptera: Noteridae), *Laccobius* (Coleoptera: Hydrophilidae), and *Aeshna* (Odonata: Aeshnidae). Not only do smaller ponds contain different invertebrate communities, it is also hypothesized that smaller ephemeral ponds are better breeding environments for the Houston toad (Gaston et al. 2010) because they are typically fishless environments, have softer benthic substrates, and less steep banks for exiting juvenile toads (Forstner & Ahlbrandt 2003).

Anthropogenic changes to land cover patterns in the area and alteration of the regulations surrounding wetlands often impact ephemeral wetlands first, leading to their loss from the landscape (Brooks & Paton 2005). In the Lost Pines region, losses of ephemeral wetlands are coupled to numerical increases of non-ephemeral man-made impoundments, thereby exacerbating the decline of its most prominent conservation icon, the Houston toad (Gaston et al. 2010). Based upon the findings of this study and others, data indicates that for conservation purposes, small ephemeral ponds in the Lost Pines region should be considered ecologically distinct and necessary to maintain high local and regional biological diversity including wild populations of the Houston toad.

The occurrence and distribution of several invertebrate taxa within GLR wetlands suggest interesting and unique patterns of organism dispersal. The amphipod, *Synurella* (Amphipoda: Crangonyctidae) was present in four wetland ponds (Ponds 3, 5A, 14 and 15). Like many of the organisms in the Lost Pines region, *Synurella* has a more eastern distribution in Texas with Bastrop County being the western extent of its range (Holsinger 1976). *Synurella* and other species of amphipods do not have desiccation-resistant life stages and require the presence of water for their continued persistence in a habitat. The occurrence of these amphipods in ephemeral ponds suggests that there is a primary source of *Synurella* in the landscape and individuals can immigrate to ephemeral ponds after habitats are re-wetted. Migration of individuals might occur horizontally and passively through surface runoff connections between ponds or through vertical movement of individuals if amphipods aestivate in damp sediments below the exposed benthic surface (Batzer & Sion 1999). Alternatively, these amphipods may use groundwater pathways to disperse to re-wetted ponds. For example, Harris et al. (2002) (Monroe Co., New York) found that another species of Crangonyctid amphipod (*Crangonyx pseudogracilis*) inhabited shallow water tables and used groundwater connections to disperse and emerge into re-wetted ephemeral ponds. Our findings indicate that future efforts should focus on the relative importance of different dispersal mechanisms of organisms which are thought to have their distributions limited to permanent ponds in landscapes.

In September 2011, the Bastrop County Complex Fire burned >12,000 hectares in the greater Bastrop area, including substantial portions of the Lost Pines in Bastrop State Park and the Griffith League Ranch. Historically, the Lost Pines area and other western forests were subjected to a periodically-occurring natural burn regime, but fires have been suppressed by humans for much of the last century resulting in fires of far greater intensity than cyclical fires that occurred pre-suppression (e.g., Minnich et al. 2000). Given the extreme intensity of the recent Bastrop County Complex Fire, the unique nature of the Lost Pines wetlands, and the listed status established by the U.S. Fish and Wildlife Service for these habitats associated with Houston toads (Gottschalk 1970), examination of the responses of these aquatic communities to this burn incident is key. This invertebrate survey can serve as baseline or pre-burn data in order to examine the aquatic invertebrate responses to this event.

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