RANGE ASSESSMENT IN GEORGIA FOR TWO THREATENED GROUNDWATER SPECIES OF THE FLORIDAN AQUIFER (*CAMBARUS CRYPTODYTES* AND *EURYCEA WALLACEI*)

FINAL REPORT SUBMITTED TO:

GEORGIA DEPARTMENT OF NATURAL RESOURCES
WILDLIFE RESOURCES DIVISION
2070 US HWY 278 SE
SOCIAL CIRCLE, GA 30025-4711

17 DECEMBER 2015

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INTRODUCTION

On 20 April 2010, the Center for Biological Diversity (CBD) petitioned the United States Fish and Wildlife Service to list 404 aquatic, riparian, and wetland species from the Southeastern United States as threatened or endangered under the Endangered Species Act (CBD 2010). This petition states,

> **"Pursuant to Section 4(b) of the Endangered Species Act ("ESA"), 16 U.S.C. §1533(b), Section 553(3) of the Administrative Procedures Act, 5 U.S.C. § 553(e), and 50 C.F.R. §424.14(a), the Center for Biological Diversity, Alabama Rivers Alliance, Clinch Coalition, Dogwood Alliance, Gulf Restoration Network, Tennessee Forests Council, West Virginia Highlands Conservancy, Tierra Curry and Noah Greenwald hereby formally petition the Secretaries of Interior and Commerce to list 404 aquatic, riparian and wetland species from the southeastern U.S. as Threatened or Endangered species and to designate critical habitat concurrent with listing."**

The list of 404 proposed species includes the Georgia Blind Salamander, *Eurycea wallacei*, and the Dougherty Plain Cave Crayfish, *Cambarus cryptodytes* (Fig. 1). Both species are found in the same habitats within the Floridan Aquifer. Clarification of the distribution, number of populations, and population status of each species is important with regard to their conservation (CBD 2010; Fenolio et al. 2013).Importantly, there are large areas between known localities wherein there are no documented occurrences of either species (Fenolio et al. 2013). The CBD petition states the following regarding the known distribution of *E. wallacei*:

> **"The Georgia Blind Salamander occurs in Jackson County, Florida, and in Dougherty and Decatur counties, Georgia, in the Marianna Lowlands-Dougherty Plain physiographic region which is a vast karst area of passageways and exposed vadose caves (NatureServe 2008, AmphibiaWeb 2009). The species is known from a deep well in Albany, Georgia, and from Climax Cave. In the Florida Panhandle the species has been detected at approximately a dozen sites which allow access to the Floridan Aquifer, which circulates in underground passageways in limestones of the Ocala and Suwannee formations (AmphibiaWeb 2009)."**

The CBD petition states the following regarding the known distribution of *C. cryptodytes*:

> **"NatureServe (2008) reports that the Dougherty Plain cave crayfish occurs in the aquifer of the Dougherty Plain (Marianna Lowlands), from Decatur County, Georgia, to Jackson County, Florida, USA. All known sites can be enclosed by 50 km circle, and all lie within the Apalachicola River basin. Skelton (2008) states that "The species is currently known from Dougherty and Decatur counties in southwestern Georgia and Jackson and Washington counties, in the Panhandle of Florida. It almost certainly occurs in Mitchell and Baker counties, Georgia, as these counties lie between Dougherty and Decatur Counties, in southwest Georgia.""**

Population level data are largely unknown for either species. The CBD petition states the following regarding known populations of *E. wallacei*:

> **"NatureServe (2008) states that there are between 6 and 20 populations with less than 1000 individuals in total. There are approximately 15-20 EOs, but these all are relatively close and may even be interconnected."**

The CBD petition states the following regarding populations of *C. cryptodytes*:

> "NatureServe (2008) states that there are between 6 and 20 populations with less than 1000 individuals in total. There are approximately 15-20 EOs, but these all are relatively close and may even be interconnected."

The status of *Eurycea wallacei* was recently summarized by Fenolio et al. (2013) and pertinent information for both species was included in the CBD petition as follows:

For *E. wallacei*:

> "The Georgia Blind Salamander is critically imperiled in Georgia (S1) and imperiled in Florida (S2). It is categorized as vulnerable by the IUCN."

For *C. cryptodytes*:

> "According to NatureServe (2008), *Cambarus cryptodytes* is narrowly endemic. While there are a moderate number of occurrences, they all lie within a small, county-sized area. In Florida this species has a status of imperiled, and in Georgia it is critically imperiled (NatureServe 2008). The State of Georgia lists the Dougherty Plains cave crayfish as Threatened (Skelton 2008). Florida lists it as a Species of Greatest Conservation Need. It is ranked as vulnerable by the IUCN and as threatened by the American Fisheries Society."

The Floridan Aquifer is a principal artesian aquifer that underlies over 250,000 km^2 in southern Alabama, southern Georgia, southern South Carolina, and all of Florida. It is the source of water for several large Southeastern U.S. cities, such as Savannah, Georgia, and Jacksonville, Tallahassee, and Orlando, Florida. Land above the aquifer has been altered from its natural state, largely for agricultural purposes. For this reason, the Floridan Aquifer has been identified as an at risk aquifer for nitrate contamination (from fertilizers) by the United States Geological Survey (Nolan et al. 1998). From a wildlife management perspective, groundwater contamination is a serious problem. Because so many groundwater species are found in single aquifer systems, a single contamination event could pose an extinction threat. For example, in 1981, liquid ammonia nitrate and urea fertilizer were spilled in the Ozark Highlands of Missouri, contaminating an underlying aquifer. Living and dead groundwater fauna ranging from stygobiotic cavefish to crayfish to cave salamander larvae washed out of a spring fed by the aquifer roughly 21 km from the spill site (Crunkilton 1984). Such an event could extirpate local populations of threatened and imperiled groundwater fauna in the Floridan Aquifer.

Figure 1. A Georgia Blind Salamander (*Eurycea wallacei*) and Dougherty Plain Cave Crayfish (*Cambarus cryptodytes*) from Hole in the Wall Cave, Merritt's Mill Pond, Jackson Co., Florida. Photographs by Dante B. Fenolio.

The Georgia Blind Salamander was described by Carr (1939) as *Haideotriton wallacei* based on a specimen taken from a 200 foot well near Albany, Georgia. However, Frost et al. (2006) recently synonymized the genus *Haideotriton* into *Eurycea* based on molecular analyses. This neotenic species inhabits the Floridan Aquifer in the Marianna Lowlands and the Dougherty Plain, where artesian waters are contained in carbonate strata of the Ocala and Suwannee formations (Means 2005). Georgia Blind Salamanders have been reported from just seven localities in Georgia (two of which have been destroyed) and 29 localities in northwestern Florida (Pylka and Warren 1958; Dundee 1962; Means 1977, 1992, 2005; Morris 2006), including 22 in Jackson County, five in Washington County, and one in Calhoun County (Fig. 2). These records include vadose caves, sinkholes, wells, and partially or completely submerged limestone cave systems (Pylka and Warren 1958; Dundee 1962; Means 1977, 1992, 2005). Georgia Blind Salamanders are at risk from several anthropogenic threats, the most serious of which are over-harvesting of groundwater and groundwater pollution (Means, 1977, 1992, 2005; USGS 2005). Consequently, the species is listed as "Vulnerable" by IUCN (Hammerson 2004) and "Imperiled" (G2) by NatureServe (Natureserve 2015) because of few known occurrences, limited geographic distribution, potential rangewide threats and declines in range and population size. The Georgia Blind Salamander is also listed as a species of conservation concern in both Florida and Georgia.

The Dougherty Plain Cave Crayfish was described by Hobbs (1941). The species also occurs in the Marianna Lowlands and Dougherty Plain sections of the Floridan Aquifer, primarily from Decatur Co., Georgia, to Washington Co., Florida, within the Apalachicola, and Choctawhatchee River and Econfina

Creek basins (Hobbs 1981, 1989; Morris 2006; P. Moler, pers. comm.). Dougherty Plain Cave Crayfish have been reported from just eight localities in Georgia in Baker, Calhoun, Decatur, and Dougherty counties, and 29 localities in northwestern Florida, including 23 in Jackson County, five in Washington County, and one in Calhoun County (Hobbs et al. 1977; Hobbs 1981; Franz et al. 1994; Purvis and Opsahl 2005; Morris 2006; Skelton 2008). The majority of records are from submerged freshwater limestone caves but the species also has been observed from wells, sinks, and vadose caves. Little is known regarding the life history and ecology of this species. The species is listed as "Least Concern" by IUCN (Cordeiro et al. 2010) due to its broad distribution and large number of occurrences. However, it is considered "Imperiled" (G2) by NatureServe (NatureServe 2015). The Dougherty Plain Cave Crayfish is designated as "Threatened" in Georgia.

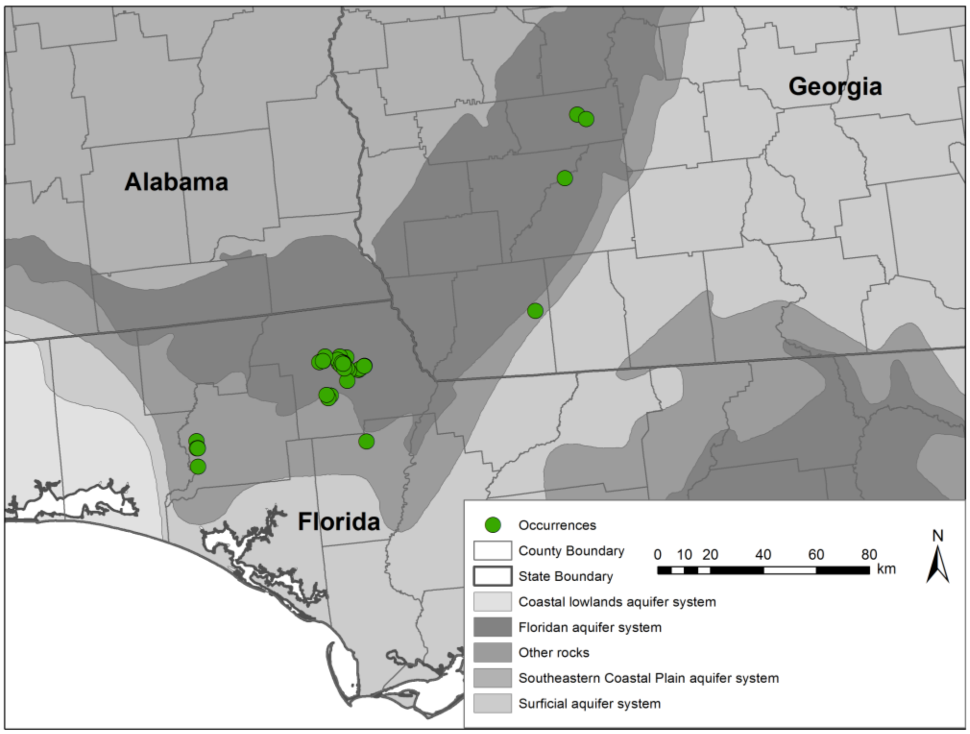

Figure 2. Distribution of the Georgia Blind Salamander (*Eurycea wallacei*) within the Floridan Aquifer in southwestern Georgia and adjacent panhandle of Florida.

OBJECTIVES

In spite of the fact that the Floridan Aquifer has been designated as an at risk aquifer for fertilizer contamination by the United States Geological Survey (Nolan et al. 1998), no regular monitoring protocols or efforts to exactly delineate the ranges of the species had been initiated or reported. Given increasing anthropogenic threats that may impact populations of both species, addressing data gaps in range delineations for the Georgia Blind Salamander and Dougherty Plain Cave Crayfish are critically important.

Our work proposed the following objectives: (1) survey wells in counties where both species have not yet been documented (Baker, Mitchell, Calhoun, Early, Miller and northern Seminole counties in Georgia); (2) document occurrences in "data gap" areas between known localities and attempt to better define geographic extent.

METHODS

For both species, we identified regions between known localities for trapping. We worked with U.S. Geological Survey (USGS) colleagues from the South Atlantic Water Science Center to coordinate permission and access to groundwater monitoring wells within the data gap areas in Georgia (as has previously been done with water authorities in Texas). Baited bottle traps were used at each locality (well water monitoring pipes) to document occurrence. Traps were modeled after a design by Dr. Andy Gluesenkamp (Texas Nongame & Rare Species Program), and have been used to monitor wells for Texas groundwater species since 2000 (Figs. 3 and 4). A similar approach has been recently employed to discover new populations of Dougherty Plain Cave Crayfish in southern Georgia (Purvis and Opsahl 2005). All well sites trapped are listed in Table 1, with locations of each well site displayed in Figs. 5 and 6. Unsalted cashew nuts were used as bait for the first five rounds of trapping after which shrimp was used for the last five rounds of trapping. All traps were supplied with several strands of cotton from a mop head to provide refugia inside of the trap (see Fig. 7). Traps were deployed beginning in September 2014 and ending in August 2015. Attempts were made to remove traps within 14 days of deployment for any given trapping period. However, logistical constraints resulted in trapping event durations between 6–36 days (mean 13.8 ± 8.1 days).

Figure 3. Both single (to the right) and double opening (to the left) well-pipe traps used in this study. Traps are weighted with fishing weights or large steel nuts to orient the traps properly for extraction from a well. Photographs by Dante B. Fenolio.

Up to two tissue samples of a target species were obtained from any single locality by using sterile forceps and scissors to cut off a walking leg (crayfish) or tail tip (salamander) that will later regenerate. Target species individuals found dead in traps were also collected. Samples were stored in 95% ethanol for future genetic analyses. Historically, few tissue samples have been available for genetic analyses of either target species. In addition, both taxa have yet to be the focus of phylogenetic and population genetic studies. Given their broad distributions, there is the potential for each species to comprise multiple cryptic species or evolutionarily significant units (ESUs). Once genetic studies are completed, all preserved materials will be deposited into a museum collections, which will be reported later to GADNR.

Figure 4. A well-pipe trap ready to be deployed (left) at a USGS groundwater monitoring well (08K001) in Early Co., Georgia (right). Mop head served as refugia for trapped individuals and cashews were used as bait at the bottom of the trap.

RESULTS

We trapped at 18 well sites located in 10 Georgia counties (Table 2, Figs. 5 and 6): Baker, Calhoun, Decatur, Dougherty, Early, Grady, Lowndes, Miller, Mitchell, and Seminole. All but one well site (11J011 in Mitchell County) were developed in the Upper Floridan Aquifer. Well 11J011 is located adjacent to Well 11J012 and was mistakenly trapped during the first round of trapping. Mean well depth for well sites was 63.8 ± 34.6 m. Well casings had diameters ranging 10.2 to 50.8 cm. In total, 99 trapping events were conducted (Table 3), representing 1,364 trap days (mean trapping event duration 13.8 ± 8.2 days). The number of trapping events at a well site ranged from one to 10 trapping events (mean 5.5 ± 2.7 trapping events). Well 07H002 was trapped only once because of collapse.

No Georgia Blind Salamanders were captured during the study. Thirty-two Dougherty Plain Cave Crayfish were captured from nine well sites in eight counties (Figs. 7–10): Baker (2 wells), Calhoun (1 well), Decatur (1 well), Dougherty (1 well), Early (1 well), Miller (1 well), Mitchell (1 well), and Seminole (1 well). The total number of crayfish captured at a well site ranged from 0 to 9 crayfish, with a mean of 3.6 ± 2.6 crayfish captured at the nine well sites where Dougherty Plain Cave Crayfish were present. Nine crayfish were captured at Well 13L012 in Dougherty County, 6 crayfish at Well 08G001 in Miller County, four crayfish at Well 10K005 in Calhoun County, and 4 crayfish at Well 08K001 in Early County.

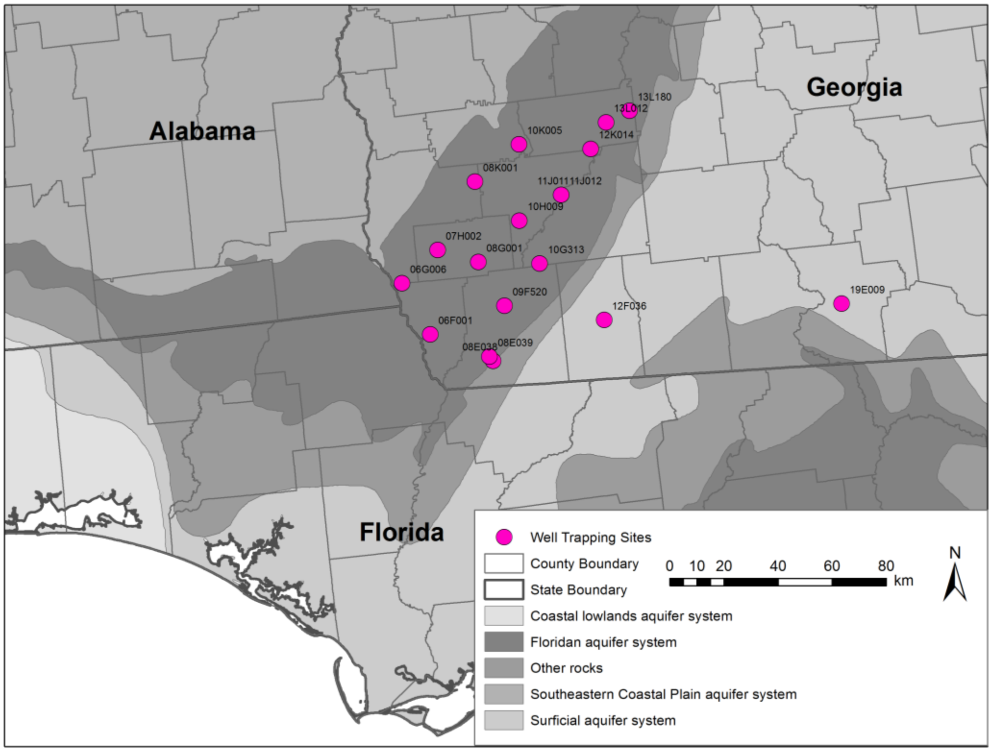

Figure 5. Location of USGS wells trapped during the current study in 10 Georgia counties in relation to aquifer systems.

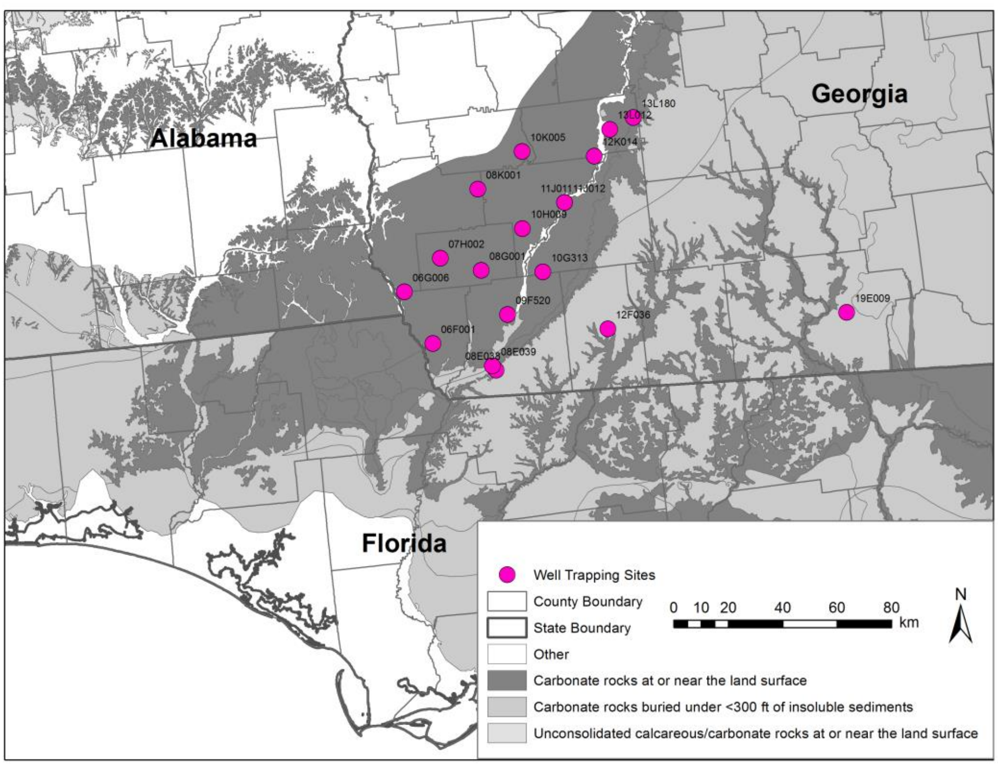

Figure 6. Location of USGS wells trapped during the current study in 10 Georgia counties in relation to karst rock formations.

The number of crayfish captured during a single trapping event ranged from 0 to 5 (Well 13L012), with a mean of 1.6 ± 1.1 crayfish captured during a single trapping event at the nine well sites where crayfish were present (Table 3). Catch per unit effort (CPUE), defined as the number of crayfish captured per trap day, ranged from 0.008 to 0.123 crayfish per trap day at sites where crayfish were present, with an overall mean of 0.048 ± 0.038 crayfish per trap day for all well sites. Mean time to first capture (TTFC) of a crayfish was 35.3 ± 24.9 trap days, ranging from 7 (Well 08G001) to 79 days (Well 10H009). Of the 32 total crayfish captured, 15 were captured alive while 17 were found dead in the trap.

Mean well depth where crayfish were present was 54.1 ± 16.3 m versus 73.5 ± 45.5 m where crayfish were not detected. The deepest well where crayfish were detected was Well 09F520 in Decatur County at 76.5 m. Well depth did not differ between groups (t=-1.20, df=10.01, *P*=0.256).

Two different baits were employed in traps during the study: cashews and dead shrimp. Cashews were used at 18 well sites and a total of 716 trap days, while shrimp were used at 10 well sites and a total of 648 trap days. Eighteen crayfish were caught in traps baited with cashews at five well sites, and 14 crayfish were caught in traps baited with shrimp at four well sites. CPUE was nearly identical between cashews and shrimp treatments, at 0.0252 and 0.0216 crayfish per trap day. Both cashews and shrimp were used at 10 well sites. At four of these well sites, crayfish were captured after the switch from cashews to shrimp as bait.

Figure 7. Crayfish captured in a well-pipe trap deployed at a USGS monitoring well (10G313) in Mitchell Co., Georgia. Cotton mop fibers served as cover for trapped individuals in the right hand image.

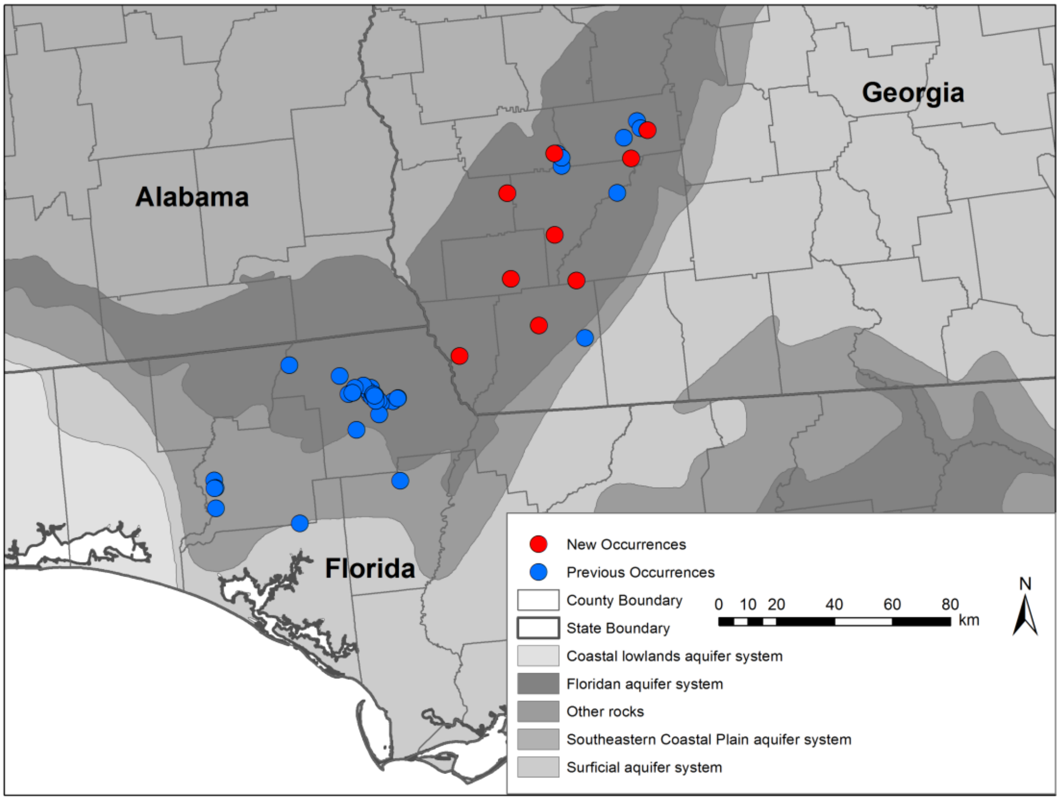

Figure 8. Distribution of the Dougherty Plain Cave Crayfish in relation to the Floridan Aquifer.

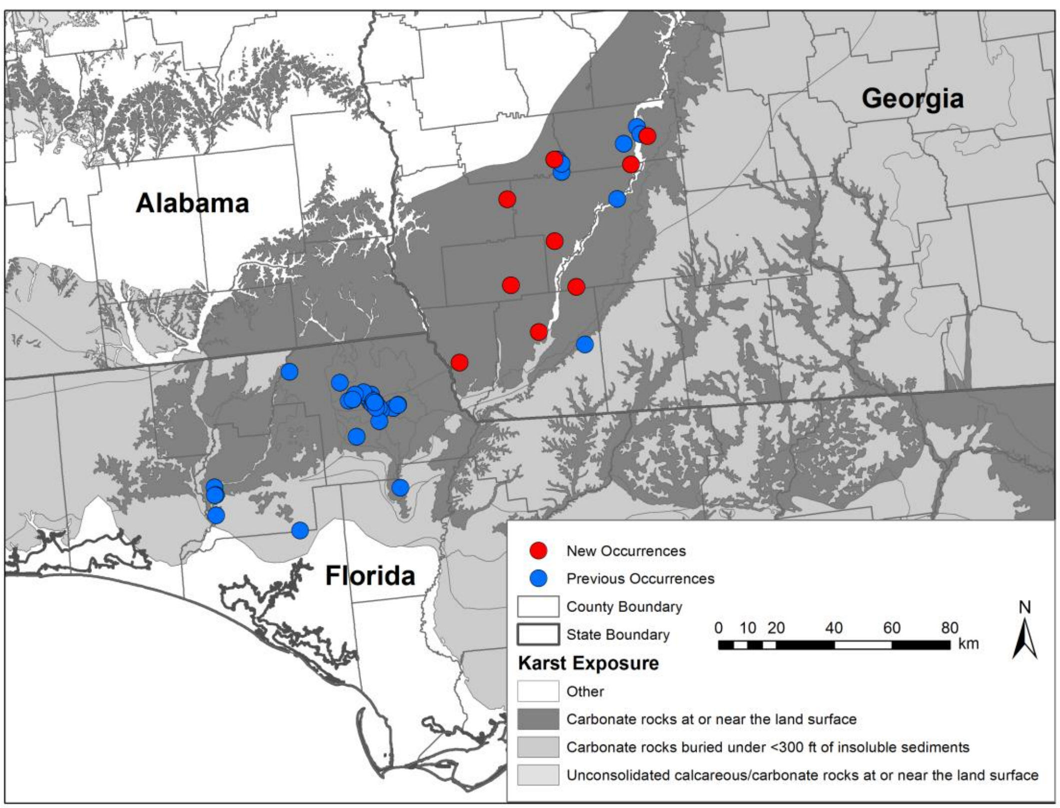

Figure 9. Distribution of the Dougherty Plain Cave Crayfish in relation to karst rock formations.

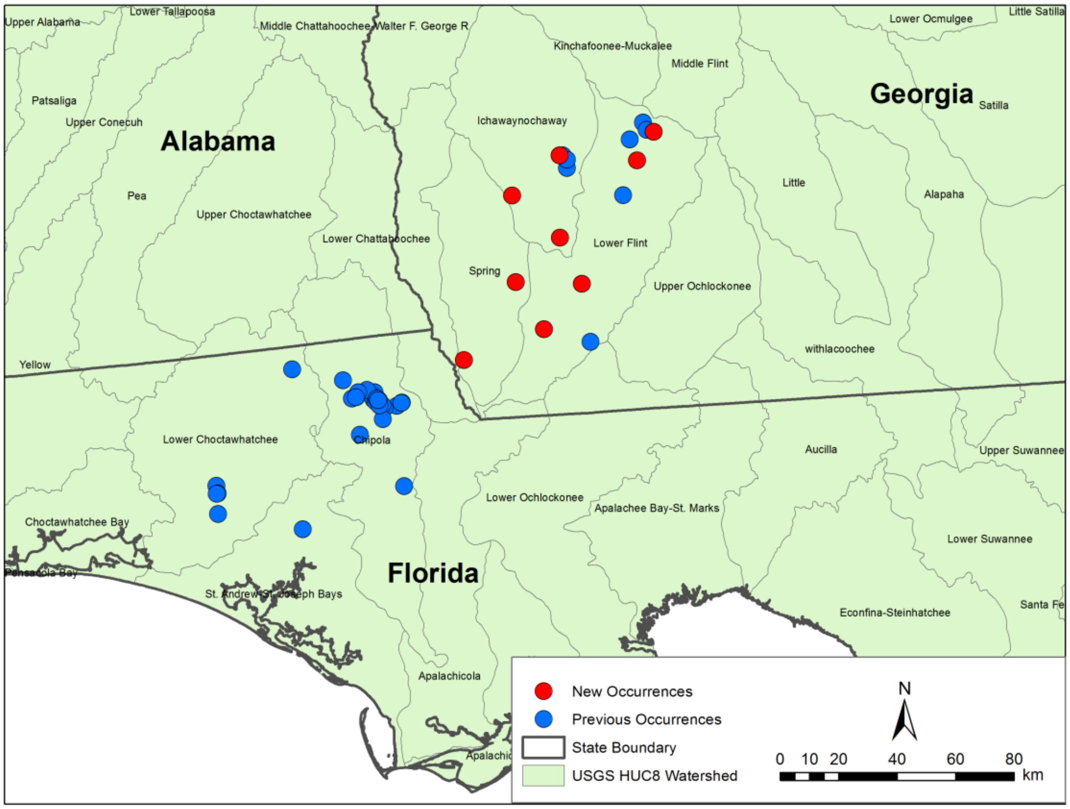

Figure 10. Distribution of the Dougherty Plain Cave Crayfish in relation to watersheds. The species occurs in six USGS HUC8 watersheds.

In addition to *C. cryptodytes*, a single specimen of stygobiotic isopod was trapped from a well (11J012) in Mitchell County on 4 March 2015. The isopod was identified as member of the *hobbsi* species group in the genus *Caecidotea* based on the presence of elongate, plumose setae along the distal margin of exopod of pleopod 1 and exopod of pleopod 2. Unfortunately, the specimen was female and could not be identified to species.

DISCUSSION

Georgia Blind Salamanders

The absence of *Eurycea wallacei* from our traps is not entirely unexpected. Baited funnel traps have proven successful in capturing other subterranean species of *Eurycea* in the United States. This method has been employed to detect larval Grotto Salamanders (*Eurycea spelaea*) in subterranean systems of the Ozark Highlands of Oklahoma (Fenolio, unpublished data). In Texas, the same well pipe trap design and bait has yielded Texas Blind Salamanders (*E. rathbuni*), as well as individuals of two undescribed *Eurycea* (A. Gluesenkamp, personal communication). However, *Eurycea* in Texas were captured at a very low rate (catch per trapping effort). In other words, there were salamanders captured in Texas using our well pipe trap design and bait but the time required to capture the individuals was far greater than the temporal window that we had traps deployed in any given locality for this study. If the history of these traps in Texas is any indicator of time involved for trapping individual salamanders in well pipe traps, we will need to extend the study and trap at specific localities for a year at minimum. We do not know the density of salamanders in the portions of the Floridan Aquifer where we trapped, but it may be lower that the large flooded conduits where divers encounter this salamander. This could be a function of surface inputs being greater closer to large surface openings, which would lead to greater energy and prey availability. The only other study that could have shed light on the successful rate of capture of *E. wallacei* using baited well pipe traps (Purvis and Opsahl 2005), also did not trap Georgia Blind Salamanders using a similar trap design during their study of 23 wells in Calhoun and Dougherty counties. We recommend a one to two year extension of this study, which would be focused on six wells, each in a different county and representing localities where the salamanders are not currently known. These localities will be trapped continually throughout the study window to determine the presence or absence of *E. wallacei* in counties between known and documented populations of *E. wallacei* in Georgia. In addition, these traps could be used at a known site for *E. wallacei*, such as Climax Cave, to serve as a positive control.

Dougherty Plain Cave Crayfish

Cambarus cryptodytes is the only stygobiotic crayfish known from subterranean waters in Georgia (Hobbs 1981; Niemiller et al. 2012). Before this study, *C. cryptodytes* was known from 37 localities in Florida and Georgia, including just eight localities in Georgia: one cave, three cave springs, and four wells in four counties. Purvis and Opsahl (2005) used a similar trap design and technique to detect Dougherty Plain Cave Crayfish from wells at the Chicakasawatchee Swamp Wildlife Management Area in parts of Baker, Dougherty, and Calhoun counties, and a well field in southwest Albany in Dougherty County. Their study yielded 14 crayfish from four wells, three at the Chickasawhatchee Swamp WMA in Calhoun County and one at the southwest Albany well field in Dougherty County. Our study increases the total number of occurrences to 46 and more than doubles the number of occurrences in Georgia at 17 localities (Figs. 8–10). In particular, new county records were established for Early, Miller, Mitchell, and Seminole counties. The species is now known from 11 counties: three in Florida and eight in Georgia. In addition, a new USGS HUC8 watershed record was established, the Spring watershed (03130010). The species is now known from six watersheds (Fig. 10). Collectively, these new records help to fill in existing distribution gaps between a cluster of occurrences in Jackson Co., Florida, and previous occurrences in Georgia (Figs. 8–10).

We estimated two geographic range metrics used in conservation assessments based on locality data from documented occurrences before and after the current study. We calculated extent of occurrence (EOO) and area of occupancy (AOO) using the web-based program GeoCAT (Bachman et al. 2011; available at geocat.kew.org). EOO was calculated as a convex hull, which is the smallest polygon that contains all occurrences and no internal angles exceeding 180°. We used a grid cell size of 2 km (4 km^2) to estimate AOO. Based on previous occurrences, we estimated EOO at 8,463.4 km^2 and AOO to 120 km^2. With the addition of the nine new localities, EOO increased slightly to 8,600.7 km^2 and AOO to 156 km^2. Our estimation of EOO is larger than that reported by NatureServe (1,000–5,000 km^2; NatureServe 2015) but significantly smaller than EOO reported in the IUCN Red List assessment (21,000 km^2; Cordeiro et al. 2010).

We detected *C. cryptodytes* as deep as 76.5 m below the land surface. This is considerably deeper than previously reports. Purvis and Opsahl (2005) trapped *C. cryptodytes* at depths ranging from 14 to 26 m below the land surface. The species can also tolerate low dissolved oxygen conditions, as low as 3.6 mg/L (Caine 1978; Purvis and Opsahl 2005), by possessing a metabolism lower than that of surface-dwelling relatives (Caine 1978). The species is more common than previous data indicated. However, the potential exists to expand the range of the species further. All records to date are associated with the Floridan Aquifer. This aquifer extends an additional 60 km to the northeast in Georgia. The Floridan Aquifer also extends to the west for ca. 160 km in a narrow band in southern Alabama. In particular, the species may eventually be detected from wells in carbonate formations that access the aquifer in Geneva and Houston Cos., Alabama, in the extreme southeastern part of the state.

Other groundwater fauna

In addition to *C. cryptodytes*, we collected a stygobiotic isopod in the genus *Caecidotea* (Isopoda: Asellidae) from a well in Mitchell Co., Georgia. Stygobiotic isopods identified as *Caecidotea* sp. have been collected previously from the Upper Floridan Aquifer in southwestern Georgia. A well driller collected a single specimen from the Wildmeade plantation in Calhoun County (Opsahl and Chanton 2006), but this specimen was not identified to species group or species. Stygobiotic *Caecidotea* were also collected from Radium Springs in Dougherty County by cave divers (Opsahl et al. 2005; Opsahl and Chanton 2006). We identified the isopod collected from a well in Mitchell County as a member of the *hobbsi* species group, which may possibly be *C. hobbsi* (Maloney, 1939). *Caecidotea hobbsi* is known from groundwater habitats in several counties of northern Florida, including caves, springs, wells, and crayfish burrows (Maloney 1939; Steeves 1964; Franz et al. 1994; Walsh 2001). A presumably disjunct population is also known from a spring on the Emory University campus in DeKalb Co., Georgia (Franz et al. 1994). *Caecidotea hobbsi* co-occurs with *Cambarus cryptodytes* at several cave systems in the Marriana Lowlands of Jackson Co., Florida. Males will need to be collected to positively determine whether *C. hobbsi* or possibly an undescribed species occurs in the Upper Floridan Aquifer of southwest Georgia.

Trap mortality

We incurred an elevated mortality rate (53.1%) for crayfish in traps during this study. Purvis and Opsahl (2005) used a similar trap design but checked traps daily during their study at the Chickasawhatchee Swamp WMA and well field near Albany, Georgia. They trapped for 191 trap days across 23 wells, capturing 14 crayfish. Although not directly reported, it is believed that all crayfish were alive at the time of capture. The cause of crayfish death is unknown. It is possible that the decay of bait created a toxic environment within the traps, although this hypothesis remains to be investigated. Regardless, it is recommended that future studies employing this trapping method increase the frequency in which traps are checked. Optimally, we recommend that traps be check within 24 to 96 hours. The amount of bait used should be no greater than the size of a dime in diameter and abundant holes should be available in the sides of the traps for ventilation.

The potential for seasonality in an aquifer and how seasons might impact trap rates

We had some success with a small subset of traps after baits were changed from cashew nuts to shrimp. The simple explanation is that shrimp is a better bait; however, caution should be taken with making a conclusion like this. We know little of seasons (if they exist) in an aquifer; yet, anecdotal information from cave divers in the Floridan aquifer suggest that both salamanders and crayfish are more readily observed during some surface seasons than during others. One factor that could influence a "season" in an aquifer would be surface precipitation. Surface precipitation could lead to increased water volumes in subterranean systems and increased water flow. Increased water flow could potentially change water chemistry and dissolved oxygen levels, particularly in areas of the aquifer more distant to a surface input. These changes could consitute a change or "season" in an aquifer. The abiotic changes could also influence food availability with more surface inputs entering the system with the rainwater. Changes in food availability would most certainly constitute a "season" in any environment. These considerations connect back with our changes of baits in that we do not know the point in which we changed baits as that point in time relates to a season in the aquifer we were studying. If seasons exist, they most definitely can affect the abundance of any species in any portion of their habitat. We simply do not know enough about seasonality in aquifers to rule out that effect with the increase in trap catches, even though we changed bait types.

RECOMMENDATIONS

We offer the following recommendations for future research activities and conservation and management actions given results of the current study:

1. Additional wells should be identified and trapped between known localities for each species. Owing to time limitations, the list of potential target sites was not exhausted in this study.
2. A subset of wells (at least six) should be sampled during a one- or two-year study window to determine the rate of capture that can be expected with *E. wallacei*. In particular, greater trapping effort appears to be required to detect this salamander, which may exist at lower densities in aquifer habitats well away from sinkholes, caves, and springs. Rates of capture for related aquifer-inhabiting salamanders in Texas suggest a minimum of one year of continuous trapping is required to detect the presence of salamanders.
3. Wells that intersect the Floridan Aquifer within carbonate formations, but which are outside the known ranges of either species, should be identified and trapped. In particular, the regions northeast of the known ranges of both species in Georgia and the region to the west in southern Alabama should be targeted to determine the extents of each species' distribution.
4. A subset of known *C. cryptodytes* populations should be monitored on a regular basis (annual or bi-annual) at select well sites. Potential wells include 10K005, 09F520, 13L012, 08K001, and 08G001. Determining capture rates will allow future detection of negative fluctuations in local populations, which could signal water quality issues, changes in the local subterranean habitat, or emergent infectious wildlife disease (all are threats in this region). Monitoring efforts such as this would constitute relatively low-cost, yet effective, surveillance of a threatened aquifer inhabiting species in Georgia. Long term data such as these are scant in the literature and the data would be publishable as well as valuable to land managers, water quality studies, and endangered species biologists.
5. Educate the general public on the sensitivity of groundwater and its fauna to pollution and exploitation - potentially using *E. wallacei* and *C. cryptodytes* as "charismatic species" to raise public awareness.

ACKNOWLEDGEMENTS

We thank Gary Holloway, Michael Peck, and John McCranie for assisting with field research. We thank A. Gluesenkamp for technical assistance with trap design. We thank S.J. Taylor for assistance with identification of groundwater isopods. This research was authorized under Georgia Department of Natural Resources scientific collection permit no. CN 27743.

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Table 1. USGS well sites trapped during the current study in Floridan Aquifer of southwestern Georgia.

County	Well Site	Latitude	Longitude	Well Depth (m)	Casing Depth (m)	Casing Diameter (cm)	National Aquifer	Local Aquifer
Baker	10H009	31.2333	-84.4986	61.0	28.0	10.2	Floridan	Upper Floridan
Baker	12K014	31.4383	-84.1850	41.8	21.0	10.2	Floridan	Upper Floridan
Calhoun	10K005	31.4814	-84.4642	42.1	12.2	10.2	Floridan	Upper Floridan
Decatur	08E038	30.7866	-84.6661	45.1	39.2	14.3	Floridan	Upper Floridan
Decatur	08E039	30.8019	-84.6781	19.7	11.0	15.2	Floridan	Upper Floridan
Decatur	09F520	30.9617	-84.5961	76.5	39.6	40.6	Floridan	Upper Floridan
Dougherty	13L012	31.5181	-84.1119	66.4	16.5	10.2	Floridan	Upper Floridan
Dougherty	13L180	31.5464	-84.0139	94.5	67.1	15.2	Floridan	Upper Floridan
Early	06G006	31.0742	-84.9864	37.5	17.7	10.2	Floridan	Upper Floridan
Early	08K001	31.3772	-84.6547	38.1	18.6	10.2	Floridan	Upper Floridan
Grady	12F036	30.8764	-84.2144	142.3	139.6	15.2	Floridan	Upper Floridan
Lowndes	19E009	30.8308	-83.2828	104.2	61.0	50.8	Floridan	Upper Floridan
Miller	07H002	31.1689	-84.8317	22.9	19.5	10.2	Floridan	Upper Floridan
Miller	08G001	31.1142	-84.6789	68.6	39.6	30.5	Floridan	Upper Floridan
Mitchell	10G313	31.0853	-84.4394	62.8	26.5	30.5	Floridan	Upper Floridan
Mitchell	11J011	31.3006	-84.3231	127.1	na	na	Southeastern Coastal Plain	Claiborne Group
Mitchell	11J012	31.3006	-84.3231	68.6	18.9	15.2	Floridan	Upper Floridan
Seminole	06F001	30.8969	-84.8986	30.0	18.9	10.2	Floridan	Upper Floridan

Table 2. Summary of trapping events at 18 well sites in southwestern Georgia from September 2014 to August 2015. CPUE – catch per unit effort defined as number of crayfish captured per trap day; TTFC – time to first capture defined as the number of trap days from the when a trap was first deployed at a well site to when a crayfish was captured.

County	Well Site	Total Trap Days	Trap Events	Mean Event Duration (days)	Crayfish Captured	CPUE	TTFC
Baker	10H009	129	9	14.3 ± 8.8	1	0.008	79
Baker	12K014	65	4	16.3 ± 12.8	2	0.031	30
Calhoun	10K005	64	4	16.0 ± 12.9	4	0.063	29
Decatur	08E038	75	6	12.5 ± 4.3	0	0.000	
Decatur	08E039	74	6	12.3 ± 4.2	0	0.000	
Decatur	09F520	76	6	12.7 ± 4.0	3	0.039	61
Dougherty	13L012	73	6	12.2 ± 3.5	9	0.123	53
Dougherty	13L180	61	5	12.2 ± 4.0	0	0.000	
Early	06G006	136	10	13.6 ± 8.4	0	0.000	
Early	08K001	64	4	12.9 ± 12.9	4	0.063	8
Grady	12F036	140	10	14.0 ± 8.5	0	0.000	
Lowndes	19E009	63	4	15.8 ± 13.8	0	0.000	
Miller	07H002	7	1	7.0 ± 0.0	0	0.000	
Miller	08G001	62	4	15.5 ± 13.9	6	0.097	7
Mitchell	10G313	63	4	15.8 ± 13.8	2	0.032	14
Mitchell	11J011	8	1	8.0 ± 0.0	0	0.000	
Mitchell	11J012	130	9	14.4 ± 8.7	0	0.000	
Seminole	06F001	74	6	12.3 ± 4.2	1	0.014	37
Total	18 sites	1,364	99	13.8 ± 8.2	32	0.023	

Table 3. Summary of trapping events at 18 well sites in southwestern Georgia.

County	Well Site	Date Start	Date End	Trap Days	Bait	Crayfish Captured	Notes
Baker	10H009	10/22/2014	10/30/2014	8	cashews	0	
Baker	10H009	11/20/2014	12/2/2014	12	cashews	0	
Baker	10H009	12/2/2014	1/7/2015	36	cashews	0	
Baker	10H009	1/27/2015	2/5/2015	9	cashews	0	
Baker	10H009	3/4/2015	3/18/2015	14	shrimp	1	1 alive
Baker	10H009	4/2/2015	4/16/2015	14	shrimp	0	
Baker	10H009	5/5/2015	5/21/2015	16	shrimp	0	
Baker	10H009	6/23/2015	6/29/2015	6	shrimp	0	
Baker	10H009	8/4/2015	8/18/2015	14	shrimp	0	
Baker	12K014	9/17/2014	9/25/2014	8	cashews	0	
Baker	12K014	10/22/2014	10/30/2014	8	cashews	0	
Baker	12K014	11/19/2014	12/3/2014	14	cashews	1	1 alive
Baker	12K014	12/3/2014	1/7/2015	35	cashews	1	1 alive
Calhoun	10K005	9/17/2014	9/25/2014	8	cashews	0	
Calhoun	10K005	10/22/2014	10/30/2014	8	cashews	0	
Calhoun	10K005	11/20/2014	12/3/2014	13	cashews	3	3 dead
Calhoun	10K005	12/3/2014	1/7/2015	35	cashews	1	1 dead
Decatur	08E038	1/28/2015	2/4/2015	7	cashews	0	
Decatur	08E038	3/3/2015	3/18/2015	15	shrimp	0	
Decatur	08E038	4/1/2015	4/16/2015	15	shrimp	0	
Decatur	08E038	5/5/2015	5/21/2015	16	shrimp	0	
Decatur	08E038	6/22/2015	6/29/2015	7	shrimp	0	
Decatur	08E038	8/4/2015	8/19/2015	15	shrimp	0	
Decatur	08E039	1/28/2015	2/4/2015	7	cashews	0	
Decatur	08E039	3/4/2015	3/18/2015	14	shrimp	0	
Decatur	08E039	4/1/2015	4/16/2015	15	shrimp	0	
Decatur	08E039	5/5/2015	5/21/2015	16	shrimp	0	
Decatur	08E039	6/22/2015	6/29/2015	7	shrimp	0	
Decatur	08E039	8/4/2015	8/19/2015	15	shrimp	0	
Decatur	09F520	1/27/2015	2/4/2015	8	cashews	0	
Decatur	09F520	3/3/2015	3/18/2015	15	shrimp	0	
Decatur	09F520	4/1/2015	4/16/2015	15	shrimp	0	
Decatur	09F520	5/5/2015	5/21/2015	16	shrimp	0	
Decatur	09F520	6/22/2015	6/29/2015	7	shrimp	2	2 alive
Decatur	09F520	8/4/2015	8/19/2015	15	Shrimp	1	1 alive
Dougherty	13L012	1/27/2015	2/5/2015	9	cashews	0	
Dougherty	13L012	3/4/2015	3/17/2015	13	shrimp	0	
Dougherty	13L012	4/2/2015	4/17/2015	15	shrimp	0	

Dougherty	13L012	5/6/2015	5/22/2015	16	shrimp	4	1 alive, 3 dead
Dougherty	13L012	6/23/2015	6/30/2015	7	shrimp	5	1 alive, 4 dead
Dougherty	13L012	8/5/2015	8/18/2015	13	shrimp	0	
Dougherty	13L180	1/27/2015	2/5/2015	9	cashews	0	
Dougherty	13L180	3/4/2015	3/18/2015	14	shrimp	0	
Dougherty	13L180	4/2/2015	4/17/2015	15	shrimp	0	
Dougherty	13L180	5/6/2015	5/22/2015	16	shrimp	0	
Dougherty	13L180	6/23/2015	6/30/2015	7	shrimp	0	
Early	06G006	9/18/2014	9/25/2014	7	cashews	0	
Early	06G006	10/23/2014	10/30/2014	7	cashews	0	
Early	06G006	11/20/2014	12/3/2014	13	cashews	0	
Early	06G006	12/3/2014	1/7/2015	35	cashews	0	
Early	06G006	1/28/2015	2/4/2015	7	cashews	0	
Early	06G006	3/3/2015	3/18/2015	15	shrimp	0	
Early	06G006	4/1/2015	4/16/2015	15	shrimp	0	
Early	06G006	5/5/2015	5/21/2015	16	shrimp	0	
Early	06G006	6/22/2015	6/29/2015	7	shrimp	0	
Early	06G006	8/4/2015	8/18/2015	14	shrimp	0	
Early	08K001	9/17/2014	9/25/2014	8	cashews	1	1 dead
Early	08K001	10/22/2014	10/30/2014	8	cashews	1	1 alive
Early	08K001	11/20/2014	12/3/2014	13	cashews	1	1 alive
Early	08K001	12/3/2014	1/7/2015	35	cashews	1	1 dead
Grady	12F036	9/17/2014	9/25/2014	8	cashews	0	
Grady	12F036	10/22/2014	10/30/2014	8	cashews	0	
Grady	12F036	11/19/2014	12/2/2014	13	cashews	0	
Grady	12F036	12/2/2014	1/7/2015	36	cashews	0	
Grady	12F036	1/27/2015	2/4/2015	8	cashews	0	depth shortened by ca. 46 m
Grady	12F036	3/3/2015	3/17/2015	14	shrimp	0	
Grady	12F036	4/1/2015	4/16/2015	15	shrimp	0	
Grady	12F036	5/5/2015	5/21/2015	16	shrimp	0	
Grady	12F036	6/22/2015	6/29/2015	7	shrimp	0	
Grady	12F036	8/4/2015	8/19/2015	15	shrimp	0	
Lowndes	19E009	9/17/2014	9/24/2014	7	cashews	0	
Lowndes	19E009	10/22/2014	10/29/2014	7	cashews	0	
Lowndes	19E009	11/19/2014	12/2/2014	13	cashews	0	
Lowndes	19E009	12/2/2014	1/7/2015	36	cashews	0	
Miller	07H002	9/18/2014	9/25/2014	7	cashews	0	well collapsed
Miller	08G001	9/18/2014	9/25/2014	7	cashews	1	1 alive
Miller	08G001	10/23/2014	10/30/2014	7	cashews	2	1 alive, 1 dead
Miller	08G001	11/20/2014	12/2/2014	12	cashews	2	2 dead
Miller	08G001	12/2/2014	1/7/2015	36	cashews	1	1 dead
Mitchell	10G313	9/18/2014	9/25/2014	7	cashews	0	

Mitchell	10G313	10/23/2014	10/30/2014	7	cashews	1	1 alive
Mitchell	10G313	11/19/2014	12/2/2014	13	cashews	1	1 alive
Mitchell	10G313	12/2/2014	1/7/2015	36	cashews	0	
Mitchell	11J011	9/17/2014	9/25/2014	8	cashews	0	
Mitchell	11J012	10/22/2014	10/30/2014	8	cashews	0	
Mitchell	11J012	11/19/2014	12/2/2014	13	cashews	0	
Mitchell	11J012	12/2/2014	1/7/2015	36	cashews	0	
Mitchell	11J012	1/27/2015	2/5/2015	9	cashews	0	
Mitchell	11J012	3/4/2015	3/18/2015	14	shrimp	0	1 *Caecidotea* sp.
Mitchell	11J012	4/2/2015	4/16/2015	14	shrimp	0	
Mitchell	11J012	5/5/2015	5/21/2015	16	shrimp	0	
Mitchell	11J012	6/23/2015	6/29/2015	6	shrimp	0	
Mitchell	11J012	8/4/2015	8/18/2015	14	shrimp	0	
Seminole	06F001	1/28/2015	2/4/2015	7	cashews	0	
Seminole	06F001	3/3/2015	3/18/2015	15	shrimp	0	
Seminole	06F001	4/1/2015	4/16/2015	15	shrimp	1	1 alive
Seminole	06F001	5/5/2015	5/21/2015	16	shrimp	0	
Seminole	06F001	6/22/2015	6/29/2015	7	shrimp	0	
Seminole	06F001	8/4/2015	8/18/2015	14	shrimp	0	