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Ecology and Biogeography of the Piedmont Blue Burrower (*Cambarus* [Depressicambarus] *harti*)

Troy Keller[1], John Rivera[1], Chester Fiegel[2], and George Stanton[1]

[1]Columbus State University and

[2]US Fish and Wildlife Service

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EXECUTIVE SUMMARY

Rare species often experience extreme risks associated with their long-term viability caused by the characteristics of the species itself, the demographics of its populations, and the degree to which it experiences environmental perturbations. These threats can interact in complex ways causing populations to decline in size into a "vortex" of increasing threats that could eventually result in their extinction. Because many crayfishes are rare and have very limited geographic distributions, crayfishes rank second only to mussels for the percentage of imperiled species in the US. *Cambarus harti* is an endemic crayfish with a known ranged limited to Meriwether County in West Central Georgia. It has been listed by the IUCN and the State of Georgia as Endangered. We conducted an intensive scientific study from May 2010 through April 2011 to generate important conservation information about this elusive species.

To achieve the goals stated above, this study collected data on *C. harti* using field surveys (burrow excavations), regular site observations (May-July 2010, January-March 2011), and spatial models (using GIS data). Our plan was to use field mark and recapture data to quantify *C. harti*'s effective population size and behavior patterns. We used geographic information systems to predict habitats similar to those of sites with known populations in order to determine where research efforts might conduct future surveys for undetected populations. Our efforts to mark and recapture *C. harti* were unsuccessful but regular observations of their type locality provided new insights concerning this elusive species' surface burrowing behavior. We found that surface burrowing behavior was more active in summer than winter however activity didn't cease entirely even during the coldest period of the winter season. Groundwater levels were inversely correlated with activity suggesting that during times when water levels dropped crayfish reduced their activity at the ground surface. *Cambarus harti* collections (using traps and burrow excavations) over the past 3 years indicate that juveniles exist in burrows year round, males are more difficult to capture than females, and females can extrude eggs during the spring-early summer (June). These observations indicate that *C. harti* shares many life-history characteristics with other species of primary burrowing crayfishes of the genus *Cambarus*.

Efforts to confirm the known distribution of *C. harti* successfully located it at 10 locations distributed through Meriwether County. Our survey discovered two new locations with *C. harti* populations. Both sites were located in the Chattahoochee watershed within a 3 km radius of the type locality in Warm Springs, Georgia. We focused our modeling efforts on a six county region in west, central Georgia (Harris, Meriwether, Pike, Talbot, Troup, Upson) because it reduced the scale of the analysis yet provided potential sites outside of Meriwether County. Using the elevation, soils,

proximity to streams, land cover, geology, and eco-region information found at all of the known crayfish sites, we developed a simple model that scored all habitats in the study region for their similarity to habitats with known *C. harti* populations. According to the model, researchers need to focus their survey efforts on headwater, riparian areas in both the Flint and Chattahoochee River Basins. Creeks in the Chattahoochee Basin with high suitability scores that do not have known populations include: Mountain, Sulfur, House, Sand, Big Branch, Turkey, Polecat, Crawford, Mud, Long Cane, Beech, Shoal, Flat, Yellowjacket , and several others. The model also finds riparian zones with high habitat suitability in the Flint River Basin such as Red Oak, White Oak, Eakins, Birch, Turkey, Basin, Tenmile, among other creeks. Preliminary collections in tributaries of the Flint have yielded a species of *C. harti*-like, blue crayfish who's identity has yet to be confirmed (Skelton personal communication).

While the discovery of *C. harti* at new locations increases the number of known sites by 20%, threats to the existing populations exist. Land use change at the locations where populations are known to exist is one of the most apparent threats. Currently *C. harti*'s endangered status protects on State owned lands. Populations that we visited were on unregulated private lands. Changes in the habitats mostly from the construction of new buildings and roads could impact habitat quality or fragment existing populations into smaller disconnected isolates. There were 2 sites (Tom Brown Spring and Stovall-Greenville Rd) that are directly affected by land clearing activities such as logging and wetland draining/alteration. The second and possibly more immediate and insidious threat to populations would alter the groundwater hydrology. Well drilling, ditching and draining that alter groundwater flow could create inhospitable conditions for this rare species. More research is needed to quantify how human activities alter hydrologic conditions and how these changes affect the viability of *C. harti* populations.

INTRODUCTION

CONSERVATION THREATS TO SMALL POPULATIONS

Populations of rare and narrowly distributed species are at risk of genetic, demographic, and environmental threats. Because genetic diversity is limited in small populations they are vulnerable to genetic drift. The limited genetic variety can result in the expression of deleterious alleles that lead to inbreeding. Small populations face risks caused by stochastic changes in the demographic structure of their population. For example populations with very few breeding animals could by chance produce only male or female offspring in a cohort. These chance events could limit future reproductive potential. Further exacerbating these already daunting challenges small populations must endure changes in their environment. In the face of these challenges small populations have few safeguards to avoid extinctions. The combination of these threats can interact in complex ways causing the population to decline, spiraling downward t a "vortex" of increasing threats that could eventually result in their extinction (Fig. 1).
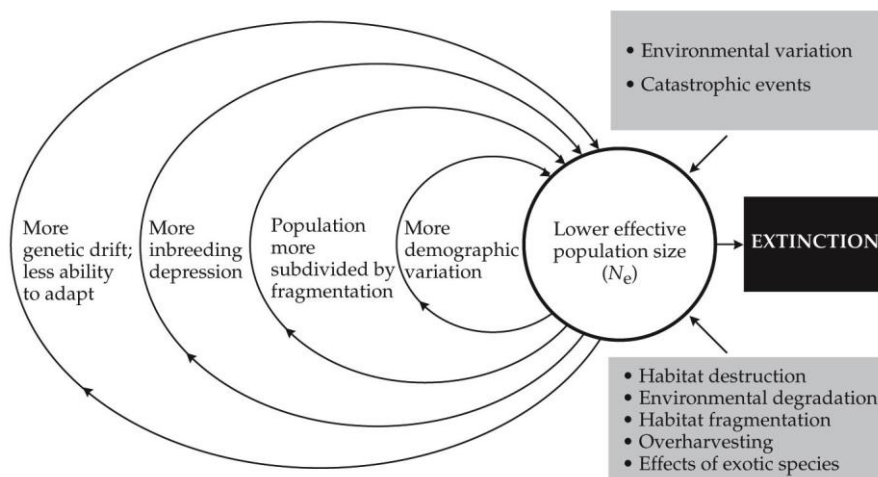
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FIGURE 1. SMALL POPULATIONS ARE PARTICULARLY VULNERABLE TO EXTINCTION FROM GENETIC, DEMOGRAPHIC, AND ENVIRONMENTAL STRESSORS. THESE STRESSORS CAUSE POPULATIONS TO BE MORE VULNERABLE TO FURTHER DEGRADATION BY OTHER STRESSORS. THIS PROCESS CAN PULL A POPULATION IN A DOWNWARD SPIRAL THAT CAN ULTIMATELY RESULT IN EXTINCTION.

The effective conservation of rare and threatened species will depend on having adequate knowledge about their abundance and distribution. While typical surveys often yield information about the number of individuals in a population these estimates often omit key demographic

information required to quantify a populations' viability. Using effective population size models can overcome these short comings inherent in standard population estimates. Effective population size for species with unequal sex ratios can be calculated as:

$$Ne = \frac{4 \times (N_f \times N_m)}{(N_f + N_m)}$$

where Ne is the effective population, N_f is the population of breeding females, N_m is the population of breeding males. This model more rigorously defines the population in terms of its most important members in the near term, reproductive adults. The application of these estimates to wild populations requires accurate information on the number of individuals of each sex and their breeding status, information often missing from many imperiled species, including *Cambarus harti*.

The spatial distribution of populations can also have very significant implications for their conservation. Metapopulation, i.e., populations of subpopulations, have complex dynamics driven by external processes such as immigration and emigration. The movement of individuals from one subpopulation to another alters population sizes in both and have the potential to improve gene flow throughout the metapopulation. Furthermore there are other ecologically important processes that occur within each subpopulation. The spatial distribution of these populations ultimately determines the likelihood of successful transfers of individuals among subpopulations. For aquatic species, dispersal among subpopulations are likely limited to areas that are hydrologically connected. For example consider the movement of an aquatic organism from subpopulation A to B (Fig. 2). In order to maintain their active association with the wetted channel this species would have to migrate downstream first and then move upstream in a different tributary. The challenges faced by migrating aquatic species are further exacerbated by in-stream barriers such as dams, levies, and culverts. These migration barriers are illustrated in Fig. 2 where
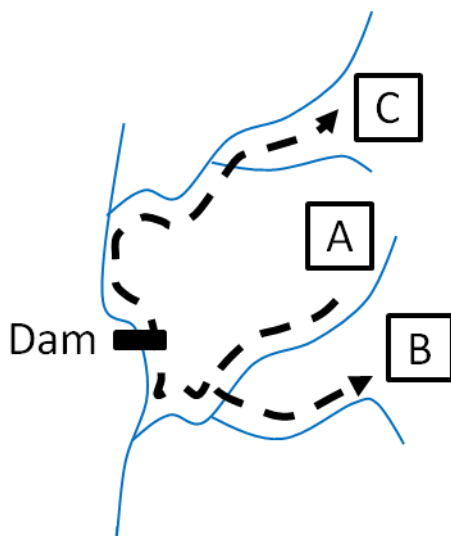

FIGURE 2. METAPOPULATIONS OF AQUATIC ORGANISMS MUST TRAVEL ALONG EXISTING HYDROLOGICAL NETWORKS AND MAY HAVE TO BYPASS BARRIERS SUCH AS DAMS ALONG THE ROUTE

individual dispersing from subpopulation A to C would have to negotiate the dam separating the two populations. Because aquatic organisms face very significant challenges to movement among

populations, it is imperative that we understand their geographic distributions, their dispersal behavior, and the suitability of habitats separating their subpopulations.

Many crayfishes have extremely limited geographic distributions which helps explain why crayfishes rank second only to mussels for the percentage of imperiled species in the US (Primack 2006). The Piedmont Blue Burrower, *Cambarus harti* (Hobbs 1981), is one of the rarest crayfish species in Georgia (Skelton *et al.* ; Taylor *et al.* 2007). Its range was originally thought to be limited to isolated seepage springs in Meriwether County. This species was described from specimens collected from only 2 locations, one site is adjacent to the Warm Springs Fish Hatchery and the other in an unnamed tributary of Flat Shoals Creek near Greenville (Hobbs 1981). Skelton *et al.* reported finding *C. harti* in 5 additional locations bringing the total to 7 known sites, all within Meriwether County, GA. *Cambarus harti's* burrowing behavior makes it an extremely difficult species to capture (Skelton *et al.* ; Stanton 2006) a fact that complicates efforts to characterize its niche and quantify its population size. *Cambarus harti* is currently listed by the State of Georgia as endangered and designated as endangered by the most recent evaluation of the status of US crayfishes (Taylor *et al.* 2007) and the IUCN (Cordeiro *et al.* 2010).

Much of what has been published about burrowing crayfish has been collected on species other than *C. harti* (for example consult Loughman 2010; Welch *et al.* 2008). Hobbs (1981) designated three types of burrowers based on their connection to surface waters. He considered primary burrowers those that nearly completed their entire life in burrows without need for entering surface waterbodies. *Cambarus harti* was designated by Hobbs as a primary burrower (Hobbs 1981). This type of behavior has important conservation ramifications. For example efforts to establish protections for rivers without creating adequate riparian buffer zones will do little to protect *C. harti*. This semi-terrestrial niche also creates the possibility that *C. harti* might exist near wetland habitats far from rivers. This subterranean existence further complicates research on this endemic species.

Despite its rarity and endangered status, there exists no active management for this species and its basic biology and ecology are mostly unknown to science. Like *C. harti* many other burrowing crayfish species have narrow geographic distributions (Skelton 2010). Environmental shifts caused by climate change and land use alteration can cause hydrological anomalies and stress crayfish populations. These threats make it imperative to prioritize the study of burrowing species such as *C. harti*. This document reports critical ecological and biogeographic data needed to enhance our knowledge of *C. harti*. We expect that our research will enable managers to make more informed decisions about the conservation of *C. harti* and other burrowing crayfish species.

GOALS AND OBJECTIVES

This research project set goals to help fill gaps in our knowledge of the ecology and biogeography of *C. harti*. This research endeavored to develop and use research tools that can be used to gather critical data for imperiled, burrowing crayfishes and to collect population information that can be used by resource managers to assess the need for additional protection for *C. harti*.

Our specific objectives for this grant included:

1. Estimate effective population size of two populations on the US FWS Warm Springs Fish Hatchery property

    a. Trap crayfish using pipe traps or netting

    b. Conduct mark and recapture study using internal PIT tags and/or other less invasive marking techniques (pleural clips, see Keller and Hazlett 1996)

        i. quantify burrow fidelity

        ii. measure exit frequency

        iii. document growth rates

    c. Collect demographic data

        i. measure crayfish burrow and animal density

        ii. record age, size, sex/reproductive form

        iii. calculate effective population size

2. Quantify geographic distribution and current threats

    a. Map the fine-scale locations of burrows at Warm Springs Fish Hatchery using DGPS

        i. quantify spatial patterns

        ii. use dye injection to examine connectivity among burrows

    b. Visit historic *C. harti* sites to document population status and local threats (e.g., construction projects)

    c. Use GIS to predict new *C. harti* habitats

        i. overlay the 6 reported *C. harti* locations to determine whether their soils, hydrology, land-use, and/or other characteristics are similar

        ii. use the best combination of environmental predictors (e.g., soils and hydrology) to locate other sites to sample (n=15)

    d. Survey the predicted areas for new populations of *C. harti*
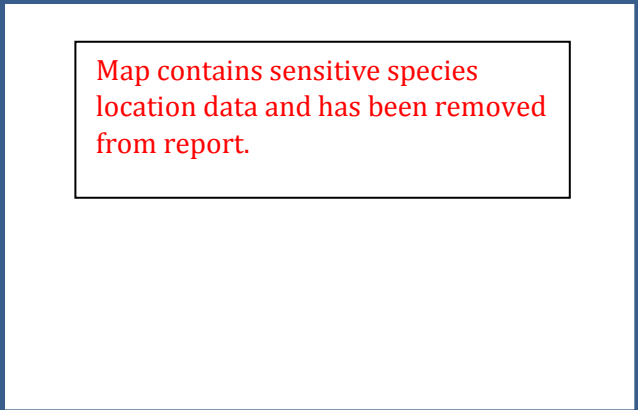
METHODS

Estimate Effective Population Size

In an effort to characterize the population size of the crayfish we set avian mist net (Welch and Eversole 2006) and pipe traps (Norrocky 1984) in 39 burrows at sites 1 and 2 (Fig. 3) adjacent to the Warm Springs Fish Health Center. Traps were set 24 h prior to sampling observations. All burrows were visited during daylight hours. We made observations 15 times from 5-28-2010 through 7-8-2010. Crayfish captured were measured for carapace length, sexed, and marked with unique pleural clip codes

Map contains sensitive species location data and has been removed from report.

FIGURE 3. THREE SITES WHERE *C. HARTI* BURROWS WERE MONITORED. THE IMAGE SHOWS THE US FISH AND WILDLIFE SERVICE'S WARM SPRINGS FISH HEALTH CENTER

(Hazlett *et al.* 1974) before being released into their burrow. All burrows were marked with a labeled flag and observations of surface activity were recorded. Burrows with some degree of surface disturbance were scored as active and cleared each day before nets were reset. Other burrow related changes since the previous visit such as new burrows, net pushed out of burrow (trap ejected), net pulled into burrow, or hole covered were recorded on the days observations were made.

We conducted a second study during an 80 day period from 1-9-2011 through 3-30-2011. A similar protocol was used to study the populations adjacent to the Warm Springs Fish Health Center except that sites were visited 2 times per week, an additional site was monitored (site 3), and 24 observations were made. We recorded the presence of chimneys, piles of mud pellets, evacuated mist nets, covered burrows, new burrows, and excavated sands. Mist net traps were set in 10 of the burrows, however we ceased trapping using avian mist nets mid-way through the study because we caught no crayfish.

We purchased, installed, and recorded surface burrow activity using an infrared sensitive Sony camera at sites 1 and 2 (Fig. 3). Data from the cameras were recorded using a digital video recording device set to record at 5 frames per second, initiated by motion sensors. While we recorded data from February to March we have yet to analyze the video records at the time of this report's writing.

To monitor groundwater temperature and water level, a Solinst™ water level pressure gage was installed in a PVC well casing placed in the ground very close to Site 1 (Fig. 3). The gage recorded readings at 15 minute intervals. We used local atmospheric barometric pressure data to correct water depth readings.

Geographic Distribution and Current Threats

To determine the spatial patterns among burrows, we created a metric grid using 2 semi-permanent stakes placed at each of the three sites. We measured the x and y locations of all burrows marked. A Magellan™ ProMark III was used to record the GPS positions of the reference stakes. All other GPS recordings were made with Garmin™ handheld GPS units.

To confirm that the sites were documented properly and that *C. harti* remained viable at historic sites, we sampled 7 sites listed in earlier surveys (Skelton *et al.*). Researchers also found *C. harti* at 3 other previously unrecorded locations. Sampling involved searching the habitats and digging burrows that showed signs of recent activity (e.g., fresh mud, new chimneys). We excavated burrows to the groundwater level using shovels and then researchers searched the burrow complex by hand. The technique minimized the likelihood of injuring crayfish in the burrows.

We used Geographic Information Systems (GIS) software (ArcMap 9.3.1, ESRI®) to predict the locations of unreported *C. harti* in a 6 county region in west, central Georgia (Harris, Meriwether, Pike, Talbot, Troup, Upson). We selected this region because it reduced the scale of the analysis yet provided the information on potential undiscovered sites outside of Meriwether County. The first phase characterized the qualities of the habitats found among the 10 known *C. harti* locations (7 historic and 3 new). We quantified the habitat characteristics by extracting the elevation, soils, geology, ecoregions, land cover, and proximity to a stream (Table 1) at each *C. harti* known location. We selected these 6 characteristics because they were available for free, covered the entire 6 county study region, and were thought to serve as useful indictors of *C. harti* habitat suitability.

TABLE 1. METADATA FOR THE SIX DATA SOURCES (FEATURES) USED IN THE GIS HABITAT SUITABILITY ANALYSIS. WEIGHT INDICATES THE WEIGHTING COEFFICIENT USED IN THE MODEL FOR EACH DATA SET. VALUES IN PARENTHESIS SIGNIFY WEIGHTS FOR OBSERVATIONS OUTSIDE OF THE MODELED VALUES.

Feature	Values Observed	Values Modeled	Field /Units	Scale	Filename	Source	Weight
Elevation	227.4 – 280.9	220 - 290	meters	1:250,000	DEMGRID	Clearinghouse	2 (1)
Soils	GA25, GA34	Observed	MUID	1:250,000	Ga_Soils	Clearinghouse	4 (1)
Geology	Mica-Schist, Mica-Schist/Gneiss/Amphibolite, Granite Undifferentiated, Quartzite	Observed	Description	1:500,000	Geology	Clearinghouse	4 (2)
Ecoregions	Southern Outer Piedmont, Pine Mountain Ridges	Observed	L4_Key	1:250,000	Ga_ecoregions	US EPA	4 (1)
Landcover	Transportation, Hardwood Forest, Mixed Pine Hardwood, Loblolly-Shortleaf Pine	Observed	Value	1:24,000	Landcover_44	Clearinghouse	4 (2,1)
Hydrography	< 160 m from Stream	Observed	Buffer	1:24,000	NHDFlowline	USGS	4 (1)

Once we had quantified habitat characteristics at the known locations, then we used a these known characteristics to score all input data sets on a scale from 0 to 4 (except 0 to 2 in the case of elevation). Professional judgement was used in creating and applying this scale. In order to generate overall habitat suitability scores, all 6 input features (e.g., soils, geology) were converted to rasters (grids). These grids had each of their cells reclassified (Fig. 4) according to the weights described in Table 1. As an illustration consider that crayfish were only found on two soil types (GA25 and GA34), thus all cells in the soils raster file were scored either a 4 if they matched the crayfish sites or a 1 if they had a type that differed. Overall habitat suitability scores for each cell were calculated by adding the value of the
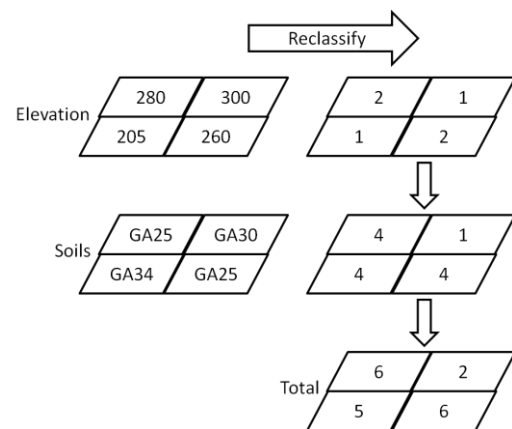

FIGURE 4. APPROACHED USED TO CALCULATE THE HABITAT SUITABILITY SCORES FOR GRID CELLS. IN THE ACTUAL GIS MODEL WE USED 6 INPUT GRIDS (TABLE 1)

reclassified scores for each of the 6 input characteristics (Fig. 4). If a cell showed characteristics that matched exactly those of all of the known locations it would receive the maximum habitat suitability score of 22 (2 points for elevation plus 4 points for the other 5 GIS input layers). Conversely cells at locations that had none of the characteristics found at crayfish sites (Table 1) would score a maximum of only 7 points.

RESULTS

Estimate Effective Population Size

During the course of this study only 2 crayfish were caught using traps. This extremely low capture rate made mark recapture invalid. This fact severely limited the study's capacity to examine key questions posed in Objective 1 of this study. Instead, we analyzed surface burrowing activity at sites in close proximity to Warm Springs Fish Heal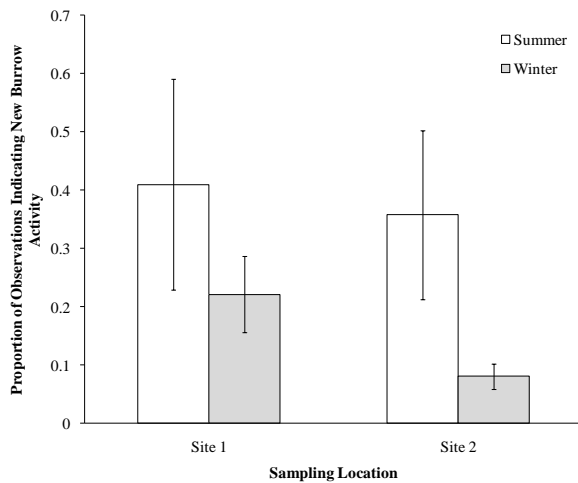th Center. These visual surveys revealed that crayfish remained active during the winter, spring and summer. New activity as indicated by the construction of chimneys, movement of sediment pellets, and hole plugging occurred during January through March of 2011 and May through July 2010. Observations indicated that surface activity changed seasonally. During the summer months burrows showed on average a 4 times greater proportion of activity during visits indicating more activity than burrows monitored during the winter-spring period. This increase in the proportion of visits showing activity during the summer was statistically significant for site 2 (t-test, $p < 0.0014$) but not significant for site 1 (t-test, $p = 0.069$). These results are preliminary at best because sampling frequency was higher during the summer than the winter-spring. However this only underscores the significance of the differences in activity since survey visits during the winter-spring integrated activity over 3-4 day periods whereas summer observations indicated changes over only a 24 hour period.

FIGURE 5. COMPARISON OF SUMMER AND WINTER SURFACE BURROWING ACTIVITY FOR CRAYFISH AT TWO SITES NEAR WARM SPRINGS FISH HEALTH CENTER. PLOTS INDICATE MEAN PROPORTION OF TIME BURROWS WERE FOUND TO HAVE NEW ACTIVITY DURING REGULAR SURVEYS. ERROR BARS ARE 95% CONFIDENCE INTERVALS

Crayfish surface activity differed among sites. We found the highest number of burrows at site 3 (Table 2). Site 3 had 6 times more burrows than site 1 and 3 times the number at site 2. While site 3 was the largest site it

TABLE 2. BURROW QUALITIES AT 3 STUDY SITES NEAR THE WARM SPRINGS FISH HEALTH CENTER FROM JANUARY THROUGH MARCH

Characteristic	Site 1	Site 2	Site 3
# Burrows	18	47	135
Burrow Area (m²)	2.8	5.2	10.9
Burrow Density (#/m²)	6.4	9.0	12.3
# New Burrows (Jan-Mar)	10	5	38
Proportion Burrows Active**	0.22	0.081	0.074

also contained nearly twice as many burrows per square meter (Table 2) and had 3 times greater number of new burrows than either of the other 2 sites (Table 2). However, at that time site 1 had on average the greatest proportion of observations showing activity (ANOVA $p < 0.0001$). These activity differences among sites 1 and 2 were not apparent during the summer observation period (t-test $p = 0.6$).

Weather and burrowing activity varied during the winter sampling period. To determine if weather conditions influenced activity patterns, we collected air and water temperature and groundwater levels in close proximity to site 1 (Fig 6). We found no significant correlation between average air (Pearson's Correlation = -0.2, $p = 0.35$) or water temperature (Pearson's Correlation = -0.39, $p = 0.07$) and the proportion of
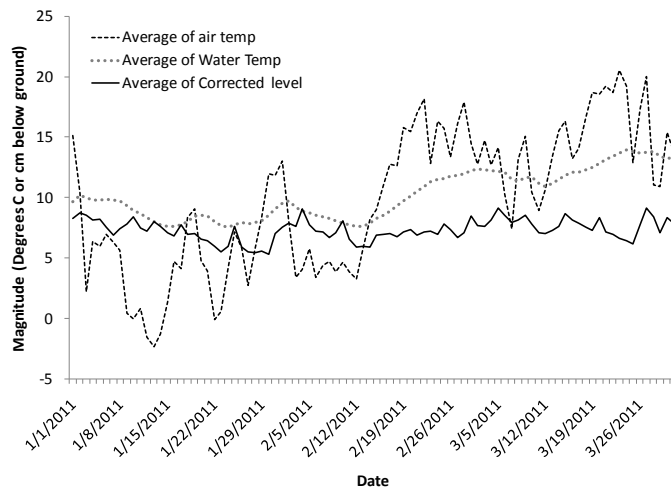

FIGURE 6 AIR AND WATER TEMPERATURES AND CORRECTED GROUNDWATER LEVEL DATA COLLECTED AT SITE 1 DURING THE WINTER OBSERVATION PERIOD. WATER LEVELS INDICATE CM BELOW SURFACE.

burrows active during that sampling event. However, surface burrow activity was negatively correlated to average ground water depth (Pearson's Correlation -0.49, $p = 0.018$). Fewer burrows showed activity when ground water levels dropped farther below the land surface. For these analyses, averages were calculated from data for the 3 or 4 days prior to sampling.
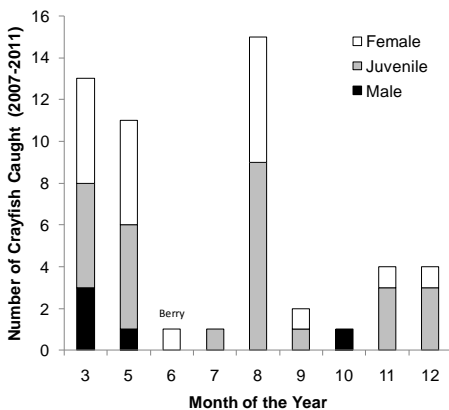

FIGURE 7. MONTHLY NUMBER OF MALES, FEMALES, AND JUVENILES *C. HARTI* CAUGHT IN THE VICINITY OF WARM SPRINGS FISH HEALTH CENTER

Records of *C. harti* collections through time have provided important information about the life history and demographics of this elusive species. Figure 7 shows the summary information for *C. harti* collected from 2007 through 2011 in the vicinity of the Warm Springs Fish Health Center. Juveniles were captured throughout the year. A large number of juveniles was captured during the study. Although sample sizes were relatively small, collections to date indicated that mature males were more difficult to collect than females.

Geographic Distribution and Current Threats

Skelton *et al.* expanded the previous reported distribution of *C. harti* from 2 to 7 locations in Meriwether County (Skelton *et al.*). During this study we identified two undocumented populations near the Roosevelt Warm Springs Institute (Warm Springs, Georgia). We also found several burrows and captured a female *C. harti* (unconfirmed) at Jack Chandler's private property near Greenville, Georgia. Mr. Chandler provided us with Smithsonian Museum records (Cat. #177145) documenting that Horton Hobbs Jr. confirmed the presence of *C. harti* at this location. There are currently 10 known sites with *C. harti* populations. Our sampling efforts confirmed the continued existence of *C. harti* at all of these sites except the population at Adam Lee Road (a tributary to Flat Shoals Creek). We visited this site in October and found little evidence of recent activity, so we did not excavate any burrows during this sampling event.

We used GIS to characterize the habitat of *C. harti* at the 10 known locations (Table 1). This information was incorporated into a model that scored locations for their similarity to *C. harti* sites. All grid cells covering the 6 county study area were modeled. Cells matching the conditions for sites with *C. harti* were scored 22 (see Methods for details). Those cells having no common
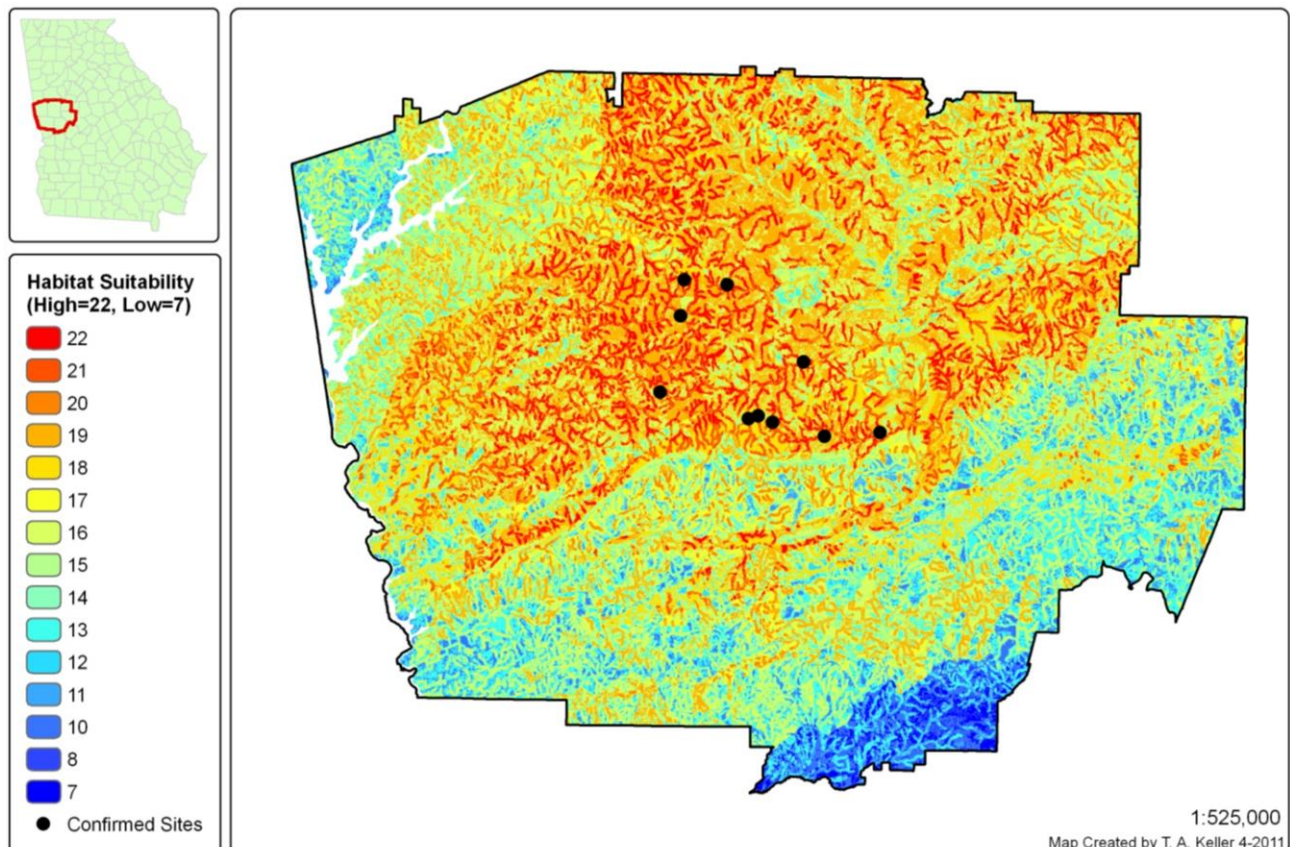

FIGURE 8 GIS MODEL PREDICTED *CAMBARUS HARTI* HABITAT SUITABILITY SCORES FOR LOCATIONS IN 6 WEST CENTRAL GEORGIAN COUNTIES. RED COLORS INDICATE LOCATIONS MOST SIMILAR TO THOSE WITH KNOWN POPULATIONS OF *C. HARTI*. POINTS INDICATE ALL KNOWN LOCATIONS FOR THIS CRAYFISH

characteristics were scored a 7. Fig. 8 shows the scores for all cells contained within the study region. The highest scores are located along river channels since the model assigned locations higher suitability scores if they were within 160 m of a river channel. The model's predictions indicate that additional efforts to locate *C. harti* habitat should focus on headwater, riparian areas in both the Flint and Chattahoochee River Basins. Creeks in the Chattahoochee Basin with high suitability scores that do not have known populations include: Mountain, Sulfur, House, Sand, Big Branch, Turkey, Polecat, Crawford, Mud, Long Cane, Beech, Shoal, Flat, Yellowjacket , and several others. The model also finds riparian zones with high habitat suitability in the Flint River Basin such as Red Oak Cr, White Oak Cr, Eakins Cr, Birch Cr, Turkey Cr, Basin Cr, Tenmile Cr, among others. There are many other habitats in the Piedmont region of West Georgia that have similar characteristics to those with extant populations of *C. harti*. There appear to be other populations of blue burrowing crayfishes that match the description of *C. harti* in counties north of this region (Skelton personal communication).

The effectiveness of the model remains unverified. The model scored 7 of the 10 known locations as having the maximum possible habitat suitability (i.e., 22). Two other sites were scored 19 or above apparently because input raster layers were not aligned perfectly. One new site was located outside the 160 m stream buffer and scored only 15 out of 22. The model's capacity to predict the distribution of *C. harti* is fundamentally dependent whether the GIS layers used to characterize its habitat determine its presence at sites. As our knowledge about the habitat preferences of this secretive burrowing species improves we can alter the GIS model and make improved predictions.

Having visited all of the known locations for *C. harti* it has become clear that there are two primary threats to the population at this time. The first threat is land use change at the locations where populations are known to exist. Currently its Endangered status protects it in known habitats on State owned lands. Populations that we visited were on unregulated private lands. Changes in the habitats mostly from the construction of new buildings and roads could destroy habitats. There were 2 sites (Tom Brown Spring and Stovall-Greenville Rd) that are directly affected by land clearing activities such as logging and wetland draining/alteration. The second and possibly more immediate and insidious threat to populations would involve changes to the land that would alter the groundwater hydrology. There is a new church and associated parking lot being constructed uphill from the type locality (i.e., Warm Springs Fish Health Center). It is unclear how development activities at White Sulfur Springs (new bathing facility, altered stream channel) will affect hydrologic conditions for downstream *C. harti* populations at this location. These activities and others (e.g., well drilling, ditching and draining) that lower groundwater levels could create

inhospitable conditions for this rare species. More research is needed to quantify how human activities alter hydrologic conditions and affect the viability of *C. harti* populations.

CONCLUSIONS

Cambarus harti is a Georgia endemic crayfish that has a very narrow distribution with all known habitats residing in Meriwether County. This restricted geographic distribution has raised concerns about its long-term viability and earned it a State and IUCN listing of Endangered. This study located 2 additional sites (Chattahoochee Basin) bringing the total number of known sites to 10. Regardless the distribution of *C. harti* is extremely limited and remains entirely within Meriwether County.

Our research on the behavior of *C. harti* populations near Warm Springs, Georgia indicates that these crayfish are extremely elusive. Crayfish successfully avoided all efforts to trap them for mark and recapture studies. *Cambarus harti* remained active even during cold weather in January. Activity was not synchronous among subpopulations. Preliminary observations suggest more surface activity during June than January-March, but we found no strong correlation between temperature and surface activity (January-March). This primary burrower appears to be less active when water levels fall deeper below the ground surface, a season pattern described for other primary burrowers (Welch *et al.* 2008).

Threats to *C. harti* clearly exist at several of the sites we surveyed. While direct habitat alteration remains a concern, less conspicuous changes to the landscape could alter the groundwater flow dynamics and potentially threaten the viability of affected populations. These threats include but are not limited to paving, new building construction, ditch and drain creation, well drilling, forest harvesting, and river downgrading.

We used geographic information (geology, soils, ecoregion, proximity to streams, elevation, and landcover) to characterize the habitats of the 10 known *C. harti* sites. Using these data we predicted the suitability of other sites in a 6 county region of west central Georgia. The model predicted many new locations that have similar habitat conditions. These results suggest that this crayfish may have a broader distribution than is currently documented. More research is needed to determine the effectiveness of this GIS model by surveying sites predicted to have high habitat suitability.

Subpopulations of *C. harti* described by Hobbs (1981) have remained viable for 30+ years. Clearly this species can tolerate some disturbance to its habitat. The future of this species remains in doubt as too little information exists about its biology, life-history and ecology. Furthermore, it is

difficult to assess how regional land use changes will influence the viability of subpopulations of this beautiful but secretive burrowing crayfish.

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