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Comparative Ecology and Conservation Status of Procambarus (Pennides) gibbus and Procambarus (Pennides) versutus in Marion County, Georgia

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COMPARATIVE ECOLOGY AND CONSERVATION STATUS OF *PROCAMBARUS (PENNIDES) GIBBUS* AND *PROCAMBARUS (PENNIDES) VERSUTUS* IN MARION COUNTY, GEORGIA

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JoAnn Chadwick

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ABSTRACT

Two crayfish species, whose conservation status was of concern, *Procambarus (Pennides) gibb*us Hobbs and *Procambarus (Pennides) versutus* Hagen, and one relatively common crayfish, *Procambarus (Pennides) spiculifer* LeConte were studied at nine creek sites in Marion County, Georgia. Major objectives of the yearlong study were to 1) compare the habitats of these species, looking for environmental differences that might account for their isolated distributions within the county and 2) assess the current conservation status of *P. gibbus* and *P. versutus*. Each study site was characterized by a one-time assessment of floodplain width, stream width, water velocity, stream depth and assessment of bed substrate and dissolved solids. Water was tested bimonthly to measure temperature, specific conductivity, turbidity, pH, and dissolved oxygen. Results indicate that *Procambarus versutus* habitat is clearly different from the habitats of the sister species by virtue of its lower pH and turbidity. *Procambarus gibbus* habitat is distinguished from those of the other two species with regard to substrate (higher gravel and coarse sand content) and higher conductivity. Wire traps baited with canned cat food were checked weekly to monitor crayfish populations. Captures indicated year-round activity from healthy populations of each species, but *P. gibbus* merits conservation because it is essentially endemic to Muckalee Creek. *P. versutus* merits conservation attention in Georgia because its range is quite restricted in the state and most, if not all of it range lies within the Fort Benning Military Reservation, where it may receive special attention but also may be subject to habitat modification dictated by issues of national security.

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INTRODUCTION

The Southeastern United States contains some of the most evolutionary significant aquatic systems in North America. This can be directly attributed to its geologic history and warm climate resulting in five large, distinct physiographic provinces: the Cumberland Plateau, Ridge and Valley, Blue Ridge, Piedmont, and Coastal Plain, each characterized by differences in climate, soils, vegetation, lithology, tectonic history, and layers of bedrock (Isophording and Fitzpatrick 1992). Large drainage systems often span more than one province, adding even more variability to ecosystems (Hackney and Adams 1992). Within each of these provinces microclimates were created that set the stage for the development of diverse flora and fauna. Species moved, adapted, or became extinct. In time, many areas across the Southeast became the northern-most range for tropical species and the southern-most range for northern species.

A recent awareness of the uniqueness of the Southeast has led to an understanding of the importance of preserving these distinctive biotic communities. At the onset of this study Georgia alone had 223 species of plants and animals protected by either state or federal law. Hundreds more were thought to be in need of conservation with population declines mostly attributed to destruction and degradation of species' natural habitats (GADNR A 2004).

According to the Georgia Department of Natural Resources (GADNR A 2004), Georgia ranks sixth nationwide in overall species diversity of vascular plants, vertebrate animals, and selected invertebrates. This includes being ranked second in the number of species of amphibians, third in freshwater fishes, third in crayfishes, seventh in reptiles, and seventh in the number of vascular plants.

Awareness of the importance of preserving biotic communities and their rich fauna and flora led Georgia to establish its Natural Heritage Program in 1986. This partnership between the Georgia Department of Natural Resources (DNR) and the Nature Conservancy are funded by donations and grants. It divides Georgia habitats into unique areas by using the five distinct physiographic provinces of Georgia (Cumberland Plateau, Ridge and Valley, Blue Ridge, Piedmont, and Coastal Plain) and further characterizes each area by its distinguishing plants and animals. Since full restoration of highly-disturbed ecosystems is impossible, the goal is to protect areas which have remained relatively undisturbed and study them to learn how they function. A particularly important component of this conservation plan relies upon citizens reporting their sightings of rare or endangered species (GADNR B 2004).

More recently, the DNR has developed a "Comprehensive Wildlife Conservation Strategy" in order to compile the most accurate data describing wildlife habitats. Population numbers and threats to each are examined so that effective plans can be developed for management and conservation. The project involved planning partnerships with both public and private stakeholders and has since been completed. It was then submitted to the U. S. Fish and Wildlife Service for approval. Approval allows Georgia to continue to receive federal monies for research, land acquisition, habitat restoration, and other conservation projects. Funding for land also allows the state to purchase additional land for public recreation, including hunting, fishing, hiking, and wildlife observation. (GADNR B 2004).

Even though information has been rapidly accumulating, many critical habitats of Georgia still remain unstudied. Little is known about many of the sixty-eight crayfish species known to exist in Georgia, several of which are endemic (Fetzner 2002).

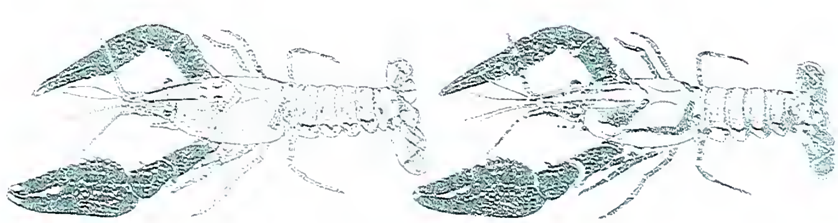
Like other native species, crayfishes are important in the environments they inhabit. They play various roles within an ecosystem and are often characterized as keystone species (Creed and Reed 2004). They often constitute the most abundant and dominate biomass within invertebrate communities. Besides their important role in food webs, crayfish alter the surrounding environment by shredding macrophytes and building burrows (Nystrum 2002). Within a stream they have been shown to travel more than 300 m in 10 days. Additionally, behaviors such as propulsion during walking, backward swimming, jabbing claws into the streambed to slow their walking movement downstream, and aggression toward other crayfish may also alter the environment by changing bedform roughness, physical particle consolidation, sand cover by gravel, and growth of filamentous algae. These studies indicate that crayfish could affect patch dynamics in streams and increase overall structure in a lotic community (Statzer, *et.al.* 2003) therefore changes in their distribution may have both positive and negative effects on other occupants of their communities.

Georgia crayfishes are assigned to family Cambaridae, of which there are two sub-families: Cambarellinae and Cambarinae. Within the Cambarinae are genus *Procambarus* and sub-genus *Pennides*. All *Pennides* are inhabitants of streams. Of eighteen species of *Pennides*, five occur in Georgia, tending to occupy similar niches within streams where their ranges may overlap, but they are not often sympatric. Although little is known about the life history and habits of some of the *Pennides*, they are all thought to occupy shallow burrows in either stream banks or streambeds. Three of these Georgia *Pennides* species are found in Marion County, within the drainage basins of the Chattahoochee and Flint Rivers, and became the subjects of this study. As noted by Hobbs (1981), all three species appear to fill similar niches in seemingly similar streams.

Figure 1. *Pennides* in Marion County (Hobbs 1981)

1a. *Procambarus gibbus*

1b. *Procambarus versutus*



1c. *Procambarus spiculifer*

Procambarus (Pennides) gibbus Hobbs (Figure 1a) was first described by H.H. Hobbs Jr. in 1968, whereas it had been previously identified as a variant of *Procambarus (Pennides) spiculifer* LeConte. Thirteen historical sites were documented for this species, recorded from 1932 through 1972, which consisted of a total of only 210 specimens (Hobbs 1981). With the exception of one site recorded in Baker County and one site recorded in Crawford County, both of which are in tributaries to Flint River, *P. gibbus* is reported only from Muckalee Creek (Figure 3), whose headwaters originate just southeast of Buena Vista in Marion County. Muckalee Creek flows from Marion County through Schley and Sumter Counties into Lee County, where it joins with Kinchafoonee Creek to become a tributary of Flint River. Hobbs (1981) noted that; "Surprisingly, *P. gibbus* has not been recorded in Kinchafoonee Creek."

The largest *P. gibbus* recorded by Hobbs was a second form (non-reproductive) male with a carapace length that measured 48.7 mm. Even now, little is known about this crayfish species, but Hobbs (1981) noted that observations made while collecting *P. gibbus* led him to believe that its habits were very similar to *Procambarus (Pennides) spiculifer* (Figure 1c). He documented collection of first form (reproductive) males in April and August. Sizes of juvenile specimens collected in September led him to conclude a prolonged hatching period between late spring and early summer months (Hobbs 1981).

Although *P. gibbus* had not been collected with any other *Pennides* species, it was collected in association with *Cambarus (Depressicambarus) latimanus*, *Cambarus (Lacunicambarus) diogenes*, *Faxonella clypeata* and *Procambarus (Scapulicambarius) paeninsulanus* (Hobbs 1981).

At the onset of this study the conservation status of *P. gibbus* was listed as one of special concern (Fetzner 2002). Stanton (2006) provided further evidence for the current conservation status of *P. gibbus* with additional sampling in Muckalee Creek headwaters in Schley, Sumter and Lee counties. Headwater streams south of Buena Vista and north of Americus had populations of *P. gibbus*. *Procambarus gibbus* was not found in the original type-locality site 3.2 miles north of Americus or south of Americus in tributaries east of Muckalee. Populations were found in Muckaloochee Creek which originates in Sumter County, to the south of Muckalee Creek, and terminates into Muckalee Creek in Lee County.

Procambarus (Pennides) versutus Hagen (Figure 1b) was first described in 1870. Its range was predicted by Hobbs (1981) as being "from the Mobile River drainage in Alabama eastward to the Chattahoochee-Apalachicola drainage in Alabama, Florida, and Georgia." Five *P. versutus* specimens were listed in *The Crayfishes of Georgia* (Hobbs 1981). Until 1980, it was documented from only two locations in Georgia; one in Marion County, 11.4 air miles NNW of Buena Vista on State Route 355 and the other in Muscogee County on Fort Benning Military Reservation. Later sampling by Stanton and Lopez indicated that the Muscogee County location was actually in Chattahoochee County (Stanton and Lopez 1982).

During additional sampling by Stanton (2006) between 1980 and 2005, *P. versutus* was collected at 29 sites in the Chattahoochee River drainage in either Chattahoochee or Marion counties. In a 1995-96 survey of the Tallapoosa River drainage in Alabama, *P. versutus* was only found at two sites, leading researchers to conclude that in Alabama it was also restricted to the Coastal Plain (Ratcliffe and DeVries 2004).

Hobbs and Hart (1959, cited in Ratcliffe and DeVries 2004) found that *P. versutus* habitat seemed to consist of sandy-bottomed, spring-fed streams and the crayfish were most often found in debris in moderately swift areas. In *The Crayfishes of Georgia*, Hobbs (1981) noted that *P. versutus* often frequented areas of streambeds devoid of litter or aquatic plants but it seemed particularly abundant in areas where beds of *Orontium aquaticum* (golden club) flourished. According to Hobbs (1981), *P. versutus* penetrates further into headwaters than *P. spiculifer* and their populations are most visible after dark when they emerge from diurnal burrows to open streambeds.

The largest *P. versutus* specimen recorded by Hobbs was a first form male with a carapace length of 39.2 mm. Unlike *P. gibbus*, first form males of *P. versutus* were collected every month of the year (Hobbs 1981).

In the survey of the Tallapoosa River drainage by Ratcliffe and DeVries (2004), *P. versutus* was not collected with any other species, but it has been found to be sympatric with several species in Chattahoochee and Marion counties. Stanton's records document H. H. Hobbs Jr. as collecting *P. versutus* and *C. latimanus* together in 1978 at a location 11.4 air miles NNW of Buena Vista in Marion County. Since 1980, Stanton has collected *P. versutus* with *C. latimanus* at two locations in Marion County; Juniper Creek and Black Creek, and 11 locations in Chattahoochee County. Stanton has also collected *P. versutus* with *P. verrucosus* at one location in Chattahoochee County. Stanton documented *P. versutus* with *P. spiculifer* at three sites in Chattahoochee County and two locations in Marion County; Juniper Creek at Route 355 and Pine Knot Creek at Route 352 (Stanton 2006).

In the absence of other *Pennides* species, the default crayfish appears to be

Procambarus (Pennides) spiculifer LeConte (Figure 1c). It is widespread and abundant in Georgia and its range surrounds that of *P. gibbus* and *P. versutus,* coming very near to streams where either *P. gibbus* or *P. versutus* is found (Fetzner 2002, Hobbs 1981). It has also been documented with other *Pennides* species. Stanton (2006) has suggested that locations where two *Pennides* species occur sympatrically represent habitats in transition. Stanton and Lopez (1982) suggested that "*P. versutus* replaces *P. spiculifer* in certain streams below the fall line of the Chattahoochee River drainage in Georgia."

Compared with either *P. gibbus* or *P. versutus*, *P. spiculifer* appears to be a rather large crayfish, since Hobbs' record size of the carapace length of a first form male was 70.4 mm, compared to 48.7 mm of *P. gibbus* and 39.2 mm of *P. versutus* (Hobbs 1981).

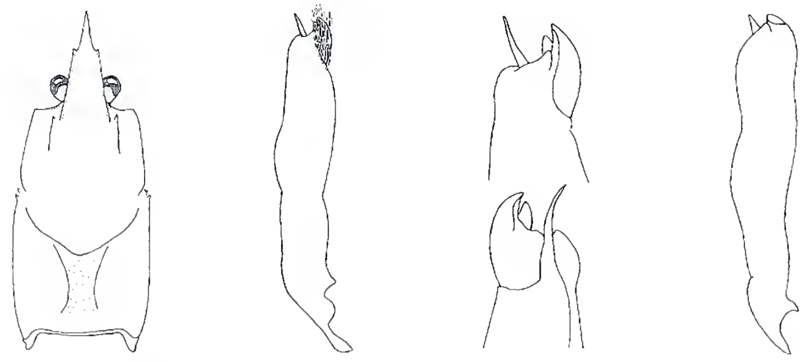
Ratcliffe and Devries (2004) characterized *P. spiculifer* as a "habitat generalist" since its range is so extensive. Hobbs noted that *P. spiculifer* tended to be equally successful in spring feed streams and streams that supported relatively heavy loads of silt, but was absent or rarely found in streams with bare sand or bed-rock bottoms. Burrows are generally simple, unbranched tunnels built within stream banks that lead down horizontally or slope downward to about 20-140 cm. During daylight hours *P. spiculifer* is typically be found near underwater roots or debris mats. Nights are spent wandering around in open water or perching near surfaces clinging to submerged vegetation, where they quickly retreat when disturbed by light or nearby commotion (Hobbs 1981).

Of the 2824 Georgia specimens collected and recorded in *The Crayfishes of Georgia* from 375 localities, Hobbs only documented sympatric collection of *P. spiculifer* with one other *Pennides; P. (Pennides) raneyi* (4 occurrences). It was also collected sympatrically with the following (the number of times with each species is shown in parenthesis*)*: *Cambarus (Cambarus) bartonii* (9), *C. (C.) howardi* (4), *C. (Depressicambarus) englishi* (4), *C. (D.) halli* (8), *C. (D.) latimanus* (127), *C. (D.) striatus* (16), *C. (Hiaticambarus) coosawattae* (2), *C. (H.) fasciatus* (7), *C. ((H.) speciosus* (1), *C. (Jugicambarus) conasaugaenis* (2), *C. (Lacunicambarus) acanthura* (6), *C. (L.) diogenes* (14), *C. (Puncticambarus) coosae* (14), *Fallicambarus (Creaserinus) hedpethi* (1), *Faxonella clypeata* (7), *Orconectes (Crockerinus) erichsonianus* (1), *Orconectes (C.) spinosus* (7), *Procambarus (Hagenides) pygmaeus* (4), *P. (H.) talpoides* (1), *P. (Ortmannicus) enoplosternum* (6*), P. (O.) fallax* (1), *P. (O.) lophotus* (1), *P. (O.) pubescens* (2*), P. (O.) seminolae* (8*), P. (Scapulicambarus) howellae* (10), and *P. (S.) paeninsulanus* (Hobbs, 1981). In their survey of the Tallapoosa River Drainage, Ratcliffe and DeVries (2004) reported finding *P. spiculifer* alone in 21 sites and sympatrically with *Cambarus englishi* (10), *C. halli* (13), *C. latimanus* (7), and *Orconectes (Trisellescens) holti* (2).

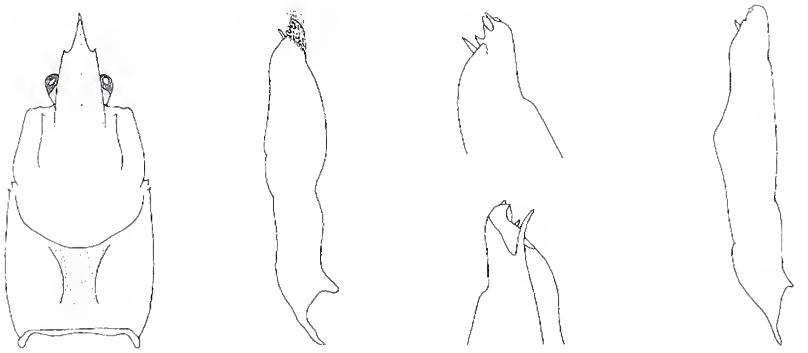
Hobbs also noted that he had not collected *P. spiculifer* in impounded areas of any stream. He suggested that this was related to destruction of lotic habitats that resulted in large quantities of silt accumulation covering hiding places and filling in burrows. Depletion of oxygen would result in benthic conditions that would become intolerable for lotic species like *Pennides* (Hobbs 1981).

Procambarus gibbus, *P. versutus*, and *P. spiculifer* can be identified as members of sub-genus *Pennides* by the presence of two cervical spines along the lateral area of the carapace (Figure 2). *Procambarus spiculifer* and *P. gibbus* usually have similar markings on their bodies and can only be distinguished from one another by the pleopods (first pair of abdominal swimmerets modified as gonopods) of first form males. In *P. gibbus* the gonopod's terminal portion becomes more subangular with successive molts until the male reaches first form (Figure 2). *Procambarus versutus* has somewhat similar markings to *P. gibbus* and *P. spiculifer* but can be distinguished from either by a median ridge along its rostrum (Figure 2). It is also characterized by differing color patterns (Figure 1) (Hobbs 1981).

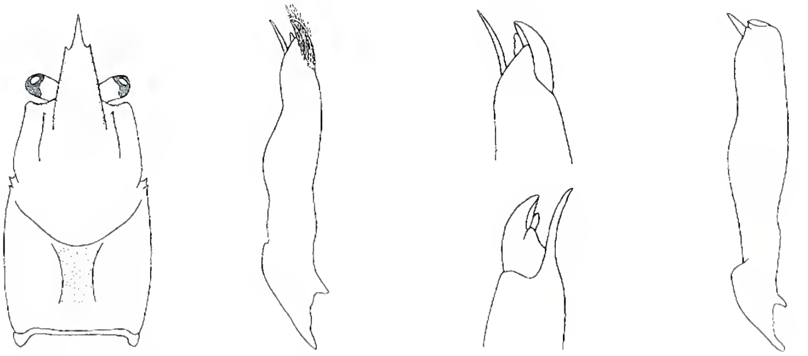
Figure 2. Carapace and Gonopod Variations in *Procambarus gibbus*, *Procambarus versutus*, and *Procambarus spiculifer* (Hobbs 1981)



2a. *Procambarus gibbus*



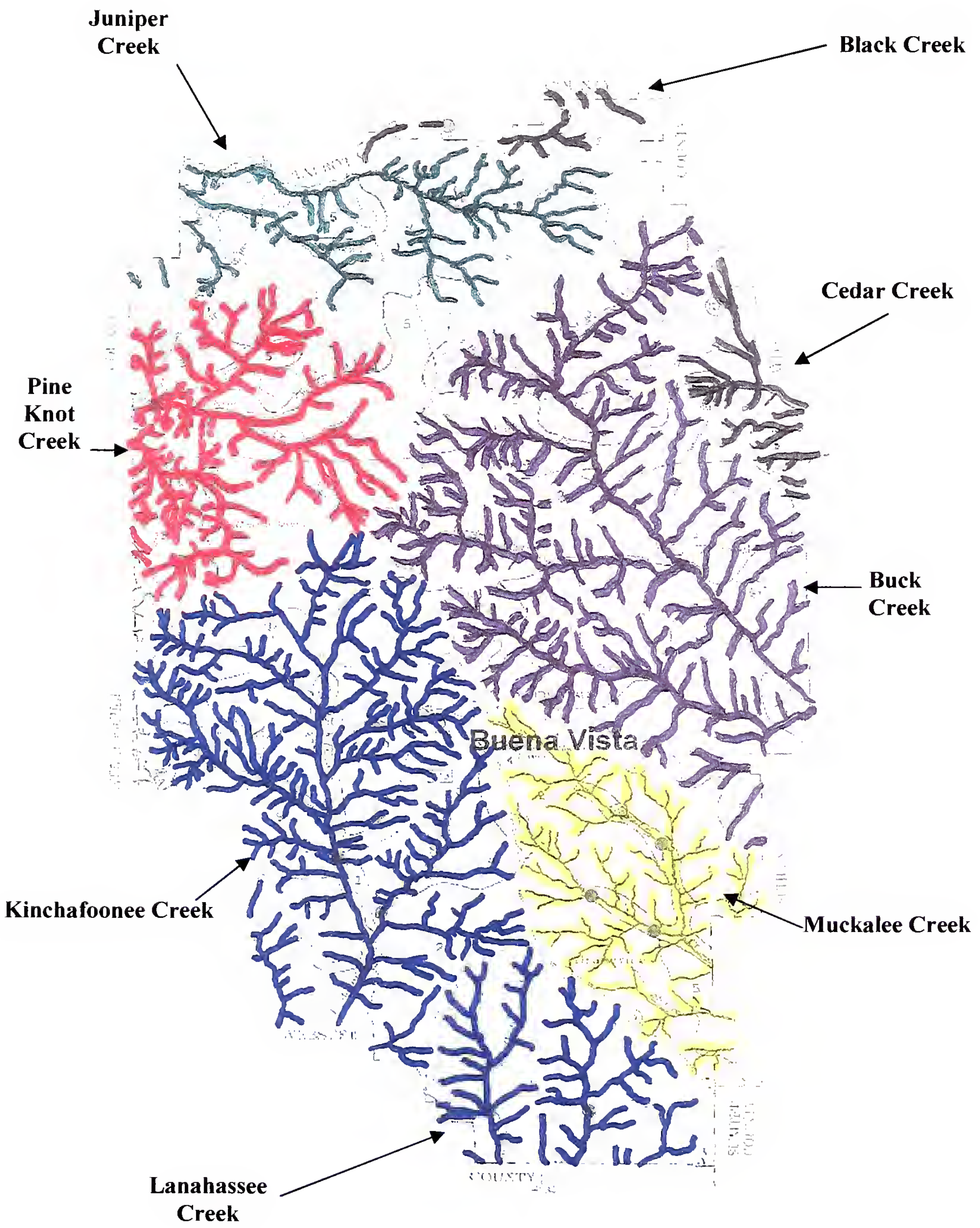
2b. *Procambarus versutus*



2c. *Procambarus spiculifer*

Eight major stream systems have their headwaters in Marion County (Figure 3). In the southern half of the county, Muckalee, Lanahassee, and Kinchafoonee creeks flow south and eventually east to converge and drain into the Flint River. In the northeastern corner Buck Creek flows easterly through Schley and Macon counties and also drains into the Flint. Cedar Creek headwaters lie just north of Buck Creek. It flows into Taylor County where it merges with Whitewater Creek, also a tributary of Flint River. Black Creek has its origins in Talbot County and flows westerly along the upper boundary between Marion and Talbot Counties until it empties into Juniper Creek. Pine Knot and Juniper Creeks drain the northern and mid-western portions of Marion County and flow into Upatoi Creek, a tributary of the Chattahoochee River.

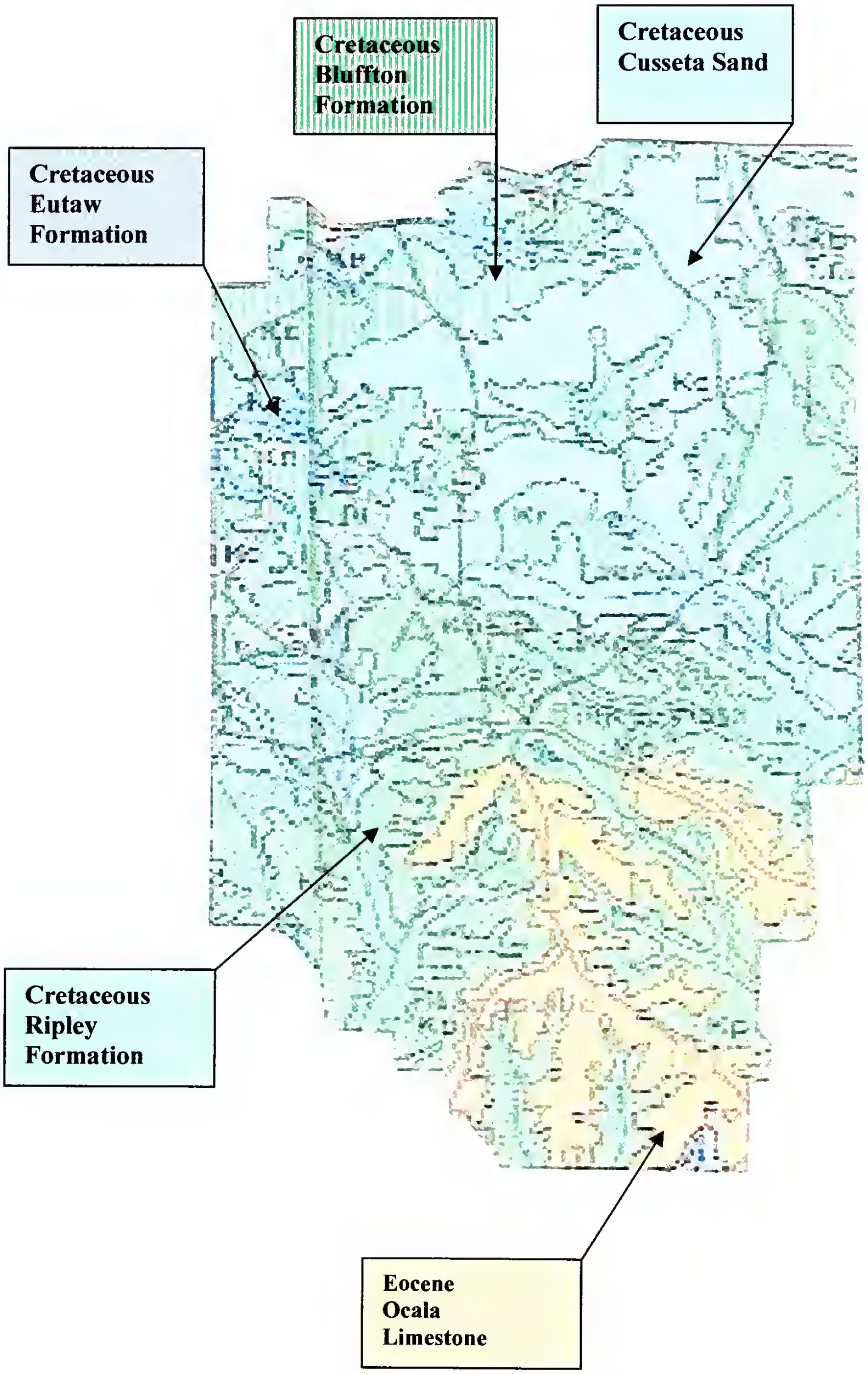
Figure 3. Map of Creek Distributions in Marion County (GIS Clearinghouse 2005)



The upper boundary of Marion County is just south of the fall line where metamorphic rock of the Piedmont dips beneath the sedimentary rock of the Coastal Plain (Bloxgeaux 1969, sited in Smock and Gilinsky 1992). From the northwestern corner of Marion County upper Cretaceous deposits of sand, gravel, and clay merge into deposits of sand, clay and marl (Figure 4). Mid to lower areas of the county contains upper Cretaceous-Tertiary deposits of sand, sandy clay and marl. In the southeastern portion of the county, just below Buena Vista these deposits change over into a layer of upper Eocene deposits consisting of sand, clay, sandy clay, marl and limestone of early Tertiary age (Cochran 2007).

Marion County is dominated by oak-pine forest in this narrow, rolling, hilly area where belts of marine sands and clays are deposited over crystalline and metamorphic rocks. Known as the Sand Hill region, it is found just below the fall line where the piedmont providence ends and gives rise to the coastal plain. It is characterized by thick beds of sandy, low-nutrient soils with areas of loam or clay. A small mid-western portion of Marion County is designated as Southern Hilly Gulf Coastal Plain. It too consists of dissected irregular plains and gently rolling hills with a mixture of clay, loamy and sandy soils, but with somewhat flattened hilltops and oak-hickory-pine forests as the dominant vegetation (EPA 2004).

Figure 4. Geologic Deposits in Marion County. (Cochran 2007)



Water chemistry is predominately controlled by the geology of surrounding soils. In the Upper Coastal Plain, acidic sand and clay soils have been leached by rapid runoff flowing over soil surfaces and filtering through sand. Blackwater streams draining from these areas tend to have lower quantities of dissolved organic compounds than those of the Lower Coastal Plain, leaving water varying shades of amber color instead of the darker water of streams found in the Lower Coastal Plain (Felly 1992, Smock and Gilinsky 1992).

Alkalinity, hardness, dissolved oxygen, cations, and nutrient content vary from one stream to another. Dissolved organic acids from mostly humic and fulvic acids, release hydrogen ions to water resulting in low pH levels. Generally, pH levels tend to fall between four and seven depending upon the stream's buffering capabilities. Both concentration and transport of dissolved organic carbon vary seasonally, and are related to frequency and duration of rainfall and floodplain inundation. Dissolved oxygen concentrations also follow seasonal patterns where the lowest concentrations occur in summer and fall when water temperatures are warmer (Smock and Gilinsky 1992).

Inorganic chemistry of blackwater streams is often based more on sodium sulfate than calcium carbonate. Where most streams have a bicarbonate regulating system for acidity, this lack of calcium carbonate tends to limit the natural buffering capacity of blackwater streams (Blood 1986, cited in Smock and Gilinsky 1992). Since dominant ions come from chloride and sodium, rain may be important in determining the overall concentration and distribution of the major elements in these streams (Beck *et al.* 1974, cited in Smock and Gilinsky 1992).

Sand Hill streams characteristically have braided channels with long reaches and numerous pools and riffles. Groundwater flow through permeable sand and gravel aquifers provide a dependable water source for most streams, therefore flow is less variable than in the Lower Coastal Plain. Unstable, loose, shifting sand tends to make stream bottoms less hospitable for organisms that need refuge. The most stable substrates tend to be debris dams and snags resulting from bank undercutting and floods. Both fish and invertebrates seek shelter where leaves and other detritus accumulate. In Upper Coastal Plain steams, debris dams increase from lower to higher stream order, unlike the opposite trend in higher-gradient streams (Smock and Gilinsky 1992)

Crayfish distribution is thought to be influenced by several chemical components of stream water. The pH is always critical because of its influence on chemical reactions that must occur for life processes. Calcium may be a limiting factor in some ecosystems since crayfish are dependent upon it for post-molting recalcification of their exoskeleton (Ratcliffe and DeVries 2004, Berrill et.al. 1985) although some studies have indicated that crayfish may have more tolerance for streams with lower pH values in soft water than previously thought, since they may absorb some calcium from their exoskeleton prior to molting (Reynolds 2002, McMahon 2002).

In their 1995-96 survey of crayfishes of the Tallapoosa River Drainage in Alabama, Ratcliffe and DeVries (2004) found the presence or absence of crayfish correlated with various geophysical and chemical parameters. They reported that "crayfishes were present at sites with lower pH, lower conductivity, shallower riffles, lower stream order, and lower link magnitude than occurred at sites where no crayfish were found."

Although only two sites were recorded for *Procambarus versutus* by Ratcliffe and

DeVries (2004), they were characterized by the lowest alkalinity and shallowest pools recorded in the study. They also had the lowest average pH (4.51).

Their results did not indicate a link between substrate composition and crayfish species but in retrospect researchers decided that their method may not have been sensitive enough to indicate minute differences in compositions between the sampled streambeds (Ratcliffe and DeVries 2004).

As previously stated, crayfishes are important in aquatic ecosystems, but as with other organisms their importance may go beyond their obvious or not so obvious roles there. Like many under studied organisms, they may be looked to in the future for undiscovered medicines, unique genetic information, or as future food supplies for increasing populations. Studies may also discover that they have more critical roles in ecosystem balance than yet understood. Finally, crayfish may be important simply because they have intrinsic value as part of the natural world (Taylor 2002, Momot 1995).

Like many native species, indications are that crayfish are declining (Creed and Reed 2004). Estimates place 65% of the 313 species of North American crayfish as rare, threatened, or close to extinction. Contributing factors to this decline seem to mirror those of other species. Major factors include limited natural ranges, habitat destruction, introduction of non-indigenous species, disease and pollution (Taylor 2002).

Taylor (2002) has suggested that almost all factors contributing to imperilment of any species stem from human population growth and a growing need for material wealth. With that in mind, efforts to save declining populations become increasingly dependant upon understanding their roles in ecosystems. Policy makers must have accurate information so that effective plans for management and conservation can be put into place. A small area of protected land costs less than an attempted recovery of a species once it is designated as imperiled. Since many problems associated with protection and restoration of critical habitat stem from rights of private land owners, education of private landowners and cooperation between landowners and policymakers should be a major priority.

To some extent, development of programs such as habitat conservation plans under the Endangered Species Act have encouraged private landowners to protect species by offering monetary compensation in the form of tax abatements. But before conservation plans or restorations of critical habitats can be effectively written and managed, studies must be carried out to obtain accurate and up-to-date information for population distributions and abundance, along with pertinent information regarding life histories (Taylor 2002).

Two general goals of this study were to increase knowledge and understanding of the life histories of both *P. gibbus* and *P. versutus* and assess their habitats comparing them for differences and similarities. Since *P. spiculifer* seems to be a default species occurring where neither *P. gibbus* nor *P. versutus* is present, its habitat was also compared to those of *P. gibbus* and *P. versutus*. Marion County is the only county known to harbor all three species.

This proposed study began by checking historical sites in Marion County creeks to determine if and what species of crayfishes were present. Study sites were then selected to compare the ecology of *P. gibbus*, *P. versutus*, and *P. spiculifer*. Measured attributes taken from each of the sites were analyzed for adaptive differences between species.

Along with comparing the ecology of the three crayfish species, the second goal of this study was to determine the conservation status of *P. gibbus* and *P. versutus* and to recommend a state response for each. This information is especially important in the case of *P. gibbus* since there have been no formal studies recorded for this crayfish since Hobbs published *The Crayfishes of Georgia* in 1981, where he listed only 13 sampled sites for this crayfish between 1932 and 1972. Only Stanton (Stanton and Lopez 1982, Stanton 2006) of Columbus State University has studied *P. versutus* in Georgia and has been able to extend the original one recorded site to include 29 sites.

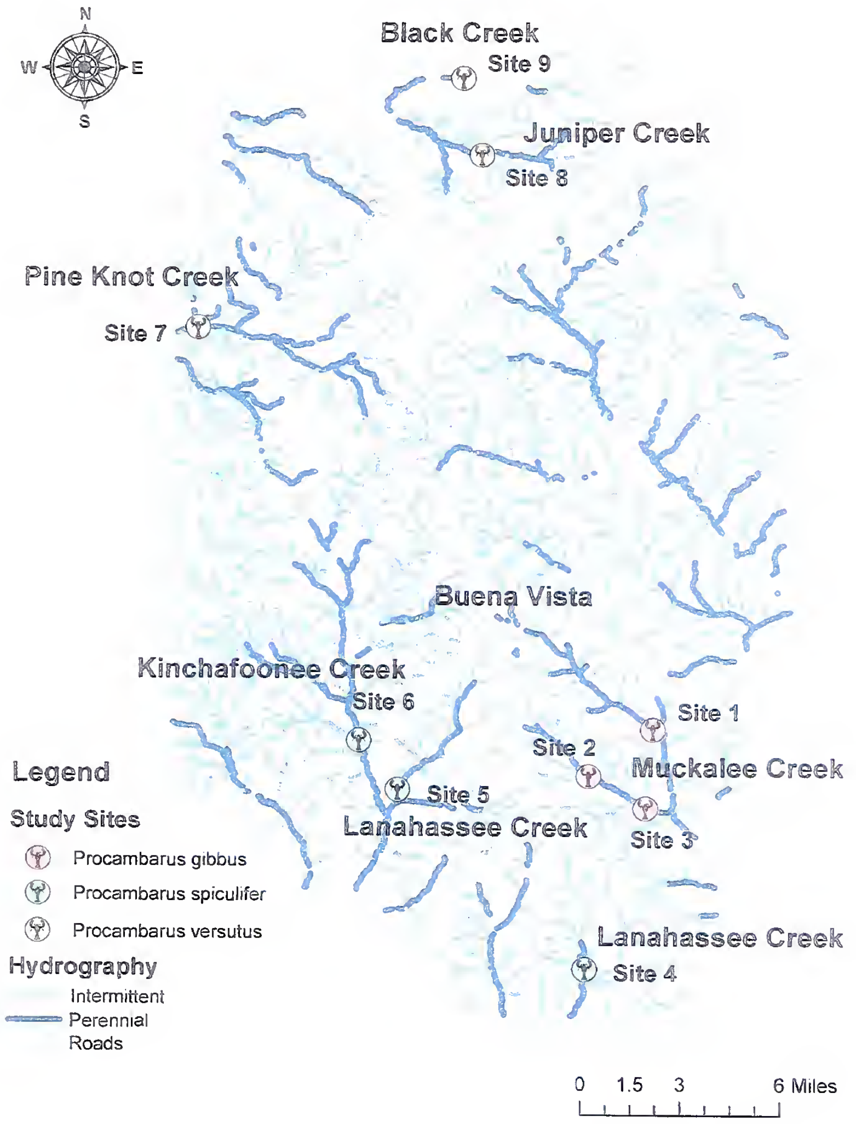
MATERIALS AND METHODS

Prospective study sites were first identified by using a United States Geological Survey 7.5 minute topographic map of Marion County and locating bridge crossings and historical sites documented by Stanton and Lopez (1982) or Hobbs (1981). Accessible sites were hand netted to determine species type and population viability. Specimen identities were verified by Stanton. Voucher specimens were preserved in ethanol and retained at Columbus State University.

The study was narrowed to nine sites consisting of three sites for each species of crayfish. Because *P. gibbus* appears to be confined to Muckalee Creek within Marion County, all three sites for this crayfish were either on Muckalee Creek or its tributaries. *Procambarus versutus* sites included Pine Knot, Juniper and Black creeks. *Procambarus spiculifer* sites were on the main branch of Kinchafoonee Creek and two Lanahassee Creek tributaries.

During the first phase, each site was numbered and marked with a GPS location. Sites were named by crayfish species (Figure 5, Table 1). The main branch of Muckalee was designated as *P. gibbus* 1, the upper tributary *P. gibbus* 2 and lower tributary *P. gibbus* 3. Lanahassee Creek's lower tributary was identified as *P. spiculifer* 1, the upper tributary as *P. spiculifer* 2. The Kinchafoonee Creek site was identified as *P. spiculifer* 3. Pine Knot Creek was designated *P. versutus* 1, Juniper Creek as *P. versutus* 2, and Black Creek as *P. versutus* 3.

Figure 5. Marion County Study Sites (GIS Map-JoAnn Chadwick, GIS Clearinghouse 2005)



Site Designation

Site 1	P. gibbus 1	Site 4	P. spiculifer 1	Site 7	P. versutus 1
Site 2	P. gibbus 2	Site 5	P. spiculifer 2	Site 8	P. versutus 2
Site 3	P. gibbus 3	Site 6	P. spiculifer 3	Site 9	P. versutus 3

Table 1. Study Sites

Site	*Procambarus gibbus*	*Procambarus spiculifer*	*Procambarus versutus*
1	Muckalee Creek at Mt. Zion Road 32.26161N 84.44858W	Lanahassee Creek at Bill Merritt Road 32.15560N 84.47756W	Pine Knot Creek at HWY 355 32.43921N 84.64869W
2	Muckalee Creek at Powell Road 32.24090N 84.47646W	Lanahassee Creek at Mill Creek Road 32.23470N 84.56007W	Juniper Creek at Anthony Road 32.51552N 84.52466W
3	Muckalee Creek at Mt. Carmel Road 32.22680N 84.45165W	Kinchafoonee Creek at Pineview Road 32.25640N 84.57708W	Black Creek at HWY 240 32.54962N 84.53298W

Study sites were assessed using *EPA's Rapid Bioassessment Protocol for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish (Second Edition)* (Barber *et al.* 1999). This onetime assessment taken during June 2005 at the study's onset included average stream width, depth, and flow rate along with information regarding adjacent land use and vegetation.

To analyze streambed composition, samples were collected from each site; dried, weighed, and then put through a sieve that separated them into gravel, course sand, fine sand or clay and silt. Individual soil types were reweighed and a percentage was calculated from the total weight of each soil sample.

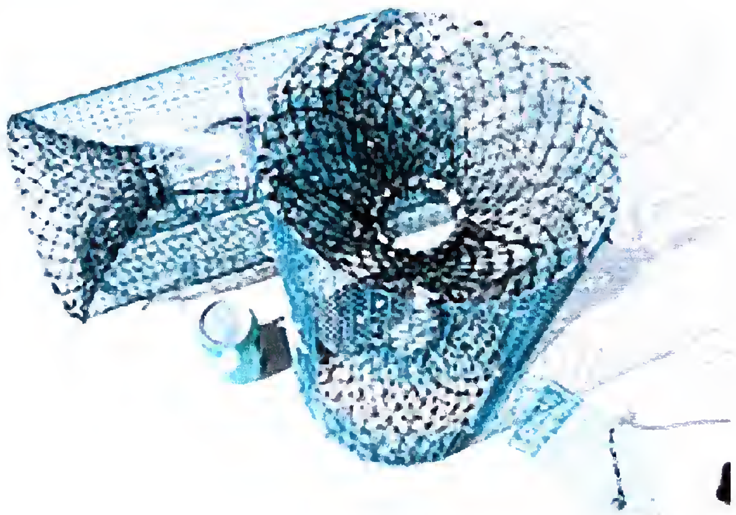
Similar tests were conducted for analyzing dissolved solids from stream water. Samples were poured through filter paper. Dried sediments were weighed and percentages of dissolved material calculated from the total weight of each water sample.

Water temperature, conductivity, alkalinity, pH, dissolved oxygen and turbidity were collected bimonthly for one year. All measurements were made using a mobile Hydrolab Surveyor 3.

Resulting data from physical and chemical measurements were averaged by crayfish species and compared among the three sister species to assess any variation in preferred habitat that correlated with range distributions. Each set of data was analyzed using SPSS 15.0 software for comparing means with univariate analysis of variance. Physical and chemical measurements for each parameter were also compared between sites for each species independently of the other two species. Multivariate cluster analysis was used to determine relational similarities among the nine creek sites using pH, conductivity, temperature, dissolved oxygen, turbidity and alkalinity in order to create a graphical tree diagram where sites were linked according to aggregate similarity.

To monitor conservation status and collect life history information for individual crayfish species, three traps were placed upstream from each bridge crossing and checked weekly. Traps were purchased from Trapper Arne's of Payson, AZ (Figure 6). They measured 45.72 cm by 24.13 cm. A mesh funnel entrance attached on each end prohibited crayfish from exiting the traps once they entered. A side door allowed for access to crayfish. Each trap was baited with a small can of cat food with three holes punched in the top. Traps were tethered by parachute rope and secured to stream banks by tying them to roots along undercut banks, snags, or structures on the shore. Species, gender, and carapace length were recorded for each captured specimen. Because of lack of availability and cost of marking equipment, captured specimens were marked with red fingernail polish and released back into the stream.

Figure 6. Crayfish Trap (Trapper Arne's 2008)



The number of trapped specimens was tabulated monthly for consistency and compared across species and replicates. Captures were graphed monthly by total number captured, gender, and species. Average carapace lengths of both males and females were calculated.

RESULTS

The goal of this study was to compare the habitat characteristics and seasonal activities of the three species of subgenus *Pennides* found living in Marion County, GA: *Procambarus gibbus, P. versutus, and P. spiculifer,* and to determine if any of the habitat attributes measured can account for the existence, in such close proximity, of these three sister species and to assess the current conservation status of each.

Stream morphology characteristics of habitat exhibited variation across species but were not significantly different (Table 2). *Procambarus gibbus* habitat exhibited the highest in average maximum stream depth (0.48m), stream width (7.54m) and floodplain width (15.2m) and had lowest water flow velocity (0.18m). *Procambarus versutus* habitat had the narrowest steam width (5.72m) and floodplain width (7.97m) and highest water flow velocity (0.31m/s). *Procambarus spiculifer* habitat was the shallowest (0.24m) with average stream width (6.83 m), floodplain width (14.5 m) and flow velocity (0.28 m/s) between those of its sister species.

Table 2. Mean Comparison of Stream Morphology by Crayfish Species

Crayfish	Ave. Depth (m)	Ave. Width (m)	Est. Floodplain (m)	Velocity (m/s)
P. gibbus	0.48	7.54	15.2	0.18
P. spiculifer	0.24	6.83	14.5	0.28
P. versutus	0.39	5.72	7.97	0.31

Substrate differences, considering gravel, coarse sand and fine sand were significant between the habitat of *P. gibbus* and those of both *P. spiculifer* and *P. versutus*. *Procambarus gibbus* habitat had higher percentages of gravel (6.24%) and coarse sand (15.28%) and lower percentages of fine sand (78.21%) than either *P. spiculifer* or *P. versutus* habitat (Table 3). *Procambarus spiculifer* substrate measurements were similar to *P. versutus* with *P. spiculifer* levels measured at 0.70% gravel, 3.01% coarse sand and 95.88% fine sand; compared to 0.07% gravel, 1.92% coarse sand, and 97.98% fine sand for *P. versutus*.

Clay and silt were more abundant in *P. spiculifer* habitats (0.41%) than in either *P. gibbus* (0.27%) or *P. versutus* (0.03%) sites but differences were not significant.

Procambarus gibbus habitat had higher concentrations of dissolved solids (0.014%) than either *P. spiculifer* (0.006%) or *P. versutus* (0.006%) (Table 3).

Table 3. Creek Bed Substrate and Sediment Load by Crayfish Species

Crayfish	% Gravel	% Coarse Sand	%Fine Sand	% Clay & Silt	% Sediment Load
P. gibbus	6.24	15.28	78.21	0.27	0.014
P. spiculifer	0.70	3.01	95.88	0.41	0.006
P. versutus	0.07	1.92	97.98	0.03	0.006

Water temperature and dissolved oxygen varied seasonally, but there were no significant differences among the three sets of habitats (Table 4). Mean water temperature was 16.47 °C for *P. gibbus* sites, 16.22 ˚C for *P. spiculifer* and 15.90 °C for *P. versutus*. Mean dissolved oxygen was 9.47 mg/L for *P. gibbus*, 10.19 mg/L for *P. spiculifer* and 10.11 mg/L for *P. versutus*.

Table 4. Yearly Mean of Water Data by Species

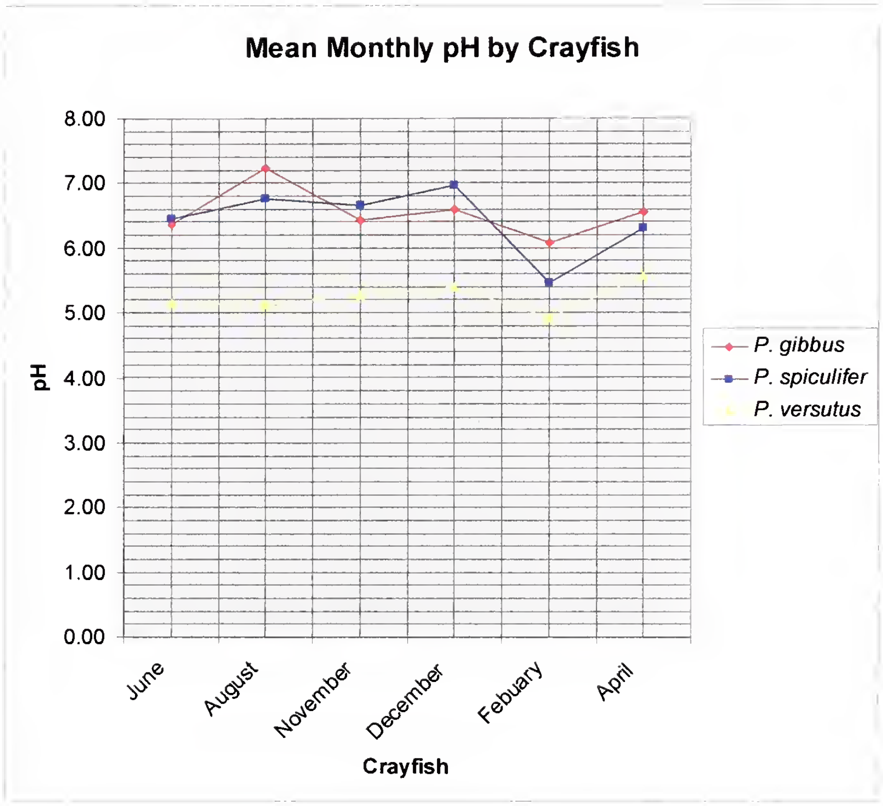
Crayfish	Water Temperature ˚C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTO)
P. gibbus	16.47	0.06	9.47	6.54	21.08
P. spiculifer	16.22	0.03	10.19	6.42	22.70
P. versutus	15.90	0.02	10.11	4.97	6.15

Mean specific conductivity measurement of *P. gibbus* habitat was significantly higher at 0.06 uS/cm than *P. spiculifer* at 0.03 uS/cm or *P. versutus* at 0.02 uS/cm (Table 4). There was no significant difference between *P. spiculifer* and *P. versutus* habitats.

Mean turbidity was significantly lower at *P. versutus* sites (6.15 NTO) than at either *P. gibbus* sites (21.08 NTO) or *P. spiculifer* sites (22.70 NTO) (Table 4). There was no significant difference between *P. gibbus* or *P. spiculifer* habitat.

Mean pH tended to be highest in winter months and lowest in either spring or summer (Figure 7). It was significantly lower at *P. versutus* sites (4.97) than at *P. gibbus* sites (6.54) or *P. spiculifer* sites (6.42) (Table 4). Mean pH was not significant between *P. gibbus* and *P. spiculifer* habitat.

Figure 7. Comparison of Mean pH by Crayfish



There were a total of 124 *P. gibbus* specimens collected, 78 *P. spiculifer* specimens and 84 *P. versutus* specimens (Table 5). For each species, more males were captured than females, most especially during summer months (Table 6). *Procambarus gibbus* and *P. versutus* male to female ratios were 3:1. *Procambarus spiculifer* sex ratio was 2:1.

Table 5. Crayfish Collection by Species and Gender

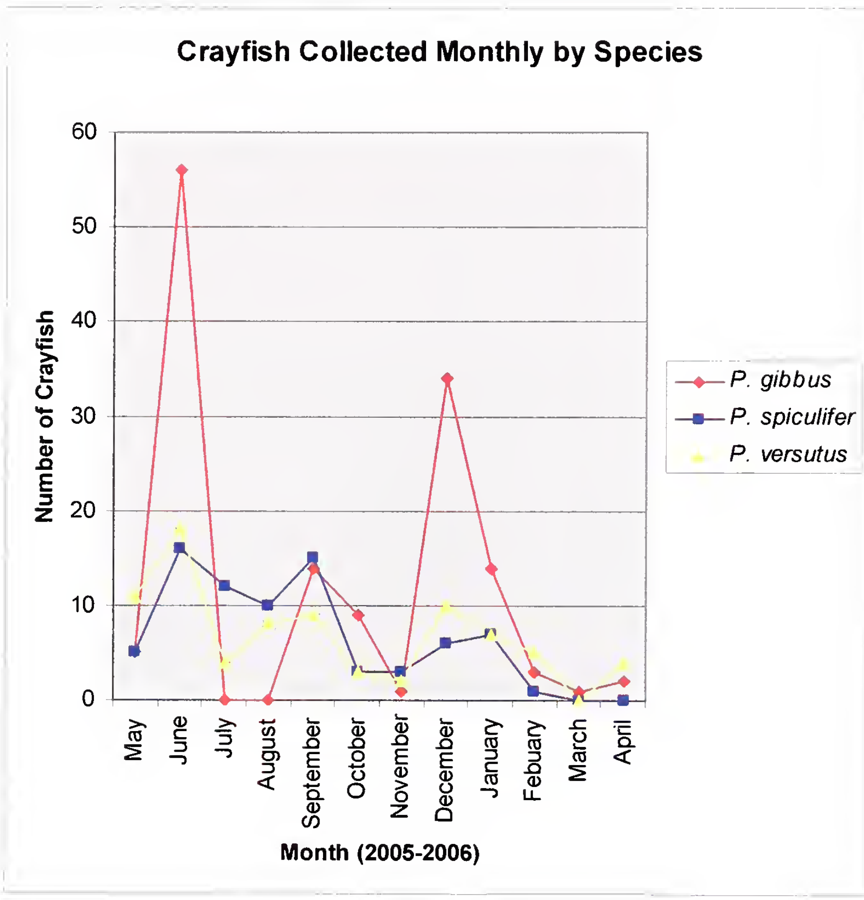
Crayfish	Males	Females	Total
P. gibbus	96	28	124
P. spiculifer	57	24	78
P. versutus	62	21	84

Table 6. Crayfish Collection by Month

Month	*P. gibbus*	*P. spiculifer*	*P. versutus*
May 2005	7	5	11
June 2005	56	16	18
July 2005	0	12	7
August 2005	0	10	4
September 2005	4	15	9
October 2005	9	3	3
November 2005	1	3	2
December 2005	25	6	10
January 2006	14	7	7
February 2006	3	1	4
March 2006	1	0	0
April 2006	4	3	8
Total	124	81	83

Procambarus gibbus captures were higher during June and December while *P. spiculifer* were highest during the period from June through September. *Procambarus versutus* was collected during every month of the year except March (Table 6, Figure 8).

Figure 8. Monthly Crayfish Collection by Species; red = *P. gibbus*, blue = *P. spiculifer*, yellow = *P. versutus*.



DISCUSSION

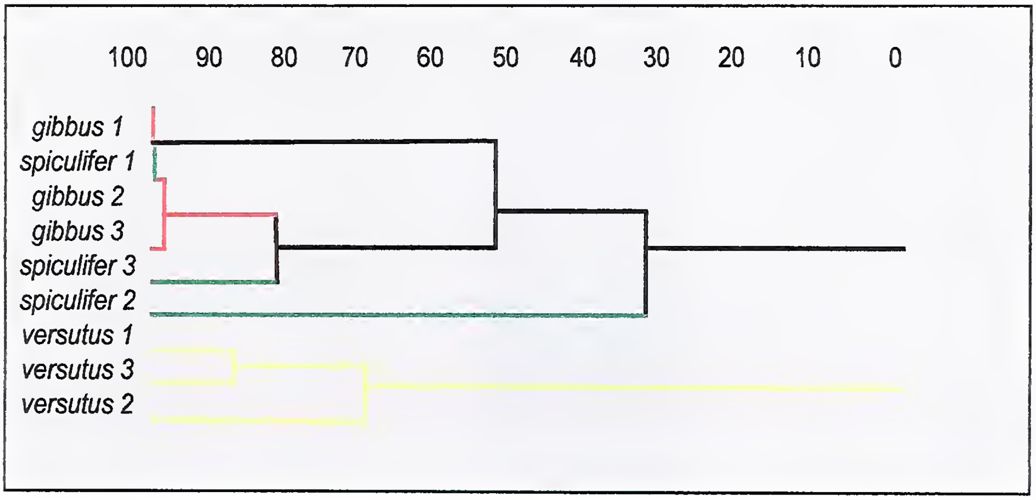
Of the habitat attributes measured, *Procambarus gibbus* habitat was significantly different from the habitats of the other two species in three cases, and those of *P. versutus* were significantly different in two cases. *P. spiculifer* habitats never displayed unique characteristics.

Table 7. Results of Statistical Analysis of Data by Species

Habitat Attribute	*Procambarus gibbus* Habitat	*Procambarus spiculifer* Habitat	*Procambarus versutus* Habitat
Geology	Ocala limestone	Ripley & Other	Eutaw & Bluffton
Stream Morphology	No significant difference	No significant difference	No significant difference
Stream Substrate Gravel Fine Sane	 Significantly more Significantly more	 Significantly less Significantly less	 Significantly less Significantly less
Water Temperature	No significant difference	No significant difference	No significant difference
Water Conductivity	Significantly higher	Significantly lower	Significantly lower
Turbidity	Significantly higher	Significantly higher	Significantly lower
pH	Significantly higher	Significantly higher	Significantly lower

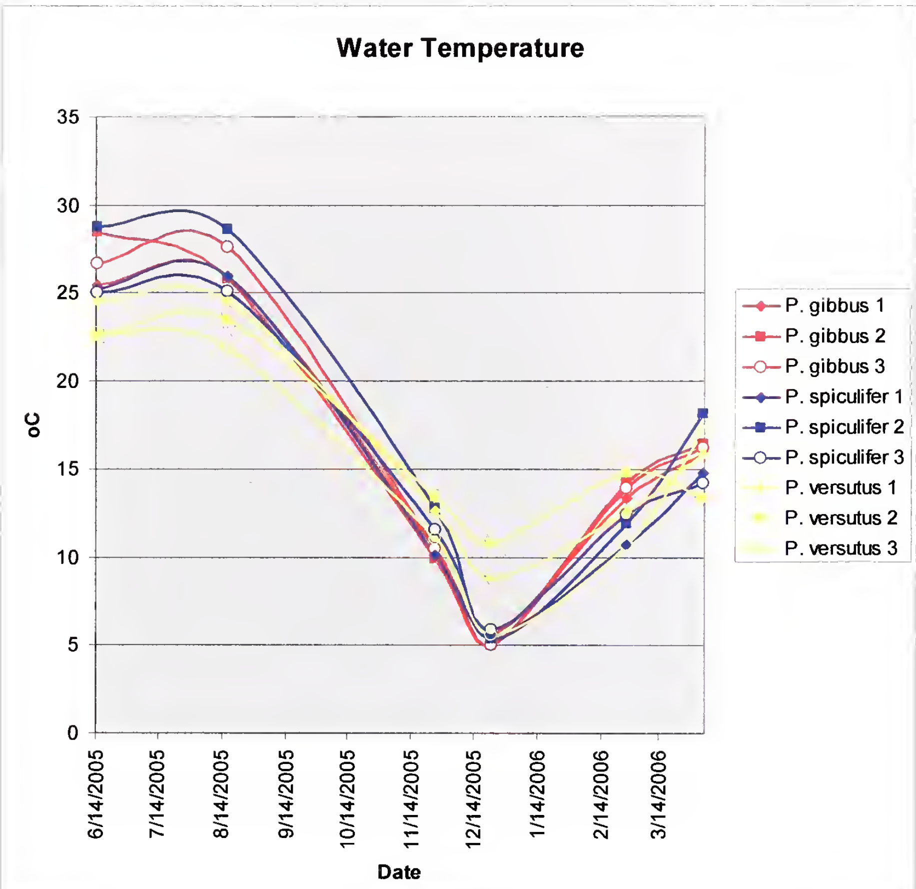
To further assess the relatedness of the nine study sites, a cluster analysis was constructed based upon water habitat attributes from bimonthly measurements of temperature, dissolved oxygen, specific conductivity, turbidity and pH (Figure 9). It indicated that the three sites inhabited by *P. versutus* were clustered together and clearly unrelated to the other six sites. Sites inhabited by *P. gibbus* and *P. spiculifer* did not clearly segregate. The lower Lanahassee Creek site (*P. spiculifer* 1) was quite similar to the first Muckalee Creek site (*P. gibbus* 1). The second and third Muckalee Creek sites (*P. gibbus* 2 & *P. gibbus* 3) were quite similar and they were most closely allied with the Kinchafoonee Creek site (*P. spiculifer* 3). The upper Lanahassee Creek site (*P. spiculifer* 2) was the most dissimilar of all the sites, but it clustered more with *P. gibbus* and *P. spiculifer* sites than it did with *P. versutus* sites.

Figure 9. Cluster Analysis of Relatedness Based on Bimonthly Water Testing; red = *P. gibbus*, green = *P. spiculifer*, yellow = *P. versutus*



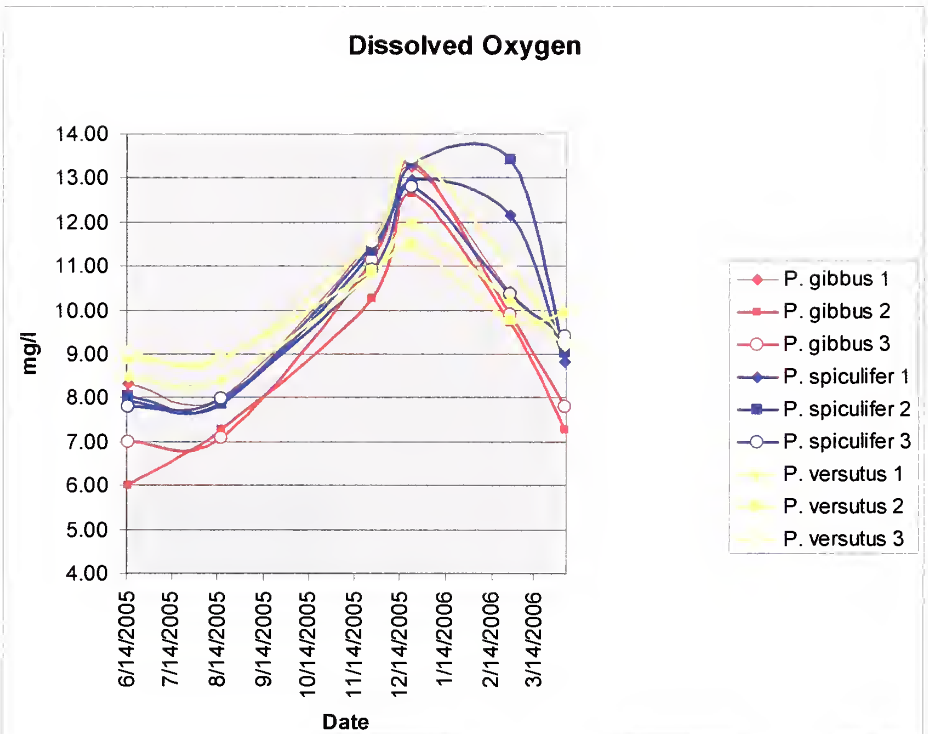
Although water temperatures in *P. versutus* study sites did not fluctuate as much as water temperature in the other two species' sites, temperature varies less in the *P. versutus* habitats. Water temperatures at Pine Knot Creek (*P. versutus* 1) and Juniper Creek (*P. versutus* 2) tended to be lower in summer and higher in winter than those at study sites inhabited by the other two species (Figure 10). Black Creek (*P. versutus* 3) also had low summer temperatures but its winter temperatures were similar to the other six study sites.

Figure 10. Bimonthly Water Temperature by Site: red = *P. gibbus,* blue = *P. spiculifer*, and yellow = *P. versutus*



Although annual mean temperatures did not vary significantly among the three habitats, during summer months, study sites did segregate by their oxygen content. Mean dissolved oxygen levels were lowest in *P. gibbus* streams and highest in *P. versutus* streams. Oxygen levels in both *P. spiculifer* 1 and *P. spiculifer* 2 (Lanahassee tributary sites) remained relatively high during winter months from December to February compared to the other seven study sites. Oxygen levels in *P. versutus* streams remained the most consistent throughout the testing period (Figure 11).

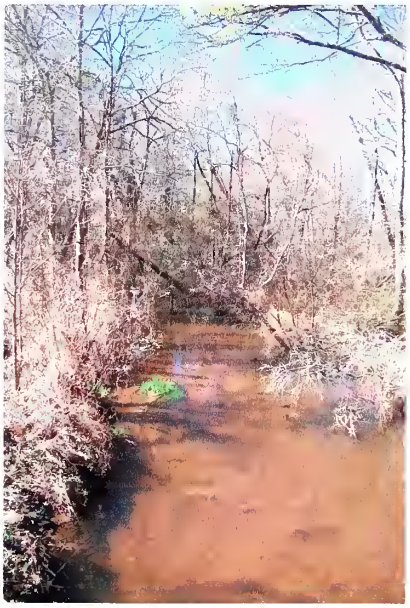
Figure 11. Bimonthly Dissolved Oxygen by Site; red = *P. gibbus*, blue = *P. spiculifer*, yellow = *P. versutus*



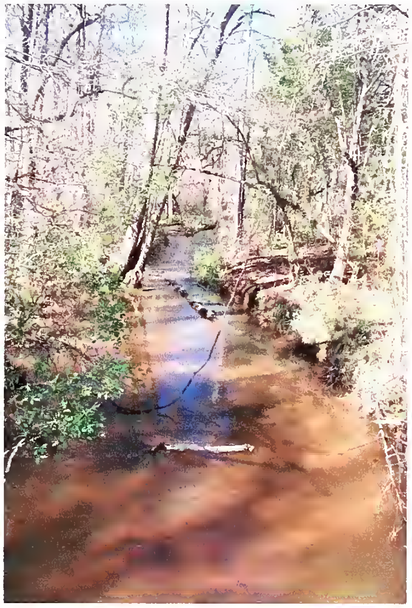
With the onset of summer heat, oxygen often becomes a limiting factor in shallow streams. In looking for differences that may have influenced the distribution of *P. gibbus* and *P. spiculifer*, it might be profitable to compare the tolerance of each species to low levels of oxygen. Although oxygen deprivation tolerance is variable among crayfish, *Pennides* species tend to live in relatively oxygen rich waters. It may be that *P. gibbus* is more tolerant of lower dissolved oxygen levels, possibly allowing it to survive in streams where *P. spiculifer* cannot, or there may be an unknown factor within Muckalee Creek that allows for *P. gibbus* survival at lower oxygen levels.

Specific conductivity remained relatively consistent with the exception of two sites that had large fluctuations in their measured values (Figure 13). Muckalee Creek (*P. gibbus* 1) had its high measured at 0.1328 μS/cm and low at 0.0688 μS/cm. Lower Lanahassee Creek (*P. spiculifer* 1)) fluctuated between a high measured at 0.0578 μS/cm and low measured at 0.0009 μS/cm. The two sites are not connected in any way but were found to be the most related of any of the nine sites from the cluster analysis. Even the appearance of the two sites was very similar (Figure 12).

Figure 12. Picture Comparison of *P. gibbus* 1 and *P. spiculifer* 1 Study Sites

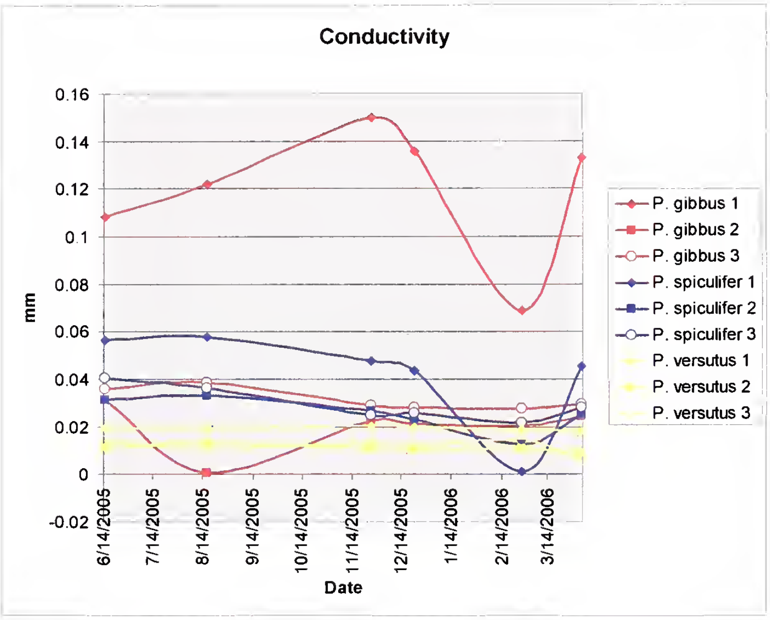


P. gibbus 1



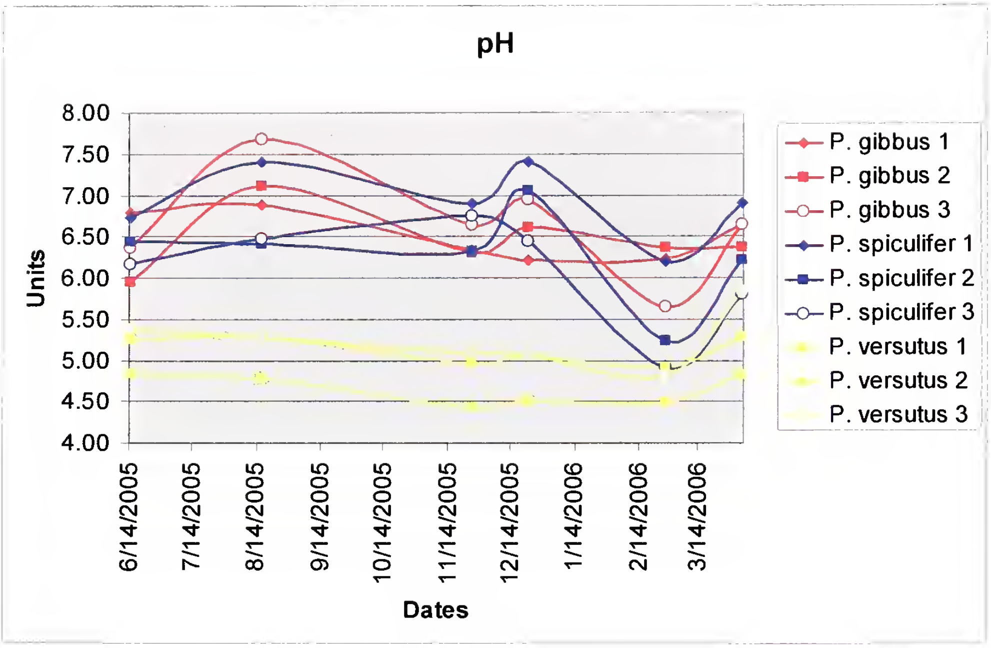
P. spiculifer 1

Figure 13. Bimonthly Specific Conductivity by Site; red = *P. gibbus*, blue = *P. spiculifer*, yellow = *P. versutus*



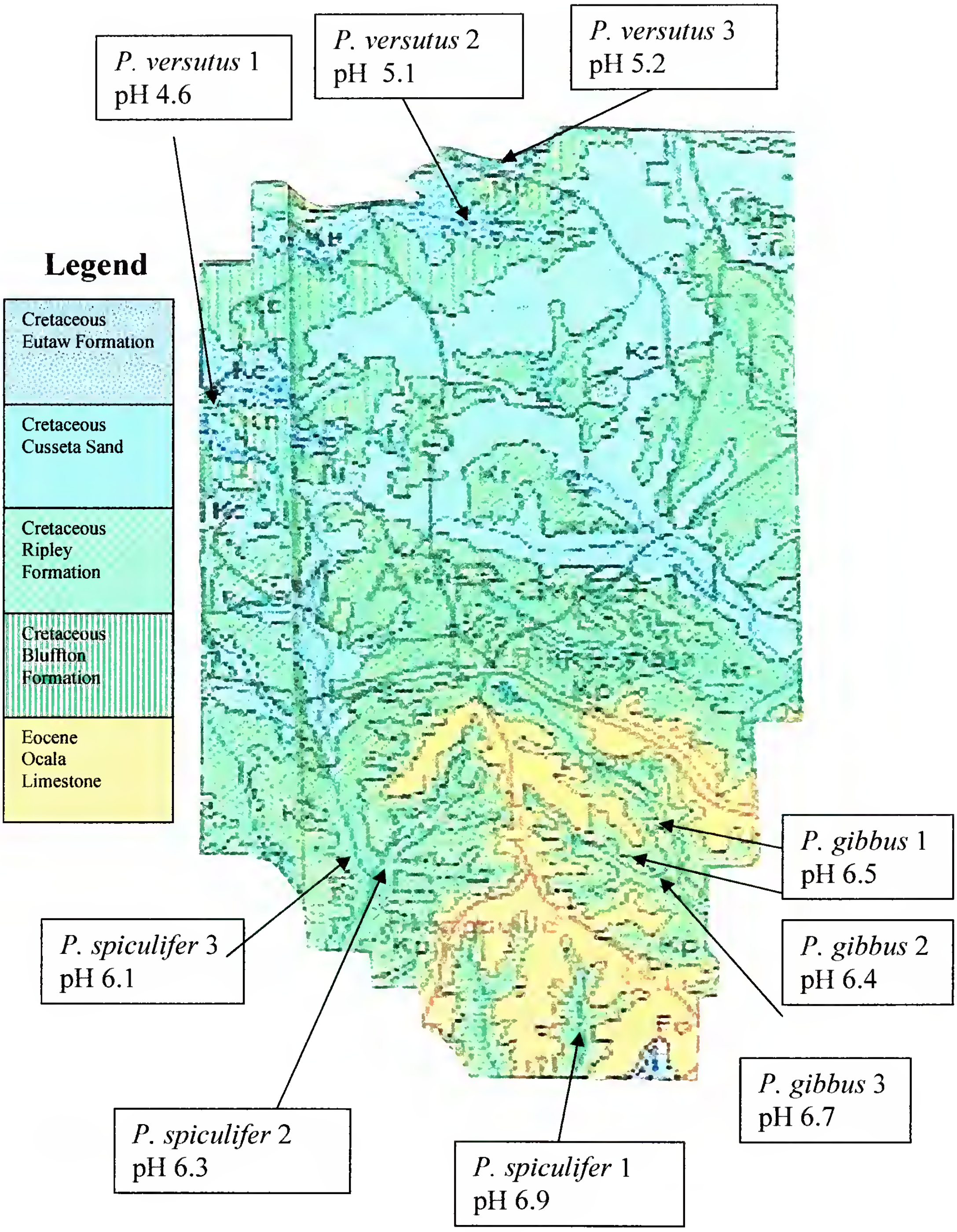
Mean pH was a dividing factor between habitats of *P. versutus* and the other two species of crayfish (Figure 14). Mean pH of *P. versutus* habitat was 4.97 compared to 6.43 for *P. spiculifer* habitat and 6.53 for *P. gibbus* habitat.

Figure 14. Bimonthly pH by Site; red = *P. gibbus*, blue = *P. spiculifer*, yellow = *P. versutus*.



Placing mean pH of each study site on a Marion County map indicated a general tendency for pH levels to be highest in upper western streams in Marion County and decreased as a progression was made to the southeastern corner. When compared with a map of geological deposits, this trend coincided with geological deposits of sand in northern sections of the county and limestone in southeastern portions of the county (Figure 15).

Figure 15. Mean pH Distributions by Creek Site and Geological Deposits in Marion County (Cochran).



Historically, *P. spiculifer* has been considered to be a larger crayfish than *P. gibbus*. In *The Crayfishes of Georgia* (Hobbs 1981) the largest *P. gibbus* was a male with the carapace length measured at 48.7 mm but this study yielded 33 of the 124 specimens captured with greater carapace lengths; the largest specimen measuring 60.8 mm. *Procambarus spiculifer* specimens were smaller than those recorded by Hobbs. At that time the largest Georgia specimen was a male of 70.4 mm (From 2824 GA specimens) but the largest recorded in this study was 58.5 mm. This difference may be accounted for by the small size of our collection or its limited range of only three sites in Marion County. The larger size of *P. gibbus* and the smaller size of *P. spiculifer* may indicate that *P. gibbus* is not a smaller species of crayfish than *P. spiculifer*.

Most crayfish captured were in June, the first complete month of the study. The following June traps were checked again to see if this trend would be repeated, but only a few specimens were captured. It cannot be determined if crayfish were learning to avoid traps or if changes in capture numbers were related to rainfall, seasonal migration or other factors.

Two other species of crayfishes were collected at various times during this study. *Cambarus diogenes* was collected in March at *P. gibbus* 1. After further research into *The Crayfishes of Georgia* (Hobbs 1981), it was learned that *C. diogenes*, considered to be a primary burrower, is sometimes common in streams during spring when searching for a mate.

Cambarus latimanus was collected from late November through February at *P. versutus* 1 (Pine Knot Creek) and *P. versutus 3* (Black Creek). Although it was only collected during cooler temperatures in this study, Stanton (Stanton and Lopez 1982, Stanton 2006) collected it with *P. versutus* on several occasions in Pine Knot and Juniper creeks during warmer months.

Although healthy populations of *P. gibbus* were found within stream reaches of this study, its conservation status should still be one of special concern since it seems to be restricted to one stream system and it was not present in all sites sampled by Stanton (2006). Stanton's sampling found populations of *P. gibbus* in Muckalee headwaters north of Americus and in Muckaloochee Creek and its tributaries south of Americus. He did not find *P. gibbus* in eastern Muckalee tributaries south of Americus. It also appears that it has been extirpated from the indicated type locality on HWY 19 just north of Americus. The common element in sites where *P. gibbus* was not found appears to be anthropogenic changes that resulted in decreased water velocity flow and siltation. Two historical sites, one in Baker County and the other in Crawford County were not sampled during this study. Additional sampling of these sites, where individual populations of *P. gibbus* were recorded in the 1970's (Hobbs 1981), may shed additional information concerning its conservation, habitat and life history. However, Stanton (2006) has concluded that efforts to protect *P. gibbus* should focus on the Muckalee Creek watershed.

Hobbs (1981) stated that *P. spiculifer* was *P. gibbus'* closest ally. First *P. gibbus* specimens were identified as *P. spiculifer* variations. This study indicated that the two species not only look similar but their habitat attributes are also somewhat similar, differing in the turbidity, conductivity, gravel substrate, and course sand substrate. Identification between the two can only be made by comparison of secondary sex characteristics between first form males. Recently developed techniques for genetic analysis may allow for comparison of genomes and further verify the relationship between *P. gibbus* and *P. spiculifer*. It would be valuable for someone to use molecular analyses to evaluate the relatedness of these three species, and especially *P. gibbus* and *P. spiculifer.*

Procambarus versutus has long been established as being unique to sandy, low pH tributaries from the Mobile River drainage in Alabama eastward to the Chattahoochee-Apalachicola drainage in Alabama, Florida and Georgia (Hobbs 1981). In Georgia this consists of three streams; Pine Knot Creek, Juniper Creek and Oswichee Creek (Stanton 2006). Results from this study indicate intact populations in Pine Knot Creek, its tributary Black Creek and Juniper Creek, but Stanton (2006) has been unable to collect any specimens from Oswichee Creek in recent years, leading him to conclude the demise of populations from that location.

Results from this study, along with Stanton's 26 year sampling of crayfish in this area of the state lead him to recommend both *P. gibbus* and *P. versutus* for consideration as candidates for protection in Georgia (Stanton 2006). The degree of protection provided by the addition of these two species to the Protected Species List recognizes uniqueness of both habitat and species. *Procambarus gibbus'* status is listed as "threatened" which establishes it as a separate species from *P. spiculifer,* endemic to Muckalee Creek, and that its habitat may be subject to human degradation. *Procambarus versutus*' status is that of "rare" indicating that its habitat is in need of protection because of its scarcity. This sets the stage for future more in depth protection of areas of their habitat, although this will most likely be challenged as the state continues to grow and land is cleared.

Results of this current study have extended our knowledge of both conservation status and ecology regarding *Procambarus gibbus, Procambarus spiculifer* and *Procambarus versutus* and it has supported the recommendation of *P. gibbus* and *P. versutus* to Georgia's protected species list. Future studies should continue to investigate the relationship between these sister species and unique variations in their environments.

REFERENCES

Beck, K. C., Reuter, J.H., and Perdue, E.M. 1974. Organic and inorganic geochemistry of some coastal plain rivers of the southeastern United States. Geochimica et Cosmoshimica Acta 38:341-364.

Berrill, M., Hollett, L., Margosian, A., and Hudson, J. 1985. Variation in tolerance to low environmental pH by the crayfish *Orconectes rusticus*, *O. propinquus*, and *Cambarus robustus*. Canadian Journal of Zoology 63:2586-2589.

Blood, E.R. 1986. Biogeochemistry of blackwater Coastal Plain streams. Association of Southeastern Biologist Bulletin 33:60.

Bloxgeaux, P.J. 1969. Soils in Georgia, Bulletin No.662. Athens; Cooperative Extension Service, College of Agriculture, University of Georgia.

Cochran, C. 2007. http://home.att.net/~cochran3/rocks01/ggmndx01.htm>Accessed 2007 Oct 14.

Creed, R.P., and Reed, J.M. 2004. Ecosystem engineering by crayfish in a head water stream community. Journal of North American Bethological Society 23 (2); 224-236.

Environmental Protection Agency. 2004. Ecoregions. <www.epa.gov/wed/pages/ Ecoregions/alga_eco.htm>. Accessed 2004 Oct 5.

Felly, J.D. 1992. Medium-low-gradient streams of the Gulf Coastal Plain. In: Hackney C.T., Adams S.M., and Martin, W.H., editors. Biodiversity of the Southeastern United States: aquatic communities. New York: Wiley and Sons. p 233-269.

Fetzner, J.W. Jr. 2002 Dec 14. Crayfish species by state. <www.crayfish.byu.edu/country pages/state pages/georgia.htm>. Accessed 2004 Aug 17.

Georgia Department of Natural Resources (A). 2004. Natural Heritage Program. <www.georgiawildlife.com.>. Accessed 2004 Oct 20.

Georgia Department of Natural Resources (B). 2004. Comprehensive wildlife conservation strategy. <www.gadnr.org/cwcs/>. Accessed 2004 Dec 15.

Georgia GIS Clearinghouse 2005. <gis1.state.ga.us/login.asp?CookieTest=2>. Assessed 2005 June 12.

Hackney, C.T., and Adams S.M. 1992. Ecological processes in the Southeastern United States aquatic ecosystems. In: Hackney, C.T., Adams S.M., and Martin W.H., editors. Biodiversity of the Southeastern United States: aquatic communities. New York: Wiley and Sons. p. 3-17.

Hobbs, H.H. Jr. 1981. The crayfishes of Georgia. Washington DC: Smithsonian Institution Press. 549 p.

Hobbs, H.H. Jr, and Harl C.W. Jr. 1959. The freshwater decapod crustaceans of the Apalachicola drainage system in Florida, southern Alabama, and Georgia. Bulletin of the Florida Slate Museum 4:145-191.

Isophording, W.C., and Fitzpatrick, J.F. Jr. 1992. Geologic and evolutionary history of drainage systems in the Southeastern United States. In: Biodiversity of the Southeastern United States: aquatic communities. New York: John Wiley and Sons, Inc. p. 19-56.

McMahon, B.R. 2002. Physiological adaptations to environment. In: Holdich DM, editor. Biology of Freshwater Crayfish. Bodmin, Cornwall: MPG Books Ltd. p 327-376.

Momot, W.T. 1995. Redefining the role of crayfish in aquatic ecosystems. Reviews in Fisheries Science 3 (1): 33-63.

Nystrom, P. 2002. Ecology. In: Holdich, D.M., editor. Biology of freshwater crayfish. Oxford: Blackwell Science. P. 192-235.

Ratcliffe, J A, and DeVires, D.R. 2004. The crayfishes (Crustacea: Decapoda) of the Tallapoosa River drainage, Alabama. Southern Naturalist 3(3): 417-430.

Reynolds, J.D. 2002. Growth and Reproduction. In Holdich, D., editor. Biology of Freshwater Crayfish. United Kingdom: Blackwell Science. p. 152-191.

Smock, L.A., Gilinsky, E. 1992, Coastal Plain Blackwater Streams, In: Hackney, C.T., Adams, S.M., and Martin W.H. editors, Biodiversity of the Southeastern United States: aquatic communities: New York, Wiley and Sons, p. 271-313.

Stanton, G.E. 2006. Evaluation of Conservation Status of Six West Georgia, Chattahoochee-flint River Crayfish Species. Report to Georgia Department of Natural Resources, Georgia Natural Heritage Program.

Stanton, G.E., and Lopez, P.T. 1982. Descriptive demography of lotic crayfish (Cambaridae) inhabiting West-Central Georgia tributaries of the Chattahoochee River. Fifty-ninth Annual Meeting of the Georgia Academy of Science 40 (9). Georgia Academy of Science. 40:9.

Statzer, B., Peltret, O., and Tomanova, S. 2003. Crayfish as geomorphic agents and ecosystem engineers; effect of a biomass gradient on base flow and flood-induced transport of gravel and sand in experimental streams. Freshwater Biology 48:147-163.

Taylor CA. 2002. Taxonomy and conservation of native crayfish stocks. In: Holdich, D.M., editor. Biology of freshwater crayfish. Bodmin, Corwall: MPG Books Ltd. p 236-257.

Trapper Arne's 2008. <http://www.trapperarne.com/traps.htm?>. Accessed 2008 May 13.

APPENDIX

Appendix 1. Statistical Results of Multivariate Water Analysis by Species

Multiple Comparisons

LSD

Dependent Variable	(I) Crayfish	(J) Crayfish	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Water Temperature (C)	P gibbus	P spiculifer	.2439	2.50445	.923	-4.7840	5.2718
		P versutus	.5700	2.50445	.821	-4.4579	5.5979
	P spiculifer	P gibbus	-.2439	2.50445	.923	-5.2718	4.7840
		P versutus	.3261	2.50445	.897	-4.7018	5.3540
	P versutus	P gibbus	-.5700	2.50445	.821	-5.5979	4.4579
		P spiculifer	-.3261	2.50445	.897	-5.3540	4.7018
Specific Conductivity	P gibbus	P spiculifer	.0246944*	.00981404	.015	.0049919	.0443969
		P versutus	.0431000*	.00981404	.000	.0233975	.0628025
	P spiculifer	P gibbus	-.0246944*	.00981404	.015	-.0443969	-.0049919
		P versutus	.0184056	.00981404	.066	-.0012969	.0381081
	P versutus	P gibbus	-.0431000*	.00981404	.000	-.0628025	-.0233975
		P spiculifer	-.0184056	.00981404	.066	-.0381081	.0012969
Dissolved Oxygen (mL/L)	P gibbus	P spiculifer	-.7228	.65863	.278	-2.0450	.5995
		P versutus	-.6406	.65863	.335	-1.9628	.6817
	P spiculifer	P gibbus	.7228	.65863	.278	-.5995	2.0450
		P versutus	.0822	.65863	.901	-1.2400	1.4045
	P versutus	P gibbus	.6406	.65863	.335	-.6817	1.9628
		P spiculifer	-.0822	.65863	.901	-1.4045	1.2400
pH	P gibbus	P spiculifer	.1089	.16782	.519	-.2280	.4458
		P versutus	1.5372*	.16782	.000	1.2003	1.8741
	P spiculifer	P gibbus	-.1089	.16782	.519	-.4458	.2280
		P versutus	1.4283*	.16782	.000	1.0914	1.7652
	P versutus	P gibbus	-1.5372*	.16782	.000	-1.8741	-1.2003
		P spiculifer	-1.4283*	.16782	.000	-1.7652	-1.0914
Turbidity (NTO)	P gibbus	P spiculifer	-1.617	4.3870	.714	-10.424	7.191
		P versutus	14.928*	4.3870	.001	6.120	23.735
	P spiculifer	P gibbus	1.617	4.3870	.714	-7.191	10.424
		P versutus	16.544*	4.3870	.000	7.737	25.352
	P versutus	P gibbus	-14.928*	4.3870	.001	-23.735	-6.120
		P spiculifer	-16.544*	4.3870	.000	-25.352	-7.737

Based on observed means.

*. The mean difference is significant at the .05 level.

Appendix 2. Creek Bed Substrate and Sediment Load by Study Site

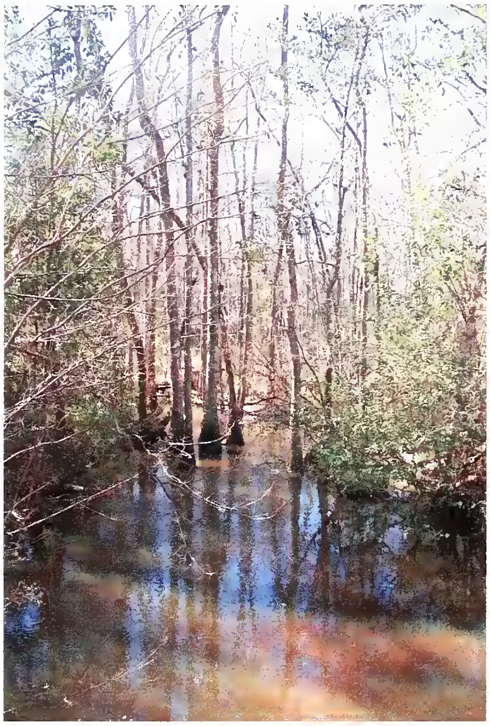
Site	% Gravel	% Coarse Sand	% Fine Sand	% Clay & Silt	% Sediment
P. gibbus 1	3.84	16.09	79.98	0.09	0.020
P. gibbus 2	4.85	12.11	82.99	0.05	0.010
P. gibbus 3	10.04	17.63	71.66	0.67	0.011
P. spiculifer 1	0.69	6.40	92.90	0.01	0.006
P. spiculifer 2	0.81	2.40	96.56	0.23	0.005
P. spiculifer 3	0.61	0.24	98.16	0.99	0.008
P. versutus 1	0.02	1.10	98.87	0.01	0.005
P. versutus 2	0	0.30	99.65	0.05	0.005
P. versutus 3	0.18	4.37	95.41	0.04	0.005

Appendix 3. Pictures of Study Sites in Marion County.

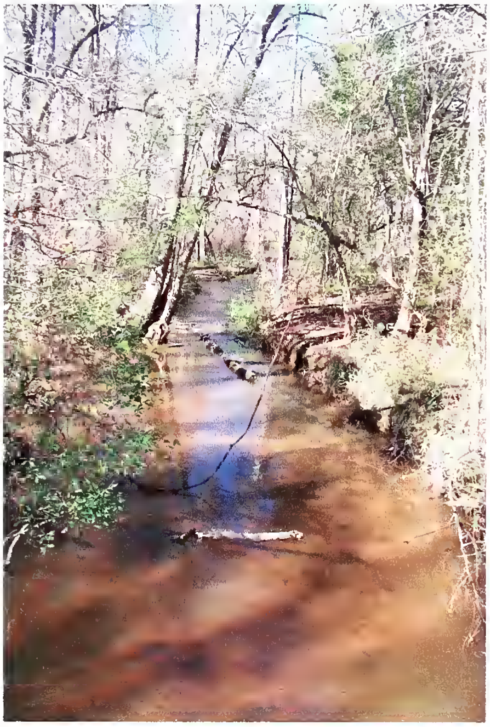
3a. *Procambarus gibbus* 1 (Muckalee Creek at Mt. Zion Road)

3b. *Procambarus gibbus* 2 (Muckalee Creek at Powell Road)

3c. *Procambarus gibbus* 3 (Muckalee Creek at Mt. Carmel Road)



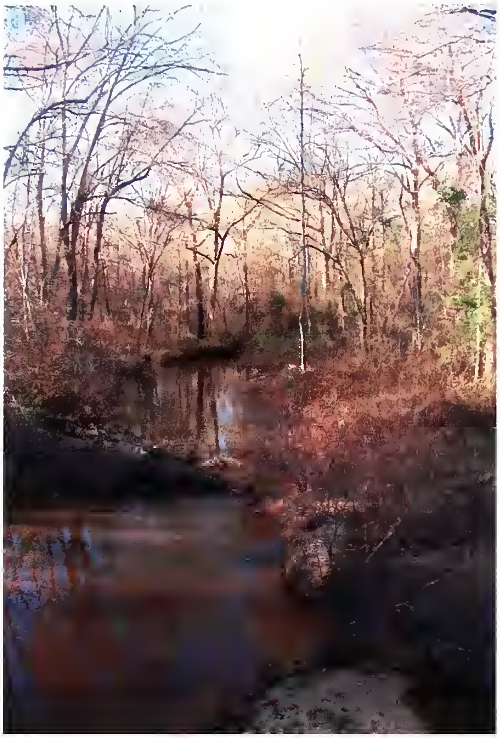
3d. *Procambarus spiculifer* 1 (Lanahassee Creek at Bill Merritt Road)



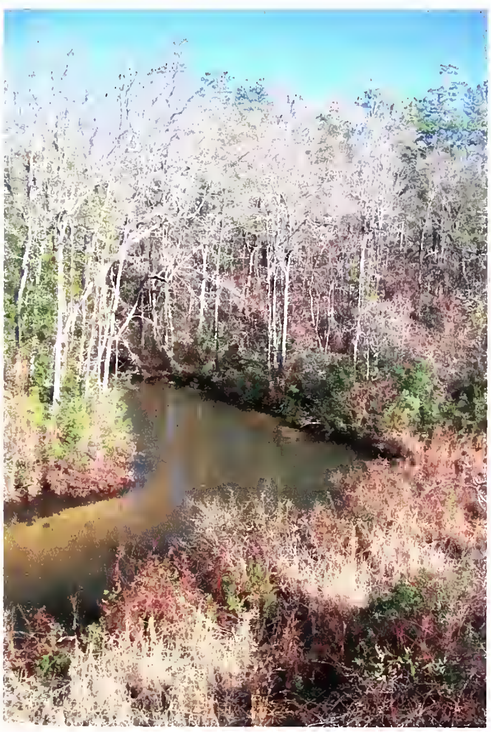
3e. *Procambarus spiculifer* 2 (Lanahassee Creek at Mill Pond Road)

3f. *Procambarus spiculifer* 2 (Pond and Dam)

3g. *Procambarus spiculifer* 3 (Kinchafoonee Creek at Pineview Road)



3h. *Procambarus versutus* 1 (Pine Knot Creek at HWY 355)



3i. *Procambarus versutus* 2 (Juniper Creek at Anthony Road)

3j. *Procambarus versutus* 3 (Black Creek at HWY 240)

Appendix 4. Monthly Crayfish Collection by Species and Gender

Crayfish	Month	Males	Females
P. gibbus	May	4	3
	June	45	11
	July	0	0
	August	0	0
	September	2	2
	October	9	0
	November	0	1
	December	22	3
	January	9	5
	February	1	2
	March	1	0
	April	3	1
Total		96	28
P. spiculifer	May	4	1
	June	12	4
	July	11	1
	August	7	3
	September	9	6
	October	1	2
	November	2	1
	December	5	1
	January	3	4
	February	1	0
	March	0	0
	April	2	1
Total		57	24
P. versutus	May	6	5
	June	16	2
	July	7	0
	August	4	0
	September	7	2
	October	2	1
	November	2	0
	December	7	3
	January	4	3
	February	2	2
	March	0	0
	April	5	3
Total		62	21

Appendix 5. Bimonthly Water Data by Study Site

Site	Creek ID	Date	Water Temperature (C)	Specific Conductivity (μS/cm)	Dissolved Oxygen (ml/L)	pH	Turbidity (NTO)
P. gibbus 1	Muckalee Creek at Mt. Zion Rd.	June 2005	25.47	0.1083	8.33	6.80	13.2
		Aug 2005	25.96	0.1218	8.02	6.89	76.2
		Nov 2005	10.49	0.1497	11.59	6.33	12.7
		Dec 2005	5.61	0.1358	13.25	6.22	7.6
		Feb 2006	13.31	0.0688	10.42	6.23	29.7
		April 2006	15.84	0.1328	9.38	6.64	17.1
P. gibbus 2	Muckalee Creek at Frank Powel Rd.	June 2005	28.45	0.0315	6.01	5.96	16.2
		Aug 2005	25.83	0.0006	7.28	7.11	18.3
		9/5/2005	21.9	0.0265	5.43	5.96	16.8
		Nov 2005	9.9	0.0226	10.28	6.30	5.2
		Dec 2005	5.03	0.0211	12.64	6.61	10.2
		Feb 2006	14.17	0.0203	9.71	6.36	48.9
		April 2006	16.43	0.0243	7.26	6.36	26.4
P. gibbus 3	Muckalee Creek at Mt. Carmel Rd.	June 2005	26.71	0.0359	6.99	6.37	13.9
		Aug 2005	27.61	0.0388	7.09	7.68	21.3
		Nov 2005	10.48	0.0291	11.13	6.64	8.9
		Dec 2005	4.99	0.0279	13.38	6.94	1.9
		Feb 2006	13.91	0.0278	9.90	5.65	12.6
		April 2006	16.21	0.0294	7.81	6.64	39.1
P. spiculifer 1	Lanahassee Creek at Bill Merritt Rd.	June 2005	25.23	0.0567	7.91	6.73	35.1
		Aug 2005	25.93	0.0578	7.88	7.40	32.4
		Nov 2005	10.11	0.0477	11.46	6.90	12.4
		Dec 2005	5.5	0.0437	12.96	7.41	7.6
		Feb 2006	10.72	0.0009	12.16	6.20	20.0
		April 2006	14.79	0.0454	8.82	6.90	38.6
P. spiculifer 2	Lanahassee Creek at Mill Creek Rd.	June 2005	28.77	0.0314	8.03	6.45	24.4
		Aug 2005	28.62	0.0331	7.86	6.41	17.0
		Nov 2005	12.75	0.0266	11.35	6.32	11.6
		Dec 2005	5.38	0.023	13.32	7.06	1.0
		Feb 2006	11.93	0.0125	13.40	5.24	14.3
		April 2006	18.14	0.0254	9.04	6.21	30.5
P. spiculifer 3	Kinchafoonee Creek at Pineview Rd.	June 2005	25.01	0.0404	7.81	6.17	42.6
		Aug 2005	25.07	0.0364	7.98	6.47	41.2

		Nov 2005	11.53	0.025	10.92	6.75	12.2
		Dec 2005	5.9	0.0258	12.81	6.44	9.1
		Feb 2006	12.4	0.0219	10.36	4.91	23.4
		April 2006	14.23	0.0283	9.41	5.80	35.1
P. versutus 1	Pine Knot Creek at HWY 355	June 2005	24.53	0.0192	8.47	4.84	6.8
		Aug 2005	24.56	0.0194	8.39	4.78	4.1
		Nov 2005	12.63	0.0203	10.81	4.42	2.2
		Dec 2005	8.75	0.0198	11.97	4.50	0.7
		Feb 2006	12.53	0.0191	10.19	4.49	1.9
		April 2006	15.83	0.0178	9.20	4.82	19.8
P. versutus 2	Juniper Creek at Anthony Rd.	June 2005	22.53	0.0112	8.87	5.25	4.4
		Aug 2005	23.42	0.0134	8.90	5.28	15.2
		Nov 2005	13.41	0.0108	10.88	4.96	8.9
		Dec 2005	10.75	0.0104	11.48	5.06	2.2
		Feb 2006	14.76	0.0105	9.77	4.91	3.7
		April 2006	13.36	0.009	9.92	5.29	9.3
P. versutus 3	Black Creek at HYW 240	June 2005	22.77	0.0137	9.02	5.38	11.2
		Aug 2005	21.84	0.0111	8.86	5.29	5.5
		Nov 2005	11.08	0.013	11.56	5.08	3.7
		Dec 2005	5.57	0.0121	13.49	5.07	2.9
		Feb 2006	10.7	0.0143	10.96	4.81	2.9
		April 2006	17.12	0.0056	9.26	5.83	5.3

Appendix 6. Crayfish Collections by Study Site

6a. Crayfish Collected at *P. gibbus* 1 (Site 1-Muckalee Creek and Mt. Zion Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2505	2005	1	P. gibbus	Female	1.55
2505	2005	2	P. gibbus	Male	1.93
2505	2005	3	P. gibbus	Male	1.89
2406	2005	1	P. gibbus	Male	3.91
2406	2005	2	P. gibbus	Female	4.51
2406	2005	3	P. gibbus	Male	3.73
2406	2005	4	P. gibbus	Male	4.13
2406	2005	5	P. gibbus	Male	5.1
2406	2005	6	P. gibbus	Male	4.15
2406	2005	7	P. gibbus	Female	3.96
2406	2005	8	P. gibbus	Female	3.58
2406	2005	9	P. gibbus	Female	4.42
2406	2005	10	P. gibbus	Male	4.4
2406	2005	11	P. gibbus	Male	4.43
2406	2005	12	P. gibbus	Male	5
2406	2005	13	P. gibbus	Female	4.23
2406	2005	14	P. gibbus	Male	4.87
2406	2005	15	P. gibbus	Male	4.46
2406	2005	16	P. gibbus	Male	4.37
2406	2005	17	P. gibbus	Male	4.25
2406	2005	18	P. gibbus	Male	4.19
2406	2005	19	P. gibbus	Male	4.32
2406	2005	20	P. gibbus	Male	4.08
2406	2005	21	P. gibbus	Female	3.89
2606	2005	1	P. gibbus	male	4.14
2606	2005	2	P. gibbus	male	5.05
2606	2005	3	P. gibbus	male	4.24
2606	2005	4	P. gibbus	male	4.68
2606	2005	5	P. gibbus	female	3.98
2606	2005	6	P. gibbus	male	4.88
2606	2005	7	P. gibbus	female	4.45
2606	2005	8	P. gibbus	male	3.56
2606	2005	9	P. gibbus	male	5.09
2606	2005	10	P. gibbus	male	5.78
2606	2005	11	P. gibbus	male	4.46
2606	2005	12	P. gibbus	male	5.15
2606	2005	13	P. gibbus	female	4.02
2606	2005	14	P. gibbus	male	4.77
2606	2005	15	P. gibbus	male	4.54
2606	2005	16	P. gibbus	male	4.68
2606	2005	17	P. gibbus	male	4.89

2606	2005	18	P. gibbus	male	4.97
2606	2005	19	P. gibbus	male	4.49
2606	2005	20	P. gibbus	male	4.79
2606	2005	21	P. gibbus	male	5.01
2606	2005	22	P. gibbus	male	5.25
2706	2005	1	P. gibbus	male	4.45
2706	2005	2	P. gibbus	male	4.95
2706	2005	3	P. gibbus	male	4.57
2706	2005	4	P. gibbus	male	3.59
2906	2005	1	P. gibbus	male	3.98
2906	2005	2	P. gibbus	male	5.01
2906	2005	3	P. gibbus	female	3.47
2609	2005	1	P. gibbus	female	3.59
2910	2005	1	P. gibbus	male	5.19
2511	2005	1	P. gibbus	female	2.9
312	2005	1	P. gibbus	female	3.94
1012	2005	1	P. gibbus	male	5.34
1012	2005	2	P. gibbus	male	4.06
1012	2005	3	P. gibbus	male	4.7
1012	2005	4	P. gibbus	male	4.16
2212	2005	1	P. gibbus	male	4.68
2212	2005	2	P. gibbus	male	5.07
2212	2005	3	P. gibbus	male	4.7
2212	2005	4	P. gibbus	male	4.73
2212	2005	5	P. gibbus	male	4.02
3012	2005	1	P. gibbus	male	3.3
3012	2005	2	P. gibbus	male	2.9
701	2006	1	P. gibbus	female	2.39
7-Jan	2006	2	P. gibbus	female	2.65
1501	2006	1	P. gibbus	male	5.01
1501	2006	2	P. gibbus	male	4.09
1501	2006	3	P. gibbus	female	4.85
1501	2006	4	P. gibbus	female	4.19
2101	2006	1	P. gibbus	male	3.86
2101	2006	2	P. gibbus	male	3.84
402	2006	1	P. gibbus	male	3.69
402	2006	2	P. gibbus	female	4.42
402	2006	3	P. gibbus	female	4.04
1803	2006	1	C. diogenes	male	4.69
1803	2006	2	P. gibbus	male	4.75
404	2006	1	P. gibbus	female	3.4
404	2006	2	P. gibbus	male	4.06
2904	2006	1	P. gibbus	male	2.32
2904	2006	2	P. gibbus	male	3.65

6b. Crayfish Collected at *P. gibbus* 2 (Site 2-Muckalee Creek and Powell Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2505	2005	1	P. gibbus	female	3.08
2505	2005	2	P. gibbus	female	3.07
2505	2005	3	P. gibbus	male	2.59
1409	2005	1	P. gibbus	male	5.14
1409	2005	2	P. gibbus	male	4.46
1409	2005	3	P. gibbus	female	3.91
312	2005	1	P. gibbus	female	4.8
312	2005	2	P. gibbus	male	5.26
312	2005	3	P. gibbus	male	5.52
312	2005	4	P. gibbus	male	5.27
1012	2005	1	P. gibbus	male	5.28
1012	2005	2	P. gibbus	male	5.91
2212	2005	1	P. gibbus	male	5.38
2212	2005	2	P. gibbus	female	4.89
2212	2005	3	P. gibbus	male	4.59
2212	2005	4	P. gibbus	male	5.35
2212	2005	5	P. gibbus	male	4.69
2212	2005	6	P. gibbus	male	5.91 Recapture
1501	2006	1	P. gibbus	male	2.41
1501	2006	2	P. gibbus	male	5.3 Recapture

6c. Crayfish Collected at *P. gibbus* 3 (Site 3-Muckalee Creek and Mt. Carmel Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2505	2005	1	P. gibbus	male	1.74
406	2005	1	P. gibbus	male	2.36
406	2005	2	P. gibbus	male	3.42
406	2005	3	P. gibbus	male	4.42
406	2005	4	P. gibbus	male	2.79
1406	2005	1	P. gibbus	female	1.96
2906	2005	1	P. gibbus	male	5.18
810	2005	1	P. gibbus	male	4.87
810	2005	2	P. gibbus	male	6.08
810	2005	3	P. gibbus	male	6.05
810	2005	4	P. gibbus	male	4.74
810	2005	5	P. gibbus	male	5.02
810	2005	6	P. gibbus	male	5.53
810	2005	7	P. gibbus	male	5.12
2510	2005	1	P. gibbus	male	5.82
312	2005	1	P. gibbus	male	5.82

701	2006	1	P. gibbus	female	3.59
1501	2006	1	P. gibbus	male	2.41
1501	2006	2	P. gibbus	male	5.3
2801	2006	1	P. gibbus	male	5.62

6d. Crayfish Collected at *P. spiculifer* 1 (Site 4-Lanahassee Creek and Bill Merritt Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2605	2005	1	P. spiculifer	Female	2.34
406	2005	1	P. spiculifer	Male	5.25
406	2005	2	P. spiculifer	Male	5.18
406	2005	3	P. spiculifer	Male	4.64
406	2005	4	P. spiculifer	Male	3.92
1406	2005	1	P. spiculifer	Male	3.5
2206	2005	1	P. spiculifer	Male	4.97
2206	2005	2	P. spiculifer	Male	5.59
2206	2005	3	P. spiculifer	Male	5.06
2206	2005	4	P. spiculifer	Male	4.58
2906	2005	1	P. spiculifer	female	4.19
2307	2005	1	P. spiculifer	male	3.56
2307	2005	2	P. spiculifer	male	4.78
2307	2005	3	P. spiculifer	male	5.68
3007	2005	1	P. spiculifer	male	4.79
3007	2005	2	P. spiculifer	male	5.19
3007	2005	3	P. spiculifer	male	5.14
3007	2005	4	P. spiculifer	male	5.6
1008	2005	1	P. spiculifer	male	5.2
1008	2005	2	P. spiculifer	male	5.14
1008	2005	3	P. spiculifer	female	4.37
1008	2005	4	P. spiculifer	male	4.48
1008	2005	5	P. spiculifer	male	5.36
1008	2005	6	P. spiculifer	female	4.46
1008	2005	7	P. spiculifer	male	5
1008	2005	8	P. spiculifer	female	4.23
709	2005	1	P. spiculifer	male	3.48
2910	2005	1	P. spiculifer	female	2.13
1311	2005	1	P. spiculifer	male	5.35
2212	2005	1	P. spiculifer	male	1.91

6e. Crayfish Collected at *P. spiculifer* 2 (Site 5-Lanahassee Creek and Mill Pond Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length cm
506	2005	1	P. spiculifer	male	5.52
506	2005	2	P. spiculifer	male	5.05
506	2005	3	P. spiculifer	male	5.09
506	2005	4	P. spiculifer	male	4.06
2906	2005	1	P. spiculifer	female	2.63
2906	2005	2	P. spiculifer	female	3.98
2906	2005	3	P. spiculifer	male	5.19
2906	2005	4	P. spiculifer	male	4.74
907	2005	1	P. spiculifer	male	5.12
907	2005	2	P. spiculifer	male	5.47
907	2005	3	P. spiculifer	male	4.19
907	2005	4	P. spiculifer	male	4.05
1708	2005	1	P. spiculifer	male	5.54
1708	2005	2	P. spiculifer	male	4.98
709	2005	1	P. spiculifer	male	4.28
709	2005	2	P. spiculifer	female	4.22
709	2005	3	P. spiculifer	female	4.46
709	2005	4	P. spiculifer	male	4.37
1709	2005	1	P. spiculifer	male	4.41
1709	2005	2	P. spiculifer	female	3.96
1709	2005	3	P. spiculifer	male	3.95
1709	2005	4	P. spiculifer	male	5.85
1709	2005	5	P. spiculifer	female	4.3
1709	2005	6	P. spiculifer	male	5.16
1709	2005	7	P. spiculifer	male	5.42
2809	2005	1	P. spiculifer	female	3.57
2809	2005	2	P. spiculifer	female	3.37
2809	2005	3	P. spiculifer	male	2.1
810	2005	1	P. spiculifer	male	5.81
2910	2005	1	P. spiculifer	female	2.87
1311	2005	1	P. spiculifer	female	4.25
2511	2005	1	P. spiculifer	male	2.29
1012	2005	1	P. spiculifer	male	5.66
1012	2005	2	P. spiculifer	male	5.23
1012	2005	3	P. spiculifer	male	5.24
3012	2005	1	P. spiculifer	female	5.08
3012	2005	2	P. spiculifer	male	3.37
701	2006	1	P. spiculifer	female	4.16
701	2006	2	P. spiculifer	female	4.29
701	2006	3	P. spiculifer	female	4.05
701	2006	4	P. spiculifer	female	4.7
1501	2006	1	P. spiculifer	male	3.48
1501	2006	2	P. spiculifer	male	5.16
402	2006	1	P. spiculifer	male	3.06

2904	2006	1	P. spiculifer	male	4.2
2904	2006	2	P. spiculifer	male	4.13

6f. Crayfish Collected at *P. spiculifer* 3 (Site 6-Kinchafoonee Creek and Pineview Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length cm
2406	2005	1	P. spiculifer	male	5.49
2906	2005	1	P. spiculifer	female	3.32
907	2005	1	P. spiculifer	female	4.37
701	2006	1	P. spiculifer	male	2.02
2905	2006	1	P. spiculifer	female	3.57

6g. Crayfish Collected at *P. versutus* 1 (Site 7-Pine Knot Creek and HWY 355)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2605	2005	1	P. versutus	female	2.48
2605	2005	2	P. versutus	female	1.9
2906	2005	1	P. versutus	male	2.92
2511	2005	1	P. versutus	male	3.4
312	2005	1	P. versutus	male	3.16
312	2005	2	P. versutus	female	3.08
1012	2005	1	P. versutus	male	3.48
1012	2005	2	P. versutus	male	2.23
2212	2005	1	P. versutus	female	4.16
2212	2005	2	P. versutus	male	3.1
701	2006	1	P. versutus	male	3.76
701	2006	2	P. versutus	male	3.94
1501	2006	1	P. versutus	female	4.16
2801	2006	1	P. versutus	female	2.9
402	2006	1	P. versutus	female	2.62
406	2006	1	P. versutus	female	3.08
406	2006	2	P. versutus	female	2.58
1305	2006	1	P. versutus	male	2.59
2905	2006	1	P. versutus	male	3.14
106	2006	1	P. versutus	male	3.99
106	2006	2	P. versutus	male	3.69

6h. Crayfish Collected at *P. versutus* 2 (Site 8-Juniper Creek and Anthony Road)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length(cm)
2605	2005	1	P. versutus	female	2.53
2605	2005	2	P. versutus	male	3
2605	2005	3	P. versutus	male	1.79
2605	2005	4	P. versutus	male	1.42
2906	2005	1	P. versutus	male	3.28
2906	2005	2	P. versutus	male	3.23
607	2005	1	P. versutus	male	1.23
607	2005	2	P. versutus	male	3.14
1507	2005	1	P. versutus	male	2.77
1507	2005	2	P. versutus	undetermined	Undetermined
2708	2005	1	P. versutus	male	3.64
1709	2005	1	P. versutus	female	1.91
1709	2005	2	P. versutus	Male	2.2
2801	2006	1	P. versutus	female	2.57
2905	2006	1	P. versutus	Male	3.59

6i. Crayfish Collected at *P. versutus* 3 (Site 9-Black Creek and GA HWY 240)

Day/Month	Year	Specimen #	Species	Sex	Carapace Length (cm)
2605	2005	1	P. versutus	Female	2.35
2605	2005	2	P. versutus	Female	2.06
2605	2005	3	P. versutus	Male	1.58
2605	2005	4	P. versutus	Male	1.34
2605	2005	5	P. versutus	Male	1.19
806	2005	1	P. versutus	Male	3.22
806	2005	2	P. versutus	Male	3.56
806	2005	3	P. versutus	Male	2.23
806	2005	4	P. versutus	Male	1.98
1406	2005	1	P. versutus	Male	3.66
1406	2005	2	P. versutus	Male	3.59
1406	2005	3	P. versutus	Male	4.15
1406	2005	4	P. versutus	Male	3.54
2406	2005	1	P. versutus	Male	3.81
2406	2005	2	P. versutus	Male	2.28
2406	2005	3	P. versutus	Male	3.76
2406	2005	4	P. versutus	Male	3.98
2906	2005	1	P. versutus	Female	2.89
2906	2005	2	P. versutus	Female	3.02
2906	2005	3	P. versutus	Male	3.55
607	2005	1	P. versutus	Male	3.3
607	2005	2	P. versutus	Male	3.29

1507	2005	1	P. versutus	Male	3.61
2307	2005	1	P. versutus	Male	3.9
1308	2005	1	P. versutus	Male	3.9
1308	2005	2	P. versutus	Male	4.16
2708	2005	1	P. versutus	Male	3.66
1709	2005	1	P. versutus	Male	2.89
1709	2005	2	P. versutus	Male	3.95
1709	2005	3	P. versutus	Male	3.44
1709	2005	4	P. versutus	Male	3.69
2609	2005	1	P. versutus	Female	2.2
2609	2005	2	P. versutus	Male	2.85
2609	2005	3	P. versutus	male	3.45
1510	2005	1	P. versutus	female	4.27
1510	2005	2	P. versutus	male	3.94
1510	2005	1	P. versutus	male	3.57
2511	2005	1	P. versutus	male	4.07
2511	2005	2	C. latimantus	female	4.51
2511	2005	3	C. latimantus	female	4.63
312	2005	1	P. versutus	male	3.12
312	2005	2	C. latimantus	female	4.78
1012	2005	1	C. latimantus	female	4.85
1012	2005	2	C. latimantus	female	4.75
1012	2005	3	P. versutus	female	1.99
1012	2005	4	C. latimantus	female	4.2
2212	2005	1	C. latimantus	female	4.09
2212	2005	2	C. latimantus	female	4.58
2212	2005	3	P. versutus	male	3.99
3012	2005	1	C. latimantus	male	3.83
3012	2005	2	P. versutus	male	3.39
701	2006	1	P. versutus	male	3.65
701	2006	2	P. versutus	male	3.95
402	2006	1	C. latimantus	female	4.03
402	2006	2	P. versutus	female	2.94
402	2006	3	P. versutus	male	4.02
402	2006	4	C. latimantus	male	3.55
1102	2006	1	P. versutus	male	2.54
604	2006	1	P. versutus	male	1.92
604	2006	2	P. versutus	male	3.59

2904	2006	1	P. versutus	female	3.28
106	2006	1	P. versutus	male	3.94

Appendix 7. Water Data from June 2005 to April 2006

Site	Month	Water Temperature C	Specific Conductivity	Dissolved Oxygen ML/L	pH	Turbidity NTO
P. gibbus 1	June	25.47	0.1083	8.33	6.80	13.2
	Aug.	25.96	0.1218	8.02	6.89	76.2
	Nov.	10.49	0.1497	11.59	6.33	12.7
	Dec.	5.61	0.1358	13.25	6.22	7.6
	Feb.	13.31	0.0688	10.42	6.23	29.7
	April	15.84	0.1328	9.38	6.64	17.1
P. gibbus 2	June	28.45	0.0315	6.01	5.96	16.2
	Aug.	25.83	0.0265	7.28	7.11	18.3
	Nov.	9.9	0.0226	10.28	6.30	5.2
	Dec.	5.03	0.0211	12.64	6.61	10.2
	Feb.	14.17	0.0203	9.71	6.36	48.9
	April	16.43	0.0243	7.26	6.36	26.4
P. gibbus 3	June	26.71	0.0359	6.99	6.37	13.9
	Aug.	27.61	0.0388	7.09	7.68	21.3
	Nov.	10.48	0.0291	11.13	6.64	8.9
	Dec.	4.99	0.0279	13.38	6.94	1.9
	Feb.	13.91	0.0278	9.90	5.65	12.6
	April	16.21	0.0294	7.81	6.64	39.1
P. spiculifer 1	June	25.23	0.0567	7.91	6.73	35.1
	Aug.	25.93	0.0578	7.88	7.40	32.4
	Nov.	10.11	0.0477	11.46	6.90	12.4
	Dec.	5.5	0.0437	12.96	7.41	7.6
	Feb.	10.72	0.0009	12.16	6.20	20.0
	April	14.79	0.0454	8.82	6.90	38.6
P. spiculifer 2	June	28.77	0.0314	8.03	6.45	24.4
	Aug.	28.62	0.0331	7.86	6.41	17.0
	Nov.	12.75	0.0266	11.35	6.32	11.6
	Dec.	5.38	0.023	13.32	7.06	1.0
	Feb.	11.93	0.0125	13.40	5.24	14.3
	April	18.14	0.0254	9.04	6.21	30.5
P. spiculifer 3	June	25.01	0.0404	7.81	6.17	42.6
	Aug.	25.07	0.0364	7.98	6.47	41.2
	Nov.	11.53	0.025	10.92	6.75	12.2
	Dec.	5.9	0.0258	12.81	6.44	9.1
	Feb.	12.4	0.0219	10.36	4.91	23.4
	April	14.23	0.0283	9.41	5.80	35.1
P. versutus 1	June	24.53	0.0192	8.47	4.84	6.8

	Aug.	24.56	0.0194	8.39	4.78	4.1
	Nov.	12.63	0.0203	10.81	4.42	2.2
	Dec.	8.75	0.0198	11.97	4.50	0.7
	Feb.	12.53	0.0191	10.19	4.49	1.9
	April	15.83	0.0178	9.20	4.82	19.8
P. versutus 2	June	22.53	0.0112	8.87	5.25	4.4
	Aug.	23.42	0.0134	8.90	5.28	15.2
	Nov.	13.41	0.0108	10.88	4.96	8.9
	Dec.	10.75	0.0104	11.48	5.06	2.2
	Feb.	14.76	0.0105	9.77	4.91	3.7
	April	13.36	0.009	9.92	5.29	9.3
P. versutus 3	June	22.77	0.0137	9.02	5.38	11.2
	Aug.	21.84	0.0111	8.86	5.29	5.5
	Nov.	11.08	0.013	11.56	5.08	3.7
	Dec.	5.57	0.0121	13.49	5.07	2.9
	Feb.	10.7	0.0143	10.96	4.81	2.9
	April	17.12	0.0056	9.26	5.83	5.3