Changes in Mussel Assemblage Composition in the Lower Flint River Basin from 1999 to 2001: An Assessment of the Impacts of 2000 Drought

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ENVIRONMENTAL PROTECTION DIVISION

GEORGIA GEOLOGIC SURVEY

Atlanta

August 2002

Project Report 50

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Prepared in cooperation with the Georgia DNR, EPD under Proposal No. 711-10136

Atlanta

August 2002

Project Report 50

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ABSTRACT

Freshwater mussel assemblages in the Flint River Basin of southwest Georgia are among the richest in the world. Historically, 29 species including 7 endemics occurred in the Flint Basin. A drought during the summer of 2000 caused record low flows and many perennial streams dried or became intermittent. Pre-drought surveys conducted in 1999 allowed an assessment of the impact of the drought on mussel assemblages. During 2001, 21 stream reaches which had abundant or diverse mussel assemblages were resurveyed. Where possible, study sites were classified as flowing or non-flowing during the drought. Ten sites were classified as non-flowing and seven of those occurred on the Dougherty Plain. Taxa richness was stable across the drought, only two of the non-flowing sites showed a loss of more than three taxa. Mussel abundance at sites classified as non-flowing showed significant declines (median value 80% decrease) compared to flowing sites (median value 5% increase). Riffle associated and non-specialist rare taxa showed the greatest declines. Mussel taxa that appear resistant to drought conditions included: *Elliptio complanata/icterina, Toxolasma paulus, Uniomerus carolinianus, Villosa lienosa,* and *Villosa vibex.* Mussel taxa that were intolerant of drought conditions included: *Elliptio purpurella, Elliptio crassidens, Lampsilis straminea claibornensis, Quincuncina infucata, Strophitus subvexus, Villosa villosa, Lampsilis subangulata, Medionidus penicillatus,* and *Pleurobema pyriforme.* Generally, greatest declines in mussel abundance occurred in the mid-reaches of the major tributaries of the lower Flint River. These reaches depend on the Upper Floridan aquifer system, heavily used for irrigation, to maintain baseflows. Declines in mussel populations appear to be associated with unusual climatic conditions and increasing demand on the area streams and the regional aquifer system for irrigation water supply.

Keywords: freshwater mussels, drought, Flint River, hydrology

INTRODUCTION

Freshwater mussel communities of the Flint River Basin (FRB) in southwest Georgia are among the richest mussel assemblages in the world. Historically, 29 species of mussels, seven of which were endemic, existed in the Flint River system (Clench and Turner 1956). Surveys conducted between 1991-1993 found that several Flint River tributaries within the Coastal Plain (lower FRB) continue to harbor a diverse mussel fauna, numbering from 9 to 16 species, including several endangered species (Brim Box and Williams 2000). However, only 22 of the 29 species originally found in the FRB were observed during the 1991-1993 survey. The area where the highest concentration of endangered species occurred, and the most abundant and diverse communities were noted, was in the tributary streams of the Flint River flowing through the Coastal Plain portion of the watershed, i.e., lower FRB. Streams maintaining high mussel diversity included Kinchafoonee, Muckalee, Chickasawhatchee, and Spring Creeks (Brim Box and Williams 2000).

In southwest Georgia, the record drought during summer and fall of 2000 resulted in variable and stressful conditions in the tributaries of the lower FRB. Across the region, many perennial streambeds went dry, while other stream segments became intermittent, resulting in constriction of aquatic habitat to isolated pools. In some locations, headwater sections sustained flow, while downstream sections stagnated (Johnson et al. 2001). In other locations, mostly larger streams, flowing water persisted throughout the drought; however, water levels dropped to unprecedented lows (USGS 2000).

The extended drought raised concerns about water use within the region and its potential impact on instream flows. Water use in the lower FRB has increased dramatically with the development of center pivot irrigation technology in the mid 1970's (Hicks et al. 1987). During a typical year, a volume of groundwater approximately equal to 20% of average annual precipitation is used for irrigation (Hook et al. 1999). Although the stream and aquifer interaction is not clearly understood, it is believed that agricultural withdrawals from the Upper Floridan aquifer result in a net reduction of groundwater discharge to streams. Based on 50 years of continuous streamflow records, declines in growing season average daily discharges have been noted since the development of irrigation (Stamey 1996). A modeling study (Albertson and Torak 2002) predicted that groundwater withdrawals from the Upper Floridan aquifer during droughts could diminish aquifer-stream connections resulting in the drying of some reaches in the lower FRB. Although the extent has not been quantified, water use from both groundwater and stream sources during extended droughts contributes to stream drying.

Drought conditions during summer and fall 2000 in the lower FRB resulted in spatially and temporally variable flowing-water habitat for stream fauna. As a group, mussels are limited in their ability to migrate into flowing-water refuges either upstream or downstream of their primary habitat. Thus, freshwater mussels must endure conditions present within their immediate vicinity. Because drought impacts were variable, mussel communities across the lower FRB were exposed to varying degrees of stress associated with stream drying and low flows.

Drought impacts are frequently incremental and prolonged, requiring mussels to endure extended exposure to stressful conditions. Early in a drought cycle, decreases in water depth and flow velocity reduce food and oxygen delivery. As drought conditions persist, mussels face hypoxia (low levels of dissolved oxygen (DO) in water, i.e., < 5 mg/L), increasing water temperature, and ultimately, anoxia (no dissolved oxygen in water) or emersion (stranded out of water and exposed to air). Drought conditions may also increase predation pressure as low clear water or emersion facilitates capture by mussel predators (Johnson et al. 2001). Despite adaptations to a wide range of environmental conditions, many mussels are considered sensitive to disturbance and unable to withstand low DO and high temperature levels (for summary, see Fuller 1974).

Mussels may also suffer lethal and non-lethal impacts from drought related habitat change. Increases in stream temperature may shorten the period of glochidial encystment (attachment of larval mussels to fish gills); slow righting, burrowing and movement responses; and increase oxygen consumption (Young 1911, Bartsch et al. 2000). Low oxygen concentration impairs respiration, slows growth, reduces glycogen stores and may inhibit reproduction (for summaries, see Fuller 1974). Decreased flow velocity during drought may be insufficient to suspend glochidia (larval mussels) and superconglutinates (larval mussel masses), resulting in reproductive failure (M. Freeman, personal communication, Institute of Ecology, University of Georgia, 2001). Mortality during drought may result from respiratory failure, desiccation of soft tissues, predation, or the accumulation of toxic levels of anaerobic metabolic wastes (Holland 1991, Byrne and McMahon 1994).

Several mechanisms for enduring drought-related environmental change have evolved among the Unionidae. Some freshwater mussels have the capacity to lower metabolic activity in response to temporary temperature changes and DO stress (e.g., *Elliptio complanata*, *Utterbackia imbecilis*, *Pyganadon grandis*) (Bayne 1967, Burky 1983, Sheldon and Walker 1989, McMahon 1991). At least one freshwater species, *Anodonta implicata*, can produce metabolic oxygen in sufficient quantities to survive anoxic surroundings (Eddy and Cunningham 1934). Upon emersion, other Unionidae may respire through "mantle exposure behavior" (MEB), a gaping behavior that permits the exchange of aerial gases through a mucus-sealed mantle margin (McMahon 1991). Others are able to switch from aerobic to anaerobic respiration during times of anoxia (Holland 1991). A final unionid adaptation is the ability to rapidly migrate deep into sediments to avoid emersion (White 1979).

SUMMARY OF PREVIOUS STUDIES

Summer 1999 Mussel Survey:

From June through October 1999, Johnson (2001) surveyed mussel assemblages and meso- and macrohabitat at 46 sites in tributary streams of the FRB, in southwest Georgia. High quality mussel habitat was present in the tributaries of the lower Flint River. The survey identified 14,873 individual mussels representing 19 species which included three endangered and four sensitive species. Mussels species were clustered into four assemblage types (riffle-associated, pool-associated, non-specialist rare, and non-specialist common) based on analysis of habitat and abundance data. Using multivariate analysis, assemblage types could be discriminated primarily on the basis of four macrohabitat and three mesohabitat metrics: average stream depth; d-link magnitude (a metric of stream size); riparian wetland cover; proportion of pool area; proportion of riffle area; and percent of fine-sediment cover. Habitat variables accounted for 49% of the variability in mussel richness observed across survey sites. Mussel assemblages and distribution of mussel populations appear to be strongly influenced by adaptations relating to flow conditions (shell thickness) and DO concentrations (hypoxia tolerance).

Summer 2000 Drought Study:

From June through October 2000, Johnson et al. (2001) measured drought-associated mussel mortality at nine sites across four tributary streams in the lower FRB. Cumulative mussel mortality ranged from 13% to 93%. Mussel assemblages at sites exposed to drying or stagnating conditions experienced the greatest mortality. Riffle-dwelling and non-specialist rare taxa (sensu Johnson 2001) appeared to be particularly susceptible to drought stresses. Mussel assemblages composed of a non-specialist common taxa demonstrated greatest survivorship during prolonged stagnation and streambed drying. Across study sites, Johnson et al. (2001) observed a reduction in the relative abundance of riffle and rare species, and an increase in relative abundance of pool and common species. Extreme drought events appear to shape the distribution patterns and assemblage structure of mussels in the lower FRB by regulating the presence of non-specialist rare and riffle taxa (Johnson et al. 2001). Regionally, populations of these drought sensitive taxa are most likely eliminated from stream reaches subject to drying and stagnation during droughts. Reaches with perennial flow are probably important refuges and may be important for subsequent redistribution.

PURPOSE AND SCOPE

The 2000 drought had widespread impact on mussel distribution and assemblage composition across the lower FRB. Pre-drought population surveys conducted in 1999 provided baseline information to assess drought impacts (Johnson 2001). The purpose of this investigation was to conduct additional field surveys and assess the regional extent of mussel population losses and site-specific changes in assemblage composition during the 2000 drought. Flow conditions, physicochemical conditions, and habitat conditions were also measured at survey sites. Specific objectives included: (1) determine the extent and nature of change in mussel assemblages as a result of drought conditions experienced during summer 2000; (2) identify stream reaches that are likely to be adversely impacted by drought; and (3) assess the relationship between mussel-assemblage composition and hydrologic conditions. This report provides information essential to understanding the regional impact of drought and water use on mussels. The results of this study expands our understanding of aquatic systems and habitats during periods of stress, and provides assistance to the Georgia Department of Natural Resources in developing criteria for establishing "allowable" minimum flows for streams within the Flint River Drought Protection Area.

METHODS

Study Area:

Mussel populations in tributary streams of the lower FRB (Figure 1), on the Gulf Coastal Plain of southwest Georgia were studied. Many of the streams originate in the Fall Line Hills physiographic district. Their flows begin as seeps and springs emanating from the Claiborne aquifer. Downstream, they flow onto the Dougherty Plain, which is classified as mantled karst topography. A surface layer of sands and clays 1-40 m thick covers the area (Hayes et al. 1983). The shallow Ocala Limestone, an extensively fractured and porous rock layer, in many areas exhibits high hydraulic conductivity. The Ocala Limestone is the principal water bearing strata for the Upper Floridan aquifer, a regionally important water resource (Hicks et al. 1981). Chemically, the Upper Floridan has significant dissolved calcium-bicarbonate (91-256 mg/L alkalinity as $CaCO_3$), circumneutral pH (6.9-7.4), and nitrate concentrations well within drinking water standards (0.47 – 2.50 mg/L) (Hicks et al. 1987).

Low topographic relief in combination with porous surface geology results in low stream drainage density and a dominance of subsurface water flow in regional hydrology (Hicks et al. 1987). Major streams and their tributaries have channels incised within the Claiborne or Upper Floridan aquifers and are perennial during average hydrologic conditions. Smaller streams with channels above the aquifers tend to be intermittent (Beck and Arden 1983, Hayes et al. 1983). Baseflow in these streams is supported largely from discharges from the aquifers (Hicks et al. 1987).

Row-crop agriculture and managed forestlands are the dominant land use within the region (~50% agriculture, ~ 30% forests) (Golladay and Battle 2001). Since 1994, agricultural lands have increased by about 20% (Litts et al. 2001). In 1999, approximately 85% of agricultural lands were irrigated, mostly by withdrawals from the Upper Floridan aquifer (Litts et al. 2001). In Georgia, permits are issued for surface and groundwater withdrawals; however, there is no requirement for reporting actual water use (Thomas et al. 2001). In 2000, state wide estimates of annual irrigation amounts were 24.7 cm with most water use in southwest Georgia (Harrison 2001, Thomas et al. 2001). At that level, water use is approximately 20% of long-term average annual precipitation of 127 cm.

Site Selection:

During June - September 2001, physicochemical conditions and mussel surveys were conducted at 21 sites on the tributary streams in the lower FRB (Figure 1). With the exception of one site (01-001), These sites had been previously surveyed in 1999 and found to support abundant and/or diverse mussel assemblages (Johnson 2001). Bridge crossings were selected for surveys at regular intervals along the longitudinal progression from headwaters to the Flint River confluence on each stream. Study areas extended from 100 to 200 m above each bridge crossing. Site numbers were originally established by Brim Box and Williams (2000) and their convention was followed in subsequent surveys (Johnson 2001). The first two digits indicate the year in which the site was originally surveyed. The last three digits represent the order in which a site was visited (i.e. 91-020, originally surveyed in 1991 and was the 20th site visited that year).

Streamflow Conditions during the 2000 Drought:

During the summer of 2000, the hydrologic condition for 20 of the mussel survey sites was documented by field observations of Jones Center Staff (i.e. Golladay and Battle 2001, Johnson et al. 2001, Stephanie Davis unpublished data on file at the Jones Research Center) or from flow records of the U.S. Geological Survey (USGS) (http://ga.waterdata.usgs.gov/nwis/). Sites were classified as flowing if they had observable moving water in the main channel during the worst drought conditions (Table 1, Figure 2). Sites classified as non-flowing were either dried completely, or dried to isolated pools with no surface flow between pools. Ten sites were classified as non-flowing and seven of those sites occurred on the Dougherty Plain. This classification was used to statistically assess physicochemical conditions during the summer of 2001 and to compare mussel population responses to the 2000 drought.

Physical and Hydrologic Conditions:

Stream temperatures were measured using Hobo Temperature Recorders (Onset Computer Corporation, Bourne MA). Recorders were submerged in survey reaches during early summer and retrieved in early autumn. Temperature measurements were recorded hourly. At some sites, temperature recorders were emersed in late summer (i.e. exposed to air, by low-flow conditions). Temperature data collected during emersion were not included in subsequent analyses.

All habitat data were collected during stable flow conditions during late August and September 2001 to determine flow and DO concentrations during the most stressful summer conditions (i.e. seasonal high temperatures). Measurements were taken at the upstream and downstream ends of each study reach. Mid-channel benthic DO concentration was measured using a YSI Dissolved Oxygen Meter (Yellow Springs Instruments, Yellow Springs OH). Ten equally spaced sampling points were established at each transect. At each sampling point the stream depth and benthic current velocity (Marsh-McBirney Flowmate, Marsh-McBirney Inc., Frederick MD) were measured, and the dominant substrate was noted.

A baseflow synoptic survey was conducted by USGS field technicians from October 18, to November 01, 2001, and stream discharge was measured at each survey site. Measurements were made during annual low flows. Measurements were made by using standard USGS methods.

Mussel Surveys:

At each site, the streambed extending from 100 to 200 m upstream from the bridge crossing was searched for mussels using standardized methods (e.g., Johnson 2001). In small streams, the entire bed surface within the selected survey reach was grubbed (i.e., surface sediments were sieved with fingers to a depth of 5 cm) or visually searched for live and dead unionids. In large streams (4^{th} order or larger; greater than 12-m wide), visual and tactile searches for live and dead mussels were conducted along five transects placed parallel to stream flow along the length of the stream reach. Transects were 2-m wide and evenly spaced across the width of the stream, with one transect on each bank. Surveys were conducted in the main channel(s) of the stream; backwater areas were not searched.

Live native mussels were identified and immediately returned to the stream bottom. If more than 1,000 individuals of any species were found before reaching the end of the survey reach, the density of the species in the completed portion of the survey reach was estimated and additional specimens of that species in the remaining survey stretch were not counted. Unionids were identified to species level, except *Elliptio complanata* and *Elliptio icterina*, which were grouped together as *Elliptio complanata/icterina* because of the difficulty of distinguishing between the two species in the field.

Data Analysis:

The hydrologic classification (i.e. flowing or non-flowing during summer 2000) was used as the basis of statistical analysis. Average temperature, DO concentration, benthic current velocity, average stream depth, taxa richness, and taxa abundance were compared at sites classified as flowing versus sites classified as non-flowing using the Mann-Whitney Rank Sum Test (Sigma-Stat Version 2.03, SPSS Science, Chicago IL).

RESULTS AND DISCUSSION

Physicochemical and Hydrologic Conditions during Baseflow Surveys:

Average weekly stream temperature (June – August 2001) ranged from 22-26 °C at the study sites (Figure 3). Generally, highest stream temperatures were recorded in July and August. Stream temperatures declined rapidly in September and by early October the average weekly temperatures were below 20 °C at all sites. There was no significant difference in either maximum average daily or maximum average weekly temperature in a comparison of sites classified as flowing during the 2000 drought compared to sites classified as non-flowing (Mann-Whitney Rank Sum Test, Figure 4).

There was some evidence to suggest that summer DO concentration was greater in streams classified as flowing during 2000 compared to non-flowing sites (Mann-Whitney Rank Sum Test, $p=0.06$) (Figure 5). This suggests that during the summer of 2001, conditions at sites classified as non-flowing may have been more stressful than at sites classified as flowing. However, at most sites DO concentration during 2001 was above the critical threshold (5 mg/L D.O.) that Johnson et al. (2001) associated with mussel mortality. There was no significant difference in benthic current velocity or average depth in sites classified as flowing during the 2000 drought compared to non-flowing sites (Figure 5).

Stream Discharge during Seasonal Baseflow:

Measurable flow was reported at all mussel survey sites during the baseflow synoptic survey (Table 2). Two streams, Cooleewahee Creek and Chickasawhatchee Creek, that originate on or flow largely across the central Dougherty Plain, had declining discharge from upstream to downstream stations. Muckalee, Kinchafoonee, Ichawaynochaway, and Spring Creeks had increasing discharge from upstream to downstream sites.

Total Unionid Abundance and Richness:

For most sites, mussel richness (# taxa) was stable across the drought. There was no difference in the percent change in taxa richness in sites classified as flowing compared to non-flowing sites (Mann-Whitney Rank Sum Test, p=0.47) (Figure 6). Of the four sites showing the greatest taxa loss (> 3 taxa), two were classified as non-flowing (97-038, 92-069). At the flowing sites that lost taxa, channel dredging was observed at one of the sites (91-020). The cause of taxa loss at the other flowing site (92-149) is unknown, although the taxa lost were not abundant (< 5 individuals per 100-m stream in 1999).

Changes in total mussel abundance between 1999 and 2001 varied greatly, ranging from a 93% decrease to a 71% increase (Table 1, Figure 7). A majority of sites on the Dougherty Plain had declines in mussel abundance. Sites classified as non-flowing had significantly greater decreases in mussel abundance than flowing sites (Mann-Whitney Rank Sum Test, p=0.006) (Table 1, Figure 8). However, drying did not result in decreases in abundance at all non-flowing sites. For example, mussel populations remained stable at 97-150 even though flow ceased. This site is noted for extensive wood debris, which may create refugia for mussels during drought conditions (Johnson 2001, Johnson et al. 2001). Also, some sites that dried were dominated by drought tolerant taxa (91-121, 91-011). A substantial decline in mussel abundance was also observed at two of the flowing sites (91-020, 97-132). At site 91-020 channel dredging was observed. Site 97-132 had poor mid-channel mussel habitat (coarse sand) and most mussels were associated with roots and stumps along the streambank. While flow persisted, channel shrinkage probably resulted in a decrease in mussel habitat. Increases in mussel abundance observed at several flowing sites (97-121, 97-115, 99-003) were probably not due to reproduction, as few small individuals were observed during 2001 resurveys. The apparent increases are attributed to greater sampling efficiency since conditions for observing mussels were better at these sites (i.e. lower flows, clearer water) in 2001 compared to 1999. All of the sites showing declining mussel populations were surveyed under comparable or more favorable conditions for observing mussels in 2001 than in 1999.

Presence and Abundance of Mussel Species:

A total of 17 mussel taxa were found during the 2001 survey compared to 19 taxa during 1999. The two taxa not observed in 2001 were *Utterbackia imbecillis* and *Utterbackia peggyae*; however, they were found in low numbers at only one site during the 1999 survey. *Lampsilis teres* was reported from one site in 2001, but not observed in 1999.

Mussel taxa found during the 1999 and 2001 surveys were grouped into three categories based on their conservation status (Table 3, Brim Box and Williams 2000). The habitat association was also noted for each taxon (Johnson 2001). Only 14 of the 22 species found in the lower FRB were present in sufficient abundance to evaluate changes associated with the 2000 drought. The first group consisted of common species and included *Elliptio complanata/icterina, Elliptio crassidens, Toxolasma paulus, Uniomerus carolinianus, Villosa lienosa,* and *Villosa* *vibex*. Populations of these species are considered stable in the Flint River and its' tributaries (Brim Box and Williams 2000). The second group was special concern species and included *Elliptio purpurella, Lampsilis straminea claibornensis, Quincuncina infucata, Strophitus subvexus,* and *Villosa villosa*. Special concern species have shown declines in populations throughout their historic range (Brim Box and Williams 2000). The third group was endangered species and included *Lampsilis subangulata, Medionidus penicillatus, and Pleurobema pyriforme*. Endangered species have experienced significant declines throughout their historic range and are considered at risk for extinction.

Populations of most of the common mussel species appear to endure drought better than other species (Table 3). As a group, most are non-specialist common in habitat preference and are stress tolerant. (Johnson 2001). However, declines in total number of *E. crassidens*, a riffle-associated species, were observed. These declines were largely due to very high mussel mortality (93%) at one site, 91-010. This site was on Chickasawhatchee Creek and it ceased flowing during the drought (Figure 2). In the lower FRB, riffle-associated species are susceptible to drought stress (Johnson 2001). Declines in the presence of *V. lienosa* were also observed. Losses were from four sites where *V. lienosa* were uncommon during the 1999 survey. At the other survey sites, populations of *V. lienosa* appeared stable. Increases in the presence and/or abundance of *E. complanata, T. paulus, V. lienosa,* and *V. vibex* were observed largely due to increases at five sites (92-158, 99-001, 99-003, 97-115, and 97-121). Changes were probably not due to reproduction, as few small individuals were observed during 2001 resurveys. The apparent increases were attributed to greater sampling efficiency since conditions for observing mussels were better at these sites (i.e. lower flows, clearer water) in 2001 compared to 1999.

Three of the special concern species, *L. s. claibornensis, S. subvexus,* and *V. villosa*, declined in abundance from 1999 to 2001 (Table 3). *L. s. claibornensis* and *V. villosa* also declined in the number of sites where they occurred. The decline in presence was particularly large for *L. s. claibornensis* decreasing from nine sites in 1999 to one site in 2001. Populations of the other special concern species appeared stable, although as a group those species were not abundant in the survey areas. *Lampsilis subangulata*, an endangered mussel, declined in presence and abundance from 1999 to 2001. In general, endangered species were not abundant in the survey reaches. Most of the special concern and endangered taxa are classified as non-specialist rare in habitat association (Table 3), and as a group, are intolerant of drought stress (Johnson 2001). Maps of individual species abundance in 2001 relative to the flow status and physiographic province are included in the appendix.

Historical Mussel Distribution:

Deforestation, intensive upland agricultural development, river impoundments, and declines in native fish species have adversely affected mussel diversity and abundance in the lower FRB (Brim Box and Williams 2000). Infrequent natural disturbances such as floods and droughts may further affect mussels by causing physiological stress or death to individuals or populations already stressed by habitat alteration. Results of the 2001 mussel survey were compared to 1999 (Johnson 2001), and 1991 - 1993 (Brim Box and Williams, 2000) surveys, as well as historic records from pre-1900 to 1989, as reported in Brim Box and Williams (2000).

Four patterns of distribution were observed and generally coincided with conservation status. Species considered stable showed little change in distribution. Species of special concern disappeared from the mainstem of the Flint River prior to the 1991 survey and were generally found at even fewer tributary locations in the 1999 and 2001 surveys. Species considered threatened or endangered were confined to fewer sites in the 1991 survey than in the historic records, but showed little change in distribution since the 1991 collections. Finally, several species were considered extirpated from the lower FRB or extinct by 1991.

Stable species that showed little change in patterns of distribution and were generally abundant in the 2001 survey included *E. complanata/icterina*, *T. paulus*, *U. carolinianus*, *V. vibex*, and *V. lienosa*. These species appear to tolerate a wide range of disturbances including drought.

The species that showed the greatest declines in distribution since the 1991 survey were those that were considered species of special concern, including *L. s. claibornensis*, *Q. infucata*, and *E. purpurella*. Each of these species was historically found in the mainstem and tributaries of the Flint River, but *L. s. claibornensis* and *E. purpurella* had both disappeared from the mainstem of the Flint River by 1991. *L. s. claibornensis* was found at fewer locations in the 1999 survey (13 sites) than in 1991 and at even fewer sites in the 2001 survey, when a total of 26 individuals were found at only two sites and no small specimens were observed. *E. purpurella* was extirpated from both the Chattahoochee and Chipola River drainages by 1991 but persisted in tributaries of the Flint River. In the 1999 and 2001 surveys, it was not found in Mill and Spring Creeks at sites where it was found in 1991, although it persisted in several other tributaries. The last species of special concern, *Q. infucata*, was still found in the mainstem of the Flint River in the 1991 survey although it had disappeared from the mainstem of the Chattahoochee and portions of the Apalachicola Rivers. In 2001, this species was not found in Cooleewahee Creek where it was observed in 1991, but was found in Spring Creek where it was not observed in 1991.

Two endangered species encountered in this survey, *M. penicillatus,* and *P. pyriforme,* showed little change in patterns of distribution since the 1991 survey. The third endangered species, *L. subangulata,* appears to have declined from 1999 to 2001. Prior to 1991, these endangered species had disappeared from many historic locations on the mainstem of the Flint River as well as several tributaries. *S. subvexus* is not a federally listed species, but was considered endangered in the ACF basin by Brim Box and Williams (2000). It displayed the same pattern of decline in the mainstem of the Flint River prior to 1991 with little change in distribution from 1991-2001. *V. villosa,* a species of special concern, also showed declines prior to 1991, although it appears to have been a fairly rare species even in the historic records. *V. villosa* showed additional declines from 1999-2001.

Several species were not encountered in the 2001 survey because they were extirpated from the lower FRB by 1991 (*Elliptio fraternal, Elliptio nigella, Lampsilis binominata,* and *Lasmigona subviridis*), or persisted at very few sites within the basin (*Alasmidonta triangulata, Amblema neislerii, Anodontoides radiatus, Anodonta heardi,* and *Pyganodon cataracta*). Since the 2001 sampling was completed, a small population of *A. triangulata* was discovered at a site on Chickasawhatchee Creek that was not a part of the 1999 or 2001 survey.

CONCLUSIONS

In the lower FRB, drought susceptibility of mussel taxa appears to be related to habitat association. Johnson et al. (2001) observed that as a group, riffle-associated taxa appear most susceptible to drought stresses with mortality averaging 53% as streamflow diminished and DO decreased below 5 mg/L. Mortality of non-specialist rare taxa averaged 35%. This was in contrast to non-specialist common species whose mortality was 9% (Johnson et al. 2001). Declines in mussel taxa observed in this study from 1999 to 2001 are consistent with the observations of Johnson et al. (2001); streams that stagnated or ceased flowing generally had the greatest mussel mortality. While all mussels present in the lower FRB are adversely affected by drought, riffle dwelling or non-specialist rare taxa should be considered particularly drought intolerant.

The results of this study and Johnson et al. (2001) indicate that of the species found in the lower FRB, *Elliptio complanata/icterina* and *Villosa vibex* appear to be drought tolerant. Johnson et al. (2001) noted that they could withstand up to 20 days of emersion and survive 110 days in hypoxic water. Several other species (*Villosa lienosa*, *Toxolasma paulus*, and *Uniomerus carolinianus*) also appeared to resist the affects of prolonged drought although their mechanisms of survival are not known (Johnson et al. 2001).

Examination of historical freshwater mussel distributions points to a general pattern of decline for many mussel species in the Apalachicola, Chattahoochee, and Flint Basin attributable to a history of multiple disturbances (e.g., Brim Box and Williams 2000). Many species classified as endangered or of special concern disappeared from the mainstem of the Chattahoochee and, to a lesser extent, the Flint River by 1991 (Brim Box and Williams, 2000). Once the distribution of a species is confined to smaller tributaries, the pattern of decline continues, thus eventually leading to extirpation or extinction of the species. Apparently, recolonization of downstream areas from smaller tributaries does not occur or occurs infrequently. Unfortunately, little is known about the metapopulation dynamics of freshwater mussels beyond the fact that their reproduction is linked to fish hosts. Once the mussel populations decline over large areas of a river, remaining isolated populations may have little chance of contributing to recovery. Subsequent disturbances, such as the 2000 drought, stress the remaining populations and probably accelerate the loss of freshwater mussel diversity from the lower FRB.

ACKNOWLEDGMENTS

Technical support for this project was provided by Brian Clayton, Raynie Bambarger, and Sean Kelley; we appreciate their tireless enthusiasm for mussel research and conservation. Annie Hill, Kim Ellis, Ryan Johnson, Walter Cotton, Anna Liner, Michael Bell, Jessica Cochrane, Keri Landry, Slaton Varner, Roger Birkhead, and Derek Fussel assisted with field work during 1999 and/or 2000. Liz Cox assisted in locating key references. Financial support was provided by The Georgia Environmental Protection Division, the Robert W. Woodruff Foundation, and the Joseph. W. Jones Ecological Research Center.

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FIGURES AND TABLES

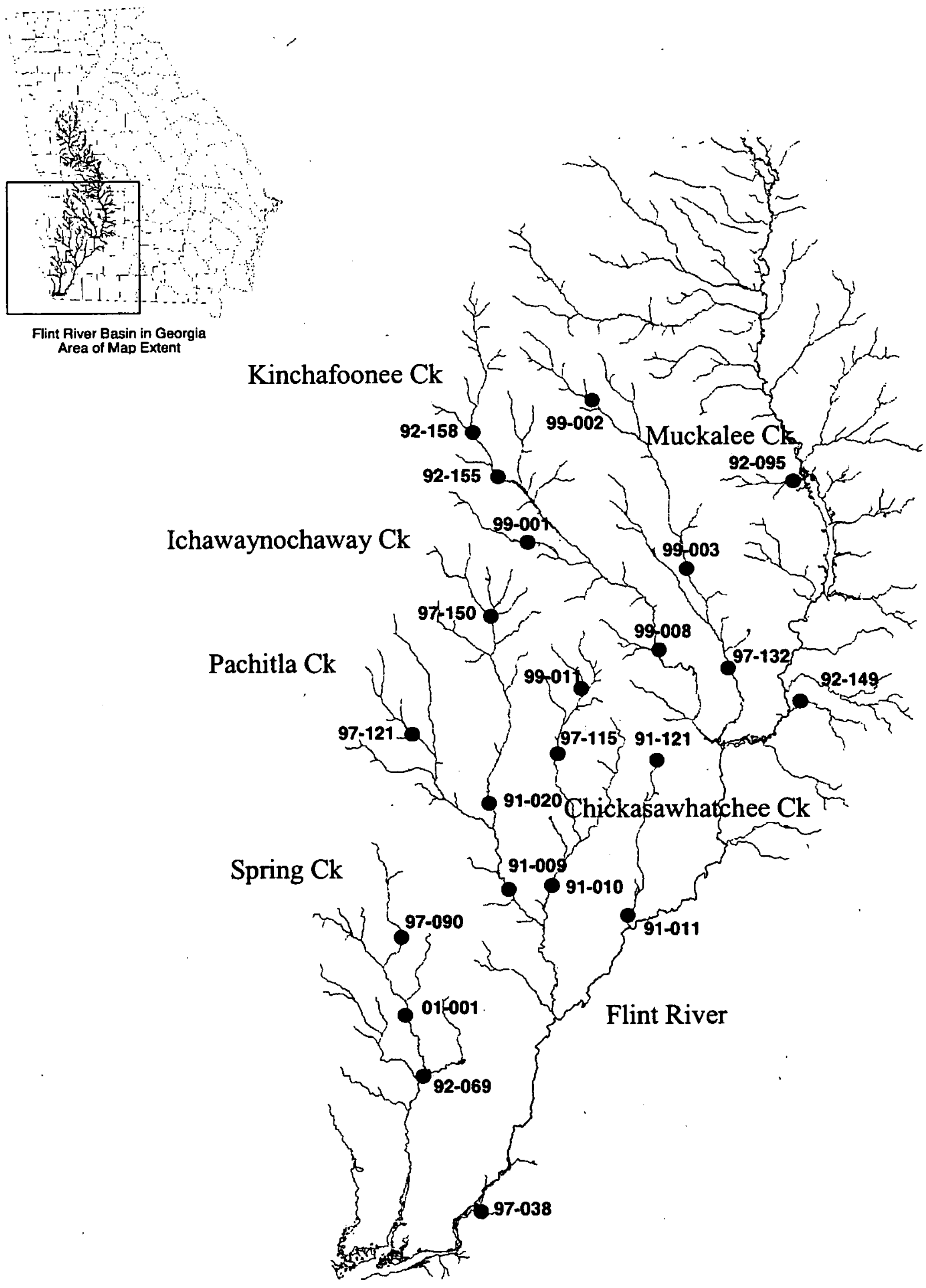


Figure 1. Location of mussel survey sites in southwest Georgia.

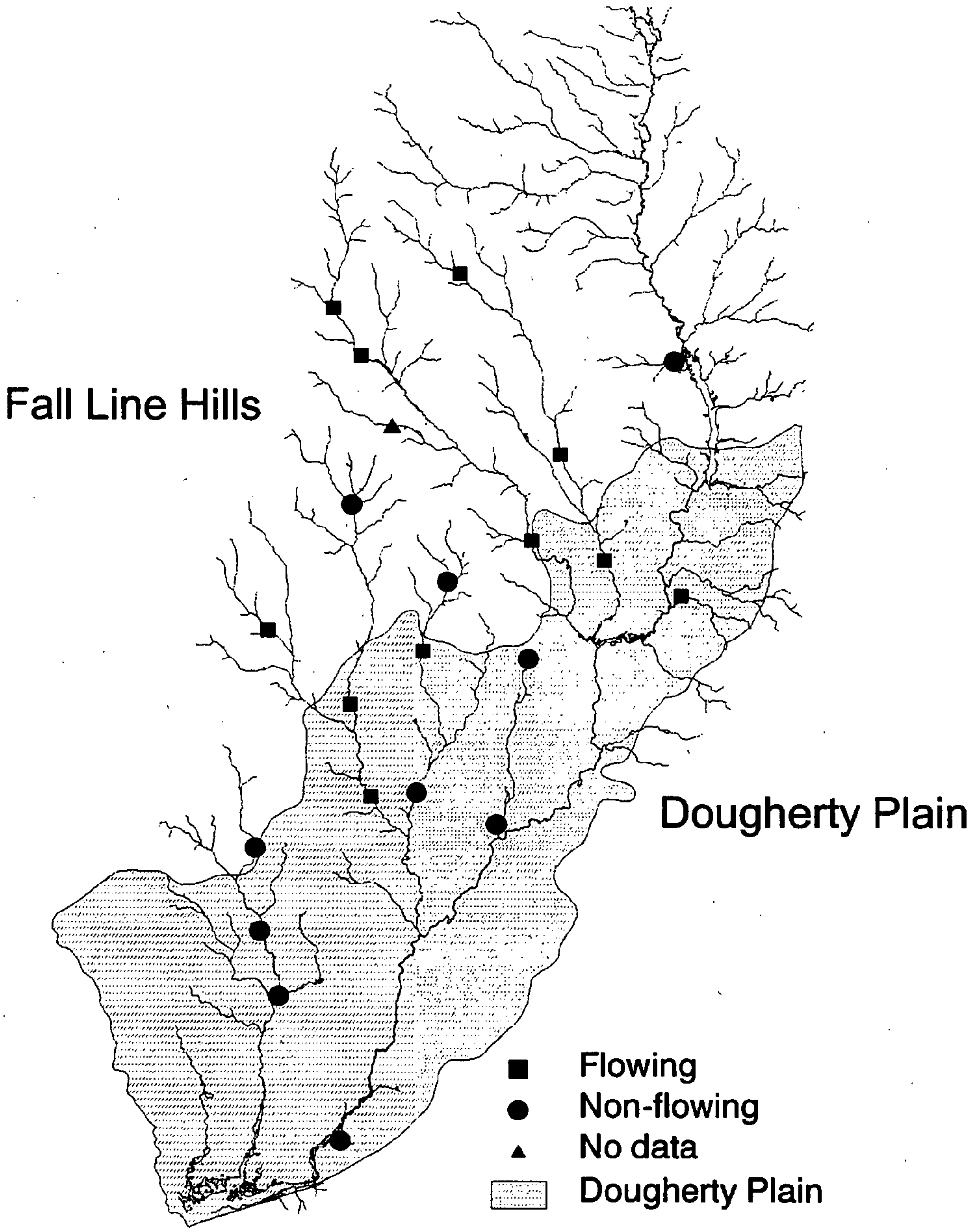


Figure 2. Flow status of mussel survey sites during the 2000 drought. Sites designated as "Non-flowing" had no observable surface flow for at least one day during summer 2000. Sites designated "No data" were not observed during the 2000 drought.

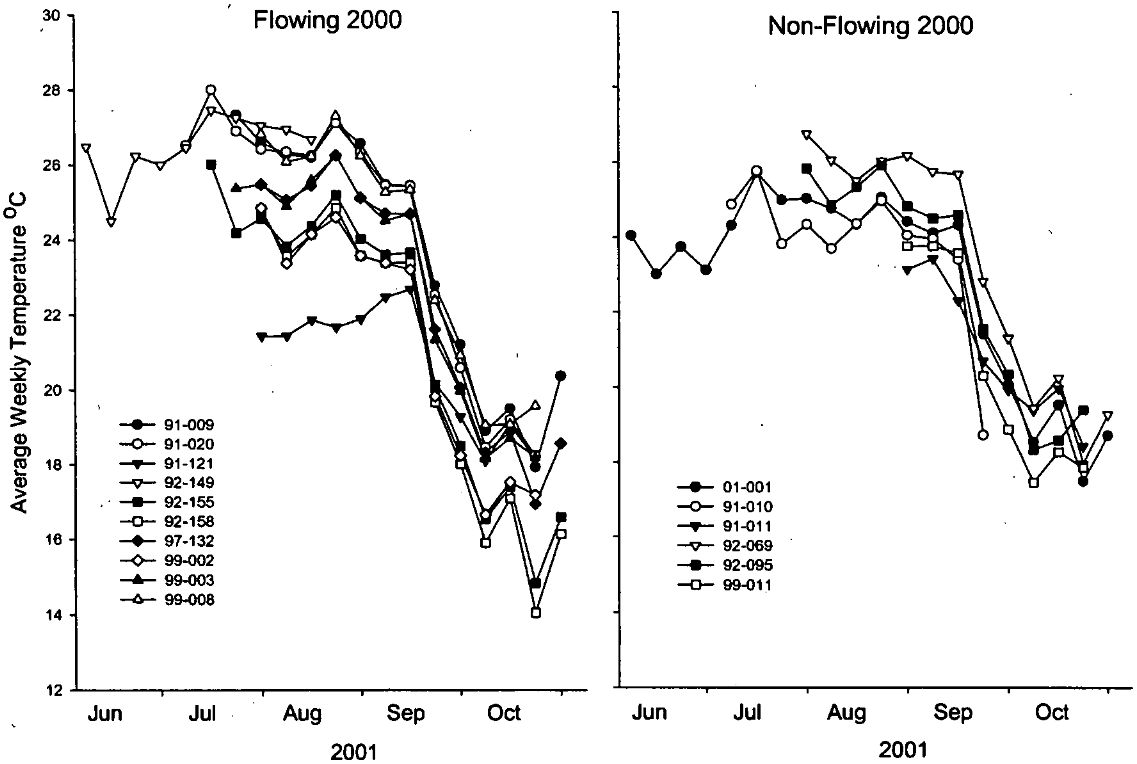


Figure 3. Average weekly temperatures at mussel survey sites during the summer of 2001. Sites were grouped based on whether they maintained flow during the 2000 drought. Actual measurements were made during 2001.

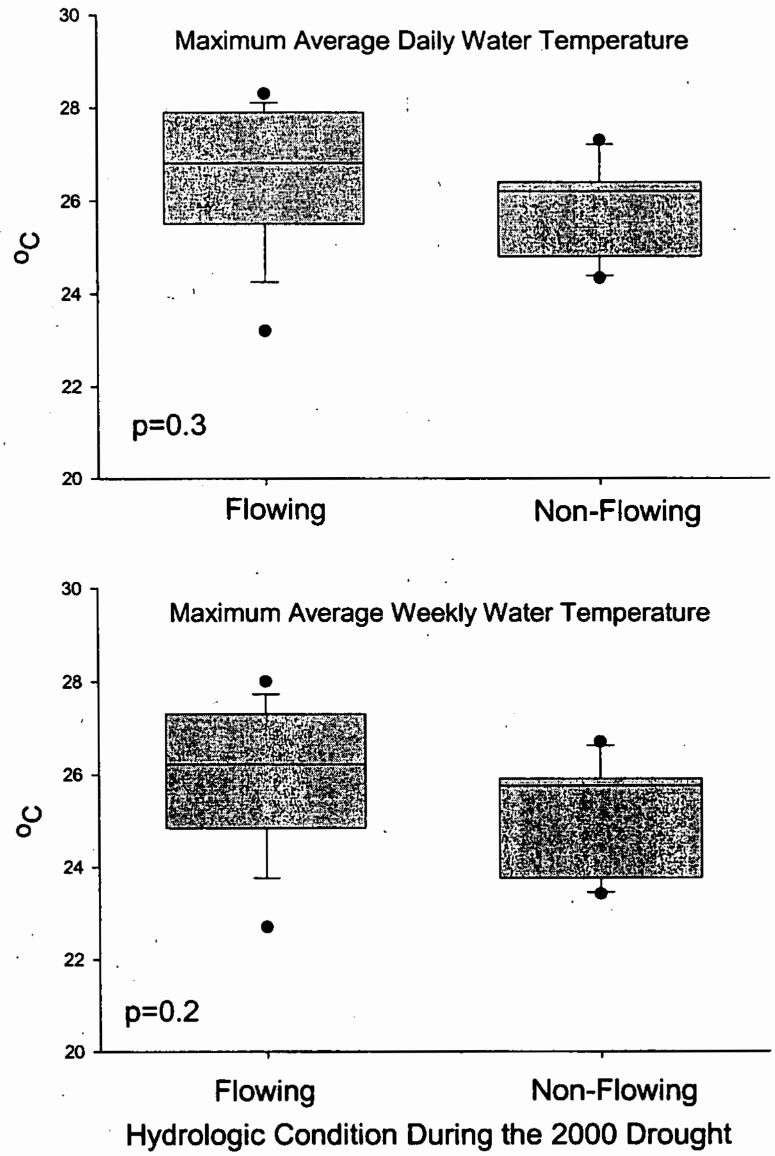


Figure 4. Maximum average daily and average weekly temperature at mussel survey sites. Sites were grouped based on whether they maintained flow during the 2000 drought. Actual measurements were made during 2001. Values are medians (horizontal lines) with boxes representing interquartile ranges. Bars represent 10% and 90% values, with points being outliers. Median values were compared using a Mann-Whitney Rank Sum Test.

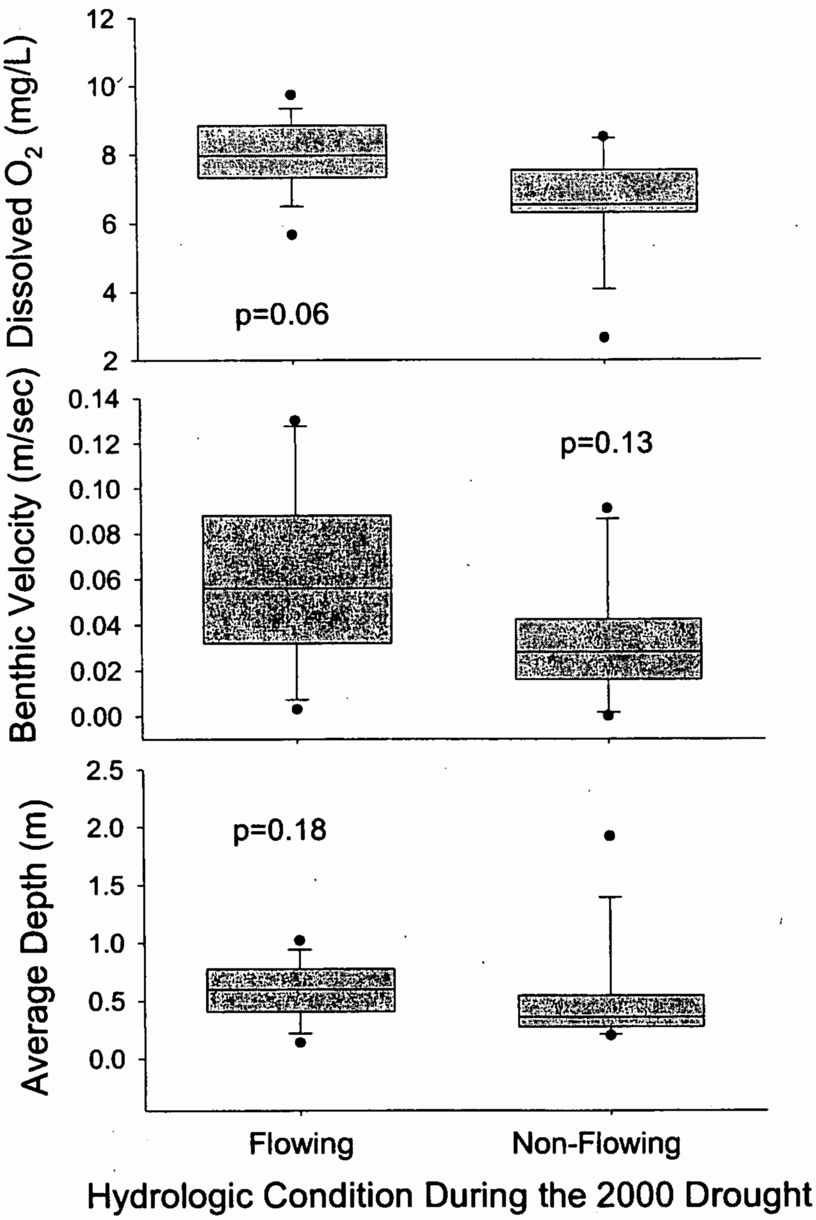


Figure 5. Physicochemical conditions at mussel survey sites during baseflow conditions in late August or early September 2001. Sites were grouped based on whether they maintained flow during the 2000 drought. Actual measurements were made during 2001. Values are medians (horizontal lines) with boxes representing interquartile ranges. Bars represent 10% and 90% values, with points being outliers. Median values were compared using a Mann-Whitney Rank Sum Test.

Table 2. Baseflow synoptic conducted between October 18, and November 2, 2001. Within a stream drainage, sites are arranged in descending order from headwaters to downstream reaches.

Site	Physiographic District	Flow (cfs)
Bear Creek 99-001	Fall Line Hills	5.85
Carter Creek 97-121	Fall Line Hills	15.40
Brantley Creek (Chickasawhatchee) 99-011	Fall Line Hills	8.08
Chickasawhatchee Creek 97-115	Dougherty Plain	9.62
Chickasawhatchee Creek 91-010	Dougherty Plain	0.10
Cooleewahee Creek 91-121	Dougherty Plain	4.40
Cooleewahee Creek 91-011	Dougherty Plain	3.44
Four Mile Creek 97-038	Dougherty Plain	0.06
Ichawaynochaway Creek 97-150	Fall Line Hills	5.46
Ichawaynochaway Creek 91-020	Dougherty Plain	72.10
Ichawaynochaway Creek 91-009	Dougherty Plain	140.00
Kinchafoonee Creek 92-158	Fall Line Hills	24.40
Kinchafoonee Creek 92-155	Fall Line Hills	33.00
Kinchafoonee Creek 99-008	Dougherty Plain	90.85
Lime Creek 92-095	Fall Line Hills	11.40
Mill Creek 92-149	Dougherty Plain	11.70
Muckalee Creek 99-002	Fall Line Hills	15.80
Muckalee Creek 99-003	Fall Line Hills	74.30
Muckalee Creek 97-132	Dougherty Plain	117.00
Spring Creek 97-090	Fall Line Hills	1.59
Spring Creek 92-069	Dougherty Plain	11.02

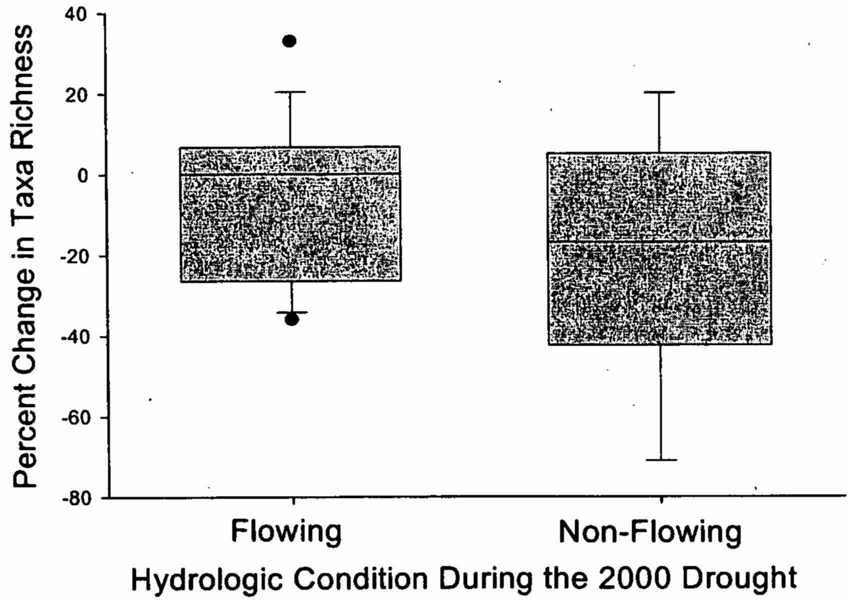


Figure 6. Percent change in unionid taxa richness from 1999 to 2001. Sites were grouped based on whether they maintained flow during the 2000 drought. Values are medians (horizontal lines) with boxes representing interquartile ranges. Bars represent 10% and 90% values, with points being outliers. Median values were compared using a Mann-Whitney Rank Sum Test and were not significantly different (p=0.5).

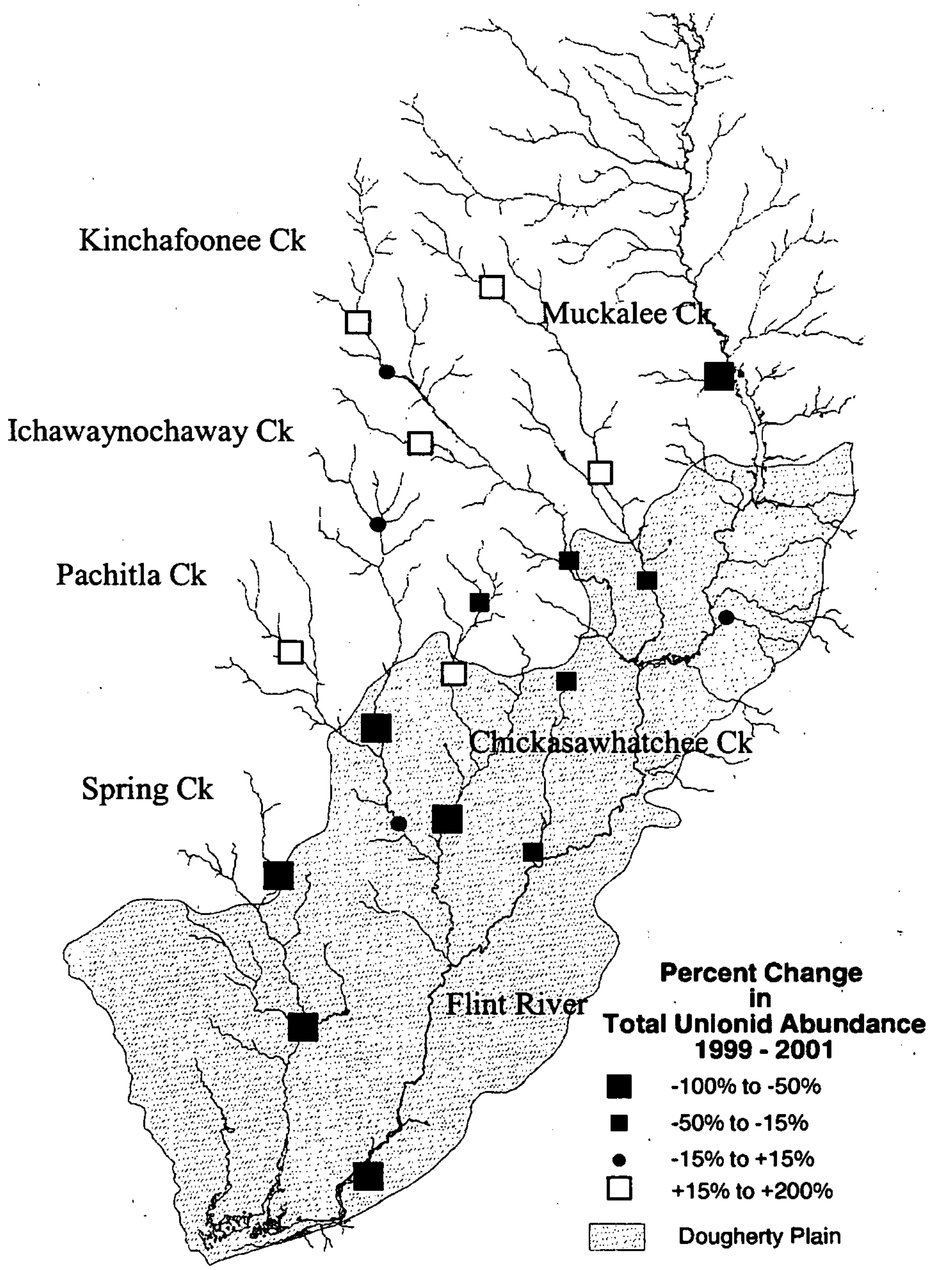


Figure 7. Percent change in total unionid abundance between 1999 and 2001.

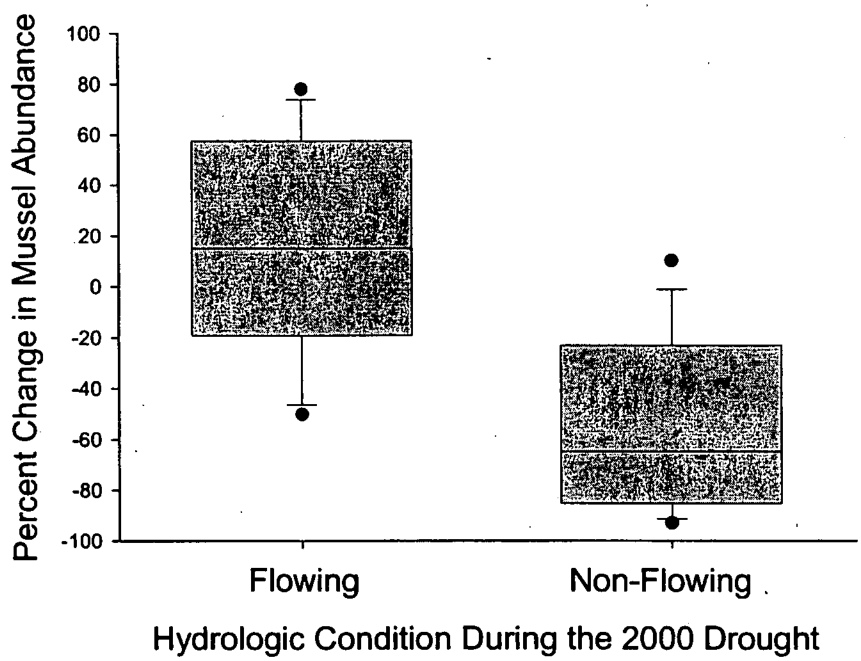
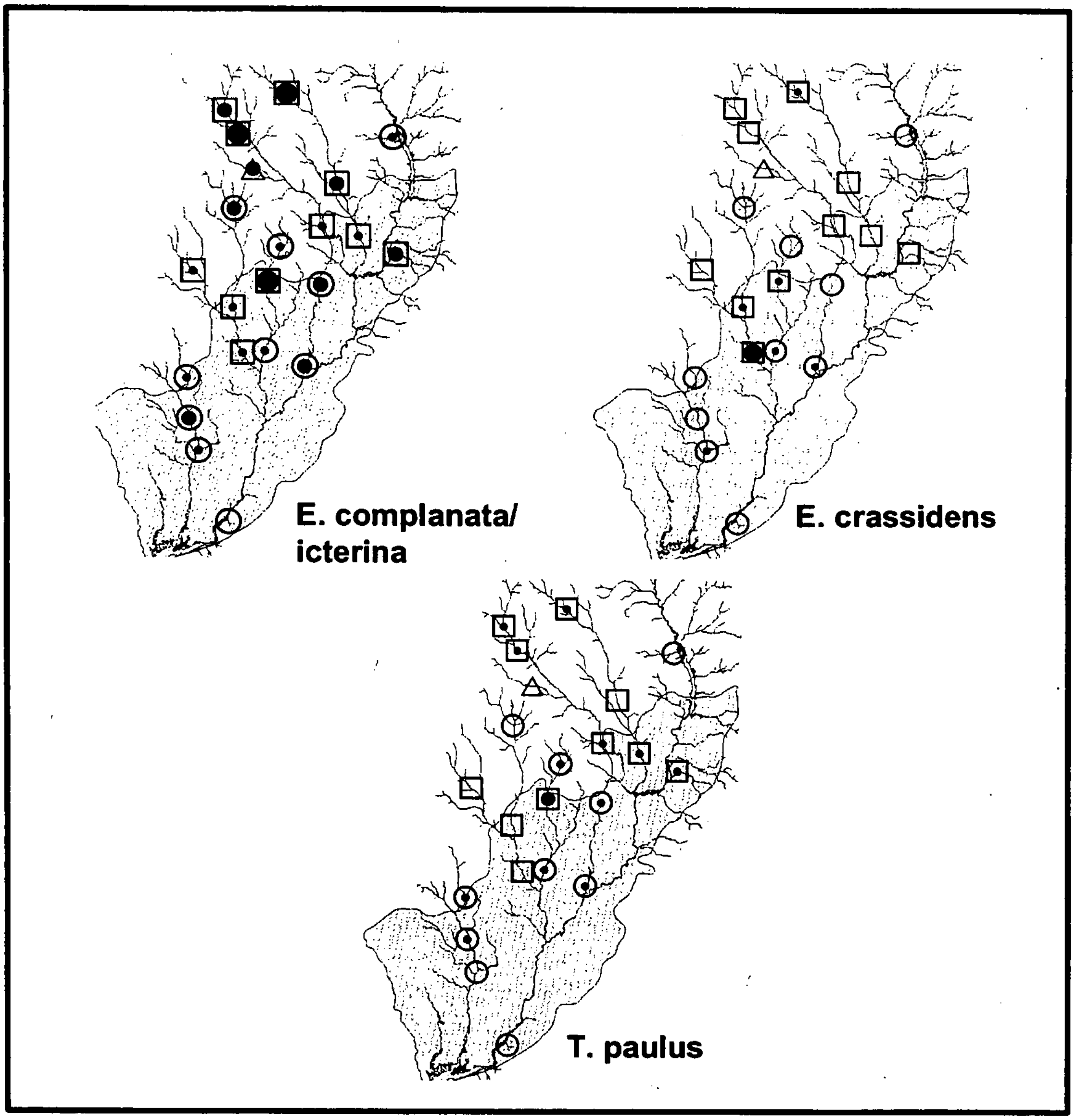


Figure 8. Percent change in total unionid abundance from 1999 to 2001. Sites were grouped based on whether they maintained flow during the 2000 drought. Values are medians (horizontal lines) with boxes representing interquartile ranges. Bars represent 10% and 90% values, with points being outliers. Median values were compared using a Mann-Whitney Rank Sum Test and were significantly different (p=0.006).

Table 3. Comparison of 1999 and 2001 mussel surveys by species. Twenty-one sites were surveyed each year. Habitat associations were designated by Johnson (2001) (n.s. = non-specialist).

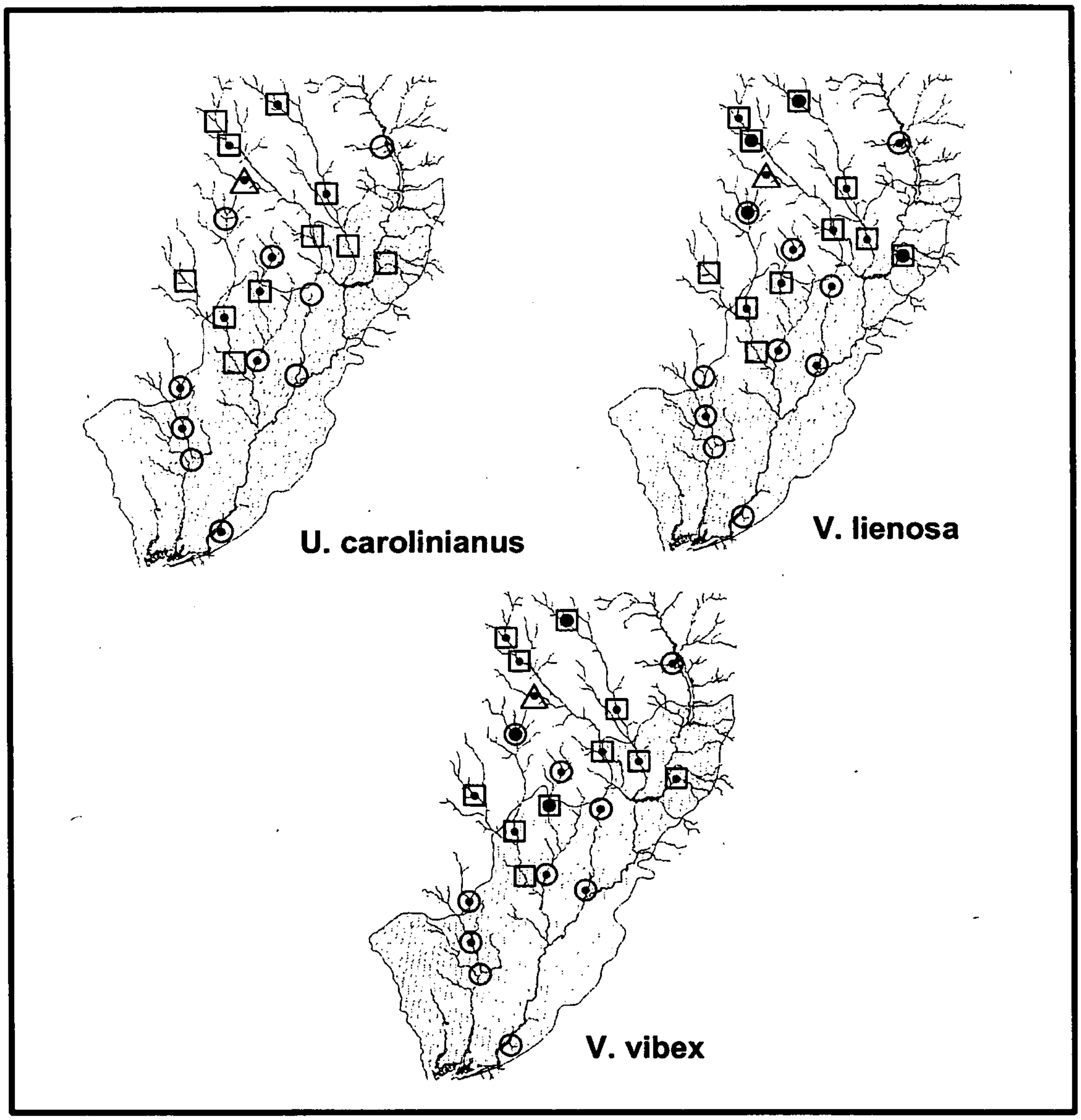
Status *Species*	Habitat Association	Sites Found 1999	Sites Found 2001	Total Found 1999	Total Found 2001
Common Species					
Elliptio complanata/icterina	n.s. common	21	20	6208	6428
Elliptio crassidens	riffle	6	7	1937	1055
Toxolasma paulus	n.s. common	13	12	231	427
Uniomerus carolinianus	n.s. common	10	10	46	74
Villosa lienosa	n.s. common	20	16	1632	1720
Villosa vibex	n.s. common	16	18	390	766
Special Concern Species					
Elliptio purpurella	n.s. rare	10	8	99	161
Lampsilis straminea claibornensis	n.s. rare	9	1	20	8
Quincuncina infucata	n.s. rare	14	11	360	543
Strophitus subvexus	n.s. rare	4	5	10	9
Villosa villosa	pool	3	1	31	1
Endangered Species					
Lampsilis subangulata	n.s. rare	11	7	131	56
Medionidus penicillatus	n.s. rare	2	1	9	17
Pleurobema pyriforme	n.s. rare	5	6	42	87

APPENDIX – FRESHWATER MUSSEL DISTRIBUTION MAPS

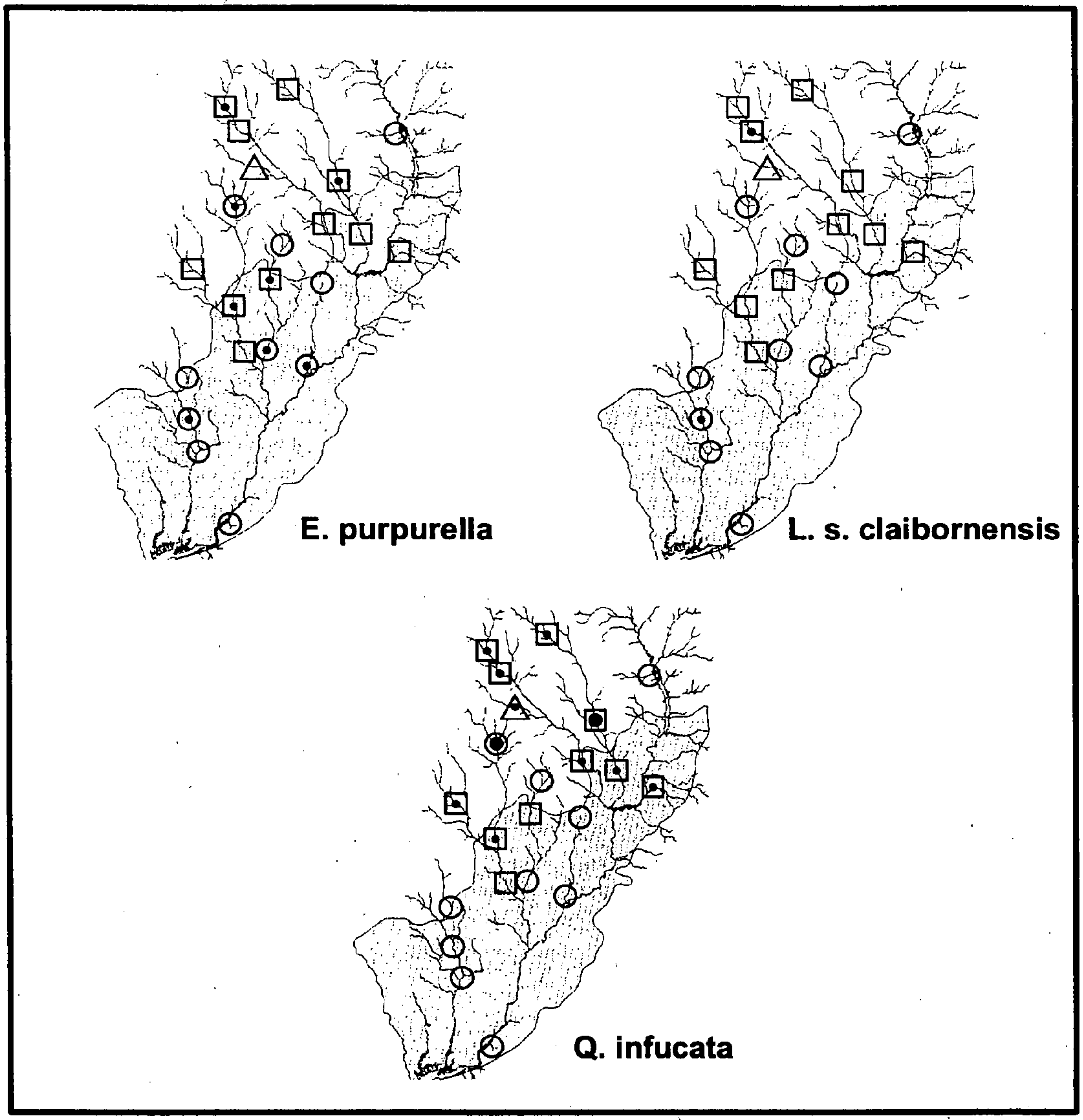


2001 Mussel Survey
Common Species
Abundance

- • 1 - 99
- ● 100 - 999
- ⬤ 1000+
- □ Flowing
- ○ Non-flowing
- △ No data
- Dougherty Plain



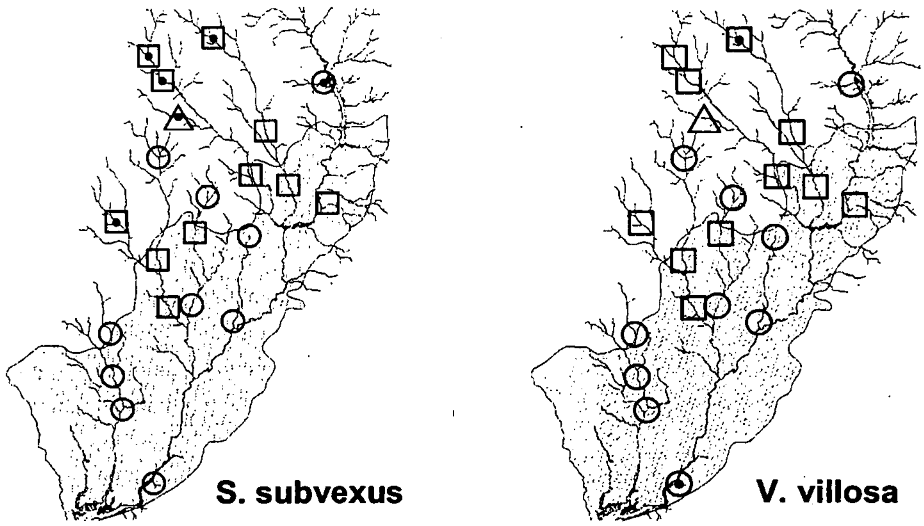
2001 Mussel Survey
Common Species
Abundance – cont.



2001 Mussel Survey
Special Concern
Species Abundance

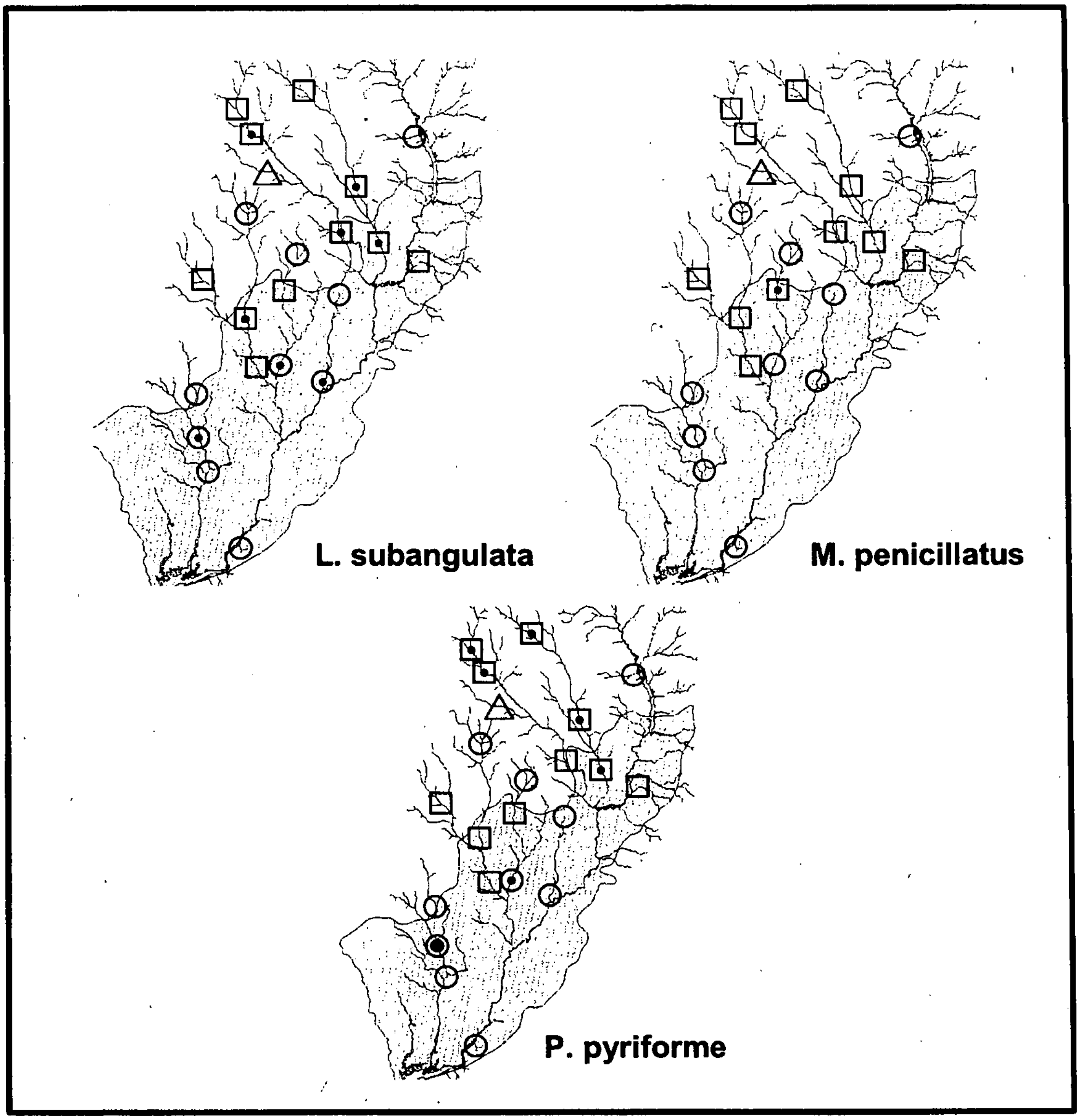
- • 1 - 99
- ● 100 - 999
- ⬤ 1000+

- □ Flowing
- ○ Non-flowing
- △ No data
- Dougherty Plain



2001 Mussel Survey Special Concern Species Abundance – cont.

- • 1 - 99
- ● 100 - 999
- ⬤ 1000+
- □ Flowing
- ○ Non-flowing
- △ No data
- Dougherty Plain



2001 Mussel Survey Endangered Species Abundance

- 1 - 99
- 100 - 999
- 1000+

- □ Flowing
- ○ Non-flowing
- △ No data
- Dougherty Plain

Cost: $65
Quantity: 55

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