# Freshwater Mussel Assessment in the Upper Nottoway River and its Tributaries on Fort Pickett, VA


Atlantic pigtoe, Fort Pickett, VA, July 2014

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**September 2014**

**Prepared for:**

**Virginia Army National Guard**
**and**
**Virginia Department of Military Affairs**
**Facilities Management–Environmental Division**
**Blackstone, Virginia**

**September 2014**

Citation:

Carey, C.S., E.D. Wolf, and V. Emrick. 2014. Freshwater mussel assessment in the upper Nottoway River and its tributaries on Fort Pickett, Virginia. Report-02-2014. Conservation Management Institute, Virginia Polytechnic Institute and State University, Blacksburg. 41 pp.

## Abstract

The upper reaches of the Nottoway River and its tributaries on Fort Pickett, Virginia are located within one of the most diverse river basins of the Atlantic Slope region. Freshwater mussels are vital components of these aquatic ecosystems and are often referred to as ecosystem engineers. Mussel surveys on Fort Pickett have historically concentrated on the central reaches of the Nottoway below the reservoir. Thus, assessments in tributaries and sites above the reservoir were needed. We evaluated a total of 68 sites across Fort Pickett and implemented a two-phase sampling design using time-constrained and quadrat-based surveys at a sub-set of these sites. We documented a total of 9 mussel species, including the state threatened Atlantic pigtoe and state species of concern eastern lampmussel. We found that mussels were patchily distributed and densities and species richness varied greatly between sites. Generally, species richness was lower and densities were higher in the tributaries compared to the main-stem of the Nottoway. Our findings of local mussel populations in the tributaries suggest that these areas may serve as spatial refugia for populations of several species. We found little evidence of recent recruitment across species, even at sites with high densities, indicating the need for water-quality testing and host fish surveys to identify management actions needed to support long-term population viability across species. Riparian and habitat protection should extend to the tributaries as well as to the main-stem of the Nottoway. Furthermore, we recommend additional surveys above the reservoir and in the Controlled Access Area, routine monitoring for Atlantic pigtoe and eastern lampmussel, as well as water quality assessments.

## Introduction

North America has the greatest diversity of freshwater mussel fauna (family Unionidae) in the world, with nearly 300 species (Haag and Williams 2014, Williams et al. 1993). Mussels are filter-feeding bivalves that live relatively sedentary lives, with many species known to have life spans exceeding 25 years. Their unique life-history requires that developing larva (called glochidia) parasitize a host fish in order to complete its life cycle and disperse throughout freshwater systems. Considered freshwater ecosystem engineers, mussels play important roles in aquatic ecosystems in their ability to modify habitat, filter large portions of the water column, and serve as a food source for other animals (Vaughn et al. 2008). They are also useful indicators of water quality and aquatic ecosystem health due to their extreme sensitivity to environmental perturbations (USEPA 2008).

Mussel populations have declined significantly in the last 100 years due to widespread habitat loss and degradation. Because of their habitat requirements, unique life-histories, dispersal capabilities, and filter-feeding traits, mussels are particularly vulnerable to habitat alterations such as impoundments, point- and non-point source pollution, and sedimentation (Haag and Williams 2014, Neves et al. 1997, Vaughn and Taylor 1999). Approximately 30 taxa are listed as extinct and 65% of the remaining taxa found in North America are listed as endangered, threatened, or of special concern—making them the most imperiled taxa in the United States (Haag and Williams 2014, Williams et al. 1993). They have one of the highest endangerment and extinction rates in the world with a predicted loss of over 50% of the remaining North American taxa within the next century (Haag and Williams 2014, Ricciardi and Rasmussen 1999). As an ecologically important and highly imperiled natural resource, freshwater mussel populations require high priority conservation efforts, such as: 1) protection of surviving populations, 2) restoration of extirpated populations, 3) protection and restoration of suitable habitats, 4) collection of population data, 5) increasing knowledge of species-specific population dynamics, and 6) the identification of factors responsible for declines (Carey et al. 2013, Haag and Williams 2014).

Mussels that occur in streams that flow into the Atlantic, from the James River basin in Virginia south to the Altamaha River basin in Georgia, belong to the Southern Atlantic province of the Atlantic Slope biogeographical faunal region (Johnson 1970). This province contains 46 species of freshwater mussels; 24 of which are known to occur (or have historically occurred) in the Chowan River basin—ranking it as one of the most diverse river basins of the Atlantic Slope region (Alderman 2005; Alderman and Alderman 2009; Bogan 2002; Haag 2012; Johnson 1970; VDGIF, unpubl. data). Located within the Chowan River Basin, the upper Nottoway River stretches across the southern end of Fort Pickett Army National Guard Maneuver Training Center (Fort Pickett) in southeastern Virginia. Since 1992, several surveys have been conducted to document mussel diversity and distribution on Fort Pickett (Chazal and Derge 2001; Fleming and Alstine 1994; Seybold 1998; Wolf 2006, 2008). Collectively, these surveys have identified 10 species on Fort Pickett within this reach of the Nottoway River: *Alasmidonta undulata* Say (triangle floater), *Elliptio complanata* Lightfoot (eastern elliptio), *Elliptio congaraea* I. Lea (Carolina slabshell), *Elliptio lanceolata* I. Lea (yellow lance), *Fusconaia masoni* Conrad (Atlantic pigtoe), *Lampsilis radiata* Gmelin (eastern lampmussel), *Pyganodon cataracta* Say (eastern floater), *Strophitus undulatus* Say (creeper), *Utterbackia imbecillis* Say (paper pondshell), and *Villosa constricta* Conrad (notched rainbow). Although it has not been documented in this reach, the federally endangered *Alasmidonta heterodon* I. Lea (dwarf

wedgemussel) may exist on Fort Pickett as it has historically occurred in the upper Nottoway River both up- and downstream of the installation.

Over the past 22 years, mussel survey efforts on Fort Pickett have been largely concentrated in the main-stem of the Nottoway River. Sampling efforts in tributaries were limited to the lower-most reaches of Crooked Creek, Hurricane Branch, and Tommeheton Creek, and to small sections of Long Branch, Butterwood Creek and Birchin Creek. Because tributaries are less impacted by the extreme variability in flow conditions of the main-stem of the Nottoway, they may offer greater habitat stability and serve as refugia for mussel species. Recent sampling efforts have also been concentrated below the reservoir, with the last surveys above the reservoir occurring over 14 years ago (Chazal and Derge 2001, Fleming and van Alstine 1994, Seybold 1998). Hence, assessments in tributaries that feed into the Nottoway and updated monitoring of sites above the reservoir were needed to accurately determine current distributions and densities of mussel species on Fort Pickett.

Of particular importance is the continued monitoring of the Atlantic pigtoe—a federally listed species of concern, state threatened species, and Army Priority Level 3 Species at Risk—that occurs within the upper reaches of the Nottoway River on Fort Pickett. As of 2012, these reaches were home to one of only two remaining viable populations of the Atlantic pigtoe in Virginia, and possibly range-wide. Recent survey efforts (2006–2012) on Fort Pickett have documented a dramatic decline in the number of Atlantic pigtoe encountered per person-hour search effort, bringing the viability of this population into question (Wolf 2012). As a Priority Level 3 Species at Risk, if the Atlantic pigtoe is federally listed (threatened or endangered), it has the potential to impact the military training mission. If there is to be any possibility of preventing this species from declining to the point that it is federally listed, and fall under the regulation of the Endangered Species Act (US Congress 1973), it is imperative that this population and its habitat be closely monitored so immediate conservation efforts can be implemented.

With mussel populations declining at alarming rates worldwide, it is important to determine current distributions and monitor population demographics to detect declines and prevent local population extirpations. This survey investigated distributions and demographics of mussels in tributaries and reassessed those in the main-stem of the Nottoway River on Fort Pickett.

The objectives of this study were to:

1) conduct a comprehensive survey for freshwater mussels across the installation, including sites and tributaries that may not have been sampled previously;

2) obtain site-specific estimates of species richness, relative abundance, and density; and

3) determine the current distribution of mussels across sites in the Nottoway River and its tributaries on Fort Pickett.

## Field Site Description

Fort Pickett Army National Guard Maneuver Training Center is a military installation located in the piedmont physiographic province of southeastern Virginia, near the town of

Blackstone, and covers approximately 16,592 ha of land in portions of three counties: Nottoway, Dinwiddie, and Brunswick (Fig. 1). The installation is characterized by low, gentle terrain underlain by a variety of igneous and metamorphic rock with sandy loam and clay loam dominant soil types. Climate on Fort Pickett is distinguished by hot, humid summers and mild winters with an annual average temperature and precipitation of 57°F and 109 cm (The Conservation Management Institute 2007).

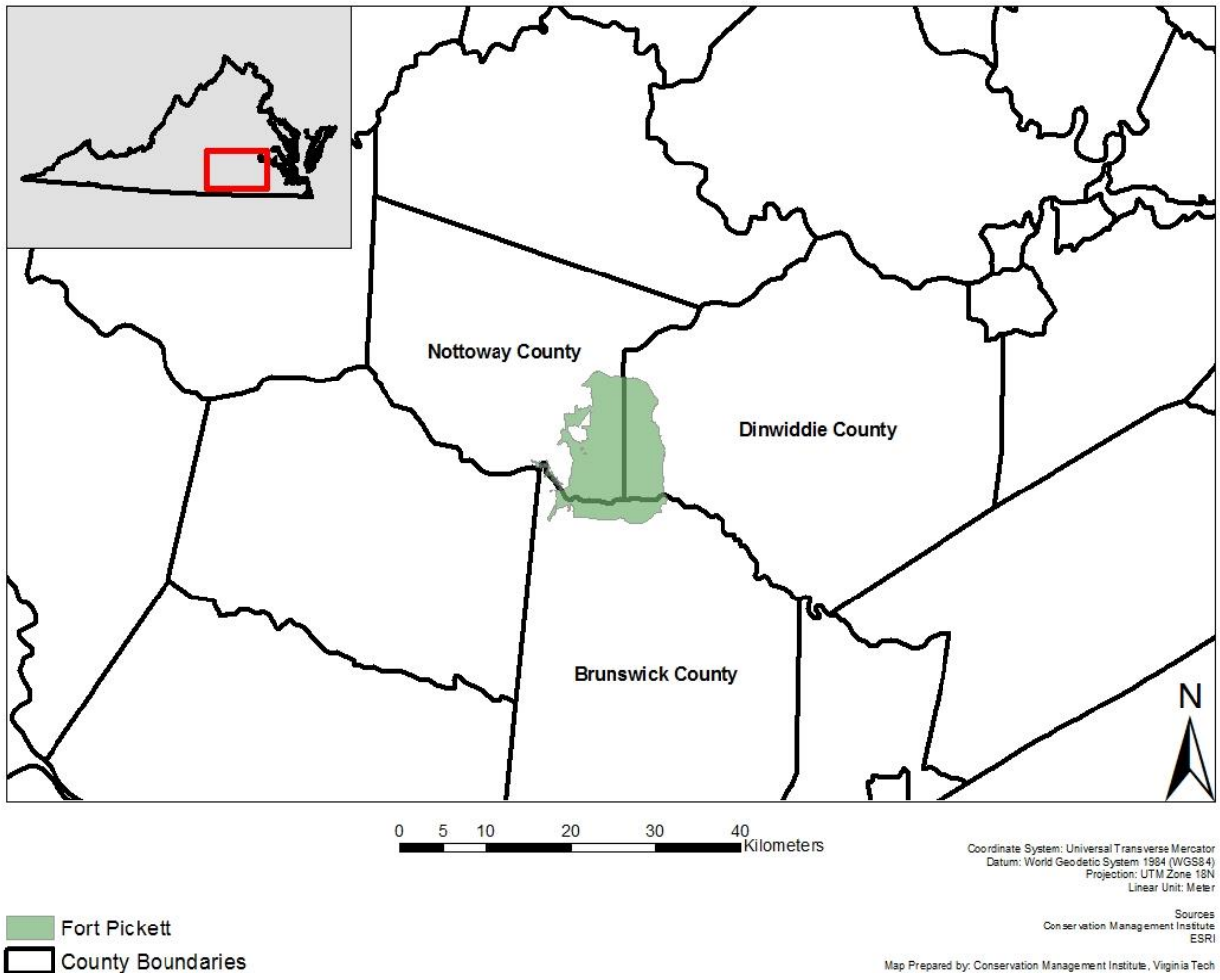


Figure 1. Location of Fort Pickett Army National Guard Maneuver Training Center in Nottoway, Dinwiddie, and Brunswick counties, Virginia.

The upper Nottoway River and its tributaries are the primary surface water drainage system for Fort Pickett—responsible for draining 3,680 km$^2$ of the southside of Virginia. The main section of the Nottoway River that flows southeast across the southern end of the installation extends approximately 14.8 river kilometers (RKM) from the Nottoway River dam at the Route 46 bridge east to Route 613. An additional 1.4 RKM stretch (i.e., non-marsh portions) of the Nottoway River on Fort Pickett is located above the Fort Pickett Reservoir. There are twelve main drainages that flow into the Nottoway River on Fort Pickett: two tributaries above the reservoir, two flowing into the reservoir, and eight flowing in below the reservoir. Drainages

flow into the Nottoway River above the reservoir through the Little Nottoway River and Reedy Branch, and into the reservoir through Crooked Creek and Cedar Creek. Drainages flow into the main-stem of the Nottoway River from the north through Hurricane Branch, Long Branch, Birchin Creek, Tommeheton Creek, and Butterwood Creek, and from the south through Wildcat Creek, Rocky Run, and Red Oak Creek.

## Methods

### Site Selection

In order to select potential sites for comprehensive surveying, we first conducted an in-depth review of sources to compile a list of potential mussel species to be encountered on Fort Pickett and their respective identification characteristics, life histories, and ecology. Sources included peer-reviewed articles, survey reports (Chazal and Derge 2001; Fleming and van Alstine 1994; Seybold 1998; Wolf 2005, 2006, 2008; Wolf and Duncan 2007; Wolf and Emrick 2013), unpublished collection data, databases, personal communications, and species distribution maps. Using this information we identified 12 reaches of historical mussel occurrences and potential suitable mussel habitat in the main-stem of the Nottoway River and the lower-most reaches of tributaries. In order to obtain good spatial coverage across areas that had not been previously surveyed, we randomly generated 56 tributary sites in ArcGIS (Environmental Systems Resource Institute, Redlands, California, version 10.1). Areas in which random points were generated were stratified by tributary and allocation of the number of random points per tributary was dependent on tributary size (i.e., length). In total, we selected 68 preliminary reaches for evaluation: 7 sites in the main-stem of the Nottoway below the reservoir, 2 sites above the reservoir, and 59 sites distributed throughout tributaries on Fort Pickett (Fig. 2).

Preliminary evaluations included visual assessment of habitat suitability (e.g., mesohabitat types, substrate composition, large woody debris, etc.) and visual and tactile searches for the presence of freshwater mussels. GPS coordinates were taken to mark areas evaluated and species encounters. In addition, we recorded the presence of fish, *Campeloma decisum* Say (pointed campeloma), *Corbicula fluminea* O.F. Müller (Asiatic clam), and individuals from the family Sphaeriidae Deshayes (fingernail clams).

These preliminary evaluations allowed us to allocate time-intensive and in-depth survey effort to areas with high likelihood of mussel presence. We used information gathered from these 68 site evaluations to aid in the selection of 18 sites for more in-depth sampling. The criteria used to select sites for further sampling included: 1) reaches where mussels (live or dead) were observed during initial evaluations or previous surveys, 2) reaches consisting of suitable mussel habitat, and 3) reaches that had not been previous surveyed above the reservoir or in tributaries.

### Habitat Measurements

We delineated each comprehensive survey site ($n$ = 18) in the field prior to sampling to characterize the physical habitat and estimate effective sampling area. Wetted width was measured at 6 equally spaced transects along the length of each reach and GPS coordinates were taken at the downstream and upstream endpoints. Dependent on average wetted width and

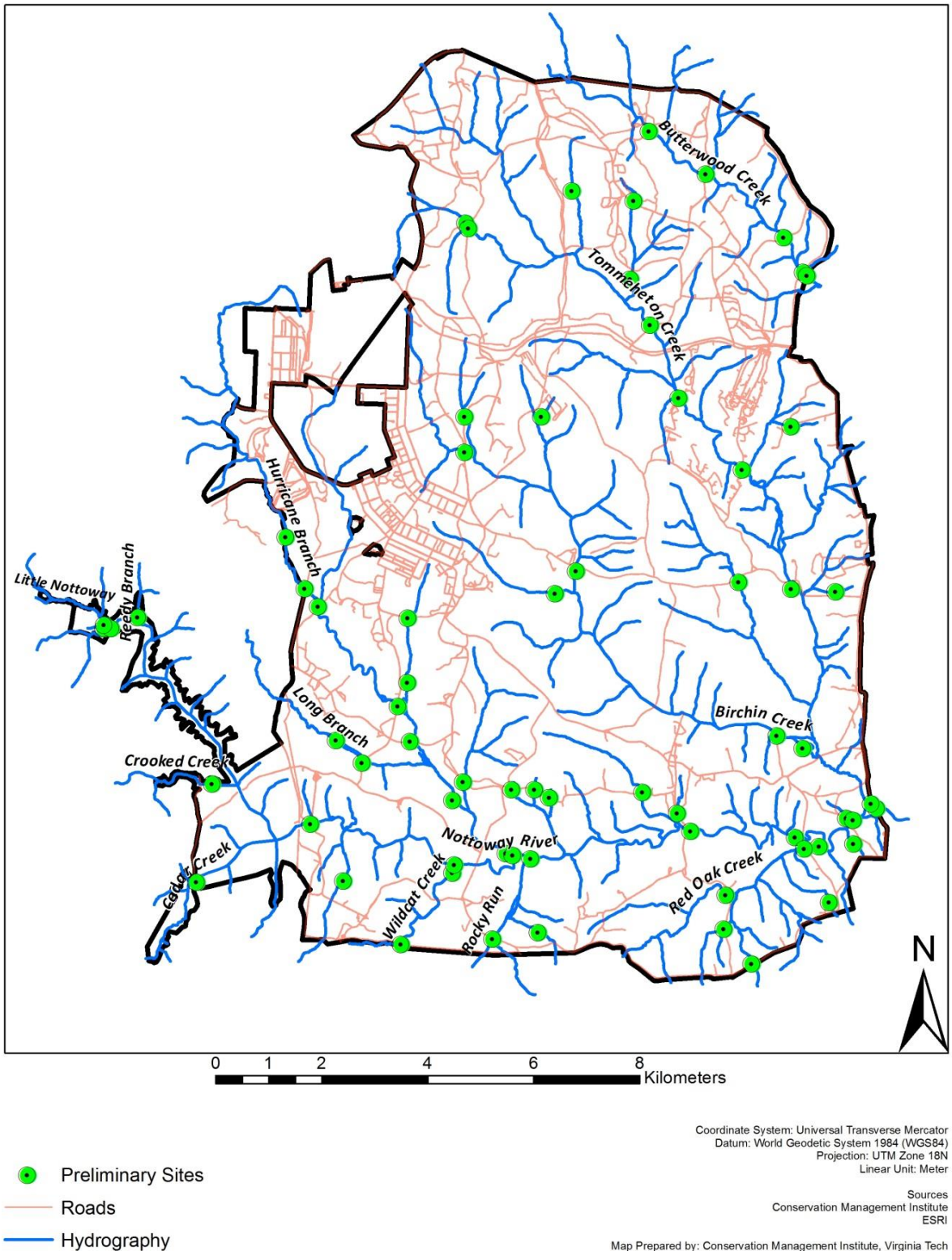


Figure 2. Distribution of preliminary sites evaluated ($n$ = 68) for freshwater mussels in the Nottoway River and tributaries on Fort Pickett, Virginia from November 2013 to August 2014.

availability of suitable habitat, each sampling reach ranged from 50–500 m in length. We also assessed stream depth, flow velocity, water temperature, substrate composition, embeddedness, turbidity, sediment deposits, and composition of large woody debris and aquatic vegetation at each site.

## Comprehensive Sampling Design

To obtain site-specific estimates of species richness, relative abundances, and densities, and effectively assess distributions across a large spatial scale, we implemented a two-phase sampling design following the general methodology in Villella and Smith (2005). During the first sampling phase, we conducted timed searches at each of the 18 sites to assess reach-specific species richness and relative abundances. Substrate surfaces were systematically and thoroughly searched (visual and tactile) for live individuals and shell material by snorkeling and using aquascopes, beginning at the downstream boundary and moving upstream for approximately 1–2 person-hours. We identified and measured all individuals and returned them to the substrate. Banks adjacent to the stream and exposed areas were searched for shell material. We pooled all eastern elliptio and Carolina slabshell encountered under eastern elliptio "complex" for data analysis because of the large variability in eastern elliptio shell morphology and taxonomic uncertainty (Johnson 1970) and to maximize survey efficiency, reduce handling stress, and minimize disturbance to dense elliptio beds. Data collected during these timed searches were used to optimally allocate quadrat-based sampling in the second phase and stratified sites based on the following criteria: 1) tributary or main-stem site, 2) catch per unit effort (CPUE), and 3) species richness. We then randomly selected a subset of the first phase sites from each stratum for second phase quadrat sampling.

We calculated the number of sampling units (0.25-$m^2$ quadrat samples) required to estimate population density (mean mussels/$m^2$) for a given level of precision at each reach following the methods found in Smith (2001) and Strayer and Smith (2003). For smaller survey reaches (< 10 m wetted width), we sampled quadrats using a systematic sampling design because mussels generally were normally distributed and it offered good spatial coverage. Because mussel density tended to be greater along the stream banks (i.e., clustered) of larger reaches (≥ 10 m wetted width), we sampled quadrats using a stratified random design so as to concentrate sampling effort where mussels were densest and to gain precision in parameter estimates. We divided larger reaches (≥ 10 m width) into two stratum, classifying areas within 3 m of stream banks as high density, and areas > 3 m from the banks (middle of channel) as low density. We calculated optimal allocation of quadrat sampling effort for each stratum using the methods found in Strayer and Smith (2003).

We hand excavated quadrats to 15–30 cm below the substrate surface identifying all mussels encountered to species, measuring for length, and documenting their position in the substrate as being observed at the surface or below before returning individuals to their collection point. We assumed that all individuals ≥ 1 year old had a 100% probability of detection within a quadrat. In the absence of sieving substrates, individuals < 1 year were difficult to detect during quadrat sampling and therefore were not included in abundance and density estimations. We completed all field surveys between November 2013 and August 2014.

### Data Analysis

We used timed search data from the first phase of sampling to estimate site-specific species richness, relative abundances, and CPUE at each study site. Species richness was defined as the number of different species encountered. Relative abundance was expressed as the number of individuals of a particular species as a proportion of the total number of mussels encountered. CPUE was calculated as the number of mussels encountered per person-hour search effort (mussels/hour).

We used quadrat survey data from the second phase of sampling to measure site-specific mussel abundances and densities. Calculations of abundances and associated variances followed formulas for systematic and stratified random sampling designs found in Smith et al. (2001) and Strayer and Smith (2003). We defined abundance as the number of mussels (>1 year old) in the study area at the time of the survey. Density was defined as the total number of mussels > 1 year old per $m^2$ and was derived by dividing the abundance estimate by the effective sampling area. We assessed data for normality and calculated 95% confidence intervals around abundance and density estimates using SAS software (SAS Institute, Inc., Cary, North Carolina, version 9.2).

## Results

### Preliminary Searches

From the 68 preliminary sites evaluated, we eliminated 2 sites in the main-stem and 48 sites in the tributaries from consideration for further surveying because of unsuitable habitat characteristics (e.g., wetland/marsh habitat, pond, intermittent streams, or no available habitat such as favorable substrate, stable banks, optimal flow, or large woody debris) and lack of evidence that mussels were present (i.e., shells or live individuals). The 18 sites selected for comprehensive sampling include 5 sites in the main-stem of the Nottoway below the reservoir, 2 sites in the main-stem above the reservoir, and 11 sites throughout tributaries (Figs. 3a, 3b; Table A1). We identified 7 species of mussels during preliminary evaluations: triangle floater, eastern elliptio complex (eastern elliptio and Carolina slabshell), eastern floater, creeper, paper pondshell, and notched rainbow (Table 1; Figs. A2, A3, A4, A5, A6, and A11). We found live individuals and shells of all species with the exception of the triangle floater and notched rainbow (no live individuals, 1 fresh dead shell each, and several relic shells). Eastern elliptio complex, followed by the creeper, were the most commonly observed species.

### First Phase Sampling: Timed Searches

We encountered a total of 9 live species collectively across the 18 sites during timed searches (Table 1; Tables 2a, 2b; Appendix B). All 9 species were encountered in the mainstem of the Nottoway River, but only 4 of these species were observed in tributary sites. We collected a total of 1,988 individuals across timed searches, comprised > 98% by eastern elliptio complex and followed distantly by creeper (0.45%; Table 2b). Catch per unit effort ranged from 0–630 mussels per hour and was greatest in tributary sites. Species richness per site ranged from 0–4 species (Table 2a) and was greater in sites located in the main-stem of the Nottoway River. We found three Atlantic pigtoe at two main-stem sites (Sites NoR_04 and NoR_08) that were 38, 49,

and 67 mm in length and estimated to be approximately 8, 15, and 33 years old using predicted age-at-length curves, respectively (Wolf 2012). Daily water temperatures during sampling ranged from 18–30°C (Table A1).

**Second Phase Sampling: Quadrat Sampling**

From our 18 timed search sites, we selected 4 sites for quadrat sampling, including 3 sites in the main-stem of the Nottoway River and 1 tributary site in Birchin Creek. We encountered a total of 452 live individuals representing 4 species collectively in quadrat sampling across sites. Greater than 99% of individuals were represented by eastern elliptio complex. We found no shell material for additional species that we did not encounter live (Table 1, Table 4). Water temperatures during sampling ranged from 25–31°C (Table A1).

Estimated abundances of mussels ranged from 0 to as high as 16,350 individuals, and densities ranged from 0 to as high as 109/$m^2$, among sites. Birchin Creek (Site BiC_02) contained the highest density of mussels. Although eastern elliptio complex were collected during timed searches, no individuals were collected inside of quadrats at sampling site NoR_02 above the reservoir. Overall, quadrat sampling revealed fewer species relative to time searches across all sites (Table 2a, Table 3).

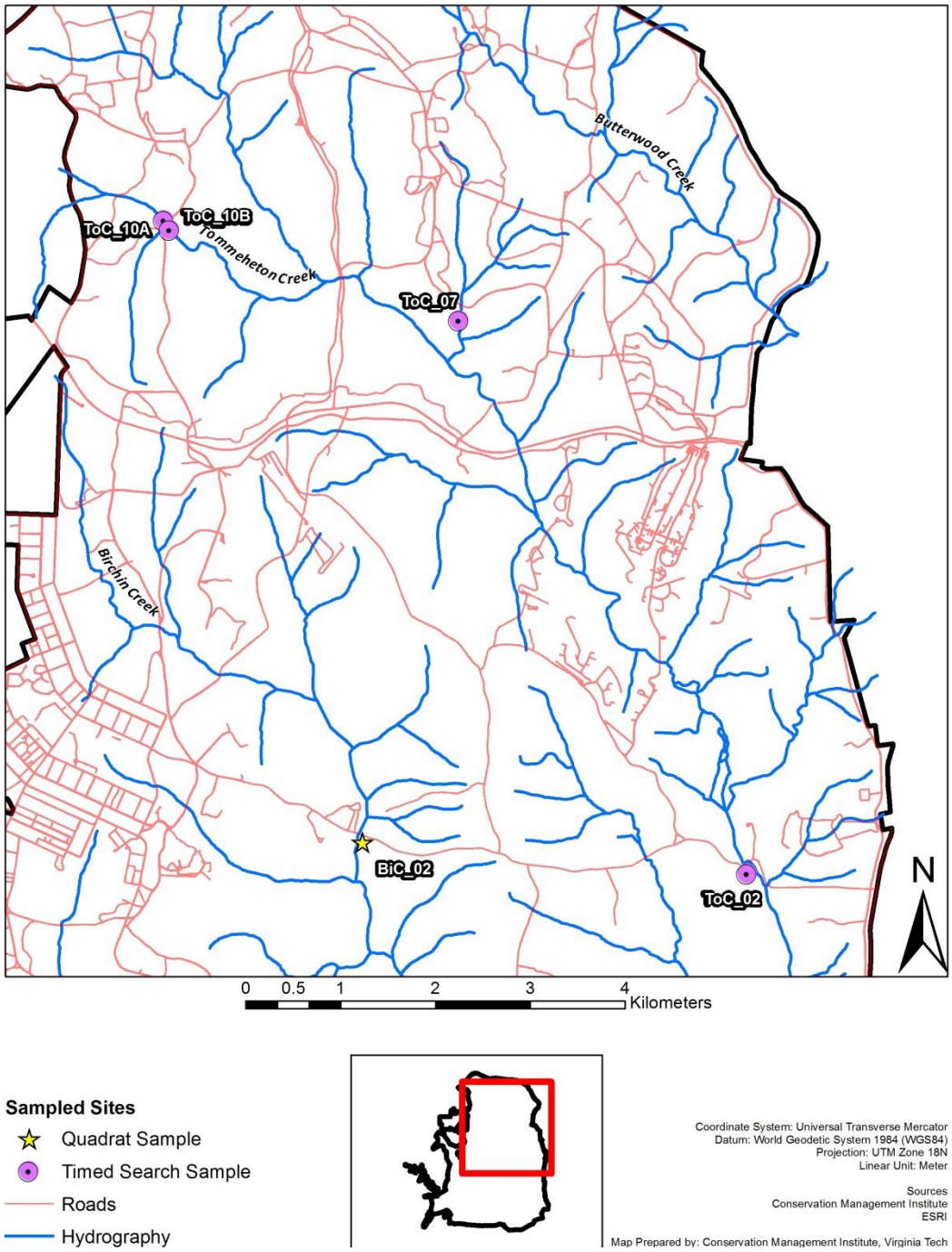


Figure 3a. Distribution of sites assessed by timed searches (circles) and quadrat sampling (stars) in tributaries located in the northern portion of Fort Pickett, Virginia from May–August 2014. Timed searches were also conducted at all quadrat sampling sites.

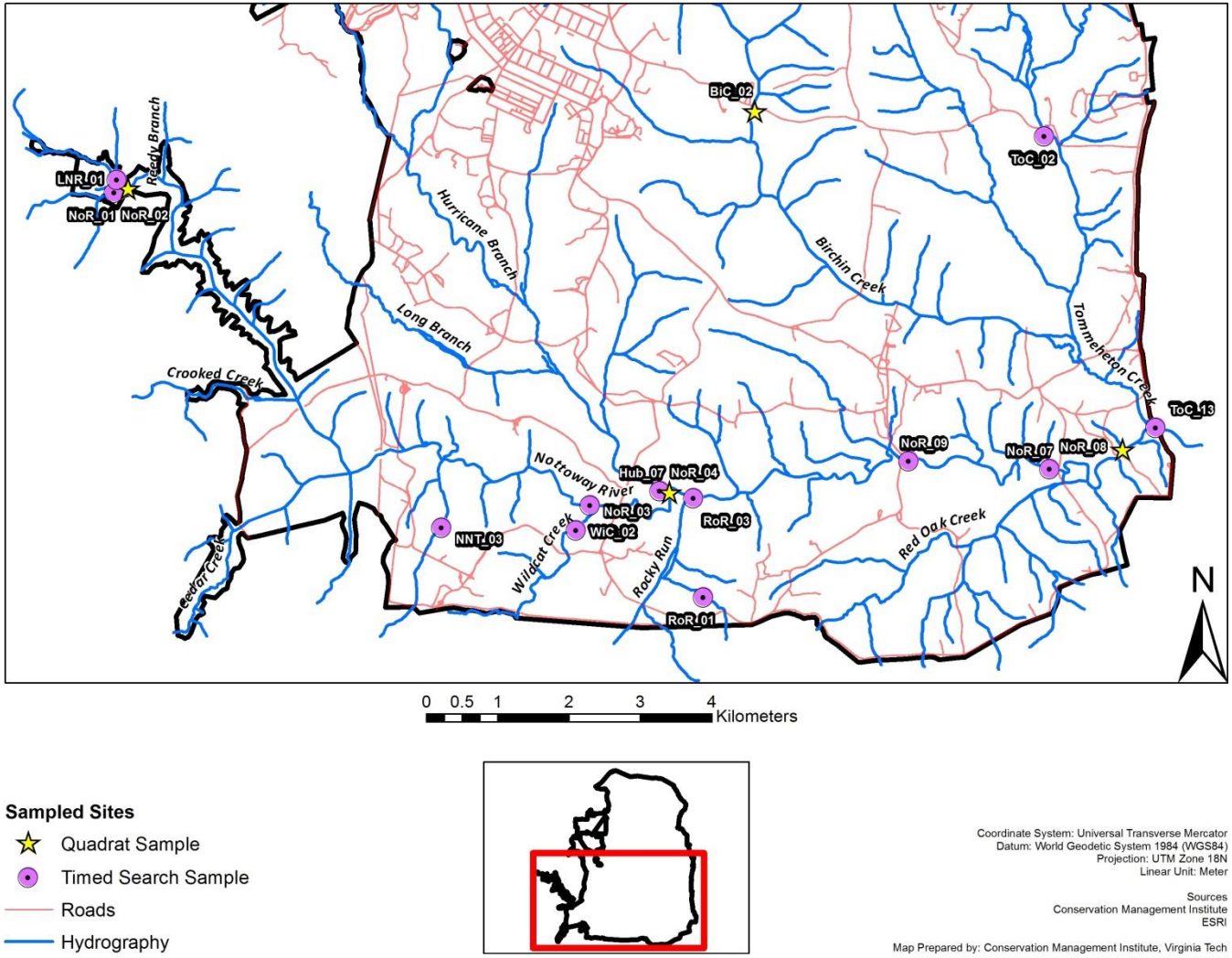


Figure 3b. Distribution of sites assessed by timed searches (circles) and quadrat sampling (stars) in the main-stem of the Nottoway River and its tributaries located in the southern portion of Fort Pickett, Virginia from May–August 2014. Timed searches were also conducted at all quadrat sampling sites.

Table 1. Freshwater mussel species of interest in the Nottoway River and its tributaries on Fort Pickett, Virginia and species encountered from November 2013 to August 2014 by survey methodology.

| Common name | Scientific name | Status[2] | Survey Methodology | | |
|---|---|---|---|---|---|
| | | | Preliminary (qualitative) | Timed (CPUE) | Quadrat Sampling |
| Dwarfwedge mussel | *Alasmidonta heterodon* | FE, SE | * | * | * |
| Triangle floater | *Alasmidonta undulata* | | ✓ | ✓ | |
| Eastern elliptio | *Elliptio complanata*[1] | | ✓ | ✓ | ✓ |
| Carolina slabshell | *Elliptio congarea*[1] | | ✓ | ✓ | ✓ |
| Yellow lance | *Elliptio lanceolata* | SSC | * | * | * |
| Atlantic pigtoe | *Fusconaia masoni* | SOC, ST | | ✓ | |
| Eastern lampmussel | *Lampsilis radiata* | SSC | | ✓ | |
| Eastern floater | *Pyganodon cataracta* | | ✓ | ✓ | ✓ |
| Creeper | *Strophitus undulatus* | | ✓ | ✓ | |
| Paper pondshell | *Utterbackia imbecillis* | | ✓ | ✓ | ✓ |
| Notched rainbow | *Villosa constricta* | | ✓ | ✓ | |

*Species not encountered during 2014 survey

[1]Eastern elliptio and Carolina slabshell individuals were pooled under eastern elliptio complex for data analysis

[2] Federal and state listed species status; FE = federally endangered, SOC = federal species of concern, SE = state endangered, ST = state threatened, SSC = state species of species concern

Table 2a. Timed search data (numbers of individuals per species per site) for sites in the Nottoway River and its tributaries on Fort Pickett, Virginia in May–August 2014 organized in descending catch per unit effort (CPUE). Catch per unit effort is defined as the number of species observed per one unit of search effort (one unit of effort = one person-hour).

| Site | Eastern elliptio complex[1] | Creeper | Eastern floater | Paper pondshell | Atlantic pigtoe | Triangle floater | Eastern lampmussel | Notched rainbow | Total | Effort | CPUE | No. species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BiC_02* | 750 | 0 | 4 | 2 | 0 | 0 | 0 | 0 | 756 | 1.2 | 630 | 4 |
| ToC_02 | 473 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 475 | 1.4 | 343 | 3 |
| NoR_04* | 199 | 4 | 0 | 1 | 2 | 0 | 0 | (1 shell) | 206 | 1.2 | 172 | 5 |
| NoR_08* | 181 | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 185 | 1.1 | 168 | 5 |
| NoR_01 | 133 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 109 | 1.0 | 109 | 3 |
| NoR_09 | 108 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 136 | 1.7 | 80 | 3 |
| NoR_03 | 42 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 45 | 2.0 | 23 | 5 |
| ToC_13 | 37 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 37 | 2.1 | 18 | 2 |
| NoR_07 | 24 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 25 | 1.7 | 15 | 3 |
| LNR_01 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0.8 | 5 | 1 |
| ROR_03 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1.0 | 3 | 1 |
| HuB_07 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 1.8 | 2 | 1 |
| NoR_02* | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1.0 | 2 | 1 |
| WiC_02 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1.3 | 1 | 1 |
| NNT_03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.9 | 0 | 0 |
| RoR_01 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.1 | 0 | 0 |
| ToC_07 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.9 | 0 | 0 |
| ToC_10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.7 | 0 | 0 |
| Total | 1961 | 9 | 6 | 5 | 3 | 2 | 1 | 1 | 1988 | 24.96 | | 9 |

*Site was also surveyed using quadrat sampling

[1]Eastern elliptio and Carolina slabshell individuals were pooled under eastern elliptio complex for data analysis

Table 2b. Relative abundances (%) for sites in the Nottoway River and its tributaries on Fort Pickett, Virginia estimated by timed searches in May–August 2014.

| Site | Eastern elliptio complex[1] | Creeper | Eastern floater | Paper pondshell | Atlantic pigtoe | Triangle floater | Eastern lampmussel | Notched rainbow |
|---|---|---|---|---|---|---|---|---|
| BiC_02* | 99.21 | 0.00 | 0.53 | 0.26 | 0.00 | 0.00 | 0.00 | 0.00 |
| ToC_02 | 99.58 | 0.00 | 0.42 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NoR_04* | 96.60 | 1.94 | 0.00 | 0.49 | 0.97 | 0.00 | 0.00 | 0.00 |
| NoR_08* | 97.84 | 1.08 | 0.00 | 0.00 | 0.54 | 0.00 | 0.00 | 0.54 |
| NoR_09 | 97.79 | 2.21 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NoR_01 | 99.08 | 0.00 | 0.00 | 0.92 | 0.00 | 0.00 | 0.00 | 0.00 |
| NoR_03 | 93.33 | 0.00 | 0.00 | 2.22 | 0.00 | 2.22 | 2.22 | 0.00 |
| ToC_13 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NoR_07 | 96.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.00 | 0.00 | 0.00 |
| HuB_07 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| LNR_01 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ROR_03 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NoR_02* | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| WiC_02 | 100.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NNT_03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| RoR_01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ToC_07 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| ToC_10 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 98.64 | 0.45 | 0.30 | 0.25 | 0.15 | 0.10 | 0.05 | 0.05 |

*Site was also surveyed using quadrat sampling

[1]Eastern elliptio and Carolina slabshell individuals were pooled under eastern elliptio complex for data analysis

Table 3. Collection data and estimated abundances and densities (mussels/$m^2$) for freshwater mussel species in the Nottoway River and its tributaries on Fort Pickett, Virginia in July–August 2014 by quadrat sampling. *n* = number of sampling units (0.25-$m^2$ quadrats). The coefficient of variation (CV = SE/mean) is equivalent to the level of precision of the estimate.

| | | | | | | | | 95% C.I. | | | 95% C.I. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Date | Quadrat Methodology | *n* | Species | no. obs. | CV | Abundance | Lower | Upper | Density | Lower | Upper |
| BiC_02 | 7/4/14 | Systematic | 12 | Eastern elliptio complex[1] | 326 | 0.17 | 16,300 | 14,511 | 18,089 | 108.67 | 96.74 | 120.60 |
| | | | | Eastern floater | 1 | 1.00 | 50 | 19 | 81 | 0.33 | 0.12 | 0.54 |
| | | | | Total | 327 | 0.17 | 16,350 | 14,560 | 18,140 | 109.00 | 97.07 | 120.93 |
| NoR_02 | 8/6/14 | Stratified | 51 | N/A | 0 | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| NoR_04 | 8/8/14 | Stratified | 50 | Eastern elliptio complex[1] | 106 | 0.15 | 1,631 | 1,554 | 1,708 | 1.73 | 1.71 | 1.75 |
| NoR_08 | 8/7/14 | Stratified | 53 | Eastern elliptio complex[1] | 18 | 0.30 | 617 | 554 | 680 | 0.12 | 0.11 | 0.13 |
| | | | | Paper pondshell | 1 | 1.00 | 34 | 23 | 46 | 0.007 | 0.005 | 0.009 |
| | | | | Total | 19 | 0.29 | 651 | 588 | 714 | 0.13 | 0.12 | 0.14 |

[1]Eastern elliptio and Carolina slabshell individuals were pooled under eastern elliptio complex for data analysis

## Discussion

The objectives of this study were to determine current freshwater mussel distributions and site-specific estimates of species richness, relative abundance, and density in tributaries and the main-stem of the Nottoway River across Fort Pickett. We conducted preliminary evaluations at many sites and a two-phase sampling design at a sub-set of sites on Fort Pickett which allowed us to effectively assess population dynamics and distributions across a large spatial scale. By expanding our search areas outside historically surveyed sites we identified distributions of freshwater mussel species on Fort Pickett that are not limited to the main-stem of Nottoway River and the lower-most reaches of its tributaries (i.e. higher-order streams). We found that mussel distributions were patchy throughout their range and that species richness and densities varied greatly among sites and across the installation. The densest mussel beds were observed in higher reaches (lower-order streams) of the tributaries—nearly 8 RKM from the main-stem of the Nottoway River—indicating that there are healthy local populations in the tributaries and that these areas may serve as spatial refugia for populations of several species from the main-stem.

Although they contained the densest mussel beds encountered, sampling in tributary sites revealed lower species richness than sites in the main-stem of the Nottoway River. Of the 9 species observed in the main-stem, only eastern elliptio, Carolina slabshell, eastern floater, and paper pondshell were encountered in tributary sites. Consistent with past species observational data from below Birchin Lake in 1999 (Roble, pers. comm.), we found eastern floater and paper pondshell to occupy sites located below Birchin (BiC_02) and Tommeheton (ToC_02) Lakes, although at significantly lower abundances relative to eastern elliptio and Carolina slabshell. Eastern elliptio, eastern floater, and paper pondshell were also observed in higher reaches of Butterwood Creek and Birchin Creek during preliminary site evaluations (Figs. 4a, 4b). Apart from these headwater and medium stream reaches, no other tributary study sites evaluated in higher-reaches contained mussels. Factors such as absence of species-specific host fish or unfavorable habitat conditions (e.g., temperature, stream flow, substrate composition, pollution, sedimentation) influence mussel distributions and are likely why we did not encounter mussels in other tributary survey sites (Vaughn and Taylor 1999). However, lack of mussel species encounters within reaches does not signify absence across all tributaries, but that none were detected given the search effort and area. Further sampling in additional tributary sites may reveal the presence of other species.

Sampling in the lower-most reaches of Hurricane Branch, Rocky Run, Tommeheton Creek, and Wildcat Creek (Sites HuB_07, RoR_03, ToC_13, and WiC_02) revealed lower species richness and densities compared to tributary sites with live mussels in higher-reaches (Figs. 4a, 4b). Eastern elliptio and Carolina slabshell were the only species encountered within these lower-most reaches. Historically, triangle floater, eastern elliptio, and Atlantic pigtoe occupied the lower-most reaches Hurricane Branch (Fleming and van Alstine 1994, Seybold 1998), with the last live Atlantic pigtoe detected in 1998. Like Chazal and Derge (2001), we only detected eastern elliptio within this reach and agree that this decline in diversity may be attributed to reduced flows and increased sedimentation that characterize portions of this reach below the Range Road culvert. In addition, during searches in fall 2013, we noted that the water within this reach was noticeably distinguished by a blue-greyish tint; a discoloration that had not been reported by previous visits and that may be indicative of other contributing water quality issues (Fig. 5). Because Atlantic pigtoe prefers swift flows, free of sedimentation and other

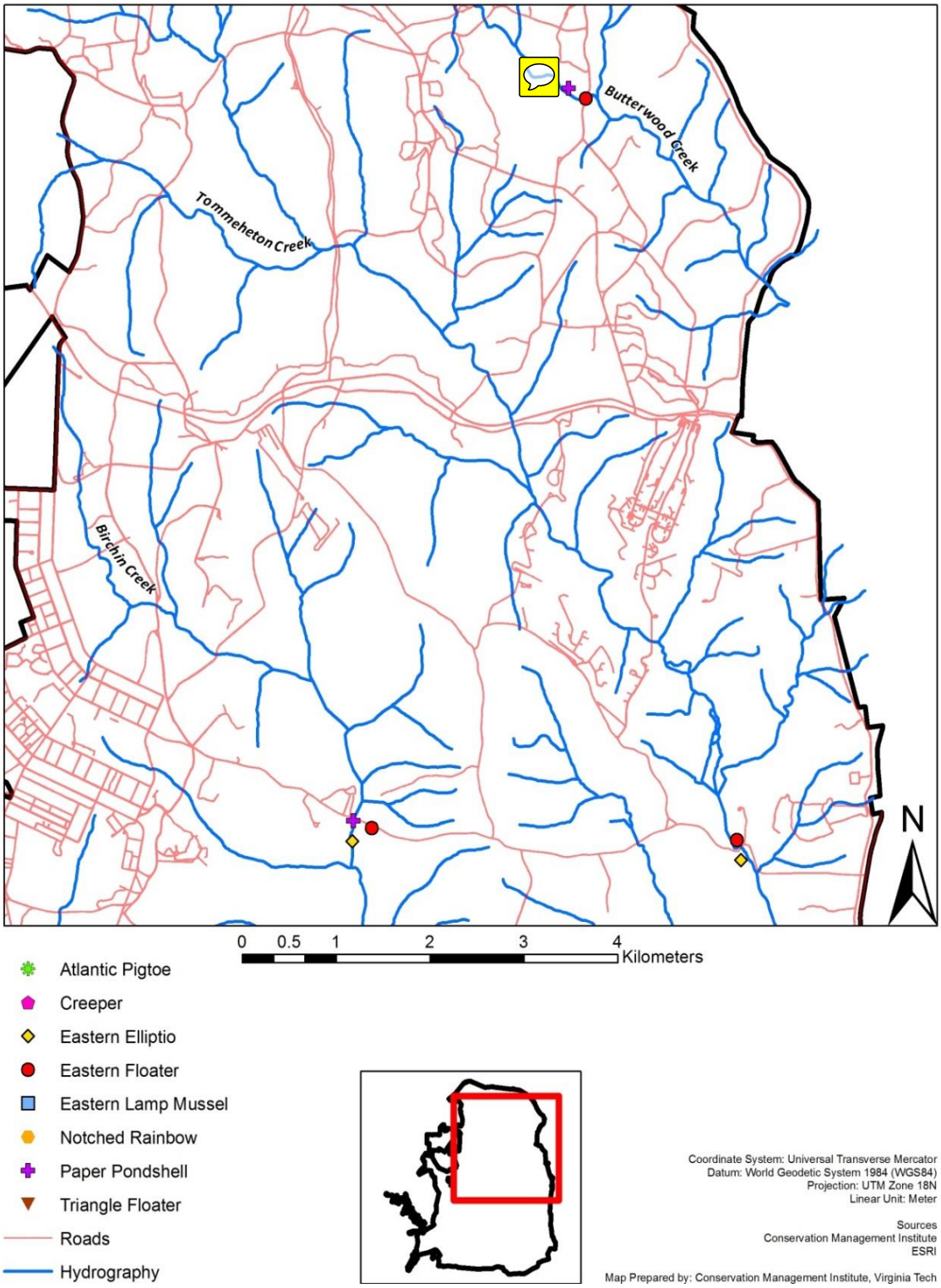


Figure 4a. Distribution of species observations located in the northern portion on Fort Pickett, Virginia from November 2013 to August 2014 collected during preliminary evaluations, timed searches, and quadrat sampling.

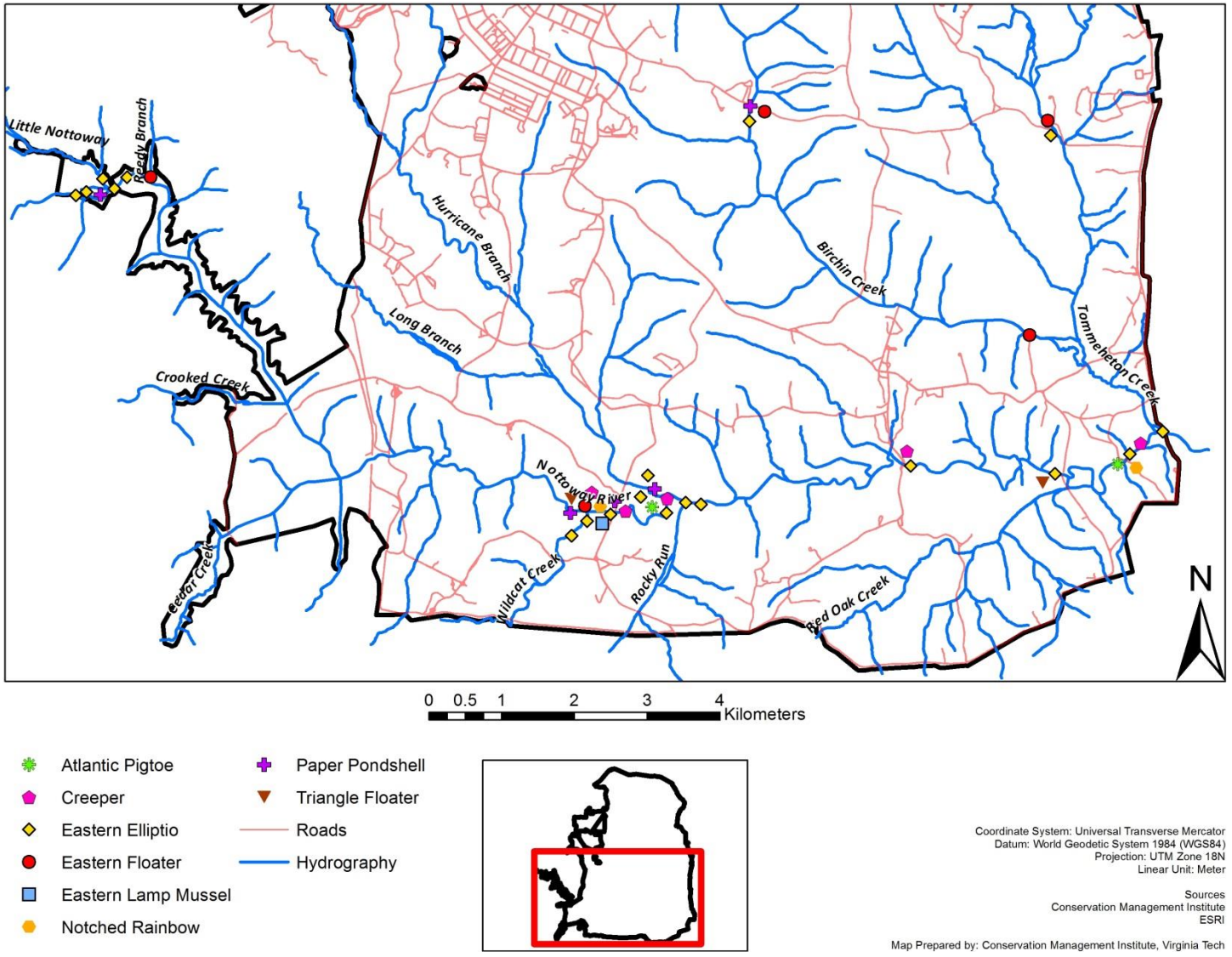


Figure 4b. Distribution of species observations located in the southern portion on Fort Pickett, Virginia from November 2013 to August 2014 collected during preliminary evaluations, timed searches, and quadrat sampling.

Figure 5. View of Hurricane Branch approximately five meters upstream of its junction with the main-stem of the Nottoway River. Bluish-gray discoloration of water observed across approximate 650 meter reach of Hurricane Branch surveyed from the confluence with the Nottoway River to Range Road crossing, in November 2013.

pollutants (Bogan 2002), it was not surprising that we did not detect this species in this reach of Hurricane Branch.

Similar to previous surveys (Wolf 2006, 2008), distributions of mussels within each main-stem Nottoway River site were clumped with individuals aggregating in patches along stable banks and areas with large woody debris. This observed patchiness can be attributed to flow refuges and stable habitats offered to mussels by large woody debris running parallel to banks and substrates characterized by clay and compacted sand (Strayer 1999, Wolf 2008). Because the substrate in the main-stem of the Nottoway River is very dynamic, consisting mostly of coarse sand that frequently redistributes, these flow refuges and stable substrates protect mussels from displacement. Correspondingly, we encountered very few individuals in the middle of reaches in the main-stem where substrates were much less stable.

Collectively, we encountered a total of 9 different species in the main-stem of the Nottoway River. With the exception of dwarf wedgemussel and yellow lance, we encountered all species of interest. As in the tributaries, eastern elliptio and Carolina slabshell (eastern elliptio complex in data summaries) were the most abundant species encountered in the main-stem; comprising 93–100% of all individuals observed within a site. Although encountered considerably less frequently than eastern elliptio and Carolina slabshell, creeper was the third most abundant species observed in the main-stem. Of the Nottoway River sites, sites located near the Hurricane Branch confluence (NoR_04), Wildcat Creek confluence (NoR_03), and below Longstreet Road ford (NoR_08) had the highest species richness observed during timed searches

(5 species at each of the 3 sites). In combination with observations made during preliminary site evaluations, Site NoR_03 had the greatest species richness ($n$ = 8) (Fig. 4b). Similarly, Wolf (2006) reported Site NoR_03 (then designated Site 23-1) to have the greatest number of species among survey sites in 2006.

Historically, Atlantic pigtoe has consistently been documented in the main-stem of the Nottoway on Fort Pickett during mussel assessments. Fleming and Van Alstine (1994), Seybold (1998), and Chazal and Derge (2001) each documented small quantities of live Atlantic pigtoe and shell material in a small number of sites ($n$ = 4–8) throughout the main-stem. Wolf (2006, 2008, 2010) reported a few individuals (1–3 individuals) in 10 of 25 sites surveyed in 2006, in 1 of 3 sites surveyed in 2007, and in 1 site surveyed in 2009. No individuals were located during 2010 searches, and only two Atlantic pigtoe were encountered in 69 hours of search effort across 6 sites in 2012 (Wolf 2012). Despite the differences in sampling designs between these assessments, it is evident that increased search efforts for Atlantic pigtoe on Fort Pickett are finding fewer live individuals over time; reflecting that the population in much of the Nottoway River has declined in recent years.

Of the 5 main-stem Nottoway River sites below the reservoir, we found Atlantic pigtoe in only 2 sites**.** While we did not encounter Atlantic pigtoe within several sites where it had previously been collected (Wolf 2006, 2008), we did document Atlantic pigtoe at a site (NoR_08) where previous surveys had not. We also documented Atlantic pigtoe at the site near the Hurricane Branch confluence (NoR_04) where it historically had been detected easily and collected in higher numbers relative to other sites on Fort Pickett, but where recent efforts have been unsuccessful (Wolf 2012, Wolf and Emrick 2011). This is the first collection of live Atlantic pigtoe at this site since 2009, signifying that they have not disappeared. These results do not signify that the population is increasing, but indicate that Atlantic pigtoe near Hurricane Branch have persisted at very low densities so as to be nearly undetectable in recent years.

Over the past 8 years, the average size (length) and age of Atlantic pigtoe encountered on Fort Pickett have been approximately 50.5 mm, equating to an approximate age of 15–16 years. During our assessments, we documented a 38 mm Atlantic pigtoe estimated to be approximately 7–9 years old, indicating that some level of recruitment was successful in 2005–2007. We did not detect any individuals that would indicate that recruitment has occurred recently (i.e., 2008–2013).

Reaches sampled in the Nottoway River above the reservoir are situated around the Little Nottoway River confluence and corresponded with sites where Atlantic pigtoe, yellow lance, eastern elliptio, and notched rainbow have been previously collected (Fleming and Alstine 1994). With the exception of eastern elliptio, and similar to observations made in 1999–2000 (Chazal and Derge 2001), our search efforts did not reveal any of these species above the reservoir. However, we collected paper pondshell; a species which had previously been undocumented in the reach. Although we did not detect Atlantic pigtoe, yellow lance, or additional species above the reservoir given our effort, they may occupy other sections. Spatially-extensive qualitative surveys should be conducted—particularly in reaches upstream of the Little Nottoway River confluence where the influence of the reservoir is less pronounced—to investigate whether imperiled Atlantic pigtoe and yellow lance still occupy the Nottoway River above the reservoir on Fort Pickett.

Unsurprisingly, eastern elliptio and Carolina slabshell were the most abundant species encountered across survey sites. They also had the largest distribution across Fort Pickett and frequently were the only species represented within a site. A common and abundant species found throughout the Atlantic slope, adult eastern elliptio have been shown to be tolerant of extremely low dissolved oxygen conditions—persisting under environmental conditions that many other mussel species cannot tolerate (Lewis 1984 as cited in Galbraith et al. 2012). Additionally, eastern elliptio are host fish generalists capable of using several fish species for glochidia development; hence, increasing their chances of successful recruitment (Lellis et al. 2013). Survey sites with the densest eastern elliptio beds, located below Birchin (BiC_02) and Tommeheton (ToC_02) Lakes, were characterized by sand substrates overlain with considerable quantities of silt (Figure 6) and higher water temperatures that approached 31°C. These conditions suggest dissolved oxygen concentrations may have been low during sampling. Although these local populations may appear self-sustaining because of high densities, eastern elliptio glochidia and juveniles are more sensitive to low oxygen conditions relative to their adult form and may not successfully develop into adults under these conditions (Galbraith et al. 2012).

Figure 6. Photograph of silt covering eastern elliptio at Site BiC_02 located below Birchin Lake on Fort Pickett, Virginia in July 2014.

The smallest eastern elliptio we encountered during timed (ToC_02) and quadrat (BiC_02) surveys were 51 and 54 mm, respectively. Sizes of eastern elliptio collected ranged from 51-121 mm with over 80% of individuals greater than 90 mm, suggesting that these local populations are composed of older age classes and possibly have little to no annual recruitment occurring in recent years. Although availability for detection at the surface varies seasonally and

with size (Amyot and Downing 1991), it is unlikely that we missed individuals in the 20–50 mm size range if they were present given our sampling effort. If low to no recruitment is occurring, populations are composed of older age classes and possibly have little to no annual recruitment occurring in recent years. Although availability for detection at the surface varies seasonally and with size (Amyot and Downing 1991), it is unlikely that we missed individuals in the 20–50 mm size range if they were present given our sampling effort. If low to no recruitment is occurring, these populations will be vulnerable to disappearing as adults reach maximum age. Because survey time was limited for these sites due to their location in the Controlled Access Area, we recommend further collection of demographic data, as well as water quality sampling, be completed to accurately determine the long-term viability of these two local populations.

Several hypotheses may explain why adult eastern elliptio are in high densities below Birchin and Tommeheton Lakes, relative to other survey sites, including:

1) The habitat below Birchin Lake appears to be a more stable (relative to habitat in the Nottoway) with characteristics such as stable substrate (e.g., sand, clay, detritus, and gravel that is more compact than many of the other survey sites), along with woody debris, vegetation, and root mats along banks that create more hydrologically stable areas and provide refuge during high flow events.

2) There is an abundance of potential host fish available at high densities. Eastern elliptio have been shown to successfully parasitize several centrarchid species including bluegill (many observed; Figure B8), largemouth bass, and crappie; all of which reside in Birchin and Tommeheton Lakes and can disperse downstream into and occupy these sites.

3) The lakes are likely very productive systems; providing mussels with steady and enhanced food resources through increased nutrient availability and quality.

4) Reduced levels of anthropogenic disturbance in the Controlled Access Area relative to training areas.

These dense local populations are ecologically significant in their ability to filter large portions of the water and supply nutrients to the water column through nutrient cycling. Dense mussel beds have been documented as capable of filtering volumes that exceed daily stream discharge, with estimates of daily filtration rates documented as high as 6–12 liters per individual (Vaughn et al. 2008). To put into perspective, if we only consider the mussels estimated to occupy the 150 $m^2$ sampled area below Birchin Lake, collectively they could filter 100,000 to nearly 200,000 liters of water a day. In conjunction with nutrient cycling, this filtering ability means they are capable of bio-accumulating any water contaminants present; a useful indicator of environmental stress (USEPA 2008).

As a biological indicator taxon, declines in mussel species diversity, abundance, and distribution on Fort Pickett may indicate the presence of underlying water quality issues that can degrade aquatic ecosystems in the larger Nottoway river watershed. Several factors that have been documented as contributing to overall habitat degradation and mussel declines in general include 1) sedimentation and nutrient pollution from point and nonpoint sources, 2) chemical pollution from copper sulfate (if used in reservoirs or lakes) and hazardous waste, and 3)

impoundments. Sedimentation and channel modification reduce channel and bank stability, increase water temperatures, and increase nutrient runoff. Pollution inputs can contaminate sediments and create toxic environments for non-target species (Dodds 2002). Increases in water depth and reduction in flows by impoundments (e.g., dams and culverts) reduce stream capability to transport sediment load—increasing silt accumulation that can smother mussels and other benthic organisms (Watters 1999).

Degraded habitats and impoundments negatively affect the vitality and growth rates of mussels and indirectly influence the viability of local mussel populations by altering fish species composition and abundance. Poor habitat quality can reduce the availability of species-specific host fish required for reproduction; reducing the likelihood of successful glochidial attachment and recruitment. Additionally, impoundments block host fish upstream passages; fragmenting local populations and increasing their susceptibility to extirpation.

## Management Recommendations

To protect and increase remaining mussel populations on Fort Pickett, management efforts should focus on conserving and enhancing existing, as well as restoring, suitable mussel habitat. Reduction of sedimentation through the establishment and maintenance of riparian buffer zones and avoidance of stream channel modifications and alterations to native vegetation proximate to streams can increase the quality and availability of healthy habitats. Restoration of riparian buffer zones would help reduce the potential for pesticides, nitrogen, phosphorus, and other pollutants from entering streams. Removal of large woody debris is not recommended as it plays an important component in shaping stream hydraulics and morphology (Shields and Smith1992; Fetherston et al. 1995) and provides habitat for mussels on Fort Pickett. Habitat protections should not only be focused in the main-stem of the Nottoway River, but should extend into the tributaries to offer spatial refugia for mussels and reduce overall vulnerability to extirpation. Not only would these actions have positive implications for mussel fauna but would have cascading positive effects on the overall aquatic ecosystem.

Even with habitat improvements, local mussel populations may still be susceptible to extirpation as a result of reduced availability of species-specific host fish. Because mussel populations are dependent on host fish availability for long-term viability, fish communities should routinely be monitored to detect vulnerabilities to local mussel populations. Fish assessments would also help predict species-specific mussel distributions so that mussel monitoring efforts can more efficiently target and identify mussel beds.

As one of the two remaining ‘viable’ Atlantic pigtoe populations in Virginia, the declining encounters of Atlantic pigtoe on Fort Pickett are a cause for concern. Given the rate of decline of Atlantic pigtoe throughout its range and its likelihood to be federally listed in the near future, research to identify—and proactive management to minimize—threats to this state threatened species, its habitat, and host fish on Fort Pickett are crucial to its conservation. We recommended that this population of Atlantic pigtoe be routinely monitored, and suggest that physiochemical water quality testing (e.g., dissolved oxygen, pH, temperature, nitrogen and phosphorus concentrations, etc.) and host fish surveys be conducted in current and historically occupied sites. An additional species to closely monitor alongside Atlantic pigtoe in future studies is the eastern lampmussel, a state species of concern. Eastern lampmussel have

occasionally been encountered on Fort Pickett (1 in 2006, 2 in 2007, and 1 in this study), but their distribution and status remain unknown. Because eastern lampmussel is a long-term brooder, monitoring should be targeted in August–September when spawning occurs and likelihood of detection is greater.

Understanding species dynamics in combination with the identification of specific factors responsible for declines can provide resource managers with data required for developing effective management plans. To accomplish these tasks, routine monitoring of freshwater mussel and fish populations, physiochemical water quality, and physical habitats, are recommended as they will provide a valuable measure of the health of freshwater mussels and the aquatic ecosystem on Fort Pickett.

## Acknowledgements

Funding for this project was provided by the Virginia Department of Military Affairs as a part of the ongoing effort to protect and enhance natural resources on military lands while supporting the training mission. We would like to thank Brian Watson from Virginia Department of Game and Inland Fisheries for providing field assistance and valuable advice for this project. We would also like to thank Maggie Pryatel from Virginia Tech and Ingrid Mans, Jesse Parker, and Nick Kalen from The Conservation Management Institute at Virginia Tech for their field and geospatial information systems assistance. Military lands are a finite commodity and conservation of their natural resources is essential to the maintenance of the high quality training environment required for the success of the training mission.

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# APPENDIX A

Stream conditions from 2014 freshwater mussel surveys on Fort Pickett, Virginia

Table A1. Site identification, date, stream conditions, and down- and upstream coordinates (UTM Zone 18, NAD 83) of timed search and quadrat sampling sites in the upper Nottoway River and its tributaries on Fort Pickett, Virginia conducted in May–August 2014. As an index of relative river depth and flow rate on the installation during sampling, we recorded daily mean discharge values (cubic feet per second) for the Nottoway River as measured at U.S. Geological Survey gage number 02044500; located approximately 4.5 river kilometers downstream of the eastern boundary of Fort Pickett (i.e., these values are not survey-site specific).

| | | | | | | Downstream | | Upstream | |
|---|---|---|---|---|---|---|---|---|---|
| Reach ID | Mainstem/ Tributary | Stream Name | Date | Water Temp (°C) | Discharge (cfs) | x | y | x | y |
| NoR_01 | Mainstem | Nottoway River | 8/6/14 | 25 | 58 | 232775 | 4101592 | 232607 | 4101456 |
| NoR_02 | Mainstem | Nottoway River | 8/6/14 | 25 | 58 | 232711 | 4101616 | 232672 | 4101538 |
| | | | *8/6/14 | 25 | 58 | | | | |
| NoR_03 | Mainstem | Nottoway River | 6/10/14 | 23 | 103 | 239234 | 4097113 | 239184 | 4097116 |
| NoR_04 | Mainstem | Nottoway River | 8/8/14 | 27 | 45 | 240334 | 4097291 | 240361 | 4097235 |
| | | | *8/8/14 | 27 | 45 | | | | |
| NoR_07 | Mainstem | Nottoway River | 6/10/14 | 27 | 103 | 245666 | 4097634 | 245638 | 4097643 |
| NoR_08 | Mainstem | Nottoway River | 7/3/14 | 27 | 57 | 246761 | 4097951 | 246724 | 4097921 |
| | | | *8/7/14 | 26 | 42 | | | | |
| NoR_09 | Mainstem | Nottoway River | 8/7/14 | 27 | 54 | 243691 | 4097749 | 243636 | 4097743 |
| BiC_02 | Tributary | Birchin Creek | 7/2/14 | 29 | 60 | 241491 | 4102421 | 241534 | 4102690 |
| | | | *7/4/14 | 31 | 51 | | | | |

*Date and stream conditions during quadrat sampling

Table A1 (cont.):

| Reach ID | Mainstem/ Tributary | Stream Name | Date | Water Temp (°C) | Discharge (cfs) | Downstream x | Downstream y | Upstream x | Upstream y |
|---|---|---|---|---|---|---|---|---|---|
| HuB_07 | Tributary | Hurricane Branch | 6/11/14 | 26 | 101 | 240202 | 4097329 | 240083 | 4097451 |
| LNR_01 | Tributary | Little Nottoway | 8/6/2014 | 25 | 58 | 232623 | 4101602 | 232592 | 4101629 |
| NNT_03 | Tributary | No-name Tributary | 6/9/2014 | 21 | 106 | 237140 | 4096813 | 237000 | 4096627 |
| RoR_01 | Tributary | Rocky Run | 5/12/2014 | 20 | 198 | 240809 | 4095836 | 241096 | 4095641 |
| ROR_03 | Tributary | Rocky Run | 6/11/2014 | 22 | 101 | 240672 | 4097226 | 240522 | 4097146 |
| ToC_02 | Tributary | Tommeheton Creek | 7/4/2014 | 29 | 52 | 245594 | 4102311 | 245619 | 4102360 |
| ToC_07 | Tributary | Tommeheton Creek | 5/14/2014 | 20 | 165 | 242551 | 4108143 | 242711 | 4108515 |
| ToC_10 | Tributary | Tommeheton Creek | 5/13/2014 | 18 | 179 | | | | |
| ToC_10A | | | | | | 239439 | 4109204 | 239297 | 4109263 |
| ToC_10B | | | | | | 239496 | 4109100 | 239414 | 4109073 |
| ToC_13 | Tributary | Tommeheton Creek | 5/13/2014 | 22 | 179 | 247156 | 4098215 | 247035 | 4098328 |
| WiC_02 | Tributary | Wildcat Creek | 6/10/2014 | 22 | 103 | 239239 | 4097088 | 239151 | 4096929 |

*Date and stream conditions during quadrat sampling

# APPENDIX B

Selected photographs from 2014 freshwater mussel survey on Fort Pickett, Virginia


Figure B-1. Atlantic pigtoe encountered (clockwise) at Sites NoR_08 (49 mm) and NoR_04 (67 and 38 mm) in the main-stem Nottoway River on Fort Pickett, Virginia, July 2014.

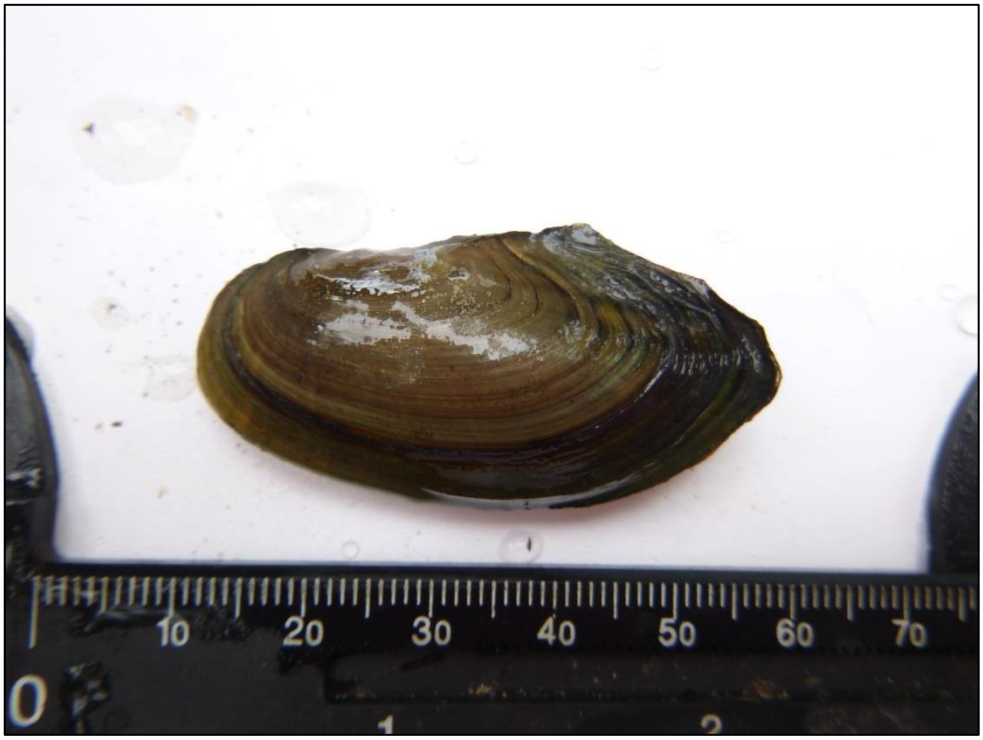


Figure B-2. Paper pondshell encountered at Site NoR_04 in the main-stem of the Nottoway River, upstream of Hurricane Branch confluence, on Fort Pickett, Virginia in August 2014.


Figure B-3. Eastern floater encountered in Butterwood Creek during preliminary evaluations on Fort Pickett, Virginia, in 2014.


Figure B-4. Triangle floaters encountered at Sites NoR_07 and NoR_03 in the main-stem Nottoway River upstream of South Shacks Hole Road bridge crossing, and near Wildcat Creek confluence (top to bottom), in June 2014.


Figure B-5. Notched rainbow encountered at Site NoR_08 in the main-stem Nottoway River below Longstreet Road ford on Fort Pickett, Virginia, in June 2014.


Figure B-6. Creeper encountered at Site NoR_03 in the main-stem Nottoway River near Wildcat Creek confluence on Fort Pickett, Virginia, in June 2014.

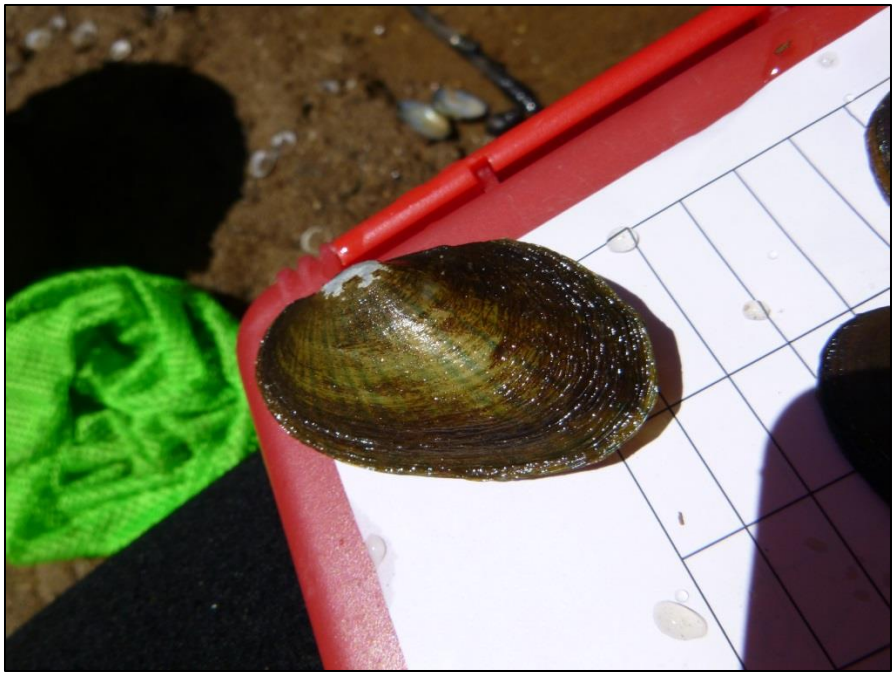

Figure B-7. Eastern lampmussel observed at Site NoR_03 in the main-stem Nottoway River near Wildcat Creek confluence on Fort Pickett, Virginia, in June 2014.

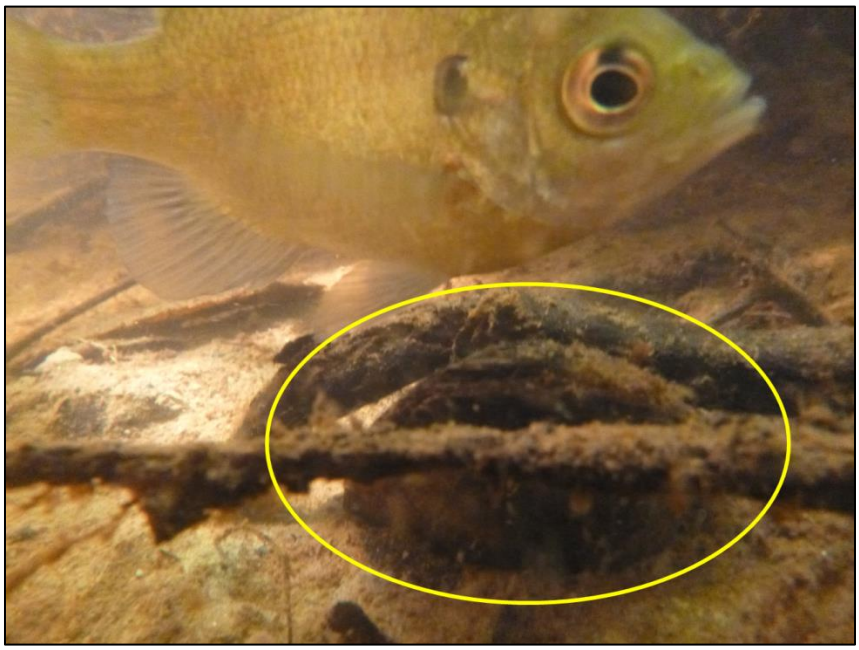

Figure B-8. Photograph of bluegill (*Lepomis macrochirus*) swimming by an eastern elliptio in Birchin Creek below Birchin Lake on Fort Pickett, Virginia, in July 2014.

Figure B-9. Photograph of quadrat sampling at Site BiC_02 in Birchin Creek below Birchin Lake. Substrate appearing black in image are hundreds of eastern elliptio.

Figure B-10. Horizontal migration of an adult eastern elliptio trying to escape to deeper water during low flow conditions in the Nottoway River on Fort Pickett, in June 2014.

Figure B-11. Photograph documenting variability of eastern elliptio shell morphology in the upper Nottoway River on Fort Pickett, Virginia, in 2014.