James River
ASSOCIATION

APRIL 2024

James River Basin Mussel Restoration Plan

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Photos in this document were provided by Daguna Consulting, LLC, the James River Association, and Virginia Tech's Freshwater Mollusk Conservation Center.

EXECUTIVE SUMMARY

Over the course of two workshops in 2023, biologists from several agencies worked with the James River Association (JRA) and Daguna Consulting, LLC (Daguna) to develop a plan for restoring freshwater mussels in the James River Basin. There is some uncertainty about which species comprise the native assemblage as historical information is sparse. Nonetheless, this plan considers 19 species and provides background information about each. Major assumptions underlying this plan are that 1) current mussel abundances are magnitudes lower than they were prior to European colonization, 2) many habitats have experienced a loss of species richness since European colonization, and 3) water quality has generally improved over the last half century without a corresponding natural recovery of assemblages. As such, the James River and its tributaries are ecologically impaired with many habitats missing a major biotic component responsible for nutrient cycling and other ecosystem services. This means direct human action is needed to restore native freshwater mussels.

The consensus among biologists was that stocking laboratory propagated and reared mussels would be the most effective means to restore assemblages. There was also consensus that 1) information about the status of mussels in the basin still limits effective management, 2) actions of other agencies and groups in the basin (such as habitat restoration, water quality improvement, and land preservation) will continue to improve habitat conditions for mussels but will be insufficient to facilitate a natural restoration of assemblages, and 3) specific goals and actions are needed to focus limited resources available for mussel restoration.

This plan provides specific goals and actions that biologists can execute in the next 10 years to 1) protect and monitor essential assemblages that remain in the basin, and 2) increase abundance and richness in habitats at relatively low risk from ongoing and anticipated human disturbance. The James River Basin has been divided into Mussel Management Units (MMUs) based on stream networks, habitat, and biogeography. Of the 28 MMUs, five have been listed as high priorities based on land use, development vulnerability models, survey data, species models, and expert opinion. More detailed information has been provided for each of those high priority MMUs, including justifications for prioritization, risk assessments, and narrowly defined goals and actions. Specific issues related to other MMUs have received more limited attention in this plan.

This plan is intended to focus the limited resources available to agencies and groups directly engaged in freshwater mussel restoration. It is one of many plans intended to protect and restore the ecological integrity of the James River Basin. It is hoped that other partners working in the James River Basin will use this plan to focus efforts on those areas where mussel restoration work will occur in the next 10 years. This plan should be revisited and revised after five years.

Funding to develop the James River Basin Mussel Restoration Plan was provided by the National Fish and Wildlife Foundation (NFWF), U.S. Fish and Wildlife Service, and Good Shepherd Fund. NFWF is an equal opportunity provider.

MUSSELS OF THE JAMES RIVER BASIN

Historically, the James River Basin may have supported as many as 21 species (Table 1). At present, it is assumed 16 species are extant. The precise number of valid taxa, historical and extant, may continue to shift as taxonomic studies, mostly driven by new genetic analyses, advance. Reexamination of museum specimens may also shift taxa and species range.

As in other river systems on the continent, the conservation status varies greatly among species of the James River Basin. Four federally-listed species persist in the basin, while two species are considered globally secured (see Table 1). The James River Basin is home to one regionally endemic species, the James Spinymussel, which is limited to only two basins in the Atlantic Slope[1]. The James River Basin lies at the transition between two mussel faunal regions: the Northern Atlantic Slope and Southern Atlantic Slope (see discussions in Johnson 1970, Parmalee and Bogan 1998, Haag 2010). The earlier work of Johnson (1970) included it in the Southern region but Haag (2010) provides a more convincing argument for placement in the Northern. Likewise, Burkhead and Jenkins (1994) grouped the James with basins to the north based on biogeography of fishes. Nedeau et al. (2000) provide an alternative explanation for faunal grouping[2]. The James River Basin likely supported only 43% of mussel species present in Atlantic drainages to the south but 67% of species comprising the Northern Atlantic Slope fauna[3]. The James River represents the northern range limit of the Notched Rainbow and Atlantic Pigtoe. Meanwhile, many species more common to the north, such as Alewife Floater and Northern Lance, are present in the basin.

The most probable species that comprise the assemblage are pictured in Table 2. Some notes justifying inclusion/exclusion are provided there.

[1] Although this species does historically and currently occur in the Upper Dan sub-basin in the Roanoke River Basin, its presence there was likely a result of stream capture in the Pleistocene, having a limited range compared to the historical widespread range in the James (Petty 2005).
[2] Nedeau et al. (2000) provides an interesting figure about middle Atlantic coastal plain refugium for alternative interpretation.
[3] Based on Table 3.4 in Haag (2012).

Table 1. Mussel species of James River Basin following Williams et al. (updated 2023) nomenclature with recent changes to scientific names listed. Conservation status according to NatureServe (https://www.natureserve.org/), State of Virginia, State Wildlife Action Plan (SWAP), and USFWS have been listed. Species have been classified as extant (E) vs. historical (H) within the basin, with historical based on nearby drainage records and/or historical records (details about inclusion as historical are in Table 2). Species were assigned to Northern Atlantic Slope (N) versus Southern Atlantic Slope (S) Faunal Regions based on Table 3.4 in Haag (2012). Species with identification issues are highlighted in gray.

Common Name	Current Scientific Name	Recent Scientific Name	G Rank	S Rank	Virginia Status	SWAP Tier	Federal Status	Extant/ Historical	Faunal Region
Dwarf Wedgemussel	*Alasmidonta heterodon*		G1	S1	SE	I	FE	H	N/S
Triangle Floater	*Alasmidonta undulata*		G4	S3	none	IVa	none	E	N/S
Brook Floater	*Alasmidonta varicosa*		G3	S1	SE	Ib	reviewed, not listed[a]	H	N/S
Tidewater Mucket	*Atlanticoncha ochracea*	*Leptodea ochracea*	G3	S3	none	IVa	none	E	N/S
Carolina Lance	*Elliptio angustata*		G4	SNR	none	IVc	none	ID[b] issues	S
Eastern Elliptio	*Elliptio complanata*		G5	S5	none	none	none	E	N/S
Carolina Slabshell	*Elliptio congaraea*		G3	SNR	none	IVa	none	E	S
Northern Lance	*Elliptio fisheriana*		G4	S4	none	IVb	none	E	N
Variable Spike	*Elliptio icterina*		G5	SNR	none	none	none	presumed misidentified	S
Yellow Lance	*Elliptio lanceolata*		G2	S2	ST	IIa	FT	E	S[c]
Atlantic Spike	*Elliptio producta*		G3	SNR	none	IVc	none	ID[b] issues	S
Atlantic Pigtoe	*Fusconaia masoni*	*Lexingtonia subplana*	G1	S2	ST	Ia	FT	E	S
Yellow Lampmussel	*Lampsilis cariosa*		G3	S2	none	IIa	none	E, limited evidence	N/S
Eastern Lampmussel	*Lampsilis radiata*		G5	S2S3	none	IVa	none	H	N/S
Green Floater	*Lasmigona subviridis*		S3	S3	ST	IIa	proposed FT	E	N/S

[a] On August 1, 2019, the USFWS determined that it was not warranted to list this species at this time after reviewing the best available scientific information.
[b] In some cases, there is genetic documentation that these species have been misidentified, in other cases, presumed identifications have not been verified.
[c] Populations present in Rappahannock and farther north in Maryland calls into question about defining as northern vs. southern.

Table 1. Continued.

Common Name	Current Scientific Name	Recent Scientific Name	G Rank	S Rank	Virginia Status	SWAP Tier	Federal Status	Extant/ Historical	Faunal Region
James Spinymussel	*Parvaspina collina*	*Pleurobema collina*	G1	S1	SE	IIIa	FE	E	*
Eastern Floater	*Pyganodon cataracta*	*Anodonta cataracta*	G5	S5	none	none	none	E	N/S
Eastern Pondmussel	*Sagittunio nasutus*	*Ligumia nasuta*	G4	S3	none	IVa	none	E	N/S
Creeper	*Strophitus undulatus*		G5	S3	none	IVa	none	E	N/S
Paper Pondshell	*Utterbackia imbecillis*		G5	S5	none	none	none	E	N/S
Alewife Floater	*Utterbackiana implicata*		G5	S3	none	IVa	none	E	N/S
Notched Rainbow	*Venustaconcha constricta*		G3	S3	none	IIIa	none	E	S

* Placement of this endemic is circular logic, it would be a northern species if the James belongs to the Northern Atlantic Slope or a southern species if James is considered Southern Atlantic Slope.

Table 2. Scaled pictures provided by Virginia Tech's Freshwater Mollusk Conservation Center (Jess Jones, Director) with notes on occurrences in the James River Basin.

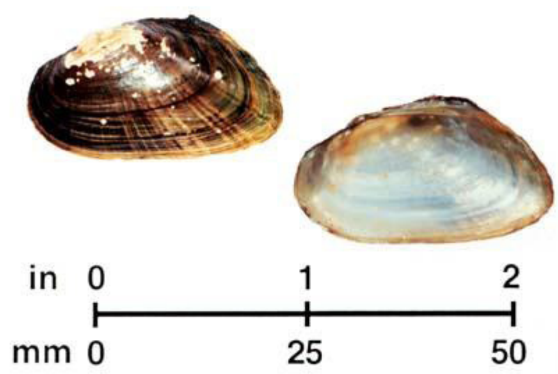
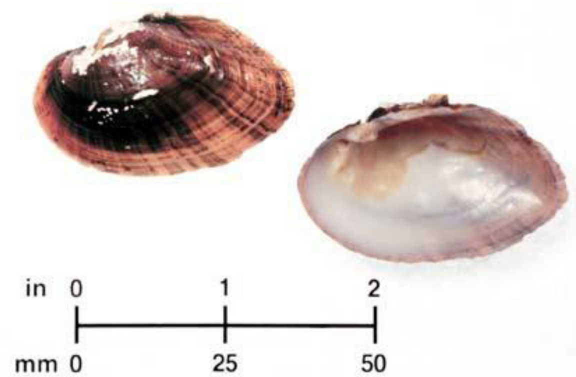
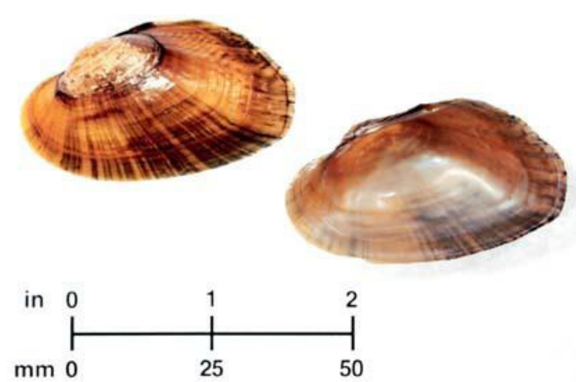
Species	Notes	Photograph
Dwarf Wedgemussel *Alasmidonta heterodon*	• A piedmont species, speculated to occupy coastal plain streams • Harvard Museum Record assigned to James River (https://mczbase.mcz.harvard.edu/guid/MCZ:Mala:223875) • Detected in basins to the north and south • Extremely small, so may be exceptionally difficult to detect during surveys • Suitable habitats may be undersampled	
Triangle Floater *Alasmidonta undulata*	• Widespread and uncommon • Detected in every type of stream in the James Basin, including tidal tributaries, mountain valley streams, and the mainstream James River	
Brook Floater *Alasmidota varicosa*	• Presumed extirpated from James River Basin • Record in the James River near Sabot Island from surveys conducted by Arthur Clark on 8/13/1997; record in Heritage Program database. • Ranges extends to the north and south of the James River Basin • Documented in the Potomac/Shenandoah Basins to the North in Virginia • On August 1, 2019, the USFWS determined that it was not warranted to list this species at this time after reviewing the best available scientific information	

Table 2. Continued.

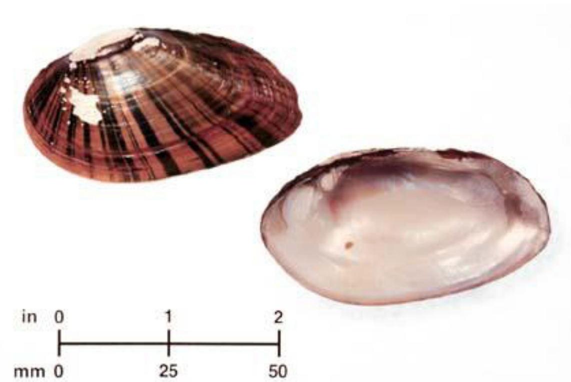
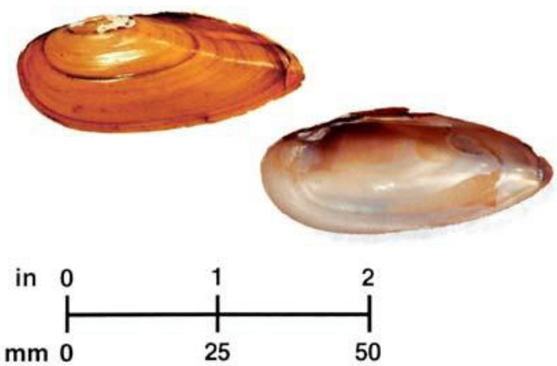
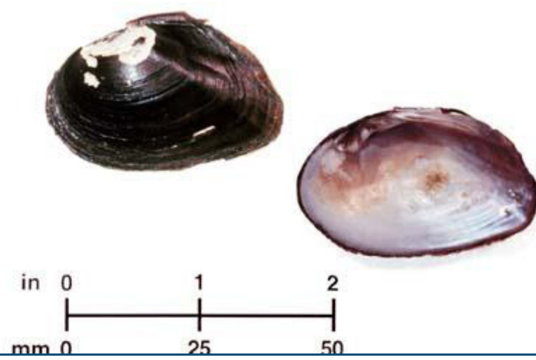
Species	Notes	Photograph
Tidewater Mucket *Atlanticoncha ochracea*	• Documentation limited distribution to only two watersheds in the James River: • Chickahominy and Appomattox	
Eastern Elliptio *Elliptio complanata*	• Wide distribution and common • Likely occupies all watersheds of the James River Basin • Most abundant/dominant species in many assemblages • Due to its abundance may have largest impact on ecosystem dynamics of streams in basin	
Carolina Slabshell *Elliptio congaraea*	• Extremely limited distribution • Maybe a cryptic species • Misidentified with Eastern Elliptio	
Northern Lance *Elliptio fisheriana*	• Historically and presently confused with other elongated species in *Elliptio* genus (*E. producta, E. augustana, E. lanceolata*) • Genetics among *E. fisheriana, E. producta, E. augustana* and within *E. fisheriana* remain unresolved, for simplicity only one is listed as extant • Assumed to the be only elongated species with dark periostracum present in the James River Basin, periostracum distinguishes it from Yellow Lance • Widespread, can be locally abundant	

Table 2. Continued.

Species	Notes	Photograph
Yellow Lance *Elliptio lanceolata*	• Early confusion of elongated species in *Elliptio* genus made understanding distribution difficult • Only confirmed to occur in Johns Creek (Valley and Ridge physiographic province), but 2019 SSA states the species occupied streams and rivers in the coastal plain. The same chart indicates that current distribution still favors coastal plain streams • Should be considered a species with possible distribution throughout all physiographic provinces	
Atlantic Pigtoe *Fusconaia masoni*	• Extreme decline in the James River Basin • Craig Creek likely the only remaining population • Population in Craig Creek may not be viable	

Yellow Lampmussel
Lampsilis cariosa
	• More common in basins proximate to James River Basin
	• Limited/questionable detections in James
	  • *Lampsilis cardium* in database could be this species
	  • Records in ww.GBIF.org
	• Group consensus at January meeting to list as part of James River Basin assemblage
	• DWR has released at two sites in the James River - Richmond and Lynchburg
		

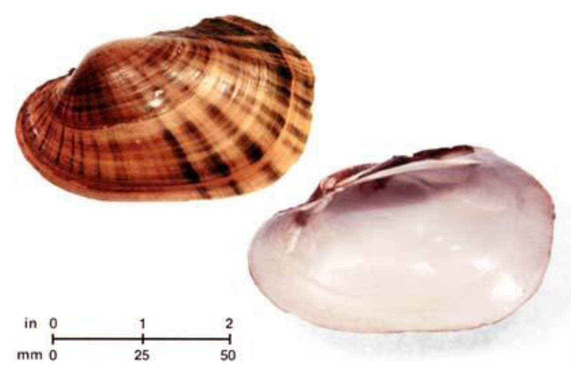
Eastern Lampmussel
Lampsilis radiata
	• More common in basins proximate to James River Basin
	• Speculated to be present
	  • No records in DCR or DWR databases
	  • Records in www.GBIF.org
	    • North Carolina Museum of Natural Sciences: NCSM 101697
	    • Smithsonian Museum of Natural History: USNM 837314
	• Group consensus at January meeting to list as part of James River Basin assemblage
		

Table 2. Continued.

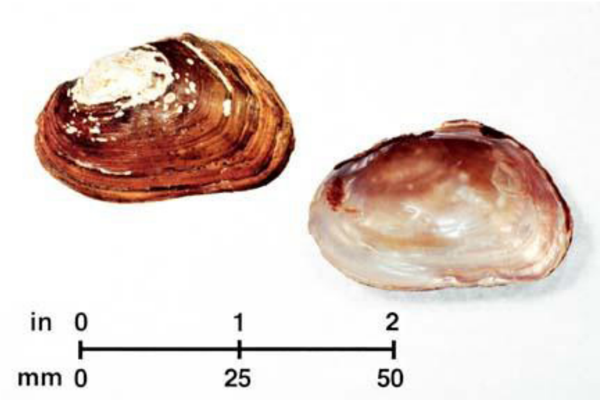
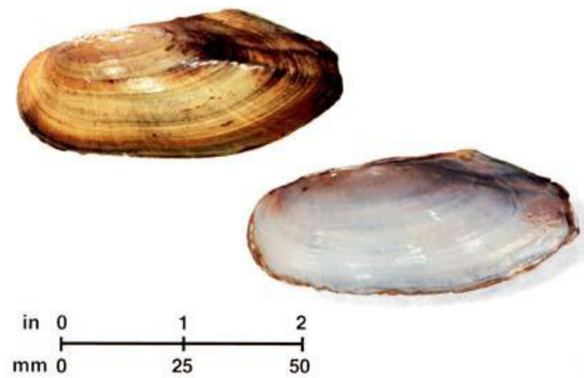
Species	Notes	Photograph
Green Floater *Lampsilis subviridis*	• Widespread in the James River Basin • Usually uncommon to rare, with the exception being the Tye River watershed • Difficult to detect	
James Spinymussel *Parvaspina collina*	• Several documented strongholds • Native distribution assumed to be widespread, now limited to isolated populations • A few locations have abundant populations • Focus of propagation and augmentation in basin	
Eastern Floater *Pyganodon cataracta*	• Common and widespread • Distribution is not well known as the species tends to occupy lentic habitats, which are undersampled	
Eastern Pondmussel *Sagittunio nasutus*	• Only known from the Chickahominy River watershed within the James River basin • Known from multiple sites through the Chowan, York and Potomac River basins, so possibly more widespread in the James River basin but occupied habitat is under sampled	

Table 2. Continued.

Species	Notes	Photograph
Creeper *Strophitus undulatus*	• Widespread, common to abundant • Can be dominant species in some habitats • Important member of many small stream mussel assemblages in James River Basin	
Paper Pondshell *Utterbackia imbecillis*	• Usually observed in impoundments • Distribution is not well known as the species tends to occupy lentic habitats, which are undersampled	
Alewife Floater *Utterbackiana implicata*	• Limited to tidal tributaries and James River below fall line • Few confirmed observations, likely undersampled	
Notched Rainbow *Venustaconcha constricta*	• Dominant species in some watersheds, including Rivanna • Otherwise widespread in basin varying from common to rare	

There is no historical data to understand precisely how abundant freshwater mussels were in the streams of the James River Basin prior to European colonization. There is some evidence to suggest that abundances may have been at least a magnitude greater in many habitats. An ongoing Capture-Mark-Recapture (CMR) study in Little Oregon Creek has demonstrated that populations of the James Spinymussel can exceed 1,000 individuals in a small stream reach (400-500 m^2, Ostby 2022a). Nedeau (2008) suggested Eastern Elliptio densities approaching 1,000 m^2 may be possible in other Atlantic Slope streams (Figure 1). Recent surveys and relocations in the James River have documented hundreds of mussels within a few meters of a river bank. Current absences elsewhere in the James River Basin provide a stark contrast, demonstrating just how much has been lost. For example, habitats where mussels were detected more than 50 years ago, such as the James River in Buchanan County and the Maury River, are now apparently unoccupied (this is not a phenomenon unique to the James River Basin, see [Chazal and Roble 2011][4]). Moreover, earlier naturalists appeared to pick up representative specimens with relative ease, compared to the efforts that modern biologists expend in search for a few mussels. In comparison, other streams in Virginia, most notably, the Clinch River, have many habitats supporting more than 5 mussels per square meter. All these pieces of evidence suggest the role that native freshwater mussels play in the ecosystem dynamics of the James River have been all but nullified. This has made setting recovery goals difficult, as there is no good reference.

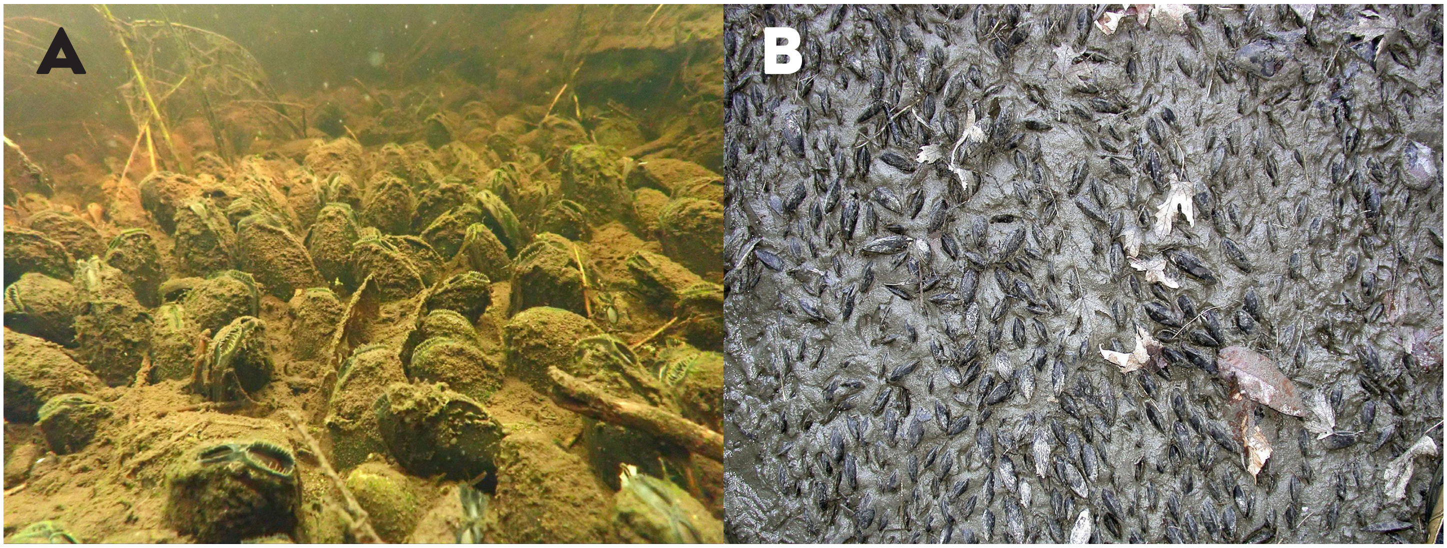


Figure 1. High densities of Eastern Elliptio in Crooked Brook Flowage near Danforth, Maine (a) and exposed bed in Holyoke Canals adjacent to the Connecticut River in Massachusetts (b). Both photographs were provided by Ethan Nedeau.

[4] Chazel and Roble (2011) document the collapse of the Shenandoah River mussel assemblages in Virginia, a decline more severe and extensive than observed in James River Basin.

ECOLOGICAL SIGNIFICANCE OF MUSSELS IN THE JAMES RIVER BASIN

The James River Basin drains slightly less than a quarter of Virginia and has been settled and intensely modified by non-indigenous people since the early 1600's. It is the third largest tributary feeding the Chesapeake Bay, providing approximately 11% of flow[5]. Its influence on the Bay is eclipsed only by the Susquehanna and Potomac rivers. Early colonists accounts of the river suggest a much greater number of fish, particularly fish migrating upriver to spawn, which helped sustain indigenous peoples and early European settlers. If extrapolated to freshwater mussels, the carrying capacity of a James River is probably orders of magnitude greater than the current condition. That loss results in significant ecological function changes such as reduced filtration leading to higher turbidity levels, less stable river beds, reduced biomass/carbon retention, reduced benthic biota productivity, and possibly less habitat for benthic species (Newton et al. 2011, Vaughn 2018).

A critical change that lower mussel populations bring to the ecosystem is reduced filtration capacity. Other less impacted river systems draining the US Atlantic Slope support native mussels densities greater than 10 mussels per square meter (m^2), a level presumed viable (Haag 2012). Currently, the highest observed James River basin densities are around 1 m^2. Even if mussels do not occupy more habitat area than currently observed, the higher densities would create a 20-fold increase in filtration capacity. To put this in perspective, for a mussel-habitat area of 30,000 m^2, which is quite reasonable in the mainstem James River, the reference (potential) and current filtration volumes attributable to mussels would be 2.6M and 132k cubic feet per day, respectively. In river flow terms this translates to filtering 30.6 cubic feet per second versus 1.5 cubic feet per second, respectively. This means that a single 'healthy' mussel shoal near Lynchburg could filter 3% of the water flowing over it during low flows compared to 0.17% under current population densities. Just 20-30 well stocked mussel shoals could filter the entire base flow of the James River while no realistic number of shoals could perform that ecological function with current mussel densities. This calculation assumes that individual mussels filter approximately 0.36 liters per hour (0.013 cubic feet per hour), which is very conservative (Kryger and Riisgard 1988, Vaughn et al. 2008).

Robust mussel populations also influence instream nutrient cycling and dynamics (Vaughn 2018). Mussels can comprise the majority of biomass in rivers such as the James. In order to achieve this biomass, mussels assimilate ingested carbon from algae, bacteria, phytoplankton, etc. into body tissue which sequesters it from the water column and maintains it at the mussel shoal. Studies suggest that mussels enhance denitrification as they metabolize this material which increases the conversion of organic nitrogen to elemental nitrogen, which can be transferred to the atmosphere. In this way, mussels may play a role in the nitrogen balance of the James River and Chesapeake Bay[6]. Finally, because mussels excrete undigested and un-ingested material as feces and pseudofeces deposited on the river bed, they provide additional food resources for benthic fauna that would otherwise be unavailable (Vaughn 2018).

[5] According to River Input Monitoring (Zhang et al. 2023).
[6] The James River basin is a major source of nutrient pollution to the Chesapeake Bay; contributing 5.4% of total nitrogen, 18% of total phosphorus, and18% of suspended solids (Zhang et al. 2023).

Diverse and dense mussel assemblages also support other aquatic life. Studies have shown that robust mussel populations increase productivity of co-occurring benthic aquatic insects (Vaughn and Spooner 2006; Spooner et al. 2012). These aquatic insects, in turn, are food for fish, birds, and mammals of the river ecosystem. Dense mussel beds also have been correlated with greater diversity and abundance of macroinvertebrates (Spooner and Vaughn 2006). Mussels also provide additional habitat for benthic algae, invertebrates and fish, both when live and via the shells left behind after death (Vaughn 2018). These functional contributions to river biotic composition increase the resiliency of aquatic ecosystems, particularly important in the face of climate change.

FISH HOSTS AND LIFE HISTORY

All but two species native to the James River Basin, Green Floater and Paper Pondshell, rely on fish hosts to reproduce and colonize habitats. Table 3 provides a list of fish hosts from the literature and those known to work in propagation facilities. Appendix A provides further details and literature citations. Mussel species distributions (both species and abundances) are, in part, limited by fish hosts (Watters 1992, Haag and Warren 1998, Vaughn and Taylor 2000). An examination of fish data provided by DWR during early stages of data review, suggests that fish are unlikely a limiting factor for mussels in the James River Basin. For example, the eight host species listed for James Spinymussel, appear ubiquitous throughout the basin (Figure 2). This was also confirmed by a model developed to explain distribution of James Spinymussel (Roderique 2018). In contrast, the Alewife Floater may exhibit a distribution defined by host fish movement (Smith 1985). This species is currently limited to tidal tributaries of the basin and to the James and Appomattox rivers below the fall line, potentially a natural zoogeographic outcome (Figure 3). Among James River species, Green Floater may be particularly adapted to recruit without requiring a fish host (Lellis and King 1998, Barfield and Watters 1998). Less is known about host fish abundances in the basin and the resulting effects on mussel populations. Vaughn and Taylor (2000) demonstrated host fish abundances can explain mussel assemblages, so they should be considered in the final determination of sites for augmentation and restoration.

Haag (2012) detailed the diversity in life history of North American freshwater mussels, clearly demonstrating that there is no prototypical species. This means that there should not be a single approach or schedule for restoring freshwater mussel assemblages. Propagation facilities are well attuned to spawning and gravidity schedules. Managers should set expectations to specific life history information, especially when gaging how long it may take for results to manifest, the breadth of habitats where restoration work can occur, and importance of generational timing for population restoration and augmentation. To that end, Table 4 provides a list compiled from the literature and from biologists participating in this plan.

[7] Limited evidence that Paper Pondshell may also bypass (Dickinson and Sietman 2008), extent unknown.

Table 3. Chart demonstrating fish hosts for James River mussel species. Red indicates that at least one species of the family is a known fish host for the given mussel species. Black indicates known host relationships (laboratory and/or natural). Superscripts on fish common names: N=native to the James River Basin, I=presumed introduced and naturalized in the James River Basin, E=present in the Chesapeake Estuary, including lower James River and tidal tributaries. In some cases only the family relationship is noted because the fish species documented is far out of range but may be worth using in propagation or laboratory settings. See Appendix A for details.

Family	Common Name	Scientific Name	Dwarf Wedgemussel	Triangle Floater	Brook Floater	Tidewater Mucket	Eastern Elliptio	Northern Lance	Yellow Lance	Atlantic Pigtoe	Yellow Lampmussel	Eastern Lampmussel	James Spinymussel	Eastern Floater	Creeper	Paper Pondshell	Alewife Floater	Notched Rainbow
Acipenseridae															Red			
	Atlantic Sturgeon[E]	*Acipenser oxyrinchus*													Black			
Anguillidae							Red											
	American Eel[N]	*Anguilla rostrata*					Black											
Catostomidae				Red													Red	
	White Sucker[N]	*Catostomus commersonii*		Black													Black	
	Northern Hogsucker[N]	*Hyprentelium nigricans*		Black														
Centrarchidae				Red	Red		Red	Red			Red	Red		Red	Red	Red		Red
	Rock Bass[I]	*Ambloplites rupestris*										Black			Black	Black		Black
	Redbreast Sunfish[N]	*Lepomis auritus*																
	Green Sunfish	*Lepomis cyanellus*					Black								Black	Black		
	Pumpkinseed[N]	*Lepomis gibbosus*		Black	Black		Black					Black		Black	Black	Black	Black	
	Orangespotted Sunfish	*Lepomis humilis*					Black											
	Bluegill[I]	*Lepomis macrochirus*					Black	Black						Black	Black	Black		
	Longear Sunfish	*Lepomis megalotis*													Black	Black		
	Smallmouth Bass[I]	*Micropterus dolomieu*										Black			Black			Black
	Largemouth Bass[I]	*Micropterus salmoides*		Black			Black	Black			Black	Black		Black	Black	Black		
	White Crappie[I]	*Pomoxis annularis*					Black								Black			
	Black Crappie[N]	*Pomoxis nigromaculatus*									Black	Black				Black		
Clupeidae																	Red	
	Blueback Herring[E]	*Alosa aestivalis*															Black	
	Alewife[E]	*Alosa pseudoharengus*															Black	
	American Shad[E]	*Alosa sapidissima*															Black	
Cottidae			Red	Red	Red		Red								Red			
	Mottled Sculpin[N]	*Cottus bairdi*	Black				Black											
	Slimy Sculpin	*Cottus cognatus*		Black	Black		Black								Black			
Cyprinidae				Red	Red			Red	Red	Red			Red		Red	Red		Red
	Central Stoneroller[N]	*Campostoma anomalum*		Black									Black		Black			Black
	Mountain Redbelly Dace[N]	*Chrosomus oreas*								Black			Black					
	Rosyside Dace[N]	*Clinostomus funduloides*								Black			Black					
	Satinfin Shiner[N]	*Cyprinella analostana*						Black		Black			Black					
	Spotfin Shiner	*Cyprinella spilotpera*		Black											Black	Black		
	Common Carp[I]	*Cyprinus carpio*		Black														

Table 3. Continued.

Family	Common Name	Scientific Name	Dwarf Wedgemussel	Triangle Floater	Brook Floater	Tidewater Mucket	Eastern Elliptio	Northern Lance	Yellow Lance	Atlantic Pigtoe	Yellow Lampmussel	Eastern Lampmussel	James Spinymussel	Eastern Floater	Creeper	Paper Pondshell	Alewife Floater	Notched Rainbow
Cyprinidae	White Shiner	*Luxilus albeolus*						X	X	X								
	Common Shiner[N]	*Luxilus cornutus*													X			
	Rosefin Shiner[N]	*Lythrurus ardens*								X			X					
	Pinewoods Shiners	*Lythrurus matuntinus*							X	X								
	Bluehead Chub[N]	*Nocomis leptocephalus*								X			X					
	Golden Shiner[N]	*Notemigonus crysoleucas*			X										X	X		
	Swallowtail Shiner[N]	*Notropis procne*								X			X					
	Rosyface Shiner	*Notropis rubellus*		X														
	Sand Shiner	*Notropis stramineus*													X			X
	Blacknose Dace[N]	*Rhinichthys atratulus*		X	X								X		X			
	Longnose Dace[N]	*Rhinichthys cataractae*		X	X					X					X			
	Creek Chub[N]	*Semotilus atromaculatus*								X					X	X		
	Fallfish[N]	*Semotilus corporalis*		X														
	Banded Killifish[E]	*Fundulus diaphanus*					X									X		
Gasterosteidae				R											R	R	R	
	Threespine Stickleback	*Gasterosteus aculeatus*		X													X	
Ictaluridae					R										R	R		
	Margined Madtom[N]	*Noturus insignis*			X										X			
	Yellow Bulhead[N]	*Ameiurus natalis*																
Moronidae						R					R	R					R	
	White Perch[E]	*Morone americana*				X					X	X					X	
	White Bass[E]	*Morone chrysops*									X							
	Striped Bass	*Morone saxatilis*									X							
Percinidae			R	R	R		R	R			R	R		R	R	R		R
	Fantail Darter[N]	*Etheostoma flabellare*													X			X
	Johnny Darter[N]	*Etheostoma nigrum*	X	X				X							X			
	Tessellated Darter[N]	*Etheostoma olmstedi*	X												X			X
	Yellow Perch[N]	*Perca flavescens*			X		X				X	X		X	X	X		X
	Logperch	*Percina caprodes*													X			X
	Blackside Darter	*Percina maculata*		X											X			X
	Shield Darter[N]	*Percina peltata*																
Salmonidae					R		R								R	R		R
	Brook Trout[N]	*Salvelinus fontinalis*			X		X								X			
	Lake Trout	*Salvelinus namaycush*					X											
Nonnative Exotics																R		R
Amphibians															R	R		

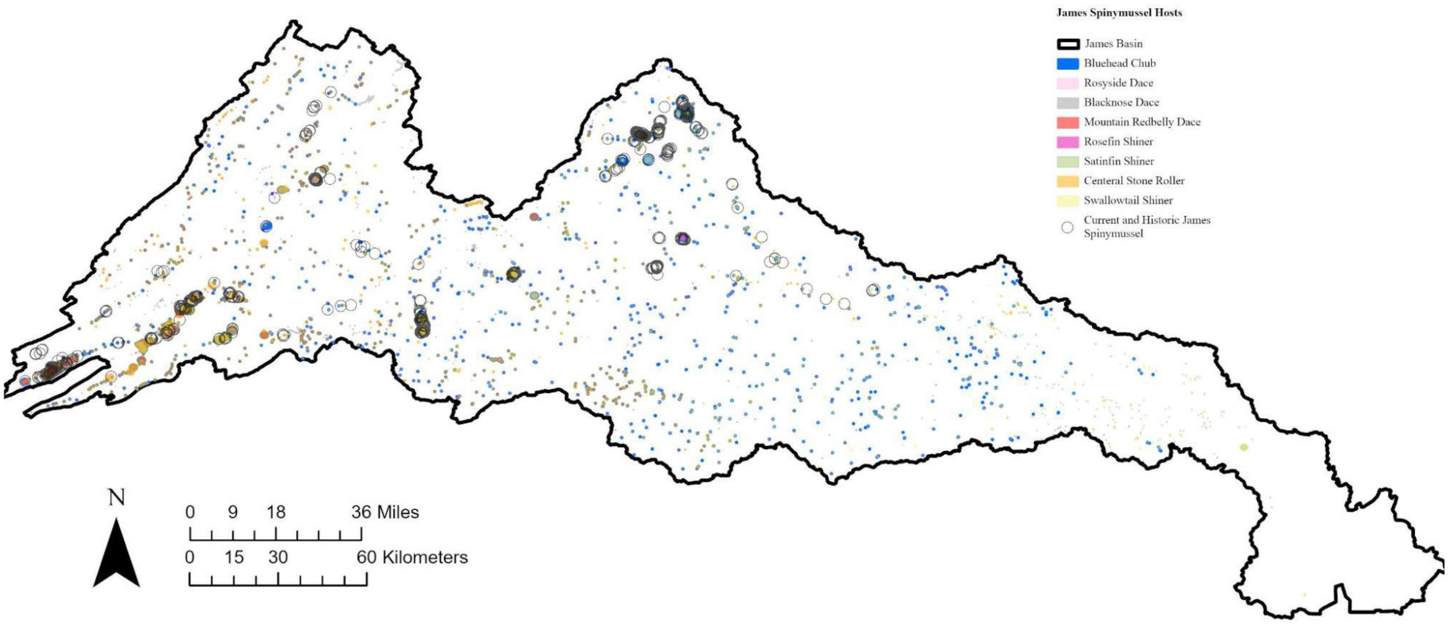


Figure 2. Observations of fish hosts for James Spinymussel in the James River Basin from the Virginia Department of Wildlife Resources WERMS database.

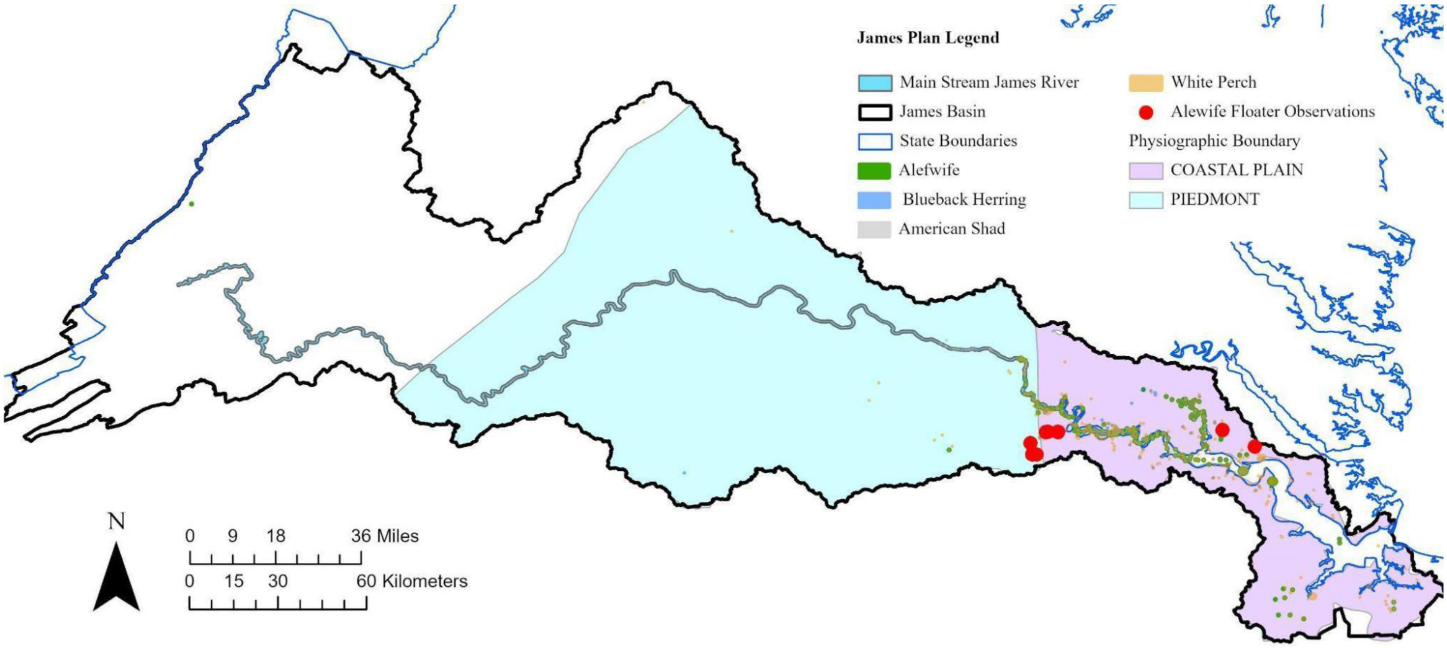


Figure 3. Alewife Floater observations in the James River Basin. Observations of its primary wild host fish are displayed. Mussel distribution data is derived from several data sources including Virginia Department of Wildlife Resources databases, Department of Conservation and Recreation Natural Heritage Database, and www.GBIF.org. Fish host data is from the Virginia Department of Wildlife Resources WERMS database.

Table 4. Spawning, gravidity and release timing for James River Basin mussels. Species are listed as long term/short term brooders. Strategies are based on Haag (2012), where Equilibrium (E) species demonstrate slow growth, late maturity and are long-lived (>30 years). They invest less in annual recruitment than do other guilds, resulting in low, but constant recruitment over time. These species tend to dominate medium to large-river habitats. Opportunistic (O) species are extremely dynamic; mature early, have high annual reproductive output, and short lifespans. They can colonize and dominate highly disturbed habitats, such as isolated backwaters, but have difficulty competing for resources in predictable, stable habitats. Periodic (P) species represent an intermediate strategy. Habitats these species tend to occupy are listed.

Common Name	Spawning	Gravidity	Release	Long Term/Short Term Brooder	Strategy	Life Span (years)	Large (James River and Large Tributaries)	Medium (Tributaries)	Small (Creeks, Headwaters)	Pool	Riffle	Run	Impoundment	Tidal Freshwater Streams
Dwarf Wedgemussel	Late Summer	Fall	Late Winter/ Early Spring	LT	P	15	X	X	X					X
Triangle Floater	Late Summer	Year Long	Late Winter/ Early Spring	LT	P	~20	X	X	X	X	X	X		X
Brook Floater	Late Summer/Fall	Late Winter/Early Spring	≥14C; Early/Mid Spring	LT	P	7-14	X	X	X		X	X		
Tidewater Mucket	Late Summer	Spring	April/May	LT	O		X			X		X	X	X
Eastern Ellipitio	Possibly 2x in a yr	End of April/Early June	June	ST	E	50+	X	X	X	X	X	X	X	X
Carolina Slabshell		March/April (Pamunkey BW)		ST		?	X	X		X		X		X
Northern Lance	Late April/ early May (assumed)	June	June	ST	P	~20	X	X	X	X	X	X	X	X
Yellow Lance	Late April/early May	May/June	June/July	ST		10+	X	X	X		X	X		
Atlantic Pigtoe	Early Spring	Late May/Early June	June/July	ST	E	50+[a]	X	X	X	X		X		
Yellow Lampmussel	Late Summer	Fall to Spring	March to June (BW)	LT		30+	X	X				X		X
Eastern Lampmussel	Late Summer/Fall	Winter	March/June	LT		30+	X	X		X		X	X	X
Green Floater		August	April	LT	O/P[b]	~10	X	X	X	X	**	X		
James Spinymussel	April/May	May/June	June/July	ST	E/P[c]	25+	X	X	X		X	X		
Eastern Floater	Fall	Winter	Spring	ST	O	<10	X	X	*	X	X	X	X	X
Eastern Pondmussel	Late Summer	Fall/Winter	February-April	LT	E/P[e]	30+	X	X		X		X	X	X
Creeper	Fall	Winter	March	LT	P[d]	<20	X	X	X	X	X	X		
Paper Pondshell		Spring/Summer		LT	O	<10	X	*	*	X			X	X
Alewife Floater	Late Summer/Fall	Winter	February-April	LT	O	20+	X	X	*	X		X	X	X
Notched Rainbow	Late Summer/Fall	Winter	March/May	LT	P	<20	X	X	X	X	X	X		

* will colonize if there is a nearby souce

** if in flow reguia (e.g. eddies, behind boulders, along banks, protected by large woody debris)

[a] Matt Johnson estimated specimen >50 yr based on examination of internal arrest line, pers. com. B. Watson 2/9/2024

[b] Observations in Virginia suggest Oppertunistic with boom and bust at sites in relatively short periods of time (e.g., Tye River), pers. com. B. Watson 2/9/2024

[c] Observation in longterm CMR study in Virginia suggest certain year classes are dominant, so somewhere between E and P, pers. com. B. Watson 2/8/2024

[d] Based on obserations made in Smith Creek, Shennandoah Basin. Relatively short lived with increases over short periods. pers. com. B. Watson 2/15/2024

[e] Based on obserations made in Nottoway and Blackwater Rivers in Virgnia; long-lived relatively high fecundity, not many spikes in numbers, pers. com. B. Watson 2/15/2024

MUSSEL HABITATS IN THE JAMES RIVER

Historically, the James River Basin was a continuum of fluvial habits, from relatively high-gradient, forested mountain headwaters to the tidal estuary. Before European colonization, stream networks were connected with few natural barriers other than the fall line and areas where salinity became too great for freshwater mussels to tolerate. There are no natural lakes in the James River Basin but the basin now contains several reservoirs and hundreds of small impoundments that, simultaneously, are barriers to fish movement and provide lacustrine habitats. Small lacustrine habitats scattered throughout the basin as retention ponds and small lakes, may functionally resemble beaver impoundments or wetlands that existed prior to European colonization. Larger anthropogenic barriers exist on the mainstream James River may greatly affect movement of fish hosts (e.g. Bosher's Low Head Dam, Scotts Mill Dam, Big Island Dam, Holcomb Rock Dam).

From a habitat perspective, the basin can be divided into five freshwater mussel habitat regions:

1. Mountain headwaters and small rivers
    a. Valley and Ridge
    b. Blue Ridge
2. Piedmont streams and rivers
3. Tidal tributaries (Coastal Plain)
4. Mainstream James River from Cowpasture/Jackson confluence to fall line (Valley and Ridge, Blue Ridge and Piedmont)
5. Tidal influenced James River below falls (Coastal Plain)

These physiographic freshwater mussel habitat regions somewhat align with underlying physiographic regions of the state (Figure 4). Underlying geology structures stream networks and shape instream habitat characteristics, including stability and streambed composition. As such, differences in physiography are important for interpreting data and planning. For example, streams have higher gradients in the Valley and Ridge, rendering many habitats unsuitable due to high shear stress. In that province, bedrock formations can also greatly influence streambed habitats (Figure 5), creating patches of habitat with long-term stability. In contrast, streambeds tend to have lower gradients and are often dominated by sand in the Piedmont (Figure 6) and Coastal Plain (Figure 7). Here mussels may move with the stream.

For the most part, distribution of mussels may not be explained by these physiographic freshwater mussel habitat regions. The exceptions include Alewife floater and Tidewater Mucket, which are more likely to be limited to tidal streams and the James below the fall line. Otherwise, most species likely inhabited all habitat regions of the James Basin. These assumptions are somewhat based on observations from other basins.

These physiographic regions are more importantly associated with patterns of human land use (Table 5, Figure 8) and vulnerability to future development (Figure 9). Many mountainous headwaters originate and flow through U.S. National Forest (USFS) with valleys and floodplains privately held and often used as pasture and hay fields. Approximately 59.6% of Valley and Ridge and 43.4% of Blue Ridge physiographic provinces are USFS land. These headwaters are at limited risk from human disturbance. Approximately, 12.3% and 10.9% are pasture or hay fields in Valley and Ridge and Blue Ridge, respectively. The Piedmont physiographic province tends to have greater urban centers with substantial risk for further disturbance, with 13.2% presently urban, compared to 5% in Valley and Ridge and 5.5% in Blue Ridge. The Coastal Plain has even greater urban land use (24.7%), mostly in the Virginia Beach–Norfolk–Newport News metropolitan area. Coastal Plains tend to have more cultivated cropland at 12.5%, compared to 1.9% in Piedmont, 0.2% in Blue Ridge and 0.4% in Valley and Ridge[8].

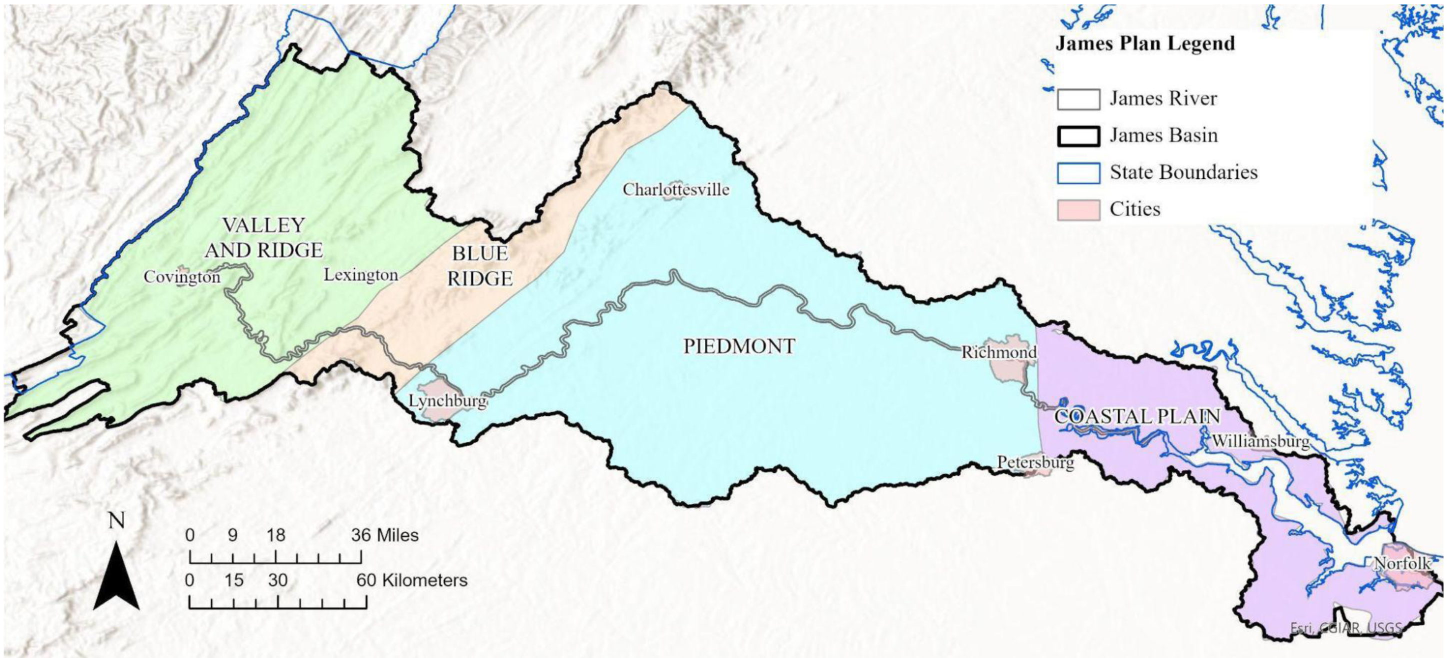


Figure 4. Major physiographic provinces of the James Basin in Virginia. The path of the mainstream James River is delineated.

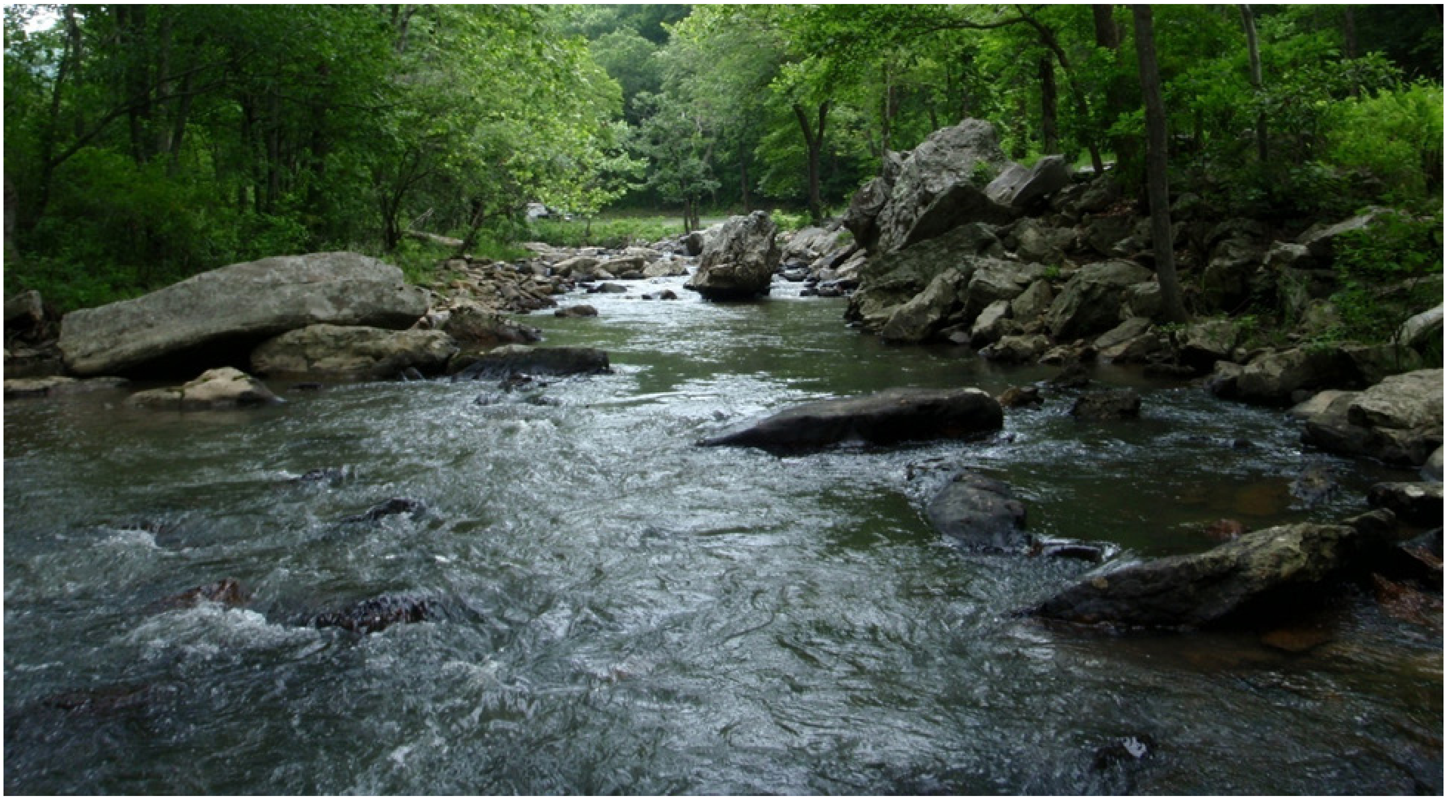


Figure 5. This reach of Mill Creek in the Valley and Ridge province was occupied by James Spinymussel. Instream habitat is controlled by bedrock ledges. Photographed during a 2009 survey.

[8] Calculated from National Land Cover Database (NLCD) 2021 Land Cover Conterminous United States (Dewitz, J., 2023, National Land Cover Database (NLCD) 2021 Products: U.S. Geological Survey data release, https://doi.org/10.5066/P9JZ7AO3)

Figure 6. Sand-dominated reach of the Rivanna River in the Piedmont as pictured during a 2011 survey. The Eastern Elliptio and Northern Lance were common in this reach.

Figure 7. Herring Creek is a typical sand and small gravel stream in the Coastal Plain Physiographic Province. Photographed in 2023.

Table 5. Land use by physiographic provinces. See Figures 4 and 8 for context. Data for this figure and all land use/land cover from 2021 National Land Cover Database (https://www.usgs.gov/centers/eros/science/national-land-cover-database).

Province	Open Water	Developed	Barren	Forest	Shrub	Grassland	Pasture/ Hay Field	Cultivated Crops	Wetland
Valley and Ridge	0.4	5.0	0.1	80.2	0.7	0.8	12.3	0.4	0.1
Blue Ridge	0.4	5.5	0.0	81.4	0.9	0.8	10.9	0.2	0.0
Piedmont	1.1	13.2	0.2	58.7	3.5	5.3	12.4	1.9	3.7
Coastal Plain	6.8	24.7	0.3	32.3	2.3	2.2	0.8	12.5	18.1

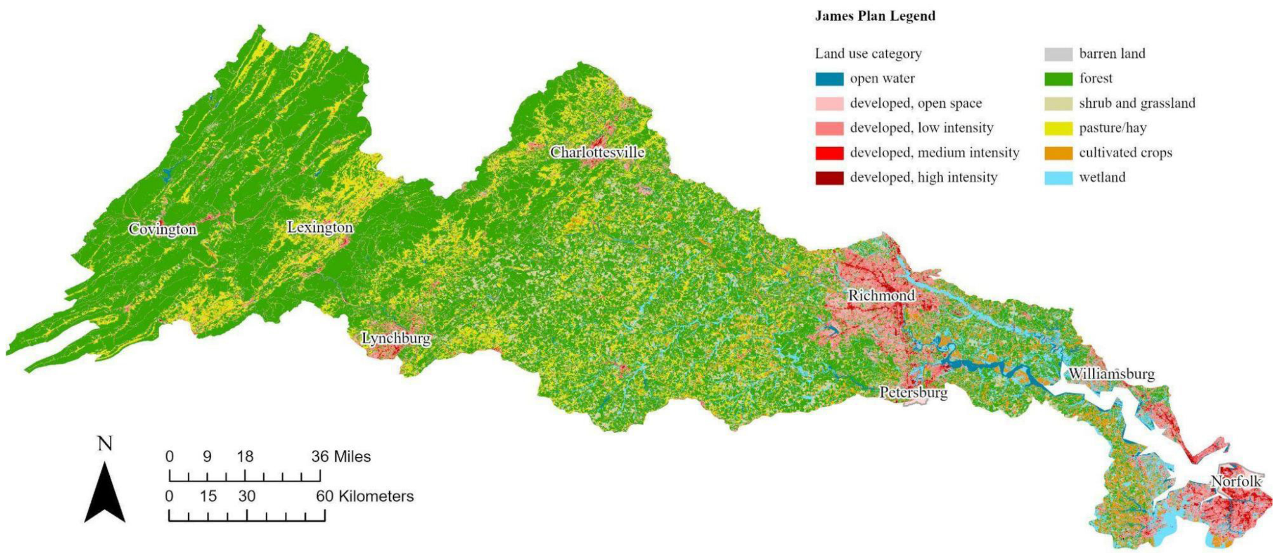


Figure 8. Land use for the entire James Basin basin. Data for this figure and all land use/land cover from 2021 National Land Cover Database (https://www.usgs.gov/centers/eros/science/national-land-cover-database).

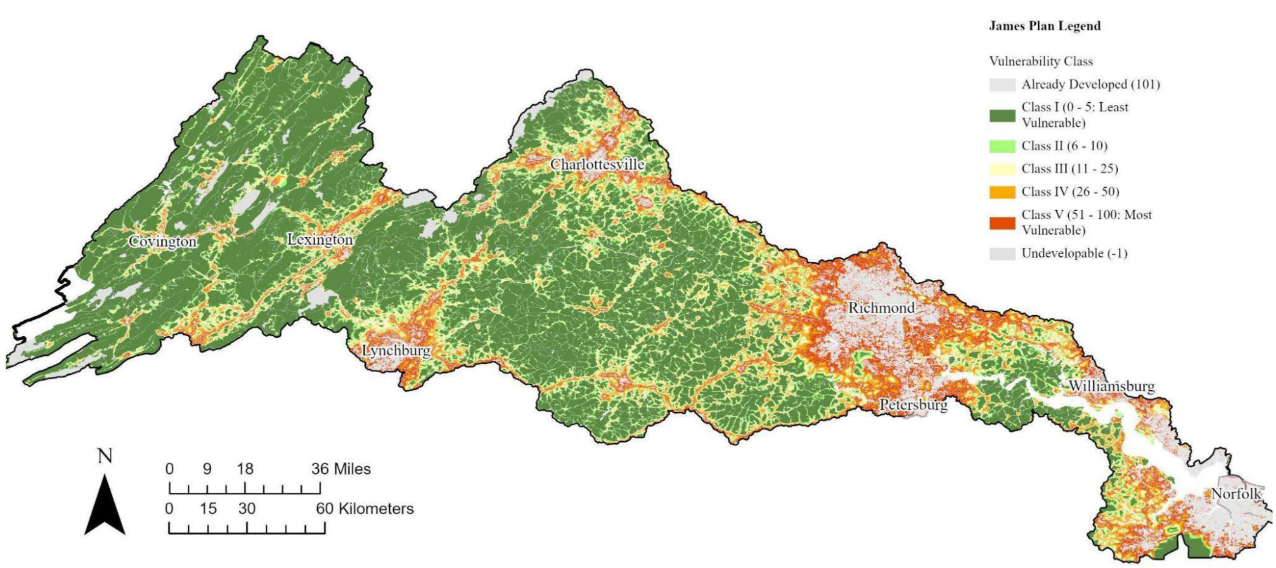


Figure 9. Raw development vulnerability models from DCR. Classes were determined by DCR. The purpose of the Development Vulnerability Model is to quantify the risk of conversion from greenspace (natural, rural, or other open space lands) to urbanized or other built-up land uses (https://www.dcr.virginia.gov/natural-heritage/vaconvisvulnerable). Portions of West Virginia are not included.

ACKNOWLEDGED UNDERLYING ASSUMPTIONS FOR THE JAMES RIVER MUSSEL RESTORATION PLAN

1. Native assemblages for many habitats are unknown and mostly inferred from an amalgam of information originating elsewhere in Virginia and a limited number of sites in small tributaries.
2. Present native mussel abundances are assumed to be well below abundances prior to European colonization.
3. Improvements to water quality, increased regulation, and habitat restoration have not reversed a trend of mussel decline.
4. Agencies and partners involved in this planning have limited power, mostly limited to mitigating immediate threats to protected species through permitting processes, consulting with other agencies, implementing voluntary habitat restoration projects, and augmenting populations and reintroducing species using propagation.
5. Boosting populations and increasing the number of occupied habitats using propagation may be the best available tools to restore mussels.

PROPAGATION FACILITIES WORKING WITH JAMES RIVER BASIN SPECIES

Mussel restoration relies heavily on propagation facilities. It is intended that propagated mussels will be the primary means of population augmentation, species reintroductions, and species establishment. Augmentation is defined as the release of a species in a river reach where it currently exists. Reintroduction is the release of a species into suitable historical habitat from which it has been extirpated, and where natural recolonization cannot reasonably be anticipated. Establishment is defined as the release of a species into suitable habitats in reaches for which no records exist of the species' historical occurrence, and where natural colonization cannot reasonably be anticipated. Species considered for establishment have a host fish in the range and are assumed to have been missed by limited sampling prior to extirpation.

ACTION DEFINITIONS

Augmentation: The release of a species in a river reach where it currently exists.

Reintroduction: The release of a species into suitable historical habitat from which it has been extirpated, and where natural recolonization cannot reasonably be anticipated.

Establishment: The release of a species into suitable habitats in reaches for which no records exist of the species' historical occurrence, and where natural colonization cannot reasonably be anticipated.

The Virginia Fisheries and Aquatic Wildlife Center (VFAWC) at Harrison Lake National Fish Hatchery is the primary facility in Virginia that handles and propagates species native to the James River Basin. Located just east of Richmond, this hatchery is a federal facility cooperatively staffed by USFWS and DWR, with funding from both agencies as well as other sources. The Harrison Lake facility has capacity to produce large numbers of juvenile mussels. Over the past 3 years, the partners have produced over 2.6 million juvenile mussels and released nearly 26,000 cultured sub-adults of nine species.

The Freshwater Mussel Conservation Center at Virginia Tech has propagated many James River Basin species and has conducted primary research on species native to the basin, most notably James Spinymussel and Atlantic Pigtoe. It is not currently focused on the basin, but is propagating species native to the basin for release into the nearby Shenandoah River, which shares most species with the James. This facility is primarily a research oriented endeavor but does produce juvenile mussels for restoration in both the Shenandoah and Upper Tennessee River systems.

White Sulphur Springs National Fish Hatchery (West Virginia), operated by the U.S. Fish and Wildlife Service, is planning to resume work with James Spinymussel, mostly focusing on the population occupying the South Fork Potts Creek of the upper James River Basin. Based on the organizational mission, White Sulphur Springs has directed most efforts to federally listed and candidate species. The capacity to participate in common species restoration has not been determined and would certainly depend on culture infrastructure, space, and funding. The Marion Fish Hatchery operated by the North Carolina Wildlife Resources Commission (NCWRC) is another nearby facility that propagates species native to the basin, with its focus outside of Virginia but a history of cooperation with DWR biologists. The NCWRC also is opening a propagation facility at Yates Mill Pond to focus on propagation of Atlantic Slope fauna, similar to the mission of VFAWC. This facility will be active in 2024.

THE PLANNING PROCESS

The development of the mussel restoration plan was a cooperative venture including representatives from the James River Association (JRA), the Virginia Department of Wildlife Resources (DWR), Virginia Department of Conservation and Recreation (DCR), U. S. Fish and Wildlife Service (USFWS), Virginia Tech (VT), and Daguna Consulting, LLC (Daguna). See Appendix B for participants. Representatives of these agencies and non-governmental organizations attended two in-person workshops (Figure 10). Additional partners were invited to participate in the in-person workshops but could not attend; these invitees provided varying levels of input. Daguna Consulting, LLC (Daguna) biologists served as facilitators and JRA staff provided technical assistance for workshops.

Figure 10. In-person workshop interactions in January 2023.

The first in-person workshop, held in January 2023, reviewed species-specific knowledge, including fish hosts, habitat preferences, and propagation. Geospatial datasets for species observations provided by DWR and DCR were displayed and discussed. There was much discussion on inclusion and exclusion of species, as some species known from adjacent watersheds had not been detected or confirmed in the James River Basin, apart from scattered museum records assigned to the area (e.g. Brook Floater and Eastern Lampmussel) and volunteer observations (www.gbif.org). The first workshop set the scope and developed a shared perspective on how to contextualize management. The consensus was to limit the plan to mussel propagation, augmentation, and continued assessments of species distribution and status. Other topics such as land use and riparian best management practices (BMPs), stream and bank restoration projects, educational campaigns, dam removal, genetic population structure, and ecology were considered important but beyond the scope of this plan. There was agreement that the plan should set a limited number of priorities and be as explicit as possible, avoiding inoperable generalities common to earlier recovery plans (e.g. habitat preservation and general education; task 2 in James Spinymussel Recovery Plan, 1990). The timeframe of the plan was also discussed, with a consensus reached around a 10-year timeline with a 5-year review. The most substantial discussions during the first workshop addressed how to structure mussel population restoration. Three alternatives were proposed:

1. Species-specific
2. Assemblage
3. Geographically

In part, due to the legal structure of the federal Endangered Species Act and the corresponding act in the Code of Virginia, conservation planning and management has defaulted to species-by-species efforts in Virginia over the past 40 years. While this perspective can detach species from a network of ecological connections necessary for persistence, it allows for narrowly defined objectives and management actions targeting specific needs of a given species. These simplistic, narrow objectives and actions can be more easily executed, quantified, and evaluated (e.g. recovery criteria). However, mussel species rarely occur in isolation and are tied to the system's ecological integrity including the health of other biota, ranging from fish hosts to plankton and microbial communities. Some ecosystems in Virginia have incredible richness, where mussel populations need to be managed as an assemblage[9]. Additionally, propagation facilities often handle and produce multiple species with the expectation that success for any given species varies by year. During a similar planning effort for the Clinch River, biologists sought to rebuild assemblages assuming multiple mussel species support each other and increase resiliency while providing propagation facilities needed flexibility (Beaty and Lane 2016). As described above, the James River Basin is a diverse network of streams draining quite different landscapes. On top of that, there is a complex matrix of historical and present land use; including forestry, heavy industry (e.g. paper mills in the Jackson River), urban and suburban development, row crop agriculture, and pasture lands (see Figures 8 and 9).

From an ecosystem perspective, the assemblage was the preferred framework for planning but those present at the first workshop struggled to define assemblage structures across the basin. While one species in particular, Alewife Floater, could be used to define one assemblage, other species appeared to be distributed across a large range of stream sizes, habitat types, and physiographic regions. Most consequently, by the time biologists focused on freshwater mussels in the James River Basin, starting in earnest in the 1970s, species distributions had been so fragmented and populations so depressed that discerning natural assemblage structure was not possible. Working on a species-by-species basis was also not desired. Much of the work in the basin had already disproportionately focused on federally listed species for which plans had already been developed or were under development (Table 6). It was presumed that a species-by-species approach would lead to a document that was a collection of 16+ somewhat redundant assessments and plans.

[9] The Clinch River of Virginia historically supported as many as 50 co-occurring freshwater mussel species (Jones et al. 2017, Ostby and Beaty 2023).

Table 6. Species Status Assessments (SSA), recovery plans, reviews, and models for imperiled species available to the planning group.

Species	SSA	Recovery Plan	Reviews	Species Models
James Spinymussel		USFWS Plan (1990)	5-Year Review USFWS (2022c)	VNHP (2022e)
Atlantic Pigtoe	USFWS (2021a)	USFWS Outline (2022a)		VNHP (2022c)
Dwarf Wedgemussel		USFWS plan (1993)	5-Year Review USFWS (2019b)	VNHP (2017)
Brook Floater	USFWS (2018)			VNHP (2022a)
Yellow Lance	USFWS (2019a)	USFWS draft plan (2022b)	5-Year Review USFWS (2023)	VNHP (2022b)
Green Floater	USFWS (2021b)			VNHP (2022d)

Based on discussions of the first workshop, a geographical approach was proposed, modified, and adopted. That geographical approach was primarily based on stream networks, physiographic provinces, and land use. However, it also incorporated critical assemblage and species information. Thus, the resulting approach was a disproportional compromise of all approaches initially discussed (geographical, assemblage, and species). The basin was divided into Mussel Management Units (MMUs) using USGS HUC10 watersheds as a base and excising reaches of the James River mainstem, from the confluence of the Jackson River and Potts Creek to tidal influence, as separate units. The tidal influence begins near the Mayo Bridge in Richmond, but mussel range is considered limited to tidal fresh salinities or the region extending west from the mouth of the Chickahominy River. This approach both acknowledged the unavoidable limitations of stream networks and the relative importance of a large river that simultaneously connected all networks and was a distinctly different ecosystem. The final map had 28 MMUs, including 4 mainstream sections (Tables 7 and 8, Figures 11 and 12).

Table 7. Rankings of Watershed MMUs and reference to detailed text where appropriate.

	Watershed MMU	High Priority	Priority	More Study Needed
1	Jackson-Dunlap			
2	Potts		X	
3	Craig	X		
4	Cowpasture	X		
5	Catawba			X
6	Upper Maury		X	
7	Lower Maury			
8	Small Direct Tributaries Potts to Pedlar			
9	Pedlar		X	X
10	Lynchburg Tributaries			
11	Tye		X	X
12	Buffalo			
13	Small Direct Tributaries Lynchburg to Rivanna		X	
14	Rockfish			
15	Hardware			
16	Upper Rivanna	X		
17	Lower Rivanna			
18	Slate		X	X
19	Willis		X	X
20	Small Direct Tributaries Rivanna to Richmond		X	
21	Upper Appomattox	X		X
22	Lower Appomattox			X
23	Chickahominy		X	
24	Small Tidal Tributaries		X	

Table 8. Rankings of Mainstream MMUs and reference to detailed text where appropriate.

	Mainstream MMU	Highest Priority	Priority	More Study Needed
25	Potts to Pedlar			
26	Pedlar to Scottsville		X	X
27	Scottsville to Fall Line	X		
28	Below Fall Line		X	

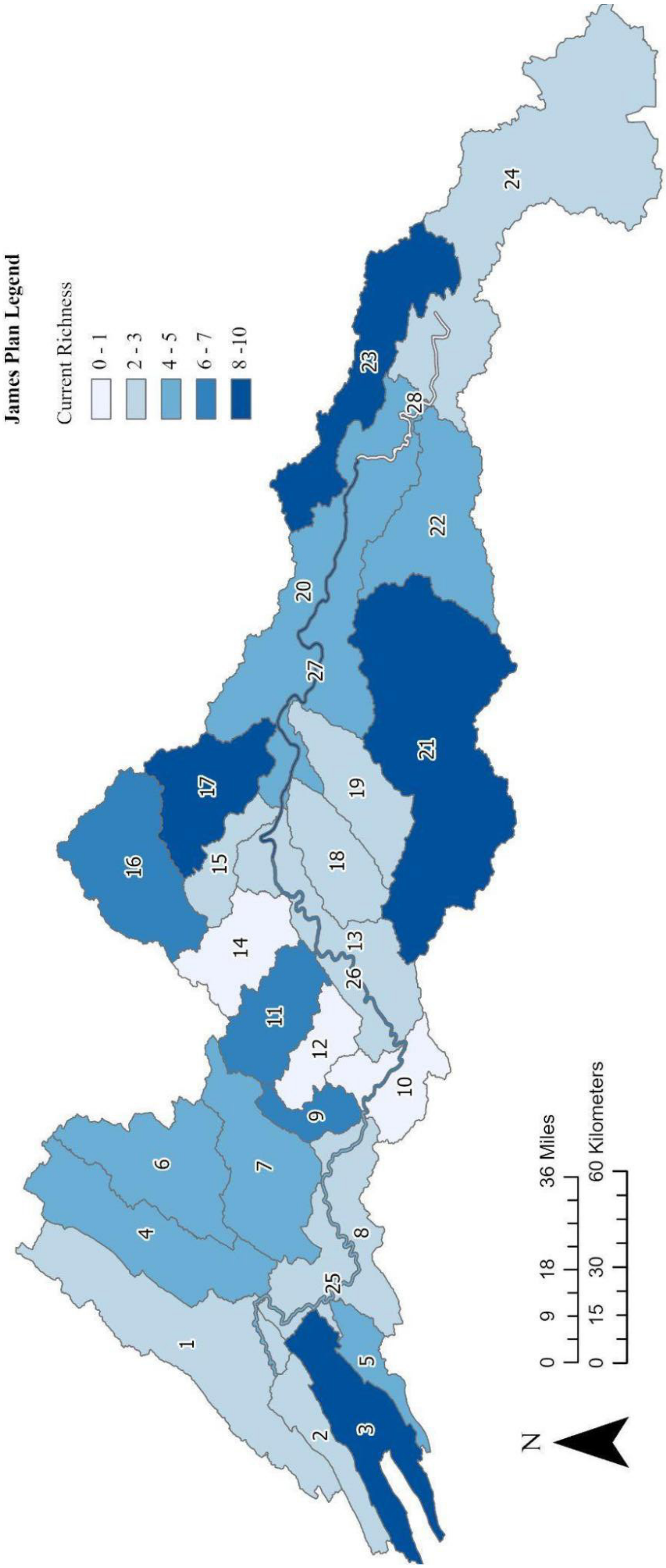


Figure 11. Map of Watershed MMUs. Numbers referenced are in Table 7.

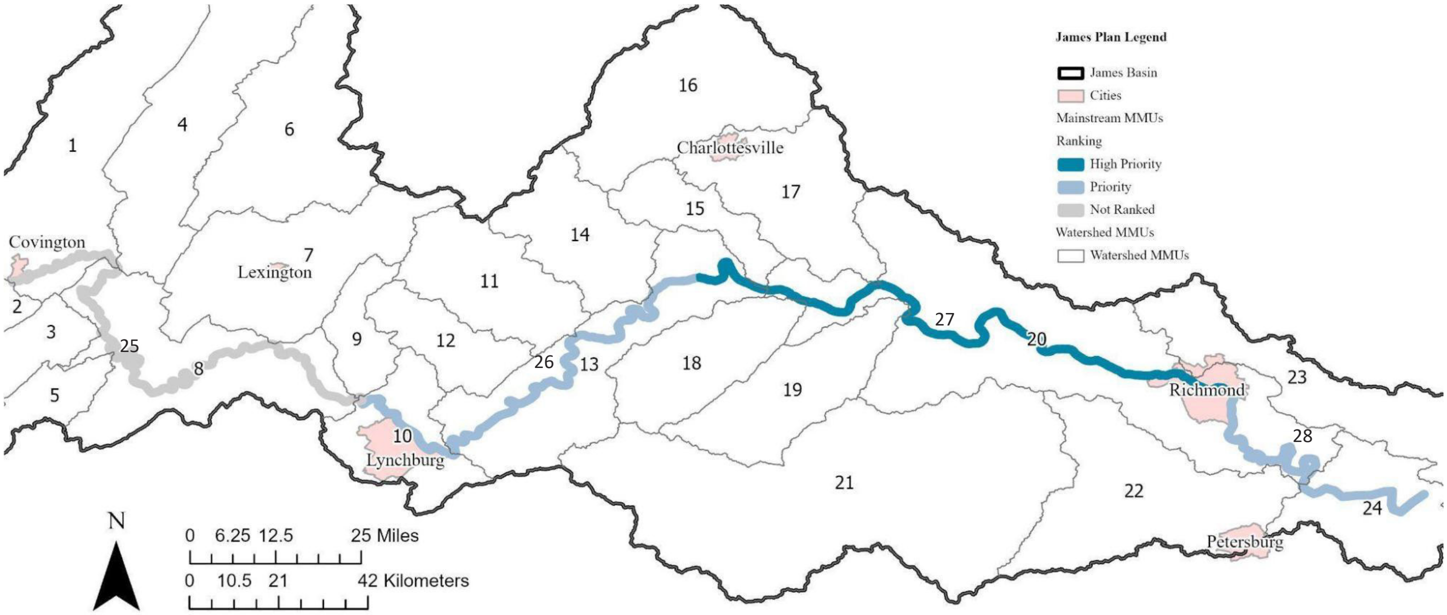


Figure 12. Map of Mainstream MMUs. Numbers referenced are in Table 8.

Many USGS HUC 10 watersheds were combined into MMUs based on 1) what was known about assemblage conditions and species in each, 2) ecosystem types present in each, 3) general land use patterns, and 4) physiography. For example, the greater Rivanna River was a major tributary to the James River and comprised 5 HUC 10s. This Rivanna River system was split into the Upper Rivanna and Lower Rivanna MMUs. Three USGS HUC 10 watersheds were combined into the Upper Rivanna MMU because each shared key characteristics. Each watershed was known to support a population of James Spinymussel, had headwaters in the Blue Ridge Mountains, and drained similar areas of agricultural and low-density residential land uses with comparable patterns of disturbance and dendritic stream networks. Compared to the Upper Rivanna, the Lower Rivanna was more drastically affected by the Charlottesville metropolitan area and had experienced a greater relative decline in assemblage condition. Additionally, the Rivanna River itself was a larger stream formed by the confluence of several streams around Charlottesville.

A major benefit of splitting areas into MMUs was the examination of survey data (Figure 13). This resulted in a map delineating which MMUs had been most successfully surveyed and which were under sampled (Figure 14). This visual presentation demonstrated the Upper Appomattox MMU had been severely undersampled, with only 4.8% of reaches surveyed since 1980. This also allowed for a comparison of richness among MMUs (Figure 15) within the context of sampling intensity. During a later review of information available after workshops concluded, MMUs were compared by mean predicted habitat suitability scores from species distribution models developed by DCR for Dwarf Wedgemussel (Figure 16), Brook Floater (Figure 17), Yellow Lance (Figure 18), Atlantic Pigtoe (Figure 19), Green Floater (Figure 20), and James Spinymussel (Figure 21).[10]

Information about present land use and development vulnerability were considered to be most important by the group due to the understanding that both were proxies for habitat disturbance, with associations between land use and mussels well documented in the literature (Arbuckle and Downing 2002, Diamond et al. 2002, McRae et al. 2004, Poole and Downing 2004). Land use statistics (Table 9), particularly in 100 m riparian buffers around streams (Figure 22), were compared among watershed MMUs. A similar exercise was conducted for the DCR vulnerability model (Figure 23).

[10] The Summary Statistics Tool in ArcGIS Pro was used to derive mean probability by MMU based on probability scores for each flowline segment in DCR Models. DCR Species Distribution Models have assigned probability of suitability on a scale from 0-1 for each of 6 species, based on stream reaches having similar environmental conditions in comparison to known presence locations.

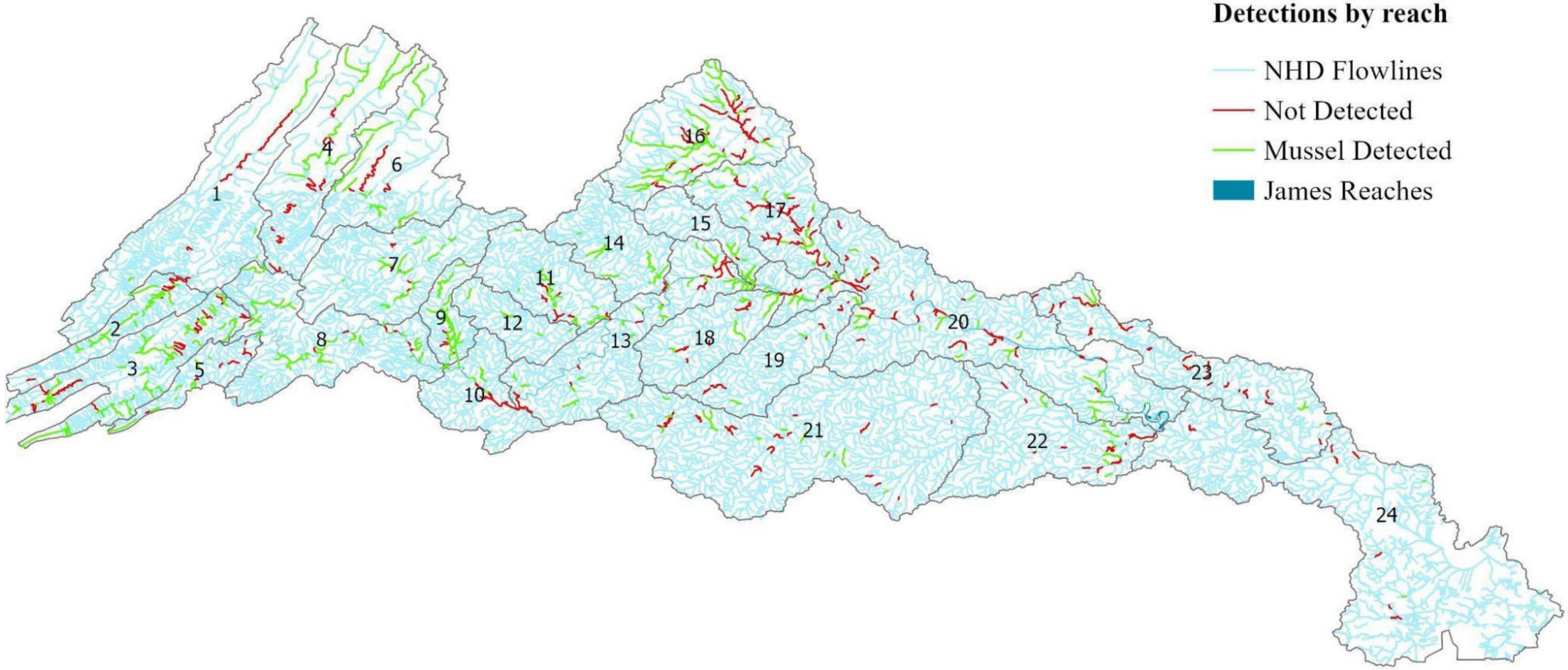


Figure 13. Detections of mussels in survey reaches from 1980 to present. Mussel distribution data was derived from several data sources including Virginia Department of Wildlife Resources databases, www.GBIF.org, and Virginia Department of Conservation and Recreation, Natural Heritage Program. Data from these different sources were checked for redundancy. Observations were assigned to the nearest stream segment from NHD data flowlines.

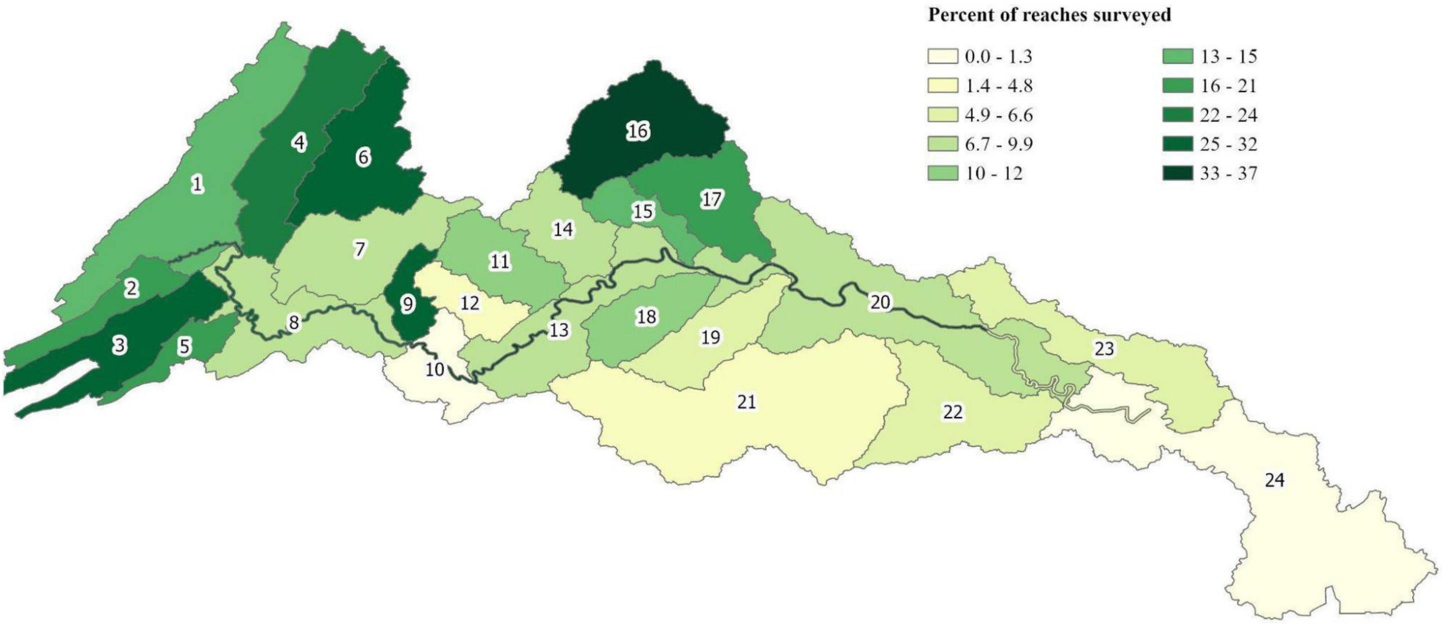


Figure 14. Percent of stream reaches in an MMU surveyed from 1980 to present. Cowpasture MMU (4) may appear to be relatively better surveyed than it actually is. This is due to the limited density of the stream network available in the NHD dataset. Mussel distribution data was derived from several data sources including Virginia Department of Wildlife Resources databases, www.GBIF.org, and Virginia Department of Conservation and Recreation, Natural Heritage Program. Data from these different sources were checked for redundancy. Observations were assigned to the nearest stream segment from NHD data flowlines.

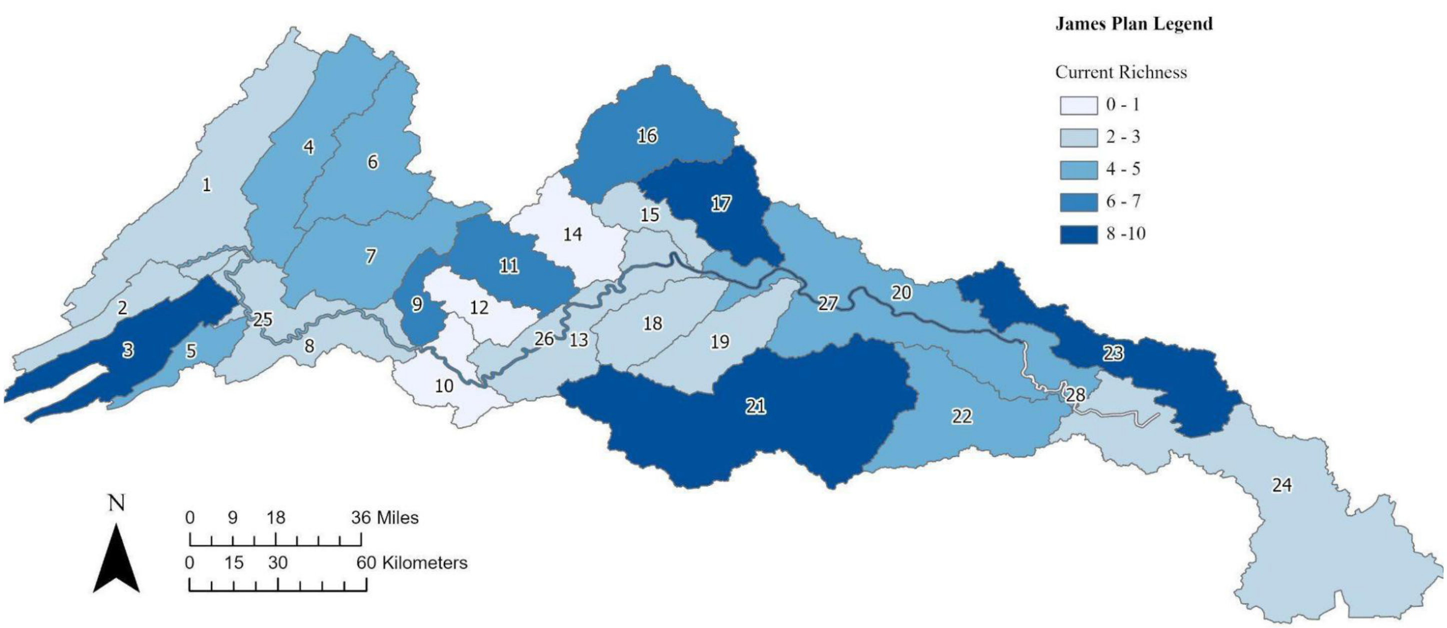


Figure 15. Current richness in MMUs based on survey data from 1980 to present.

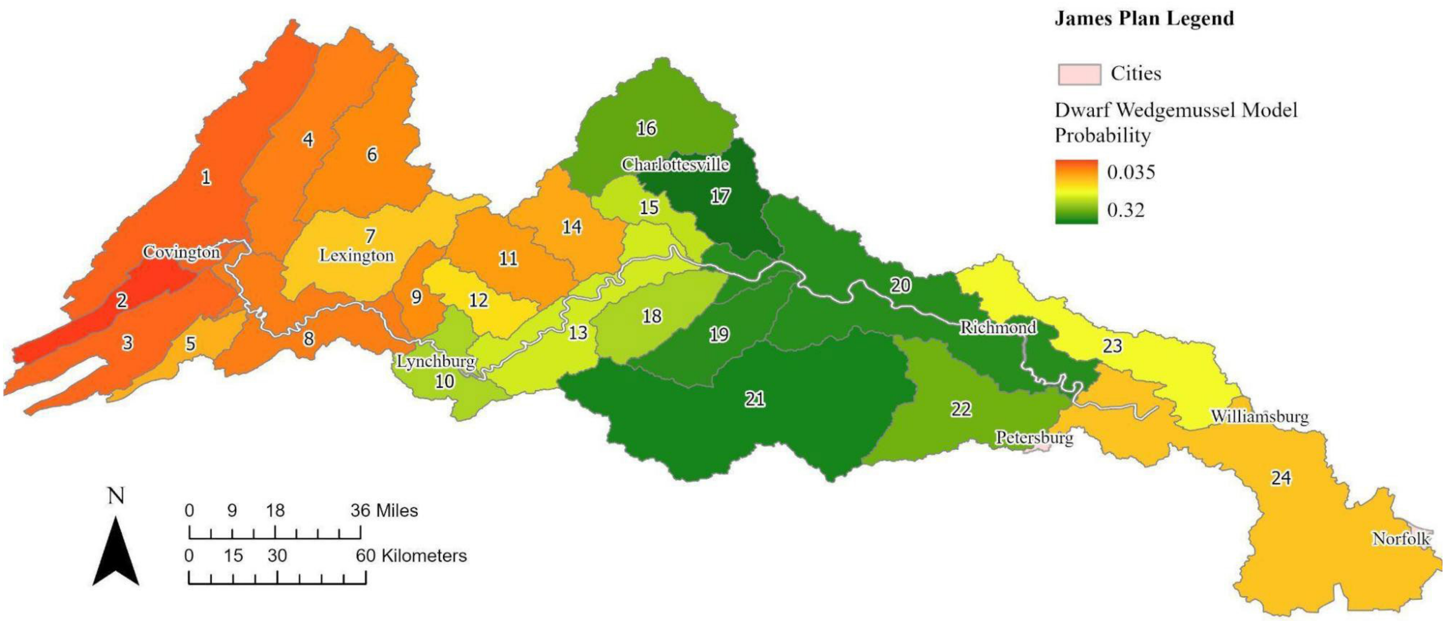


Figure 16. Relative mean habitat suitability by watershed MMU for Dwarf Wedgemussel. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

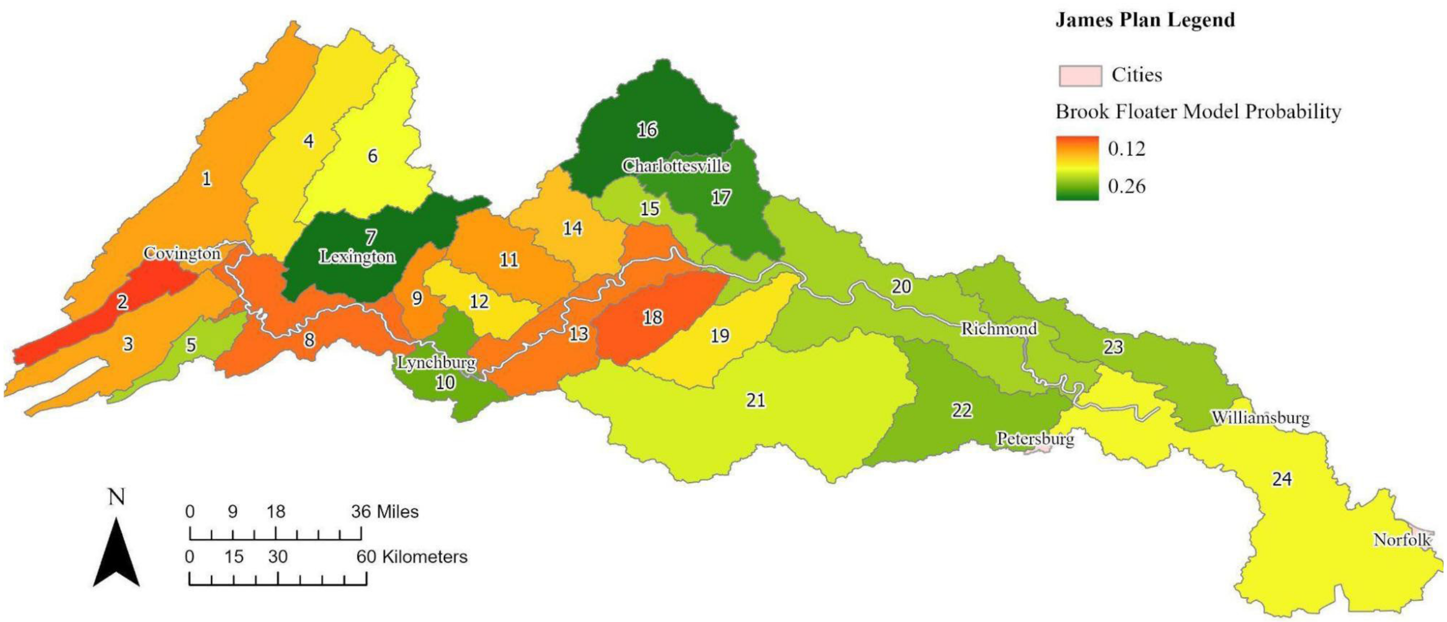


Figure 17. Relative mean habitat suitability by watershed MMU for Brook Floater. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

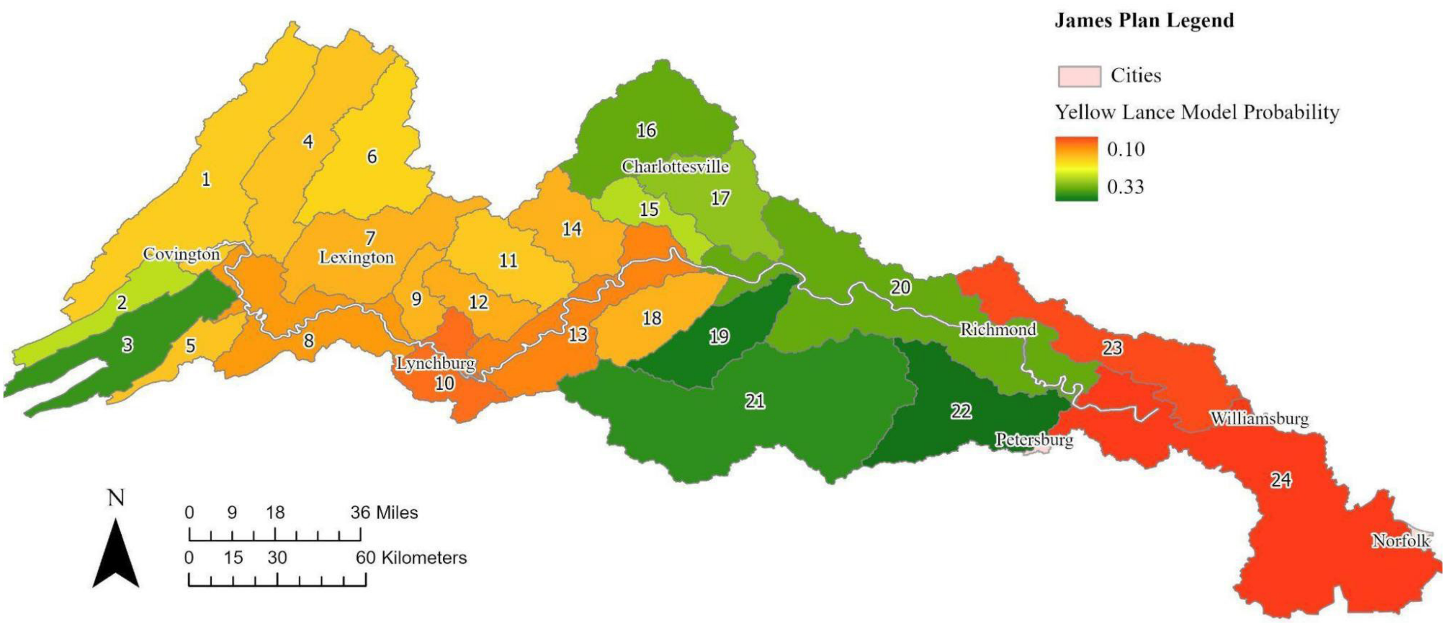


Figure 18. Relative mean habitat suitability by watershed MMU for Yellow Lance. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

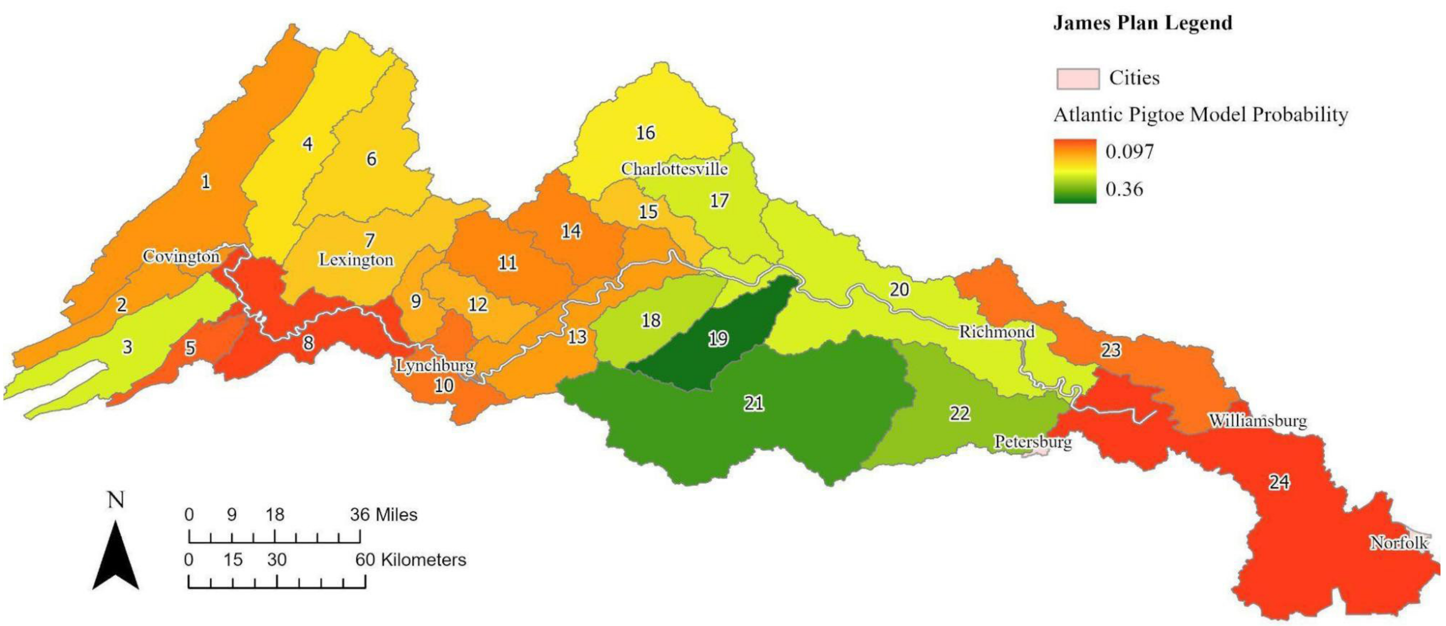


Figure 19. Relative mean habitat suitability by watershed MMU for Atlantic Pigtoe. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

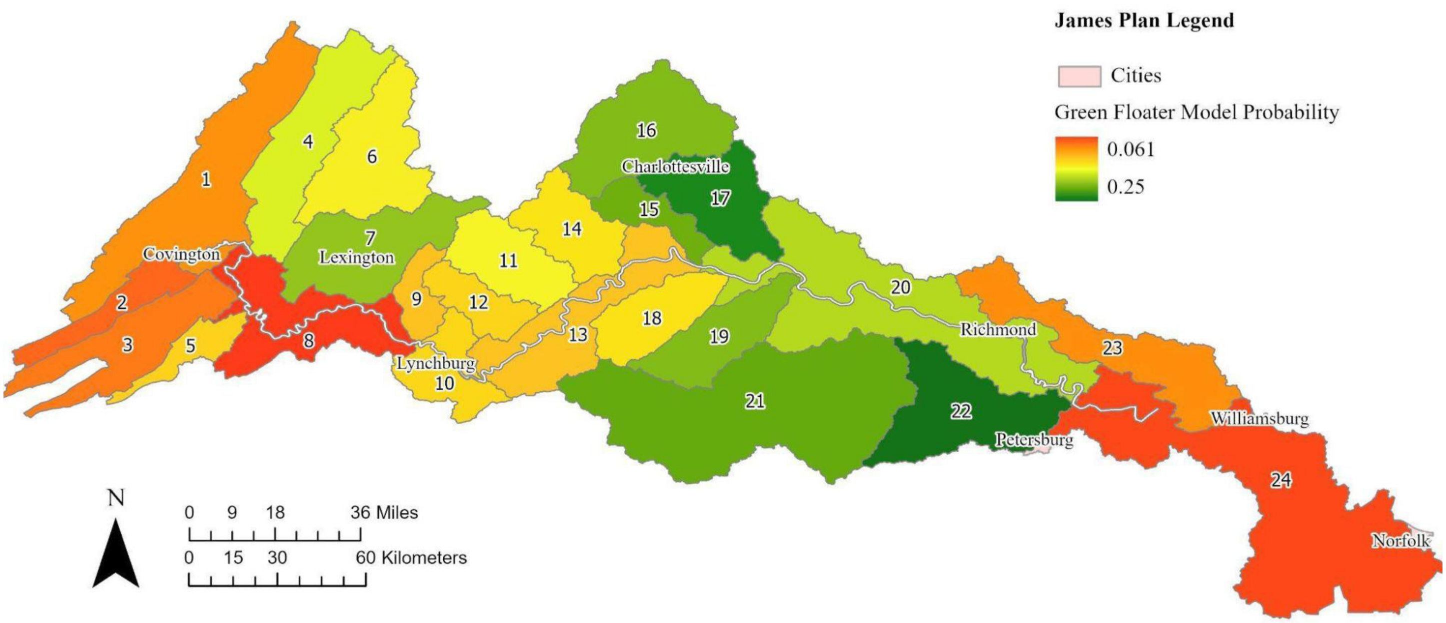


Figure 20. Relative mean habitat suitability by watershed MMU for Green Floater. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

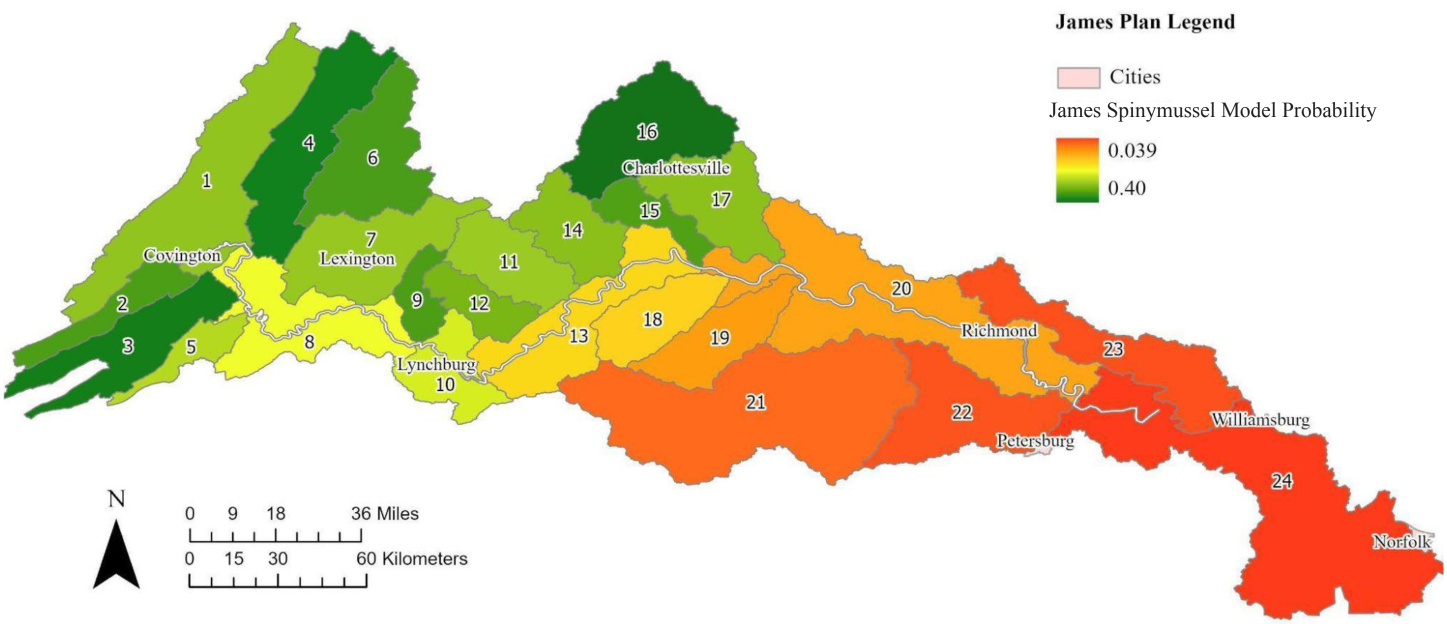


Figure 21. Relative mean habitat suitability by watershed MMU for James Spinymussel. Probability values are from DCR models. Scale is relative and differs by figure. (Data source: Virginia Natural Heritage Program 2017).

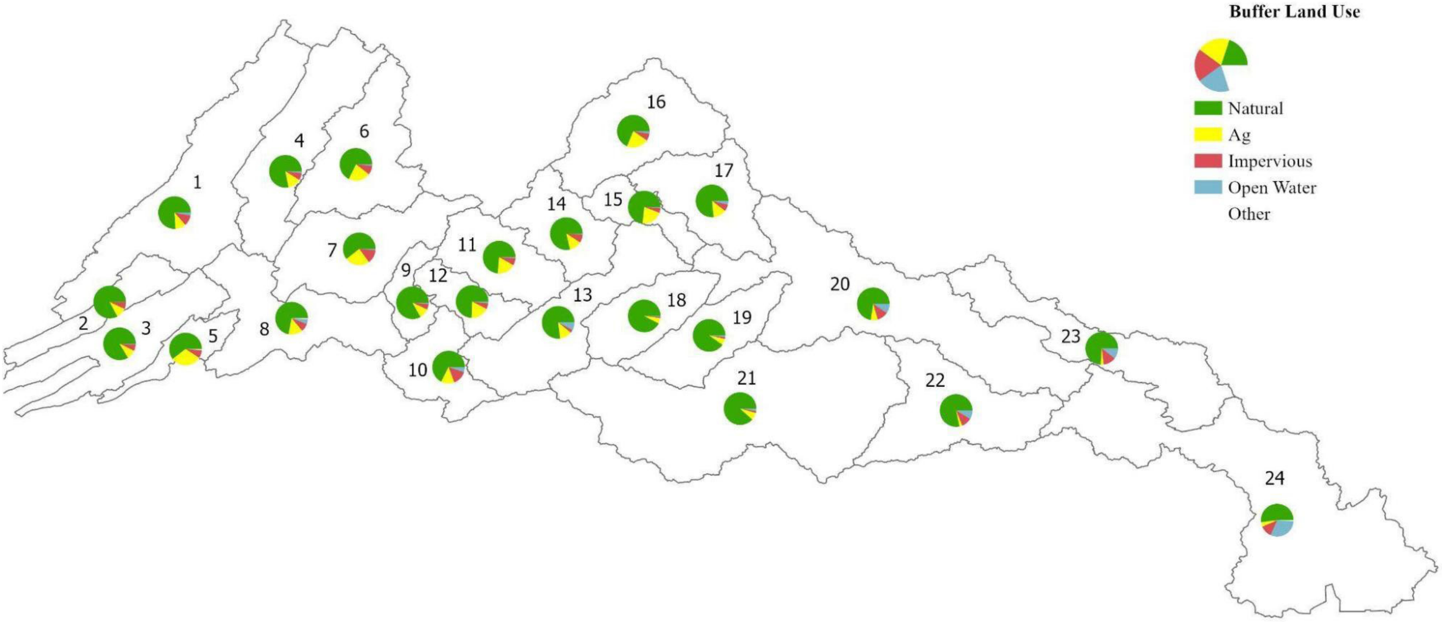


Figure 22. Land use in a 100-m buffer of flow lines by watershed MMU. This data was derived from NLCD data (https://www.mrlc.gov/data) with data clipped to buffers around NHD flowlines.

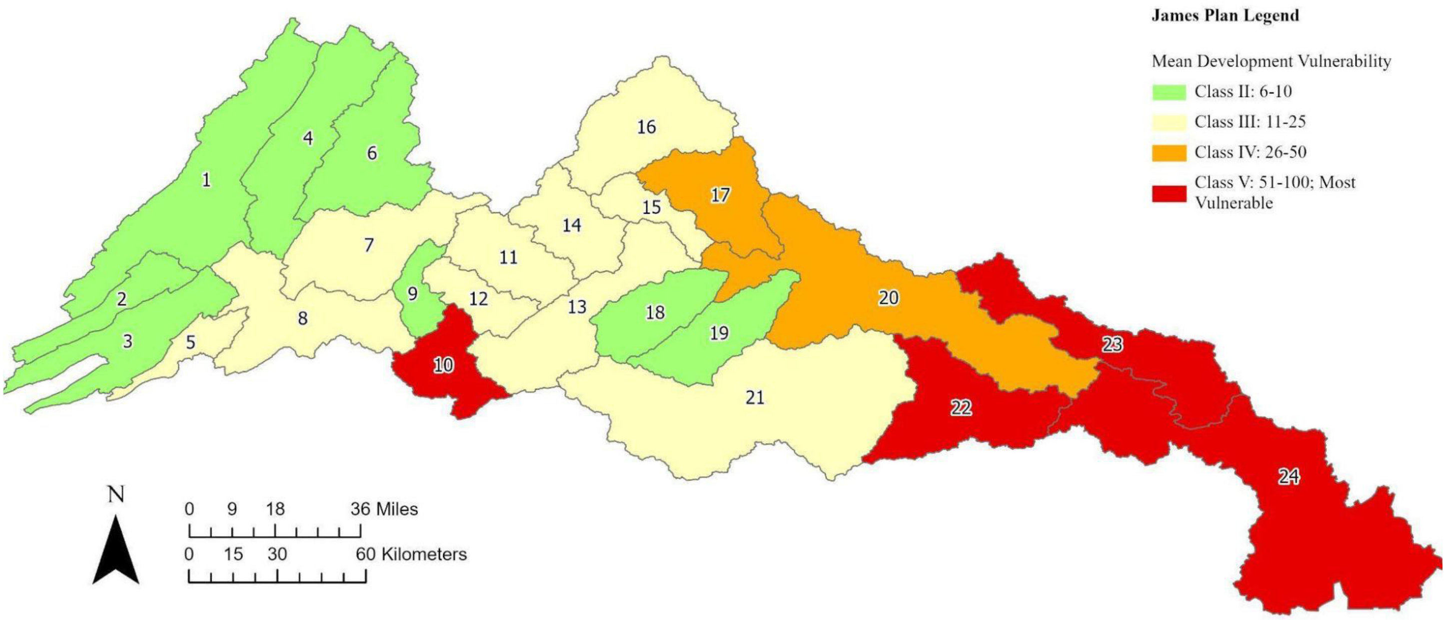


Figure 23. Mean development vulnerability by MMU. Classes were determined by DCR. See raw data displayed in Figure 9.

Table 9. Comparison of proportion of barren, open water, natural, agricultural, and impervious land covers for buffers (100 m) and entire watershed land use for each watershed MMU. Natural land use was forest types, wetland types, herbaceous, and shrub/scrub combined. Agricultural combined cultivated crop, hay/pasture. Impervious included all developed categories.

Legend Number	Watershed MMU	Buffer Barren	Watershed Barren	Buffer Open Water	Watershed Open Water	Buffer Natural	Watershed Natural	Buffer Agricultural	Watershed Agricultural	Buffer Impervious	Watershed Impervious
1	Jackson Dunlap	0.1	0.1	1.8	0.8	74.4	87.0	18.0	6.9	5.7	5.0
2	Potts	0.0	0.0	0.1	0.0	60.6	90.1	30.4	6.0	8.0	3.4
3	Craig	0.0	0.0	10.4	0.2	73.7	89.4	2.8	6.4	12.7	3.5
4	Cowpasture	0.0	0.0	2.0	0.2	78.0	87.9	13.1	8.3	7.0	3.3
5	Catawba	0.5	0.3	0.8	0.1	83.6	68.4	9.2	24.1	6.3	6.3
6	Upper Maury	0.0	0.0	1.0	0.2	73.3	80.3	20.9	14.4	4.8	3.7
7	Lower Maury	0.0	0.0	2.9	0.2	75.8	66.1	10.4	24.5	10.6	9.0
8	Tributaries Potts to Pedlar	0.0	0.0	8.6	1.0	78.2	78.4	2.6	13.7	10.3	5.5
9	Pedlar	0.0	0.0	1.3	0.3	60.6	86.8	24.4	8.2	13.7	4.7
10	Lynchburg Tributaries	0.0	0.1	3.6	1.0	76.5	73.1	13.0	12.3	6.8	12.0
11	Tye	0.0	0.0	1.2	0.3	83.1	78.4	10.0	16.1	5.7	5.1
12	Buffalo	0.0	0.1	0.1	0.4	82.8	75.1	10.2	17.6	6.8	6.7
13	Tributaries Lynchburg to Rivanna	0.0	0.1	0.9	1.7	78.6	75.8	12.3	16.8	8.2	5.7
14	Rockfish	0.0	0.0	0.8	0.2	92.3	84.8	5.5	8.5	1.3	6.4
15	Hardware	0.0	0.1	7.9	0.3	77.0	73.4	12.0	21.1	3.1	5.1
16	Upper Rivanna	0.0	0.0	5.1	0.5	67.4	68.4	13.2	20.4	14.2	9.7
17	Lower Rivanna	0.1	0.1	4.8	0.8	72.0	70.2	14.2	14.5	8.1	14.0
18	Slate	0.0	0.0	9.4	0.2	72.3	85.5	6.8	9.8	11.2	4.5
19	Willis	0.1	0.1	30.5	0.4	51.8	79.8	4.5	14.7	11.8	5.0
20	Tributaries Rivanna to Richmond	0.2	0.3	1.1	2.6	73.6	62.6	18.2	12.1	7.1	22.1
21	Upper Appomattox	0.0	0.1	2.4	0.7	88.2	76.4	7.2	16.9	2.0	5.7
22	Lower Appomattox	0.2	0.4	1.4	2.7	67.7	67.7	21.7	7.6	9.0	20.9
23	Chickahominy	0.1	0.2	2.4	4.0	68.3	62.9	21.7	8.0	7.1	23.9
24	Small Tidal Tributaries	0.1	0.3	1.7	20.7	90.3	40.1	6.2	11.8	1.8	23.3

PRIORITIZATIONS

The major goal of the second workshop was prioritization of actions by MMU. These discussions were informed by land use maps, development vulnerability, survey effort, and, to a large extent, by knowledge of biologists in the room. The 28 MMUs were considered High Priority, Priority, or unlisted (see Tables 7 and 8, Figures 11 and 12). It was decided that the number of High Priority MMUs would be limited to 5 or fewer. This was done to focus efforts over the next decade with the assumption that:

- capacity and funding would not be dramatically increased,
- that the partners in the workshops would be those most responsible for executing the plan, and
- that MMUs with the lowest risk for future disturbance would be disproportionately important.

For each High Priority MMU, specific goals and geographic areas of action were identified. Goals include richness, density, and occupancy targets when applicable. Actions included propagation, definitions of restoration sites and site extent, surveys, monitoring, and identification of broodstock. Other priority MMUs had potential for augmentation, reintroduction, or surveys if funding and partners were available but were considered secondary priorities for the goals of this Plan for a host of reasons, including risk of further degrading impacts or redundancy in representation.

Not ranking 39% of MMUs was an intentional decision. There will be opportunities to work in MMUs not listed as priorities in this plan. In fact, some funds and partners may be limited to areas that are not priorities. For example, there are ongoing efforts to release Alewife Floater to restore ecosystem services. Priority or not ranked MMUs may be considered high priorities for federally listed mussels in order to achieve recovery, as described in Recovery Plans and 5-year reviews. There are also programs and incentives to restore riparian corridors and stream reaches occupied by mussels. However, when given the opportunity to be strategic, funding and resources should be steered to identified priority MMUs which have the greatest potential for success and conservation value.

HIGH PRIORITY MUSSEL MANAGEMENT UNITS

UPPER APPOMATTOX

The Appomattox River is a prominent habitat in this MMU (Figure 24). Many dendritic networks feed the river. A review of survey data clearly demonstrated that the Upper Appomattox MMU has been under sampled (Figure 25). Despite a paucity of sampling, databases suggest mussel richness may be relatively high for the James River Basin, with nine species detected in the last 40 years (see Figure 15). Additionally, species models developed by DCR suggest stream reaches in the MMU have relatively higher suitability, compared to other MMUs, for Dwarf Wedgemussel (see Figure 16), Yellow Lance (see Figure 18), Atlantic Pigtoe (Figure 19), and Green Floater (Figure 20). Land use patterns suggest that this MMU has little historical or limited foreseeable development pressure (Figure 26). It has relatively high forest cover for the Piedmont physiographic province (76.4%)[11], including two state forests within its boundaries (Figure 27). The riparian zone exhibits even greater forest cover with 88.2% forested. The low density of roads and limited development, only 2% land in any type of development and 5.7% impervious cover in the riparian zone, in the MMU have led to a gap in knowledge, as permitting has not triggered investigation and natural history assessments have not occurred.

The largest risks to the streams are around Farmville, Appomattox, and suburban Richmond (Figure 28). Farmville is located in the middle of the MMU. Only one of two major VPDES[12] permits in the entire MMU is for the Appomattox River near Farmville. The Town of Appomattox is located in the headwaters of the Appomattox River. Suburban and exurban Richmond suburbs are on the periphery of the MMU. Most of the MMU is in private ownership with limited public conservation lands (see Figure 27).

The primary focus for this MMU is to better understand the condition of assemblages. While it has been assumed that the road network has limited investigations, Figure 29 demonstrates that many roads cross or access the Appomattox and notable tributaries. Funding should be sought to comprehensively survey the entire stream network, with the greatest priority for sampling:

1. higher order named streams
2. areas with low development pressure (see Figure 28)
3. areas between road accesses (need to be explored with non-motorized watercraft)
4. reaches with higher probability for Dwarf Wedgemussel, Atlantic Pigtoe, Green Floater, and Yellow Lance suitable habitat (Figures 30, 31, 32, and 33).

[11] Compared to 58.7% for Piedmont Province in the James River Basin, see Table 9.

[12] As part of the Clean Water Act, the Virginia Department of Environmental Quality (DEQ) issues permits for point source discharges to surface waters, including discharges from Municipal Separate Storm Sewer Systems (MS4s) and from industrial activities. The permitting program is known as the Virginia Pollutant Discharge Elimination System (VPDES). Major permits are considered sewage with a design volume equal to or greater than 1.0 million gallons per day and industrial discharges requiring EPA review (https://www.deq.virginia.gov/permits/water/surface-waters-vpdes). These are considered important risk factors for restoration.

HIGH PRIORITY STREAMS

Streams that should be a focus of study include (see Figure 24 for location reference):

- Appomattox River
  - variable development vulnerability
  - highest vulnerability near Farmville
  - headwaters have larger tracts of public lands
  - modeled suitability for Dwarf Wedgemussel, Yellow Lance, Atlantic Pigtoe, Green Floater
  - mussels have been repeatedly detected in the last 40 years, so assemblage considered extant

- Flat Creek
  - tend to have low vulnerability risk, high risks near US 460 corridor
  - modeled suitability for Dwarf Wedgemussel, Atlantic Pigtoe, Green Floater
  - mussels have been repeatedly detected in the last 40 years, so assemblage considered extant

- Deep Creek and West Creek Network (including Cellar and Sweathouse Creek)
  - mostly unsurveyed, some detection in headwaters of Deep Creek
  - modeled suitability for Dwarf Wedgemussel and Yellow Lance in Deep Creek, Atlantic Pigtoe in West Creek

- Buffalo Creek
  - lower reaches may be at risk from development around Farmville but most of the network has low vulnerability
  - modeled suitability for Dwarf Wedgemussel, Yellow Lance, Atlantic Pigtoe, Green Floater
  - there has been no sampling in the last 40 years

- Bush River Network (including Sandy River, Briery Creek)
  - variation in network vulnerability
  - public lands along Biery Creek
  - two large impoundments may affect
  - some detections in the last 40 years
  - modeled suitability for Dwarf Wedgemussel, Yellow Lance, Atlantic Pigtoe, more limited suitability for Green Floater

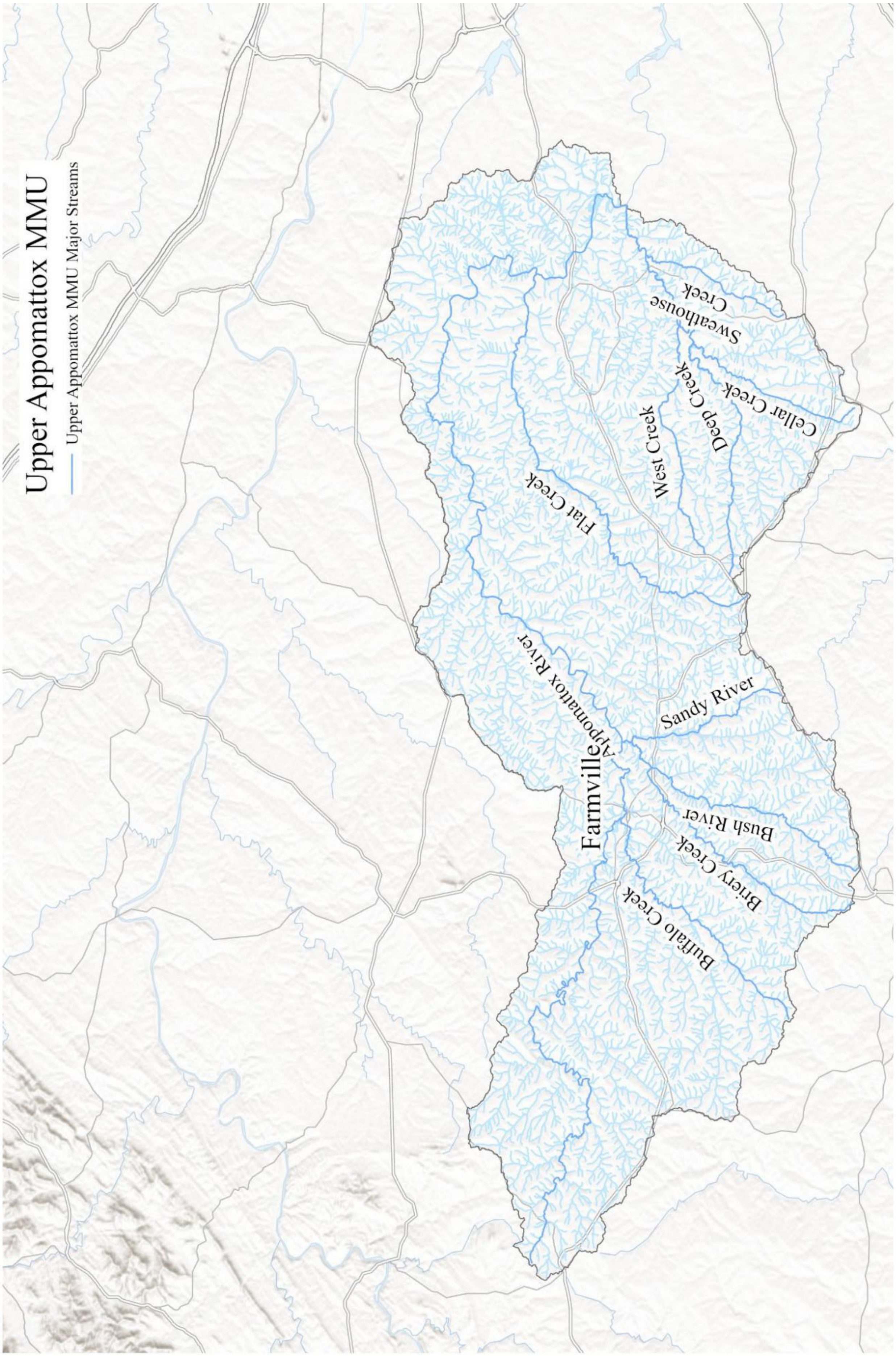


Figure 24. Referenced streams in the Upper Appomattox MMU identified for specific actions.

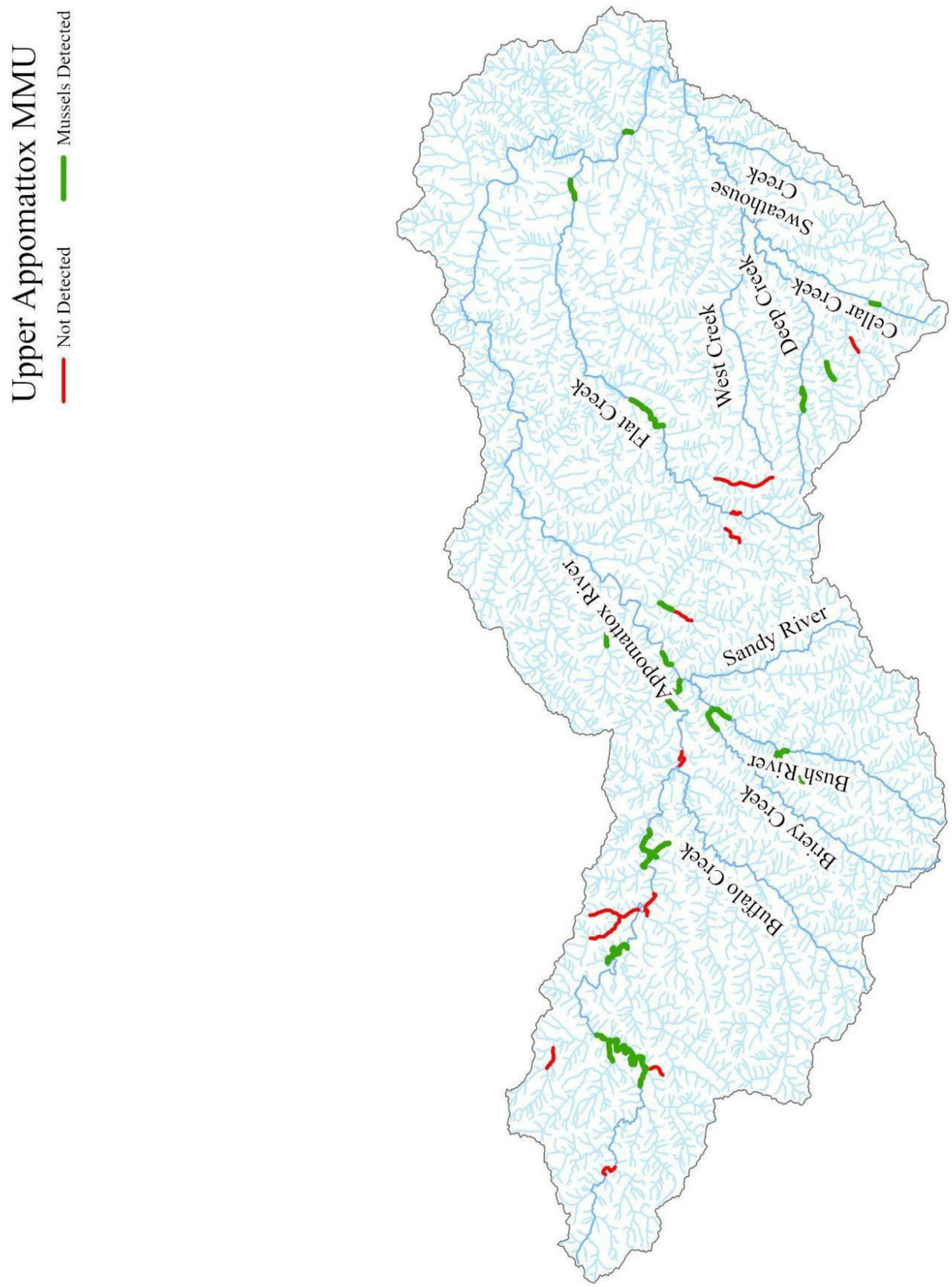


Figure 25. In the last 40 years, few stream reaches have been surveyed in the Upper Appomattox MMU. Referenced streams are labeled.

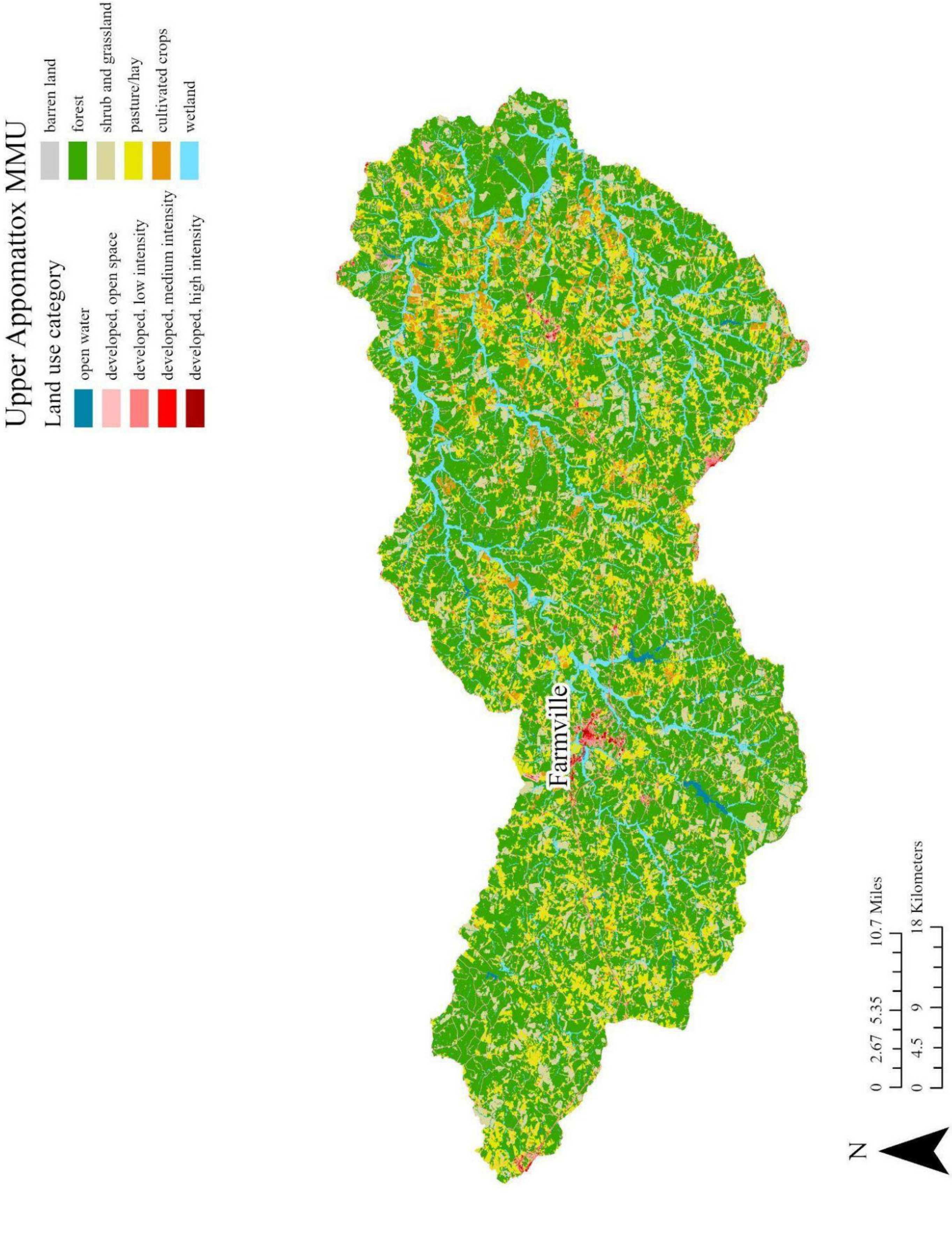


Figure 26. Land use in the Upper Appomattox MMU is predominantly natural, with 76.4% of the MMU considered natural (forest, wetland, grasslands, shrub) and 88.2% of the riparian buffer considered natural.

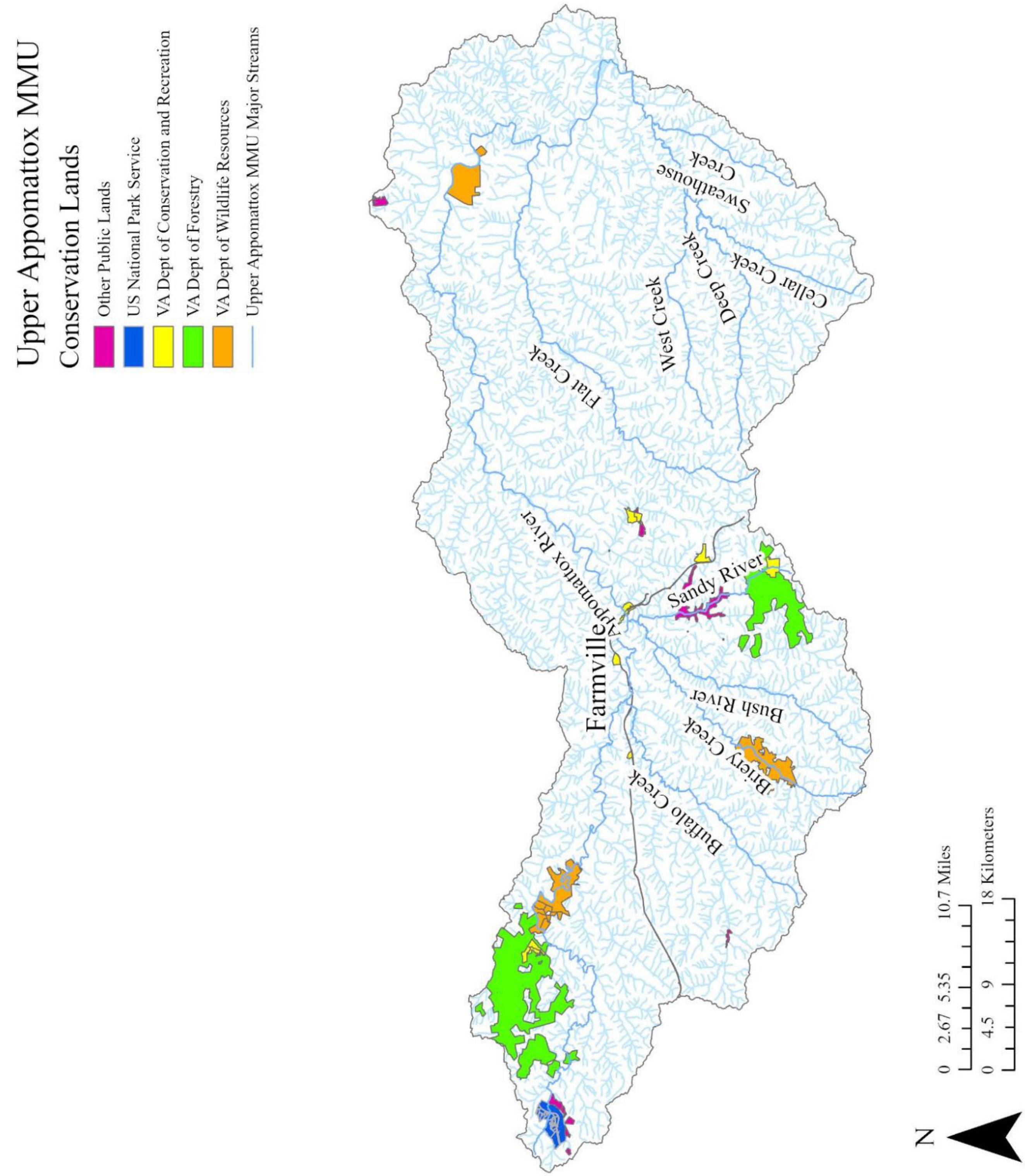


Figure 27. The extent of public lands are limited in the Upper Appomattox MMU.

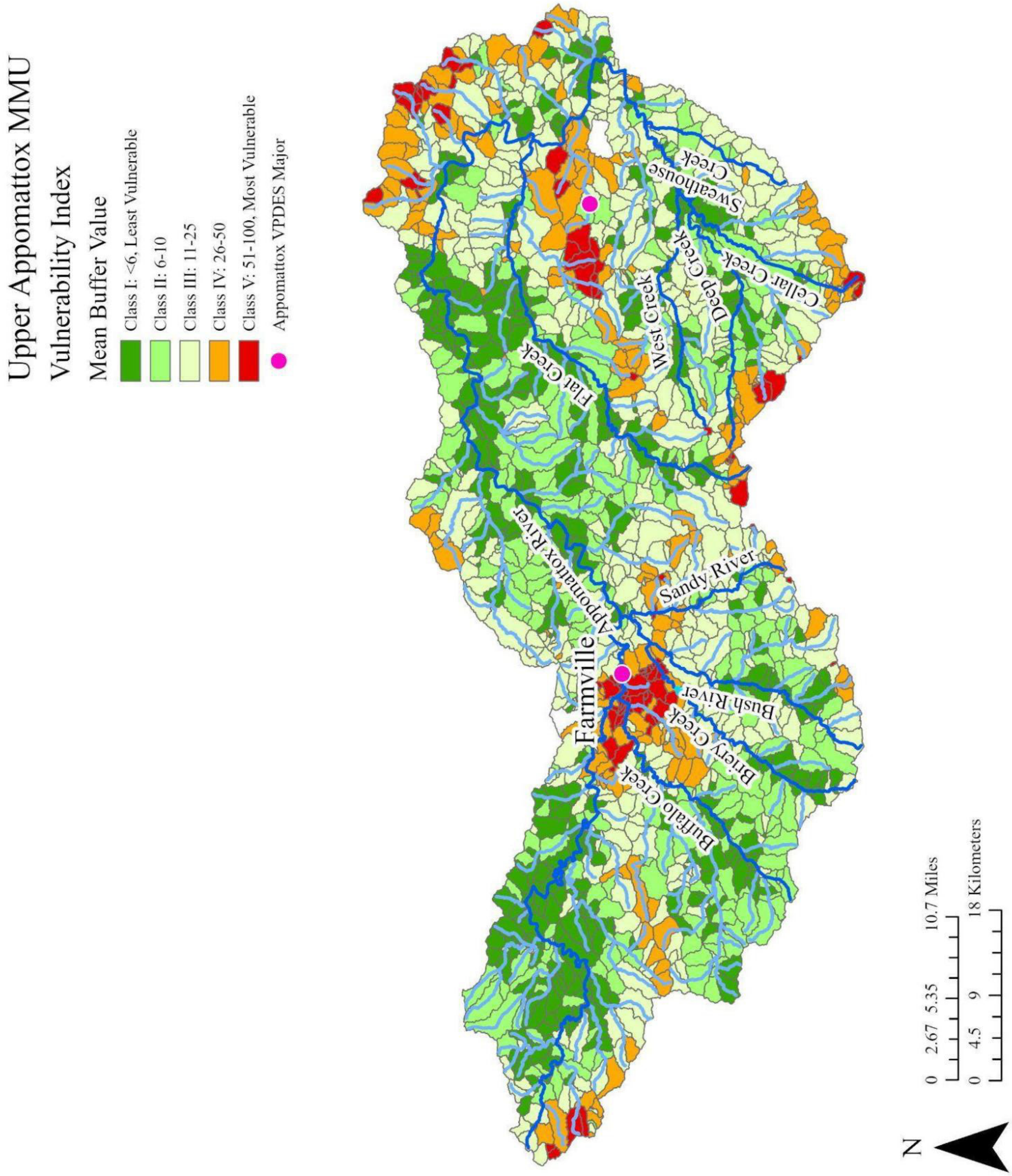


Figure 28. Mean Development vulnerability in riparian buffers of the Upper Appomattox MMU. The location of major permits from the VPDES dataset are also shown.

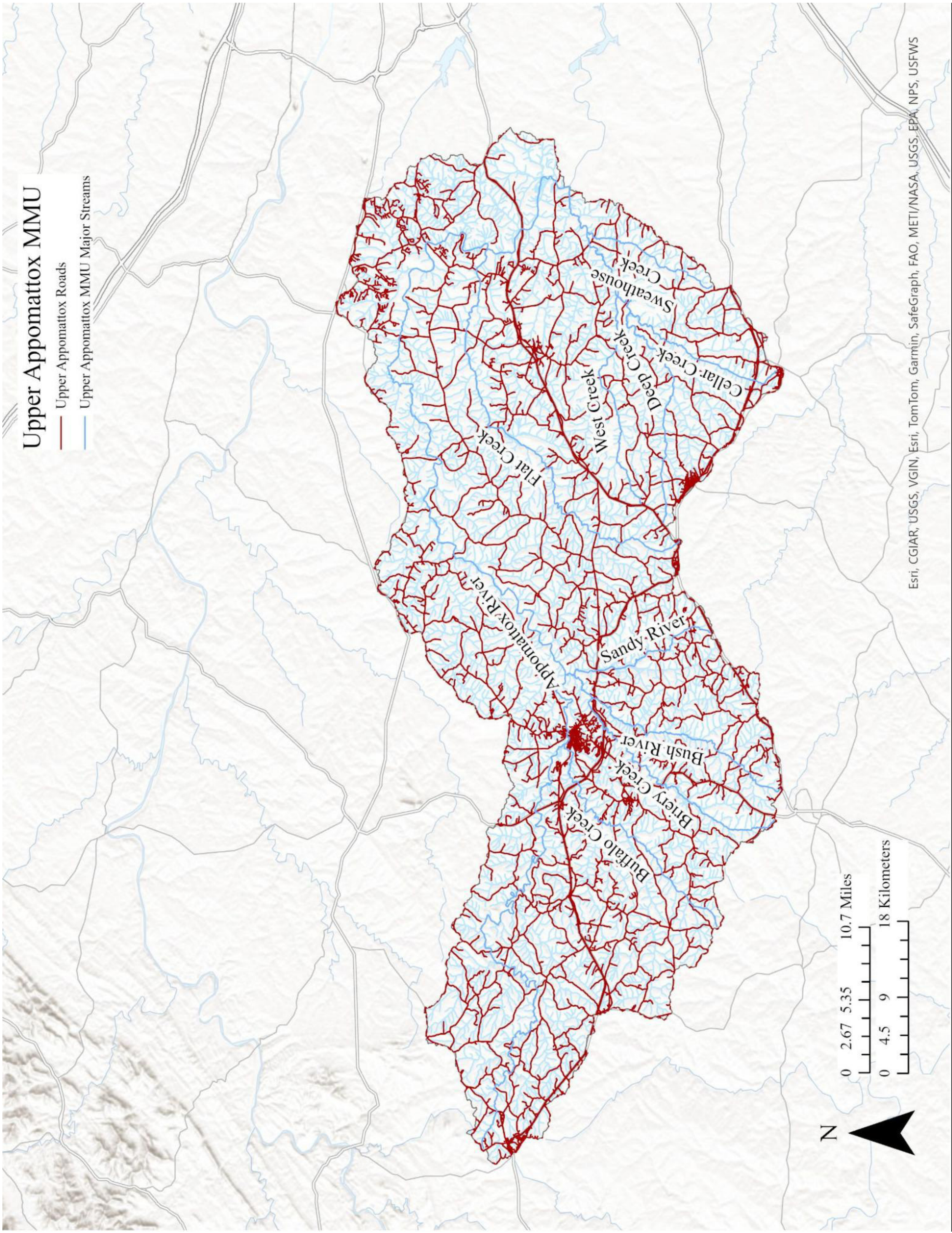


Figure 29. The road network for the Upper Appomattox MMU may facilitate greater access to potential habitat than assumed.

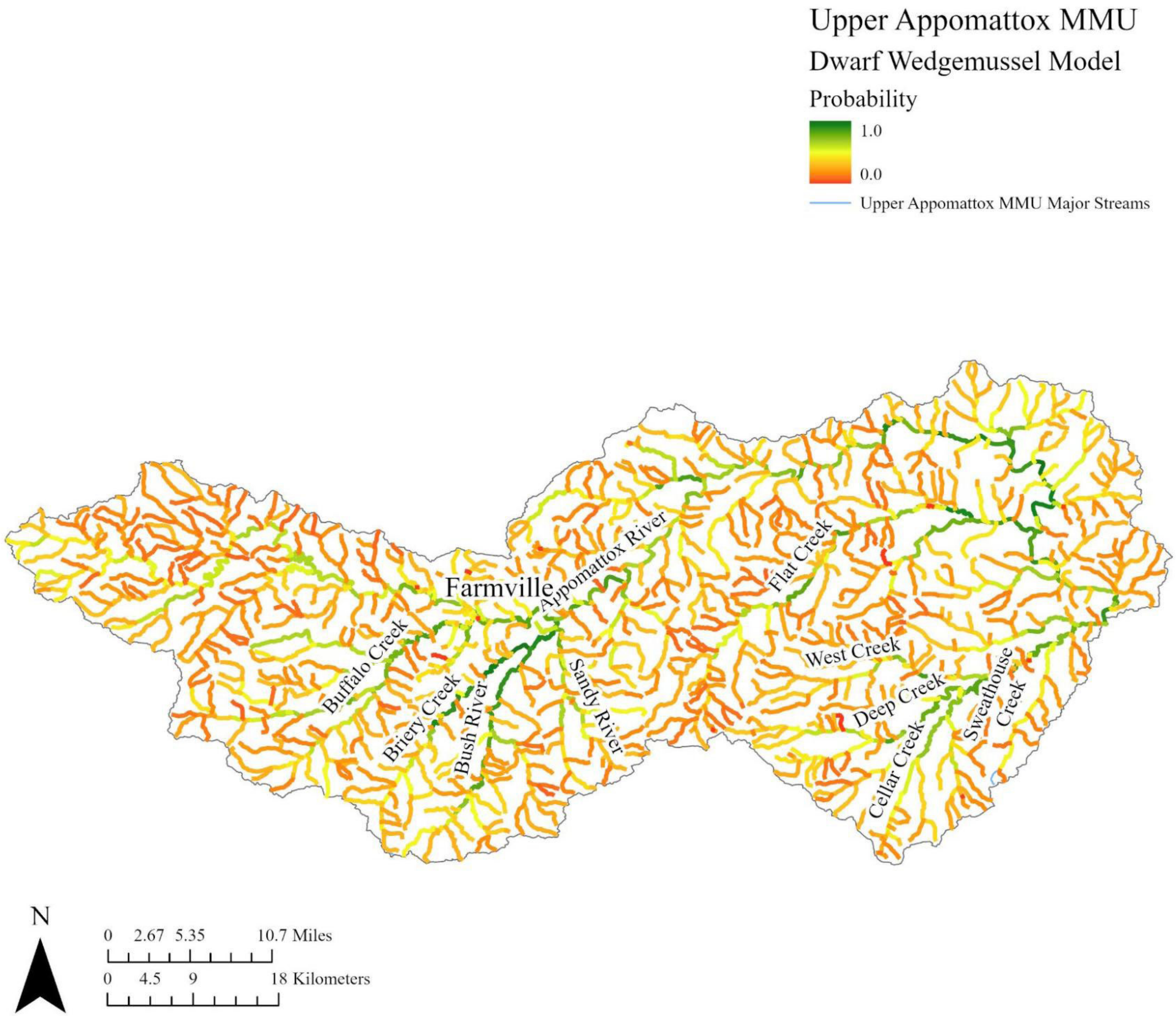


Figure 30. Many major reaches of the Upper Appomattox MMU have relatively high probability for Dwarf Wedgemussel habitat (Data source: Virginia Natural Heritage Program 2017). Notable streams include Briery Creek, Bush River, Appomattox River, Flat Creek, and Deep Creek.

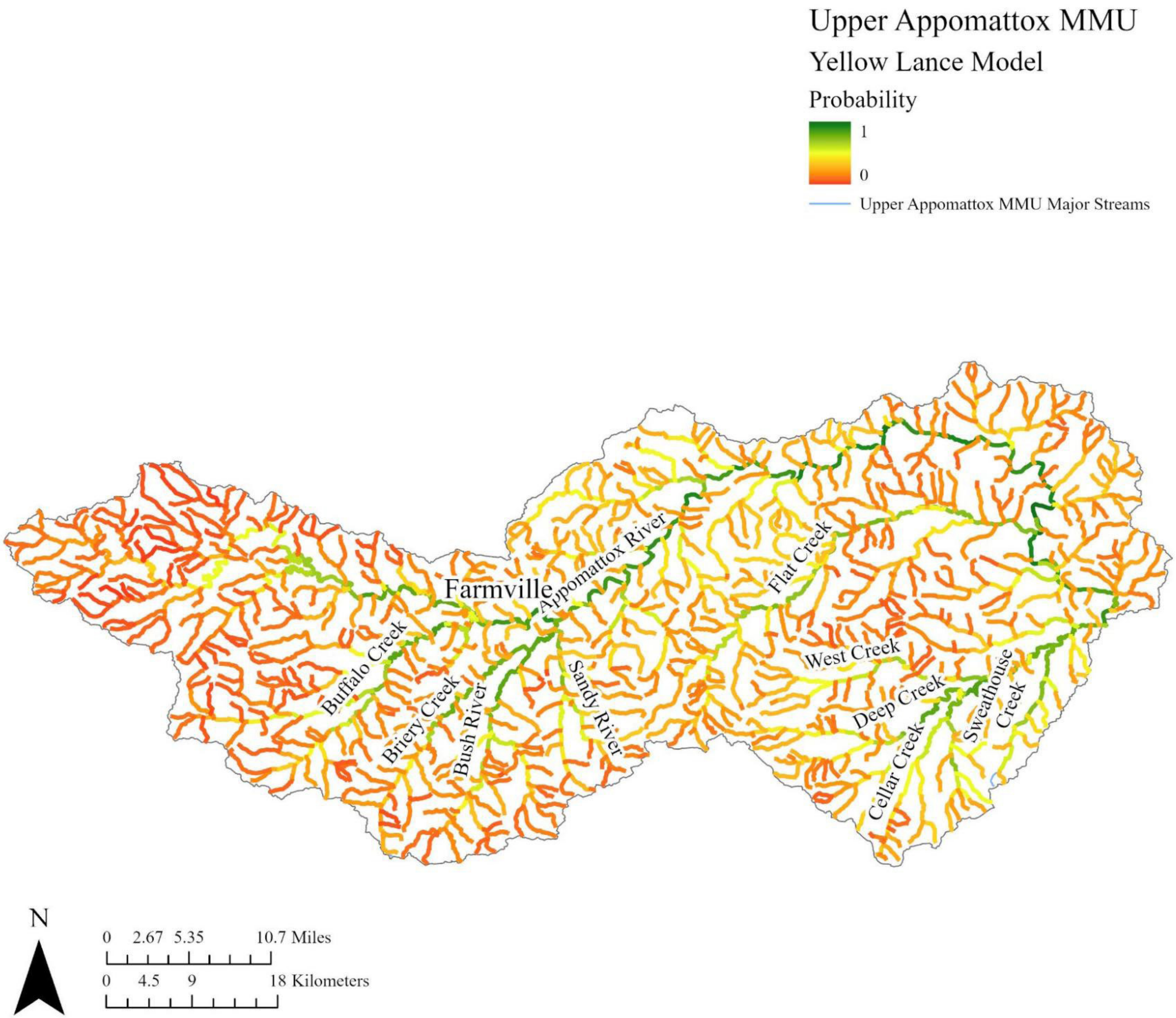


Figure 31. Many major reaches of the Upper Appomattox MMU have relatively high probability for Yellow Lance suitable habitat (Data source: Virginia Natural Heritage Program 2022b). The reach of Appomattox River in this MMU is of note.

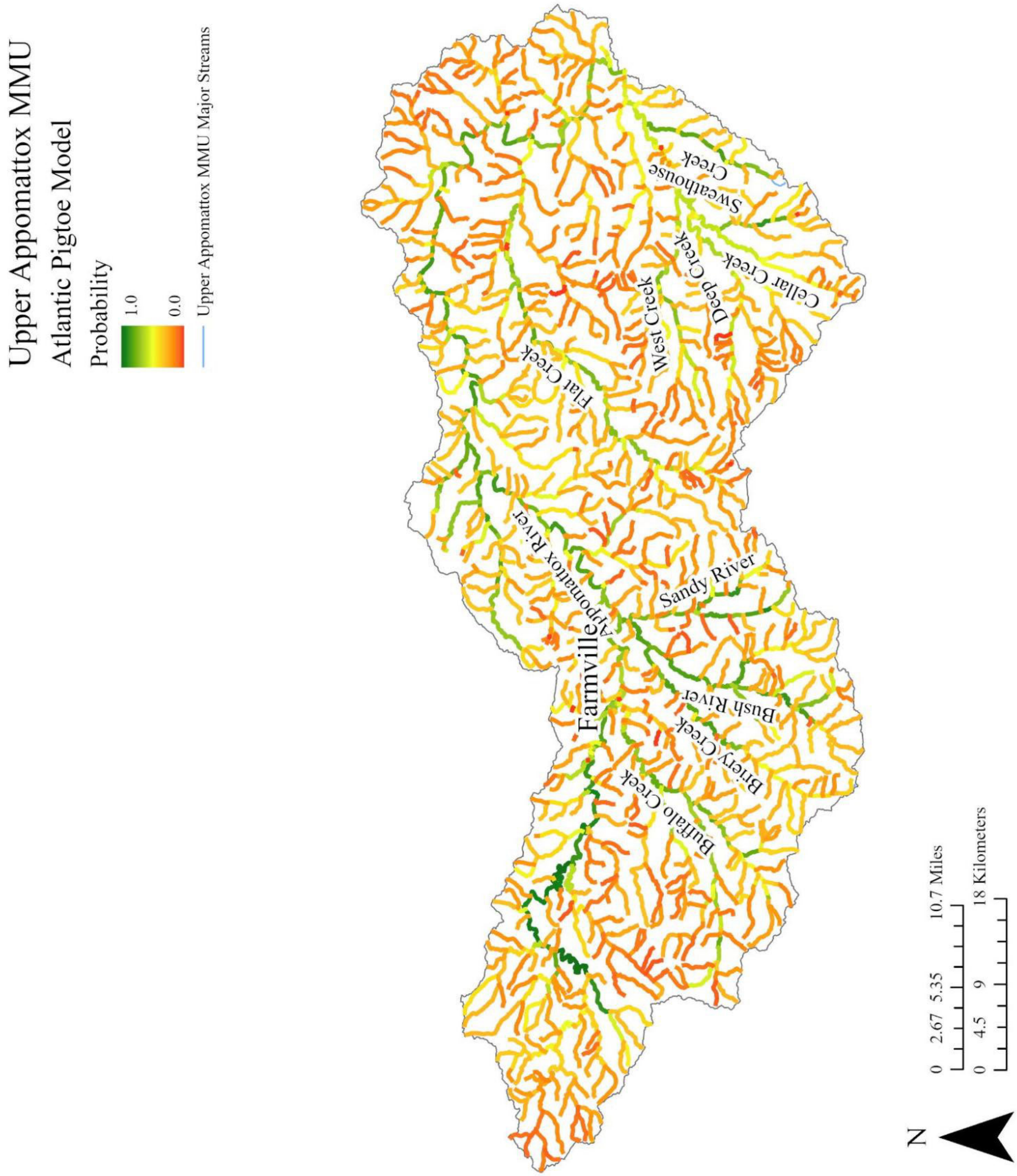


Figure 32. Many major reaches of the Upper Appomattox MMU, most notably the upper reaches of the Appomattox River, have relatively high probability for Atlantic Pigtoe suitable habitat (Data source: Virginia Natural Heritage Program 2022c).

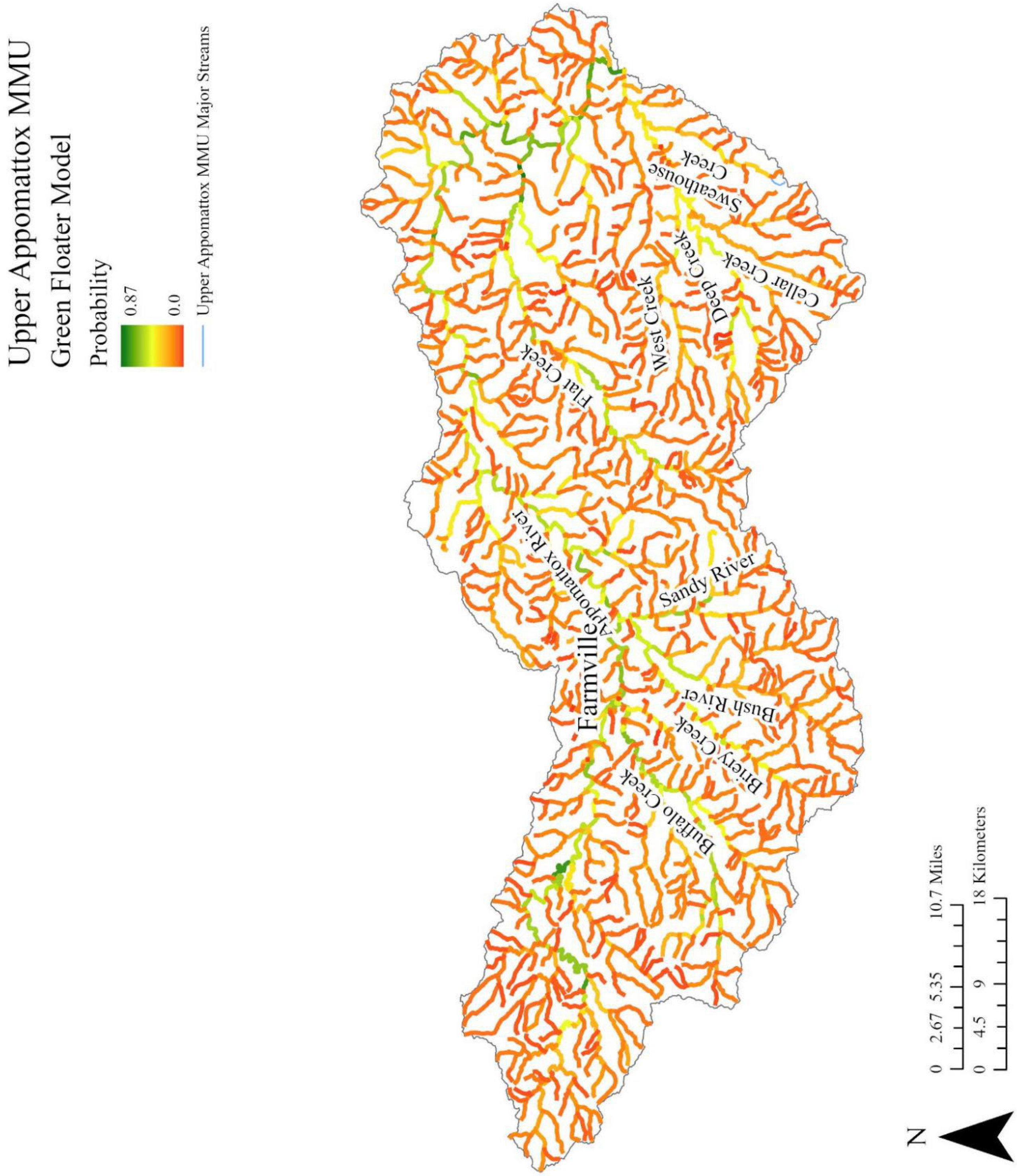


Figure 33. There are some more limited reaches of the Upper Appomattox MMU that have habitat for Green Floater according to DCR models (Data source: Virginia Natural Heritage Program 2022d). These habitats tend to be in the Appomattox River.

COWPASTURE

Like other nearby MMUs in the Valley and Ridge Physiographic Province (such as Jackson-Dunlap, Craig, and the Upper Maury), the Cowpasture stream network is trellised, comprised of small tributaries draining steep slopes entering named streams flowing through parallel valleys (Figure 34). There are two major streams in this MMU: the Cowpasture and the Bullpasture[13]. The tributaries to these streams are typically small—no greater than 3rd order—with little meandering. These tributaries are typically cool and high gradient, originating from forested slopes. As such, they are generally unsuitable for mussels. In contrast, Cowpasture and Bullpasture rivers meander through valley bottoms that are mostly hay field, pasture, and forest, with limited row crop agriculture (Figures 35, 36, and 37). These larger streams tend to have lower gradients with patches of gravel and sand substrate into which mussels can burrow. The stability of streambed habitats is unknown but presumed similar to other nearby MMUs like Craig and the Upper Maury, which can support mussel beds with high spatial fidelity over time. Mussel density appears much lower than what has been documented in places like Mill Creek (Upper Maury MMU) and in habitats of the Johns Creek watershed (Craig MMU). Most surveys detect fewer than 50 live mussels at a site. Present densities are presumed to be low (<0.25 m^2) with Notched Rainbow likely to be most abundant.

This MMU has received limited study in the past decade. Most mussels are understood to persist in larger streams. While it appears that 24.3% of stream reaches have been sampled, the analysis was limited by comparably sparse delineation of streams in the NHD dataset, so actual sampling is more limited. Species documented as extant in the MMU include Triangle Floater, Eastern Elliptio, Northern Lance, James Spinymussel, Eastern Floater, Creeper, and Notched Rainbow. There are possible historical records for Yellow Lance and Green Floater assigned to the MMU[14]. No more than four species are usually detected at a site with Notched Rainbow being the most likely detected and exhibiting the highest relative abundance. Models developed by DCR suggest varying degrees of habitat suitability for several species (Figures 38, 39, 40, 41, 42, and 43), with James Spinymussel, Atlantic Pigtoe, and Green Floater scoring highest. Nevertheless, some reaches are relatively high for Brook Floater and Yellow Lance, which generally score poorly in the James River Basin (see Figures 17 and 18).

There are no urban centers in the Cowpasture MMU, so risk from development is less of a threat compared to other parts of the basin (see Figure 35). Much of the MMU is public land (Figure 44). Fortunately, public land and mussel habitat appear to overlap in some portions of this MMU. These are opportunities to cooperate more closely with the U. S. Forest Service. Otherwise, access for restoration work will be challenging as many suitable habitats exist in reaches that flow through privately held land, where river crossings are few and far between (Figure 45)[15]. Fortunately, development vulnerability and known point-source pollution risks are low (Figure 46).

[13] Stuart Run often appears as a third major stream and is marked on figures for this MMU. Mussels have been detected in Stuart Run.
[14] The yellow lance is based on Clarke and Neves (1984) according to DCR, but the actual record does not appear in the reviewed text. Yellow lance is only verified in Johns Creek. Green Floater shell record from Alderman (1996), but there is questioned validity regarding this identification.
[15] The Cowpasture River Preservation Association (https://cowpastureriver.org/) appears active and maybe a point of contact.

GOALS FOR THE COWPASTURE MMU

1. Augment 2-3 habitats, including the Walton Tract, to create assemblages comprised of 5 species from the following:
    a. Triangle Floater
    b. Eastern Elliptio
    c. Northern Lance
    d. James Spinymussel
    e. Creeper
    f. Notched Rainbow
    g. Green Floater[16]

ACTIONS FOR THE COWPASTURE MMU

1. Surveys of Cowpasture, Bullpasture Rivers to
    a. document assemblage condition
        i. use survey figures and suitability models to prioritize
    b. identify habitats suitable for augmentation
        i. use suitability models and vulnerability figure to prioritize
    c. identify locations for broodstock
    d. collect information needed to set a density goal for best habitats
    e. if time, survey Stuarts Run
2. Initiate/maintain contact with local land owners
    a. develop a list of names and contacts
    b. share amongst partners
3. Continue and expand efforts to propagate and augment the following species into 2 additional habitat areas:
    a. James Spinymussel
    b. Triangle Floater
4. Continue releases of propagated mussels to Walton Tract in the Cowpasture River with approval and in coordination with the USFS to achieve a total mussel density of 5.0 mussels/m^2 and an assemblage of 5 species.

Other notes: Broodstock may need to originate from other populations in the John's Creek drainage (Craig MMU), or Mill Creek, which is just to the east of this MMU in the Upper Maury MMU.

[16] Green Floater is currently proposed federally listed, and if finalized, would be contingent upon USFWS and DWR approved propagation plan and discussion, see section on Endangered Species Regulatory Hurdles.

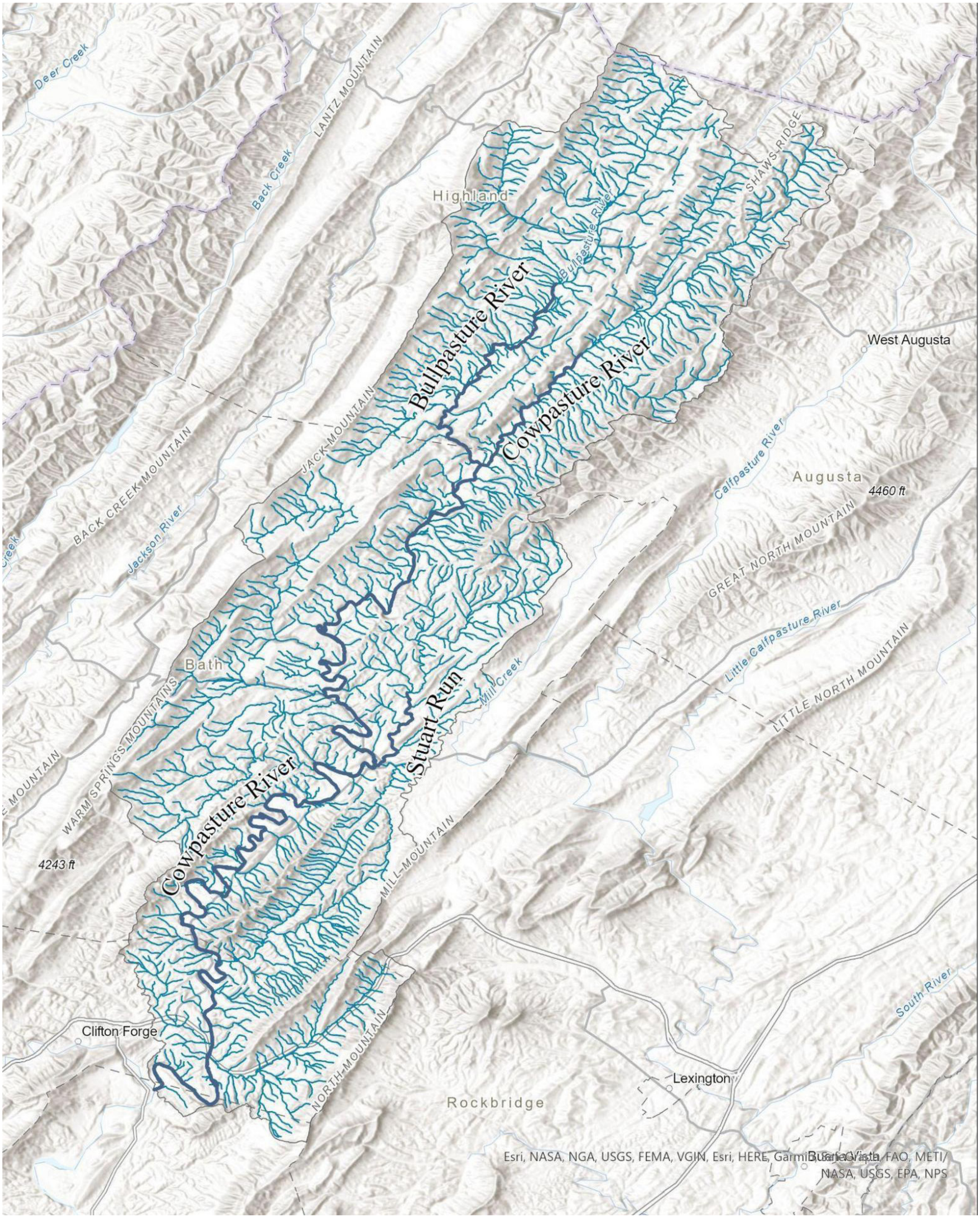


Figure 34. Stream network of Cowpasture MMU with major tributaries labeled.

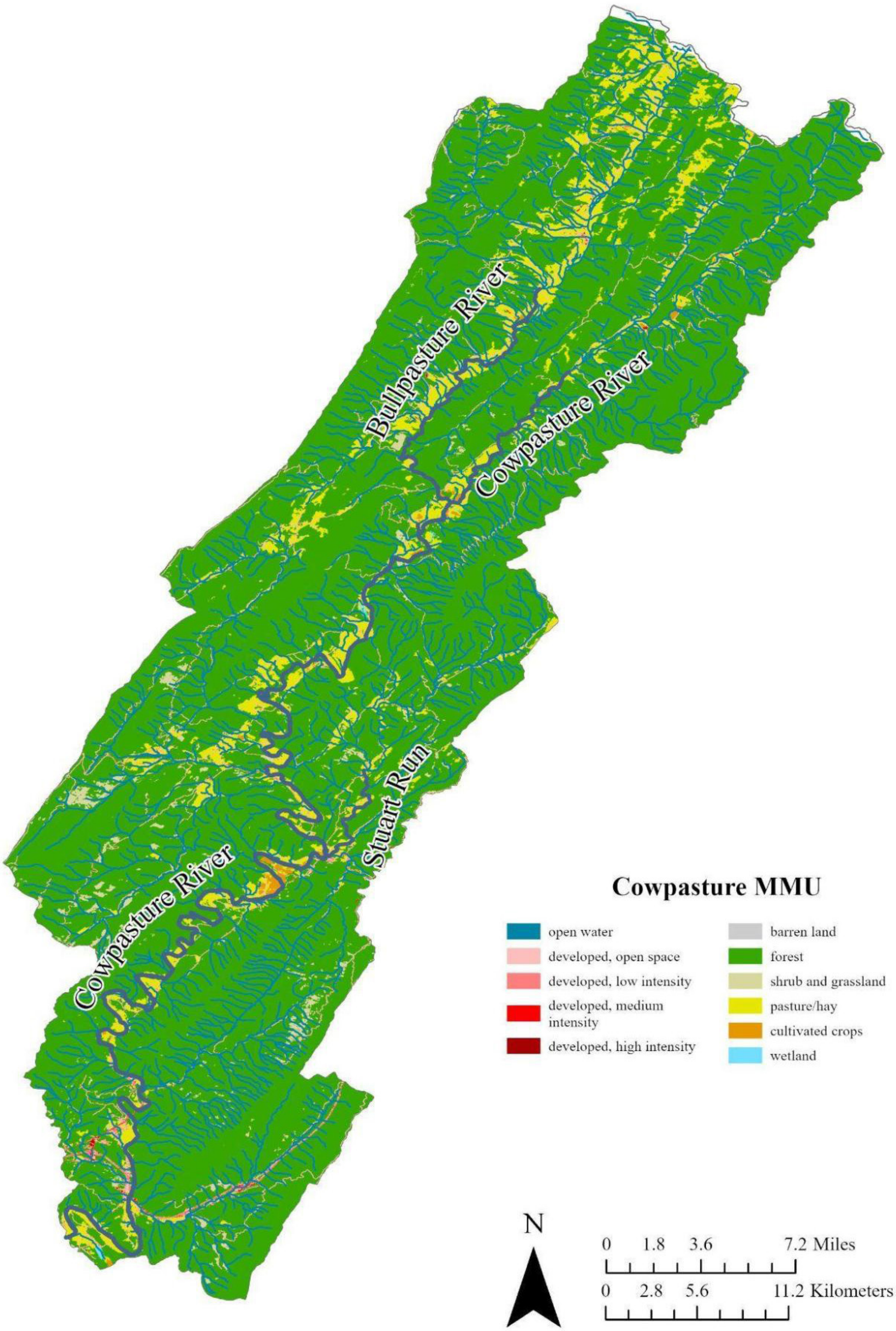


Figure 35. Land use in Cowpasture MMU.

Figure 36. Typical stream reach in the lower Cowpasture River (4/10/2009). Notched Rainbow were detected during the survey.

Figure 37. Typical land use in the Cowpasture MMU, with forested mountain and pasture/hayfield valleys. Photograph taken from bank of survey reach shown in Figure 35.

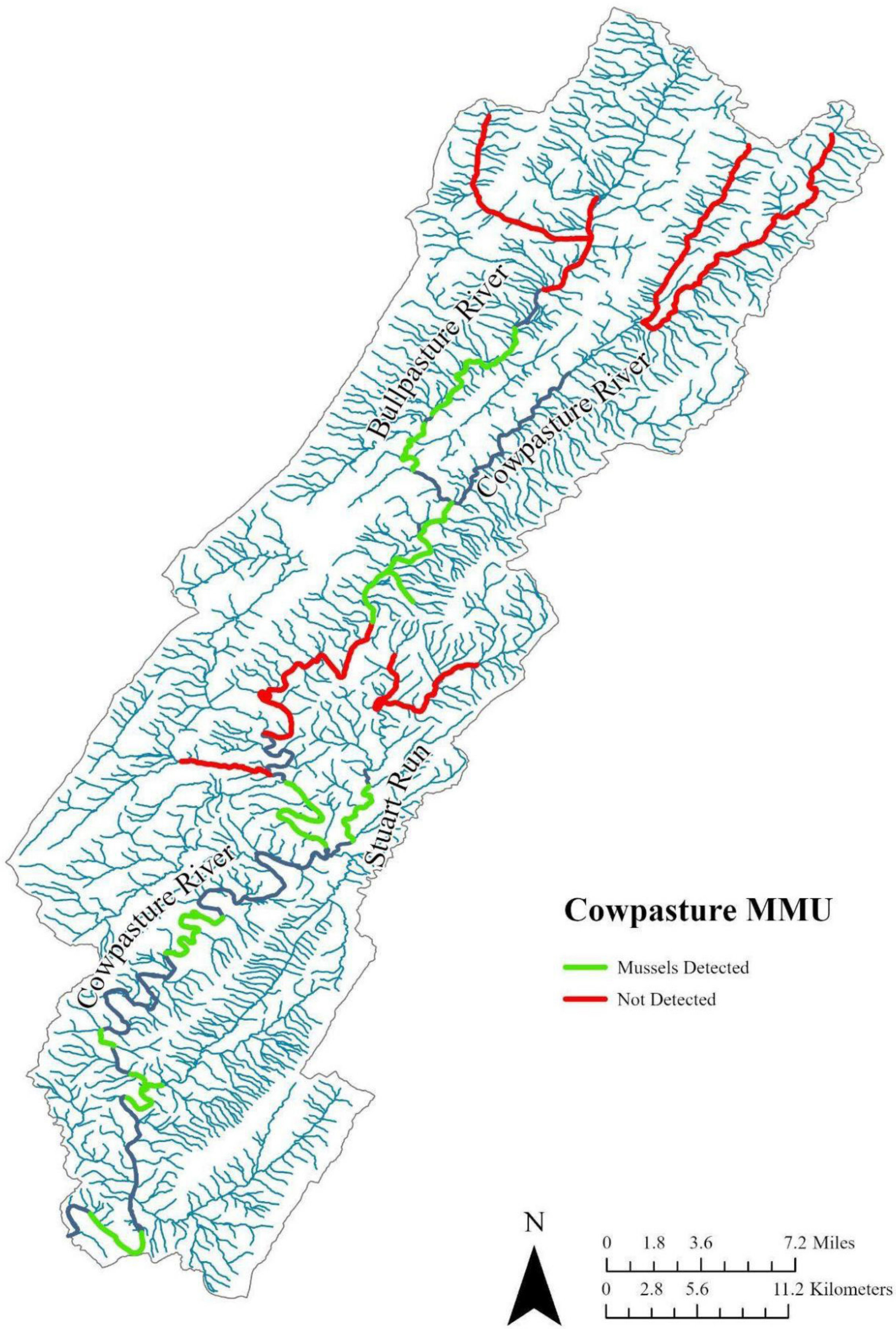


Figure 38. Reaches sampled in the last 30 years in the Cowpasture MMU.

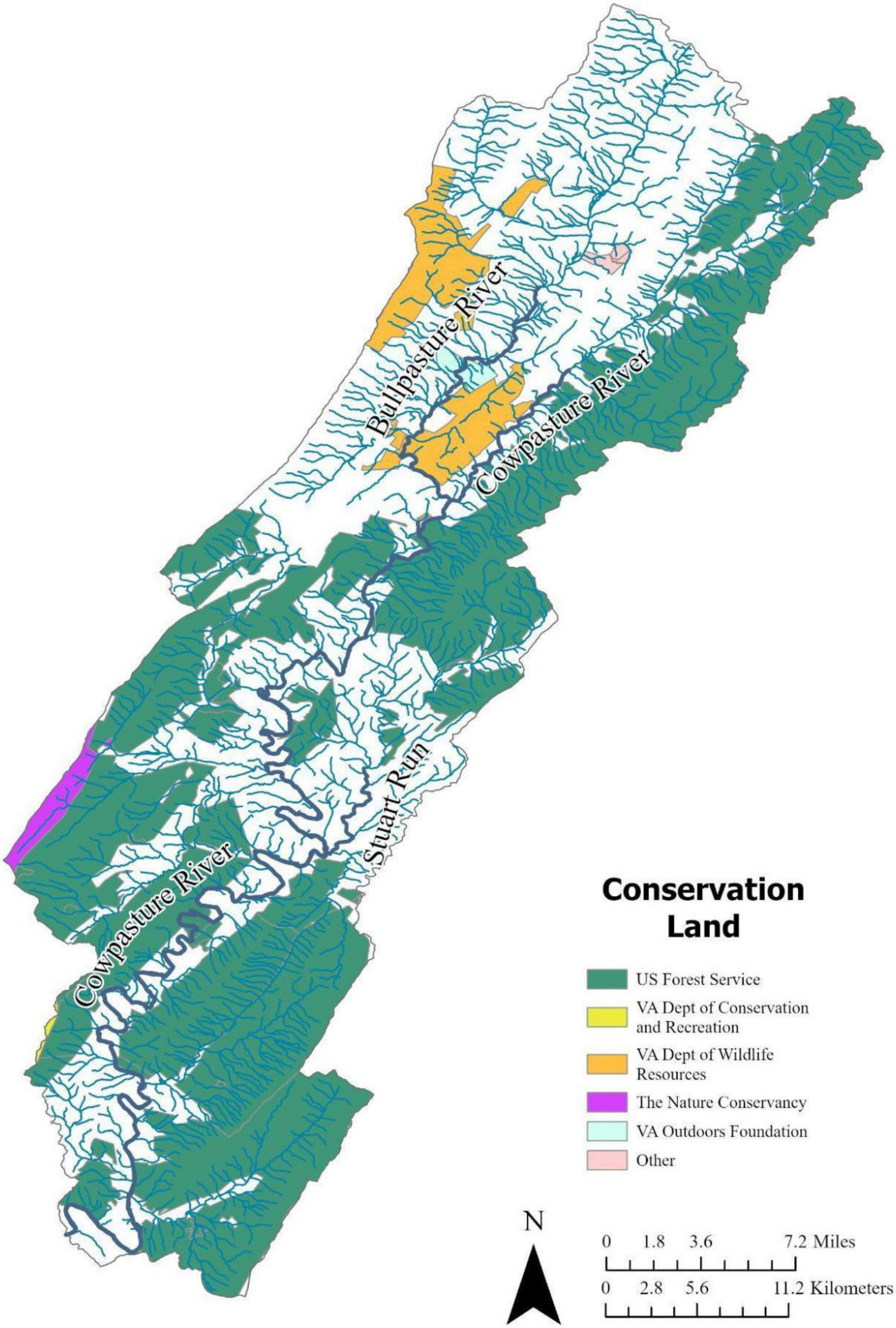


Figure 39. Conservation land in Cowpasture MMU.

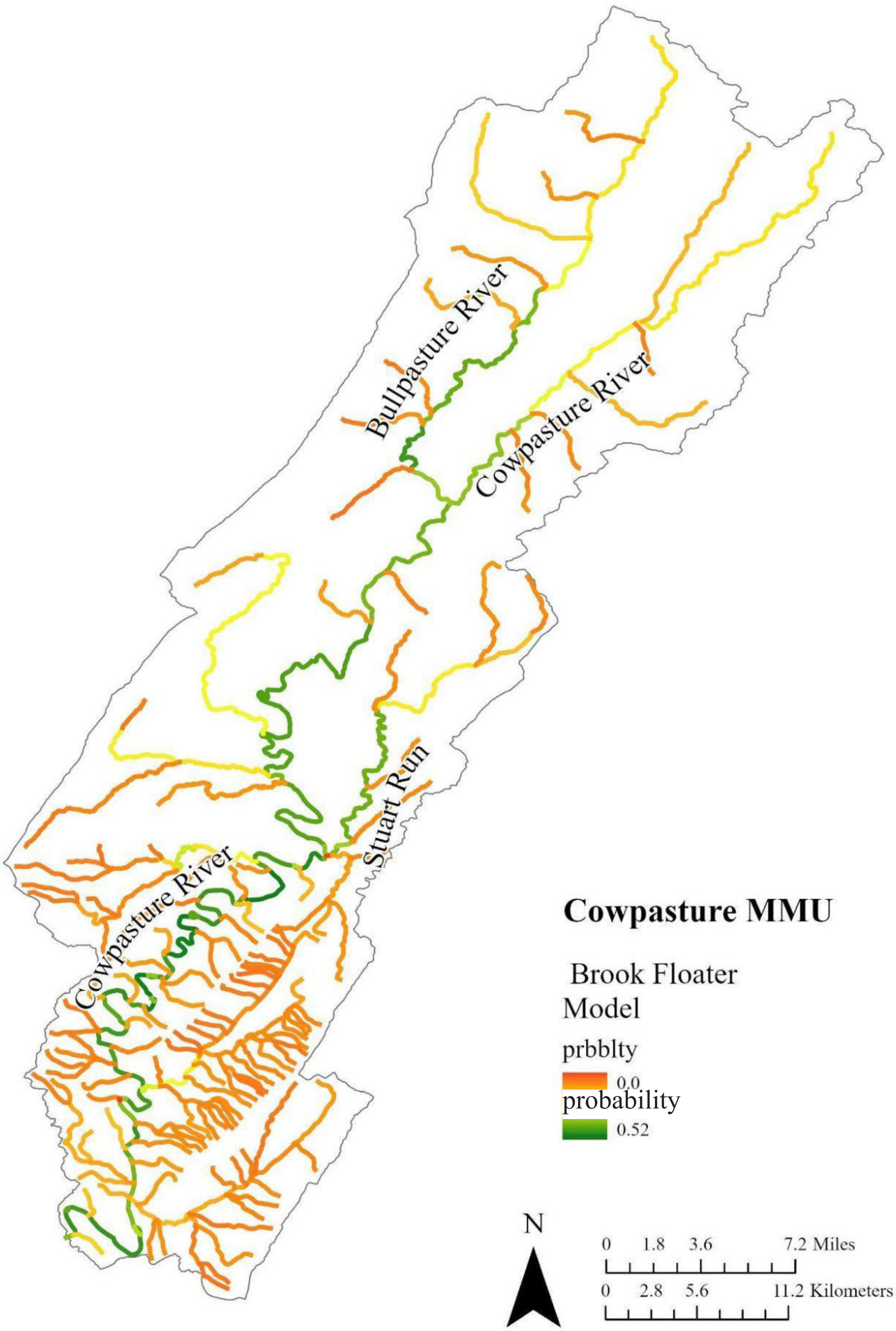


Figure 40. Habitat model for Brook Floater demonstrates some moderate suitability in the Cowpasture and Bullpasture Rivers (Data source: Virginia Natural Heritage Program 2022a). These probabilities are lower than comparable models. This may be due to the absence of this species.

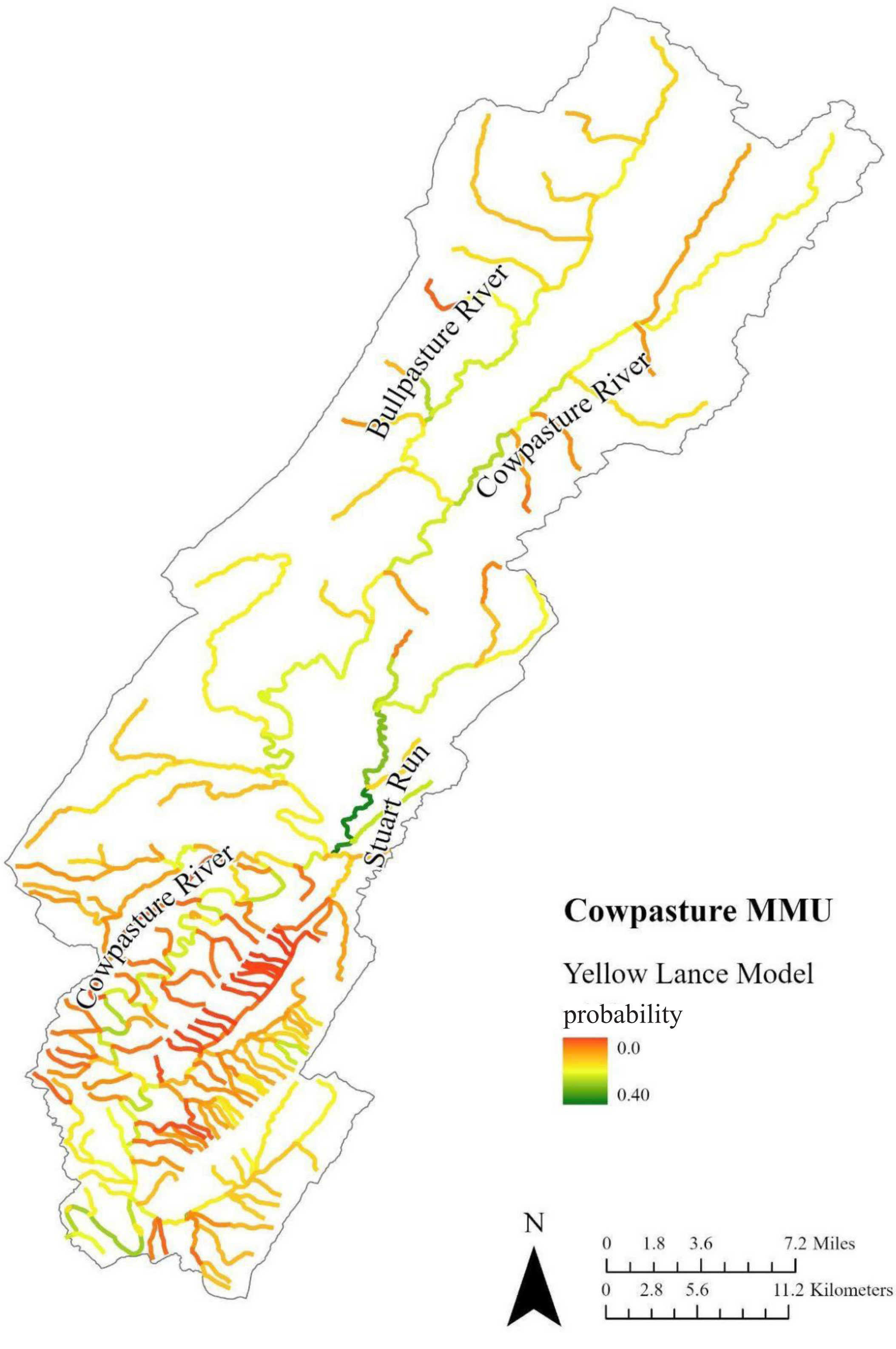


Figure 41. Habitat model for Yellow Lance demonstrates some moderate suitability in the Cowpasture and Bullpasture Rivers (Data source: Virginia Natural Heritage Program 2022b). These probabilities are lower than comparable models.

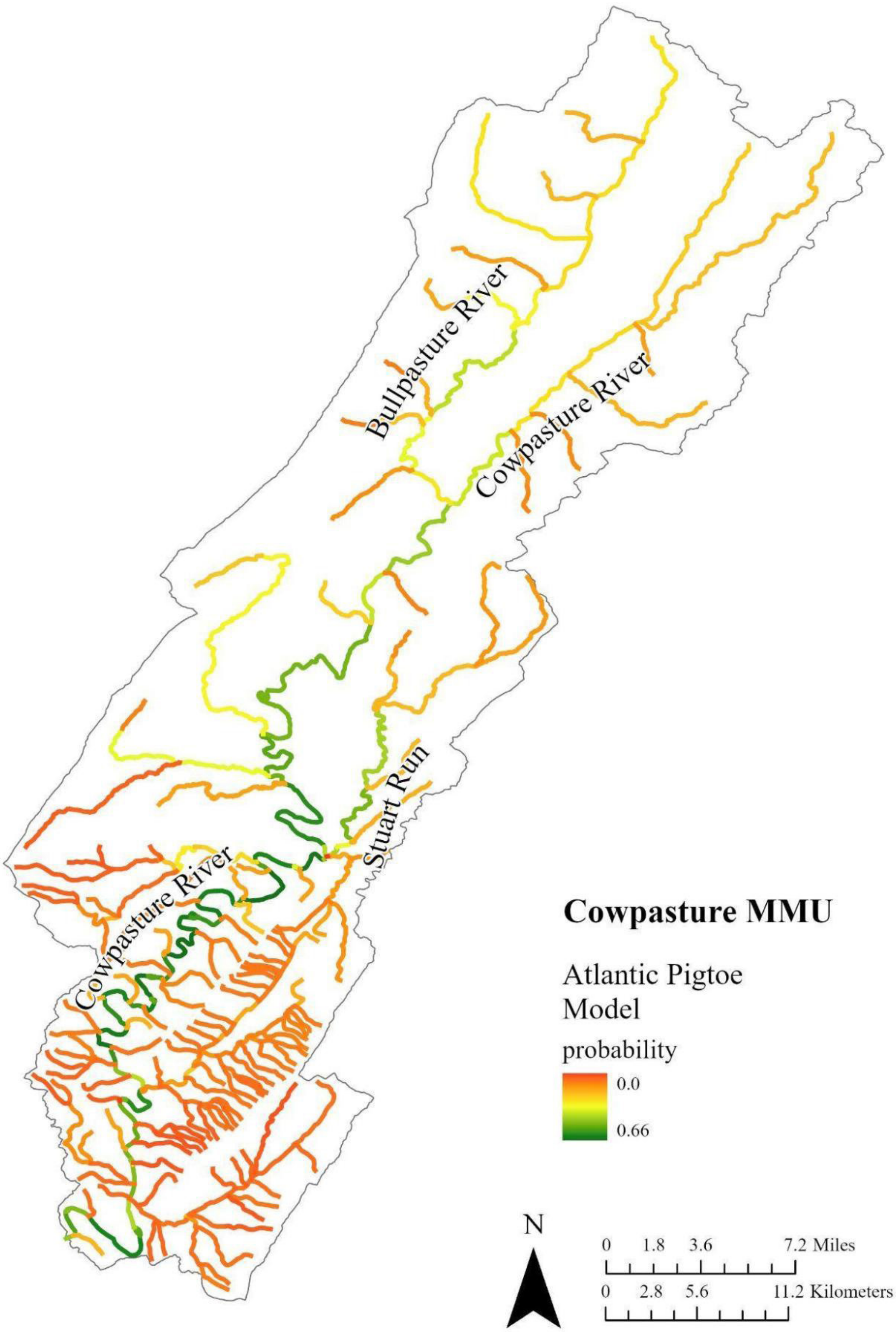


Figure 42. Habitat model for Atlantic Pigtoe demonstrates some moderate suitability in the lower reaches of the Cowpasture River (Data source: Virginia Natural Heritage Program 2022c).

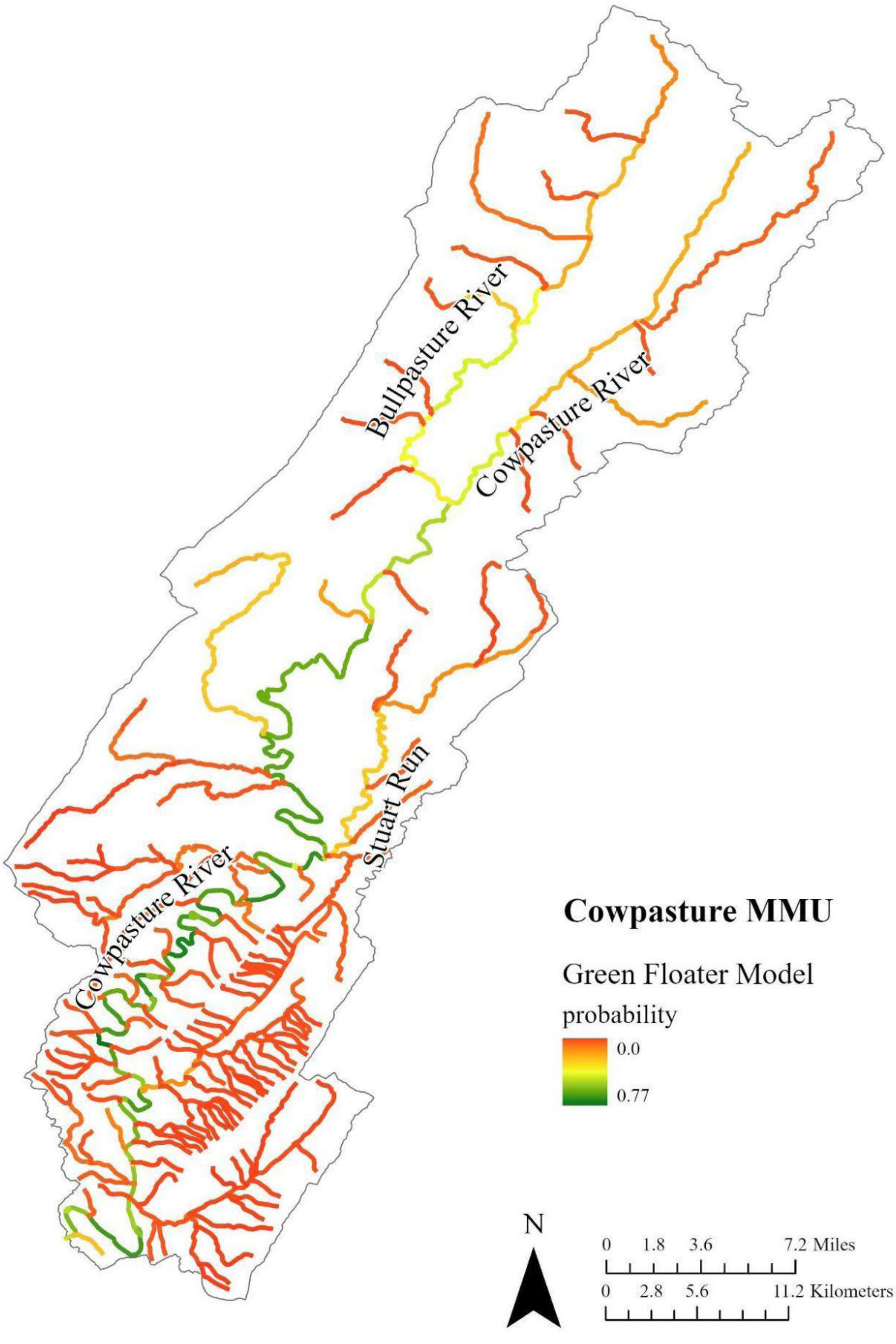


Figure 43. Habitat model for Green Floater suitability in the Cowpasture River downstream of the confluence of the Bullpasture and Cowpasture rivers (Data source: Virginia Natural Heritage Program 2022d).

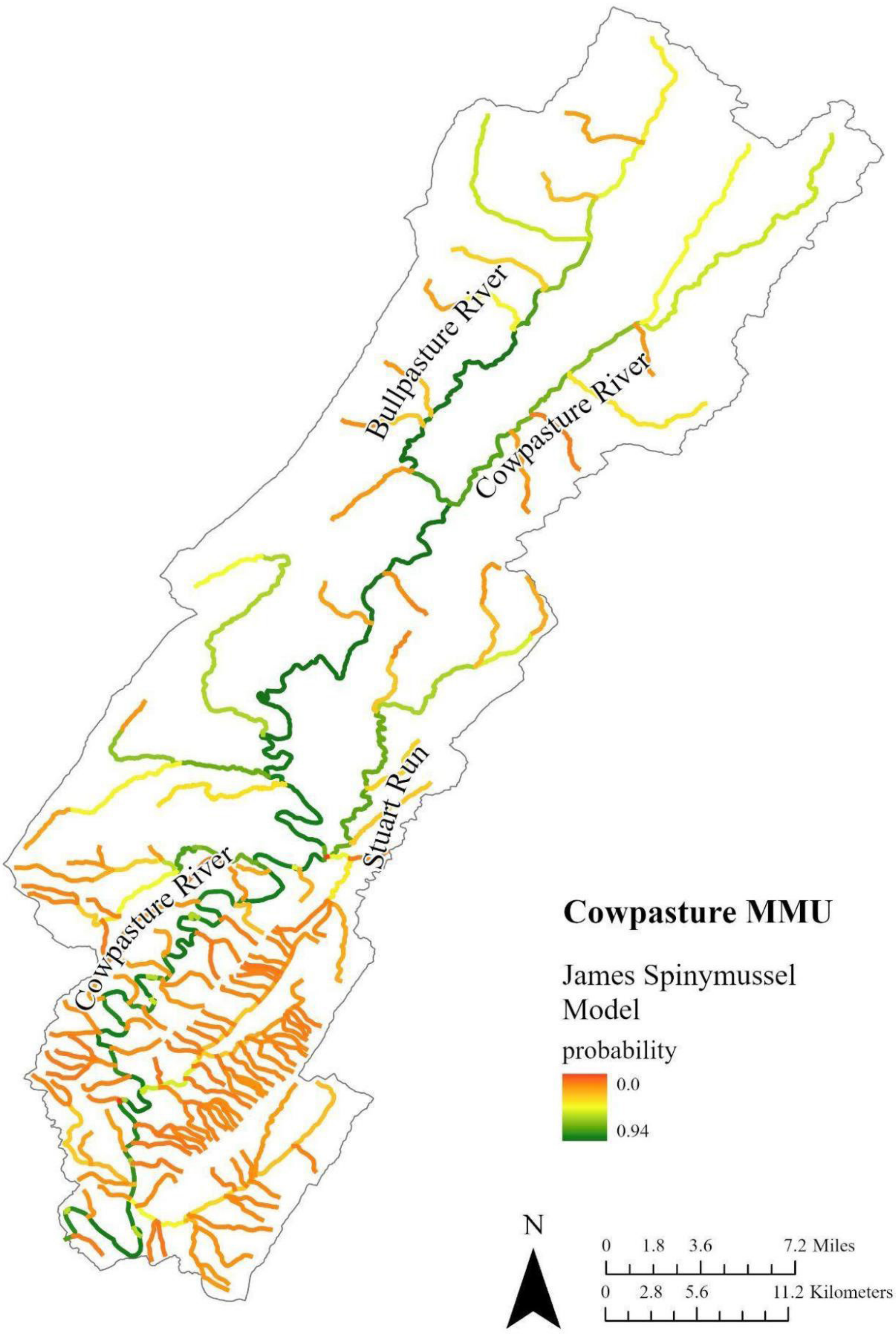


Figure 44. Models suggest relatively high suitability for James Spinymussel in the Cowpasture and Bullpasture rivers (Data source: Virginia Natural Heritage Program 2022e).

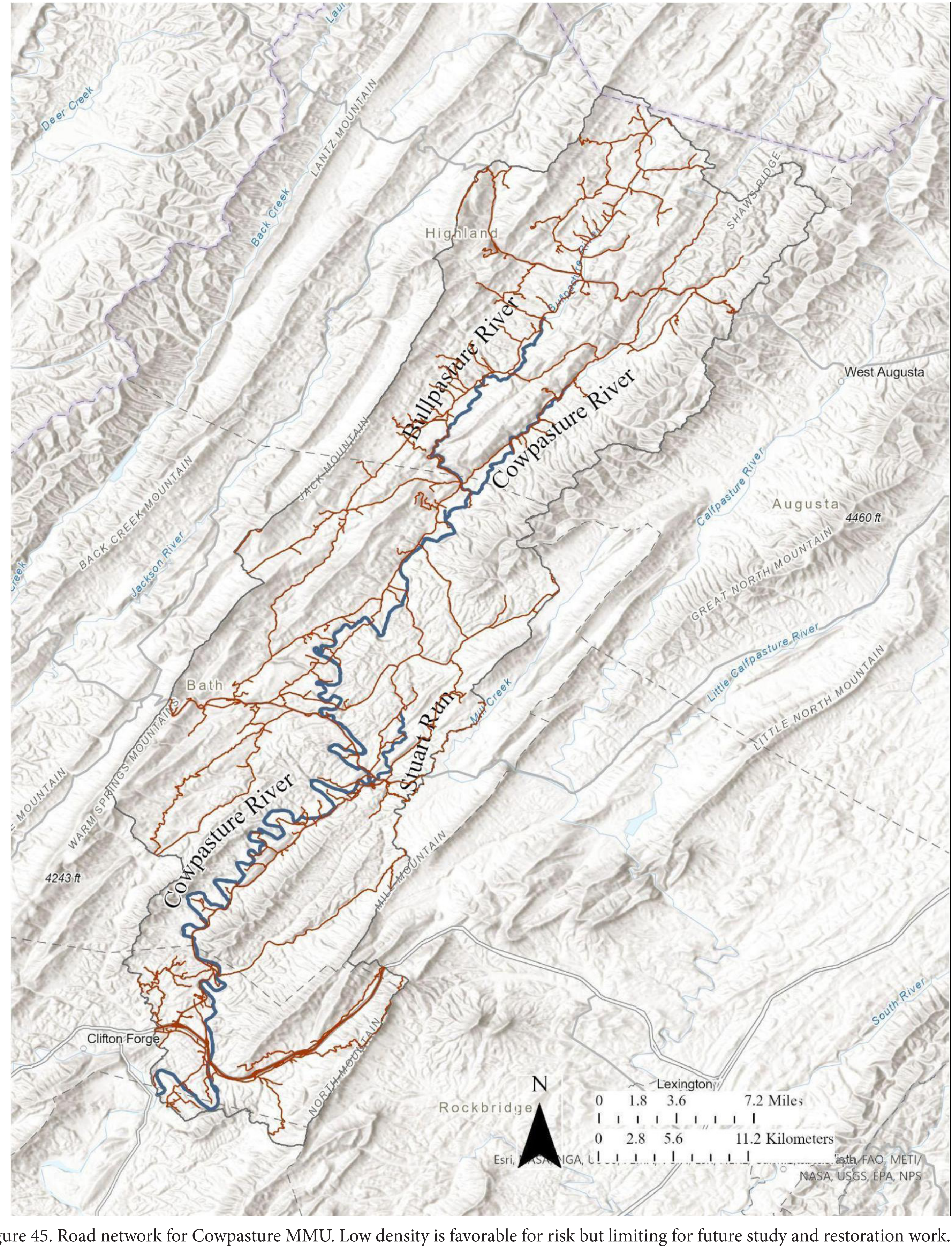


Figure 45. Road network for Cowpasture MMU. Low density is favorable for risk but limiting for future study and restoration work. This emphasizes the need to develop landowner relationships.

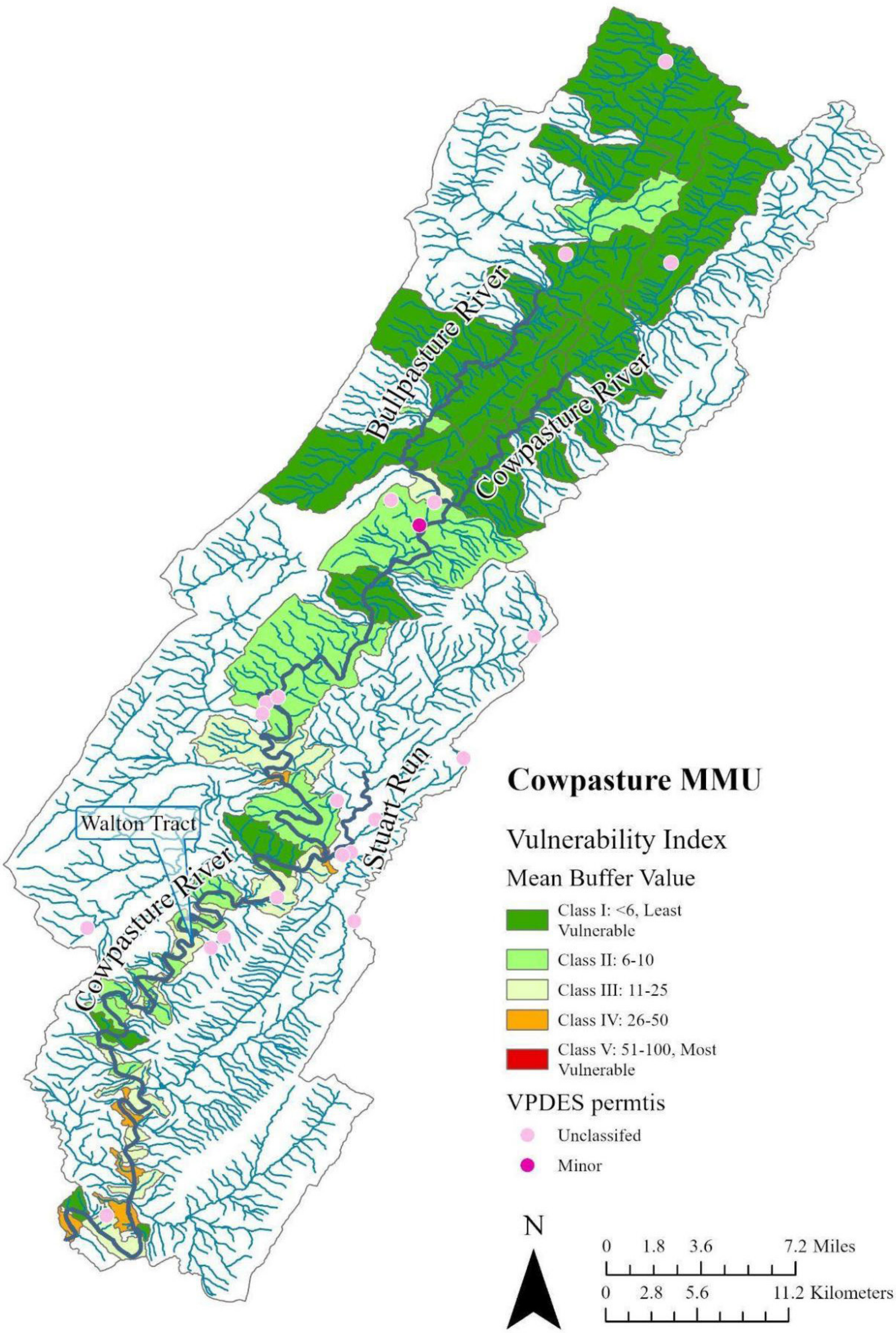


Figure 46. Mean Development vulnerability in riparian buffers of main branches of the Cowpasture MMU. There are no VDPES permit records listed as major in the MMU, only minor or unclassified. Unclassified tend to be for residences.

UPPER RIVANNA

The Upper Rivanna MMU ends at the confluence of the North and South Forks of the Rivanna River in Charlottesville. Upstream of that point, the MMU is a complex dendritic network comprising several small rivers and branching tributaries (Figure 47). Headwaters drain the Blue Ridge physiographic province with lower elevations in the Piedmont. This transition greatly affects instream habitats. The western fringe of the MMU is protected land (Shenandoah National Park); however, most of the MMU drains privately owned lands (Figure 48). Some private land management in the MMU introduces immediate risks to habitats inhabited by mussels (Figure 49). The major streams of the MMU are the Moormans, Mechums, North Fork Rivanna, and South Fork Rivanna. The James Spinymussel has been documented in all these major streams in the past 40 years. The Upper Rivanna MMU is a stronghold for this species with populations persisting and evidence of recruitment in Buck Mountain Run, Swift Run, and Rocky Creek. Roderique (2018) identified several stream reaches in this MMU as Priority Conservation Areas in an independent modeling exercise. Models developed by DCR likewise rank streams in this MMU as highly suitable habitat for James Spinymussel and simultaneously hint at challenges for conservation and development risk (Figure 50). The two other species common and widespread in this MMU are Notched Rainbow and Creeper. Other species, including Triangle Floater, Eastern Elliptio, Green Floater, and Eastern Floater, are rarely encountered but present. There is a record for Atlantic Pigtoe, but this species has not been documented in recent decades.

While this MMU has been the most studied of all MMUs in the James River Basin (Figure 51), there is a high degree of heterogeneity in spatiotemporal knowledge. Swift Run and Rocky Creek have been extensively studied. And due to suburban expansion, Ivy Creek has been frequently surveyed. Other streams, including the Mechums, Moormans, Lynch, and Roach rivers have been under sampled in the last 20 years. Higher gradient streams flowing off forested slopes of the Blue Ridge Mountains are dominated by bedrock, boulders, and cobble (Figure 52). These higher elevation streams appear to contain unsuitable habitats, with many surveys failing to detect mussels in these small higher gradient streams (see Figure 51) even when mussels occupy lower gradient habitats 1-2 kilometers downstream. Mussels tend to occur in lower gradient streams, flowing through the Piedmont, where sand and gravel can dominate the streambed (Figure 53). The stream reaches that support mussels flow through a mosaic of pasture and hay fields, forests, low-density residential areas, and lands used for other agricultural pursuits such as vineyards and equestrian facilities. Land use in the MMU is 68.4% forest, 20.2 % pasture, and 9.8% impervious cover (Figure 54). Lower reaches of the streams face growing development pressure (Figure 55). The degree of impervious surfaces are approaching critical levels needed to support complete communities of aquatic biota in small streams (Center for Watershed Protection, 2006; Stanfield and Kilgour, 2006; Utz et al, 2009; Hilderbrand et al, 2010).

Research conducted over the last decade has demonstrated that long-term stable habitats for mussels are rare in this MMU (Ostby 2022b). Only one stream, Rocky Creek, appears to support stable mussel beds, with the same mussels present and detectable year after year. Density could be documented in that stream. Quantitative quadrat surveys demonstrated that mussels were present at approximately 1 m^{-2} with James Spinymussel at 0.5 m^{-2} (Ostby and Angermeier 2012, Ostby 2015). Attempts to quantify density in Swift Run and Buck Mountain Creek demonstrated that even the best habitats support low density mussel populations (<0.5 m^{-2}). Additional work by JMU and Daguna Consulting (Ostby 2022b) has demonstrated that mussels are moving from upstream to downstream, likely being transported along with streambed sediment. Mussels are inconsistently detected in the reaches of Swift Run. Nonetheless, recruitment is ongoing. A recent survey of Buck Mountain Creek (Ostby 2022c) only detected a single small, young James Spinymussel in seven person-hours of search, further illustrating the nature of populations in that stream being low density with ongoing recruitment. Only one continually occupied site in Rocky Creek has been documented, meanwhile intensive searches for a source population in the Swift Run watershed failed to detect any of this species but did detect others (Ostby 2019). Thus, the spatiotemporal distribution appears highly variable. As such, populations of the entire MMU should be considered a single metapopulation with a strong pattern of downstream migration.

GOALS FOR THE RIVANNA MMU

1. Identify additional populations of James Spinymussel through surveys of 20 new sites
    a. undersampled streams suggested above
    b. in areas modeled as suitable habitat for listed species (Figures 56, 57, 58, 59)
2. Maintain occupancy of James Spinymussel, Creeper and Notched Rainbow in defined sites in the following streams[17]:
    a. Swift Run (100% from Amicus Road to mouth)
    b. Buck Mountain Creek (60% from Davis Shop Road to mouth)
    c. Wards Creek/Rocky Creek (100% from impoundment to mouth)
    d. at least one additional stream (TBD)

ACTIONS FOR THE RIVANNA MMU

1. Continue monitoring Rocky Creek as it is essential source of broodstock
    a. may need genetic assessment
2. Survey Moormans and Mechums rivers, and other under sampled streams
3. Augment populations of James Spinymussel by releasing mussels at the upstream extent of mussel occurrences in Swift Run (Amicus Road), Buck Mountain Creek (Davis Shop Road), and at least one additional stream (TBD)

ALTERNATE GOALS FOR THE RIVANNA MMU

1. The DCR model for Brook Floater suggests suitable habitat for this species (Figure 56) despite high risks.
2. Models for Green Floater suggest potential for habitat, surveys in higher scoring streams and potential opportunities for augmentation, expansion, or reintroduction (Figure 59).

[17] Based on occupancy models developed by T. W. Lane and B. J. K. Ostby, details in reports, sites are defined as 600-1,200 meter long reaches (Ostby 2022b)

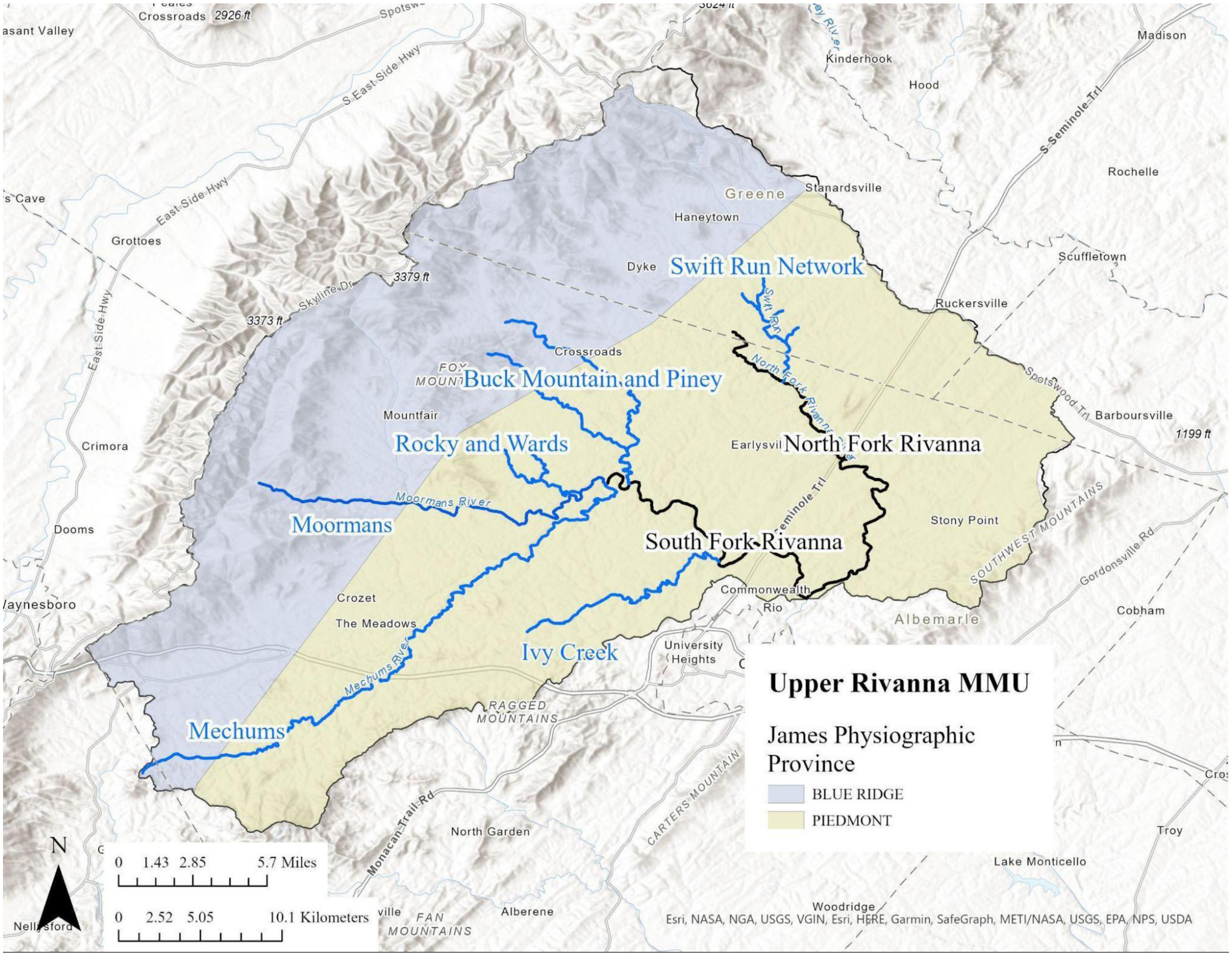


Figure 47. Upper Rivanna stream network with referenced streams labeled.

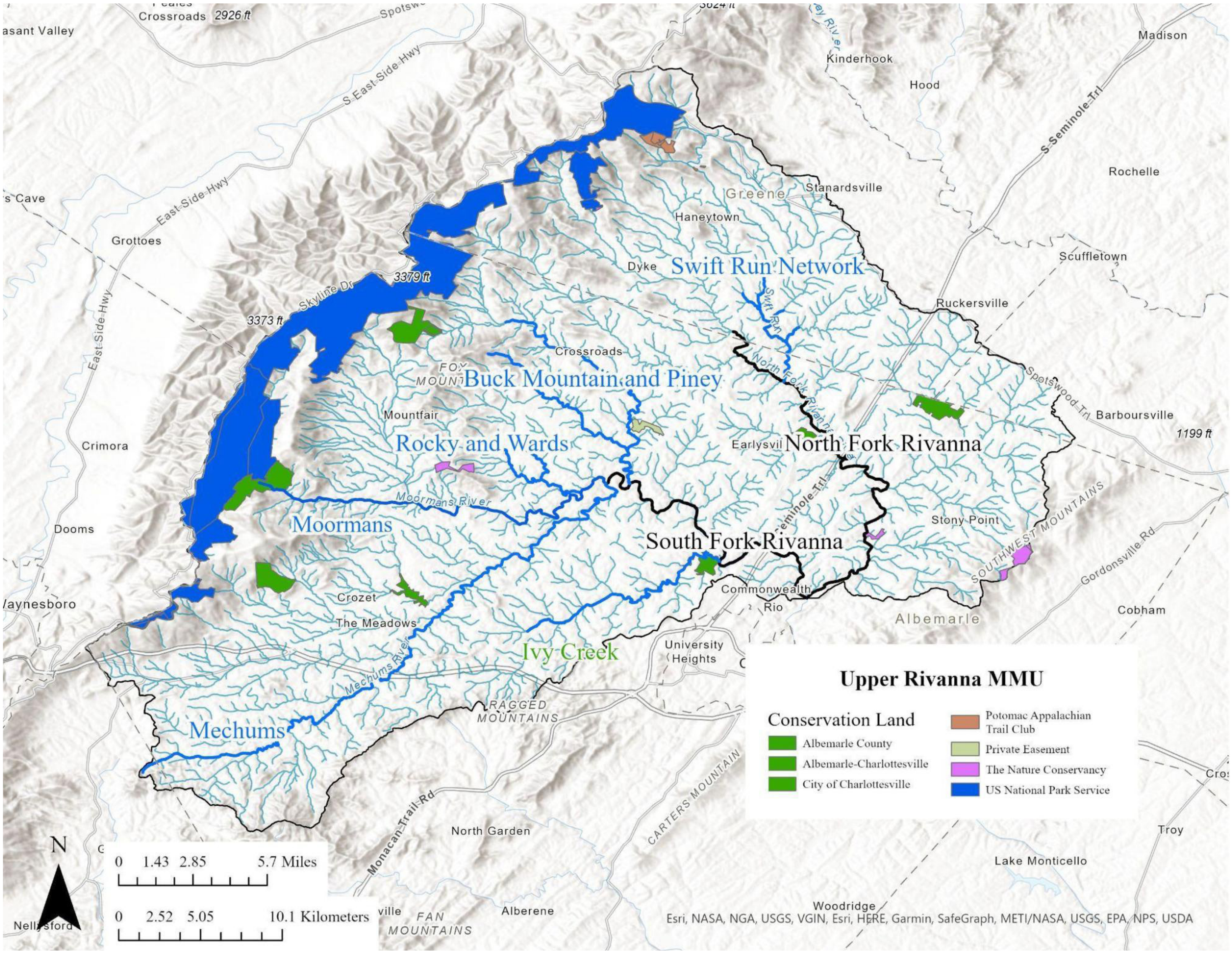


Figure 48. Conservation lands in Upper Rivanna MMU.

Figure 49. Risks to mussel habitats in the Upper Rivanna MMU, such as this eroding bank observed during a survey of the North Fork Rivanna River near Advance Mills (A) and exposed banks in Swift Run (B), need to be considered during assessments of restoration habitats. These habitats still support James Spinymussel.

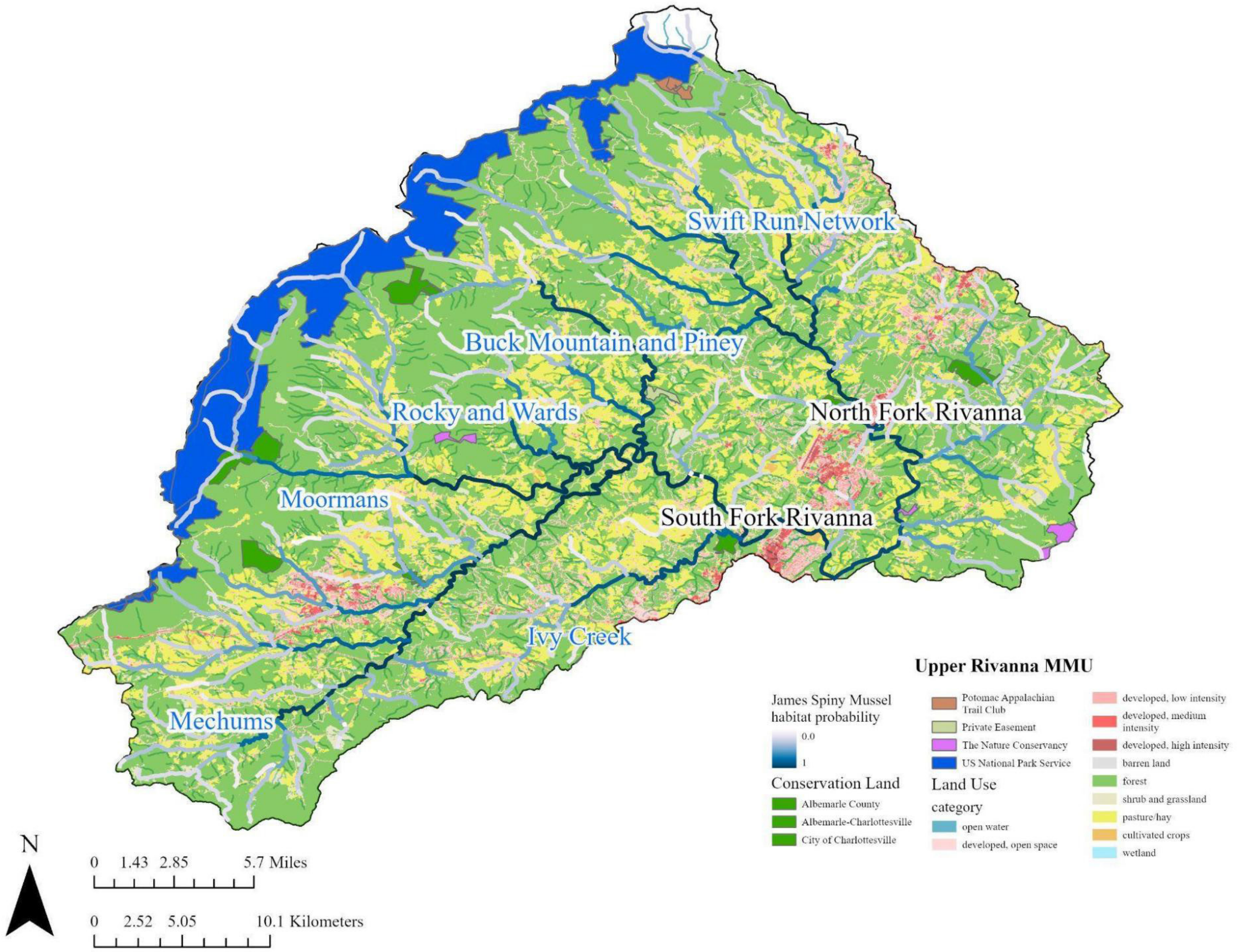


Figure 50. Models for James Spinymussel habitat suitability (Data source: Virginia Natural Heritage Program 2022e) in context of conservation lands and land use in the Upper Rivanna MMU. Darker blue streams demonstrate relatively higher suitability probabilities according to models. This information is detailed in figures below for other species. It is presented here in context to demonstrate challenges of restoration work in this MMU.

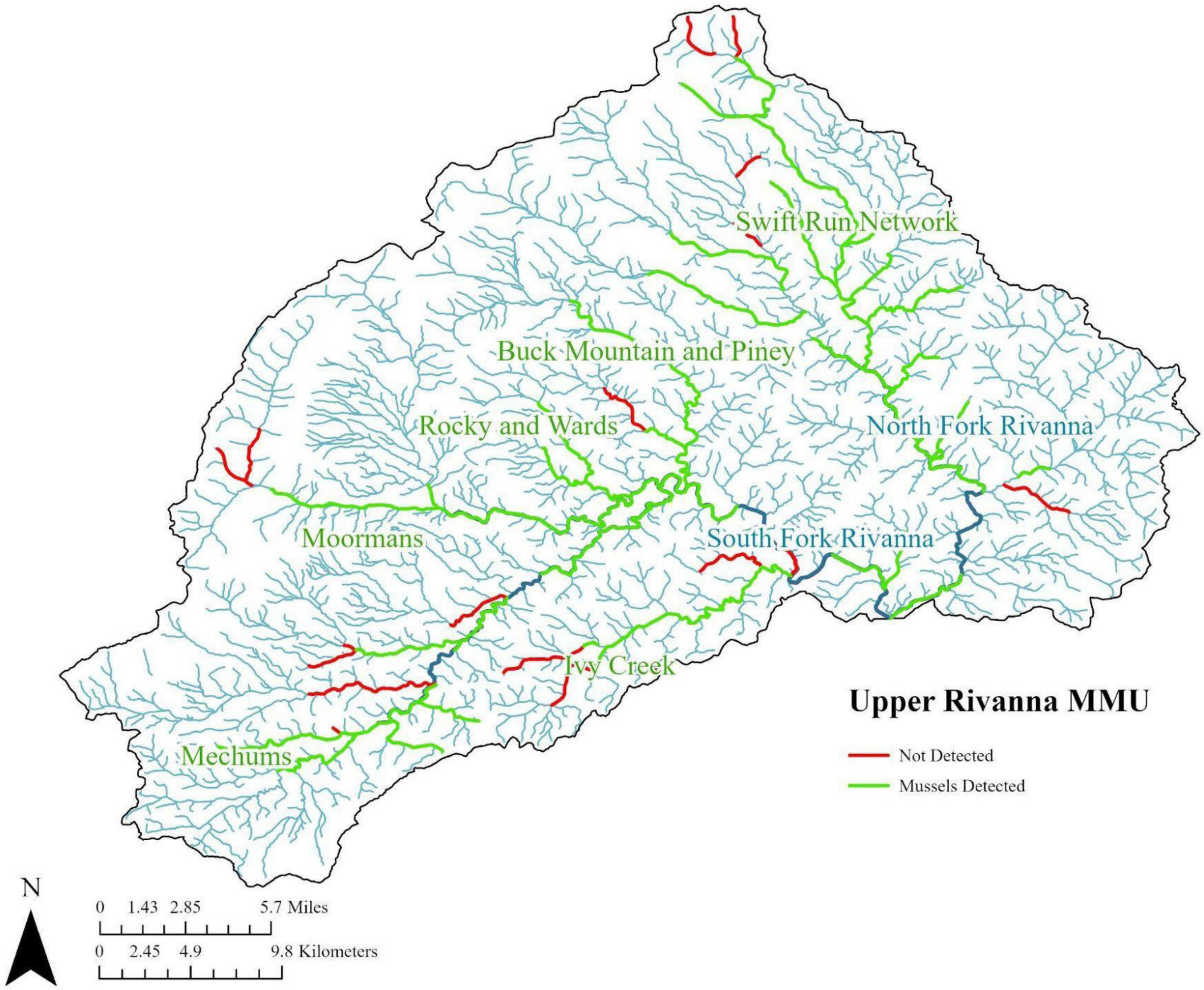


Figure 51. Reaches sampled in the last 40 years in the Upper Rivanna MMU demonstrate many named streams have been surveyed and that mussels have been detected in most. This was one of many reasons this MMU is considered a high priority.

Figure 52. High gradient habitats, such as this in Wards Creek near the Route 671 bridge received high EPA scores, flow through forested lands but do not support freshwater mussels.

Figure 53. Sand and gravel habits in Swift Run near confluence with North Fork Rivanna.

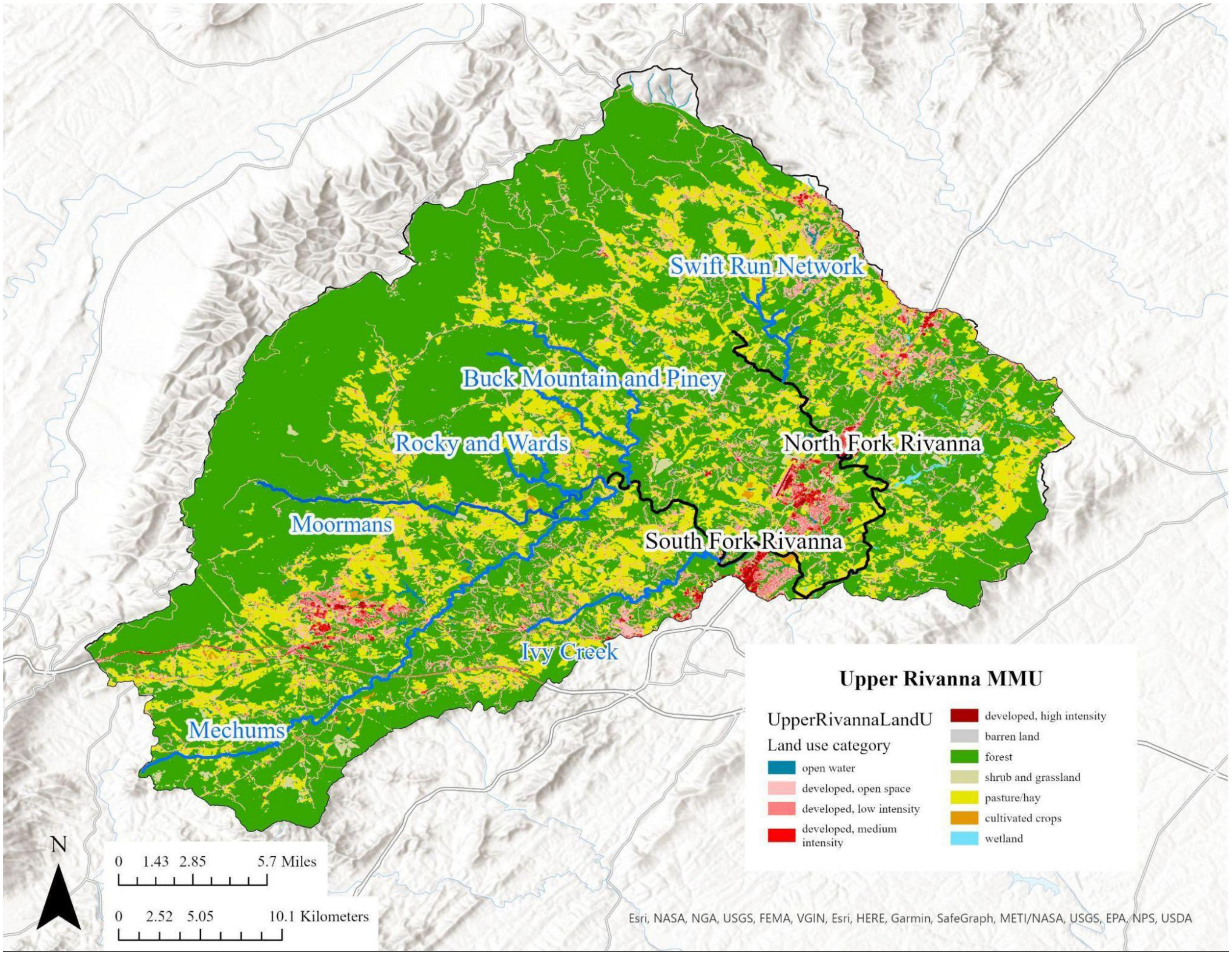


Figure 54. Upper Rivanna MMU land use with major mussel streams labeled.

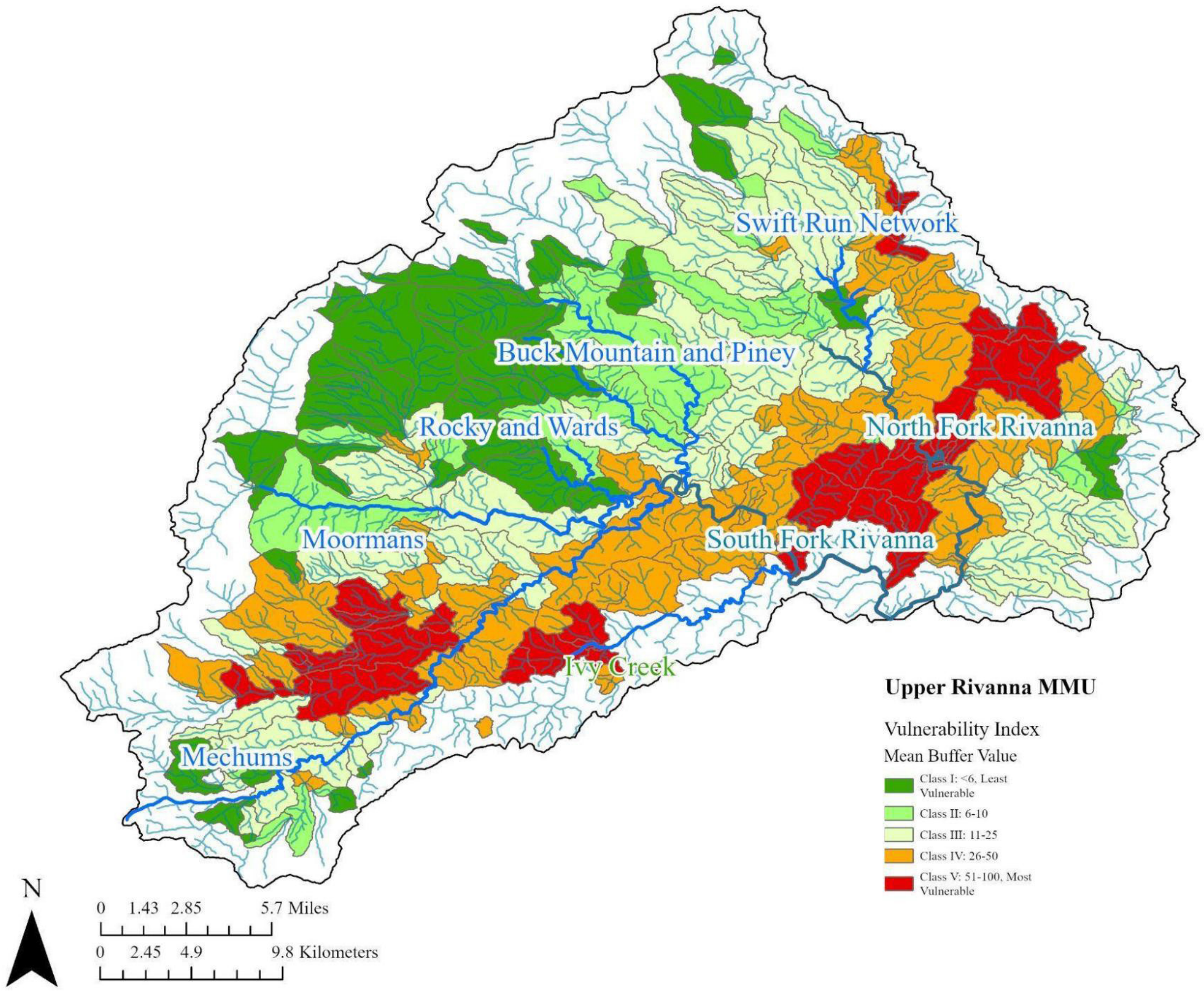


Figure 55. Development vulnerability in the Upper Rivanna MMU.

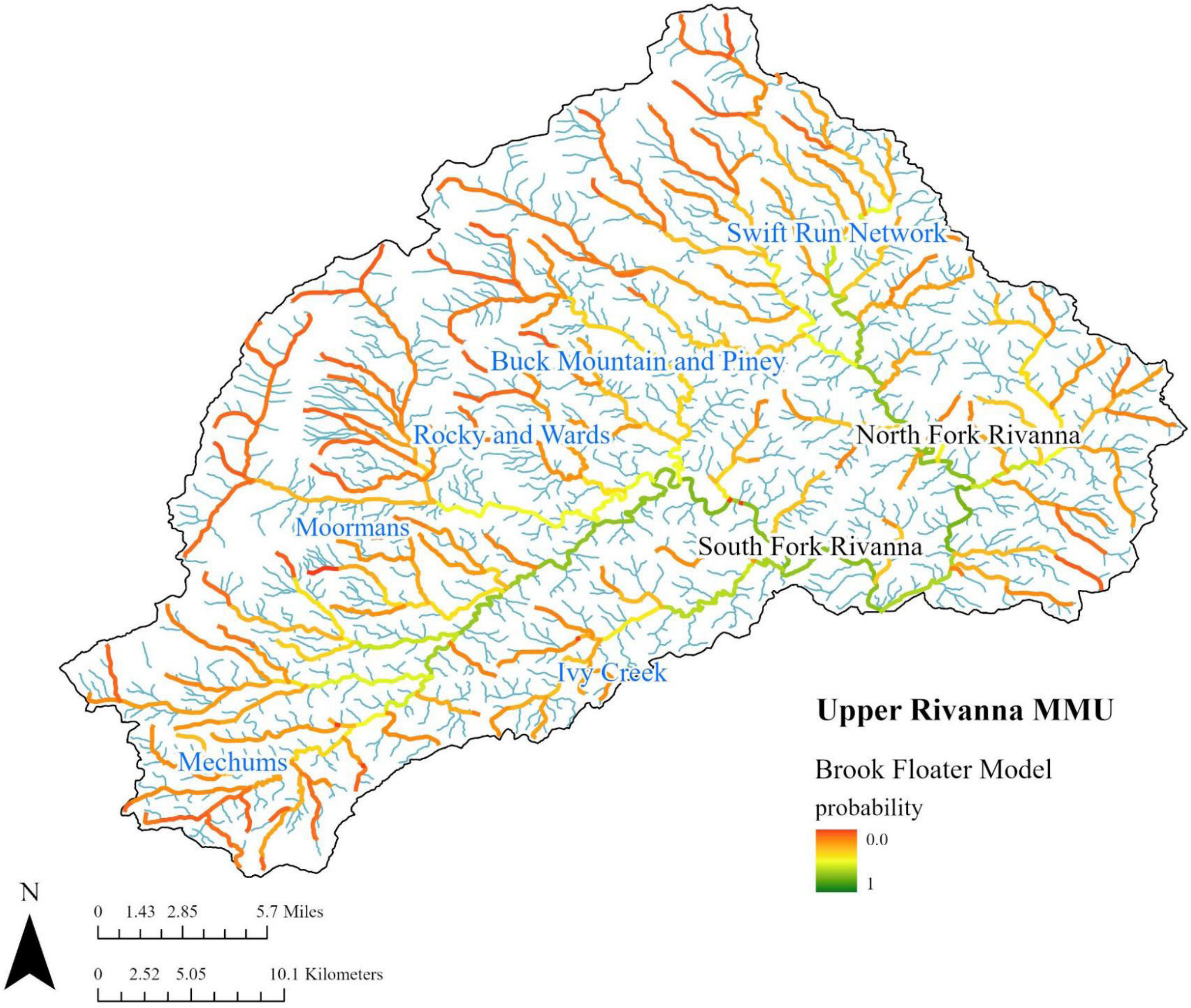


Figure 56. The Habitat model for Brook Floater demonstrates some moderate suitability in the North Fork, South Fork Rivanna, and lower Mechums (Data source: Virginia Natural Heritage Program 2022a). The Upper Rivanna appears to have more suitable habitat for this species compared to other MMUs (see Figure 16).

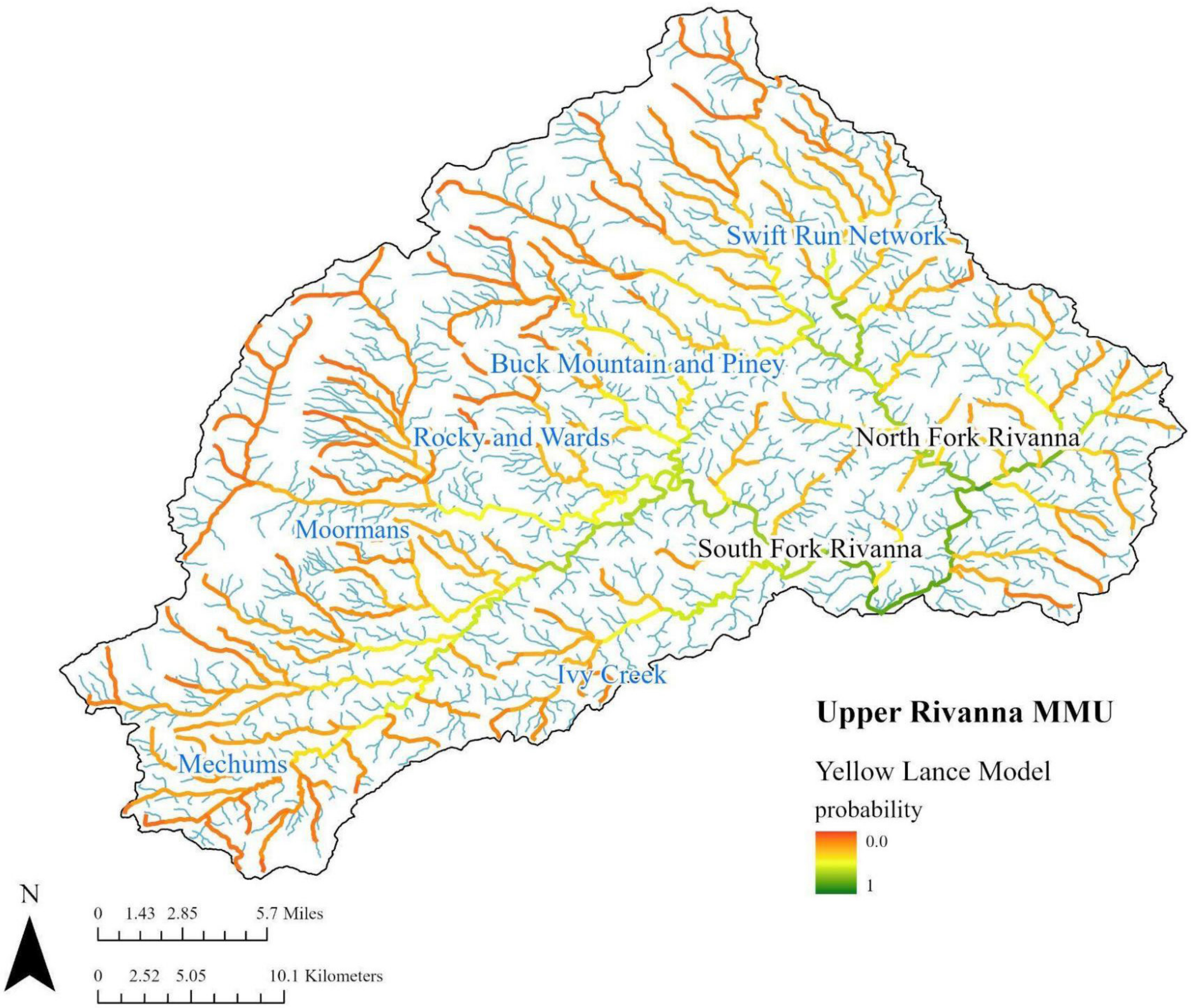


Figure 57. Models demonstrate some habitat suitability for Yellow Lance, with best scores in areas of higher vulnerability and impervious land use in lower South Fork Rivanna and North Fork Rivanna (Data source: Virginia Natural Heritage Program 2022b). The Yellow Lance has not been detected in this MMU but based on DCR models, some habitats are considered moderately suitable.

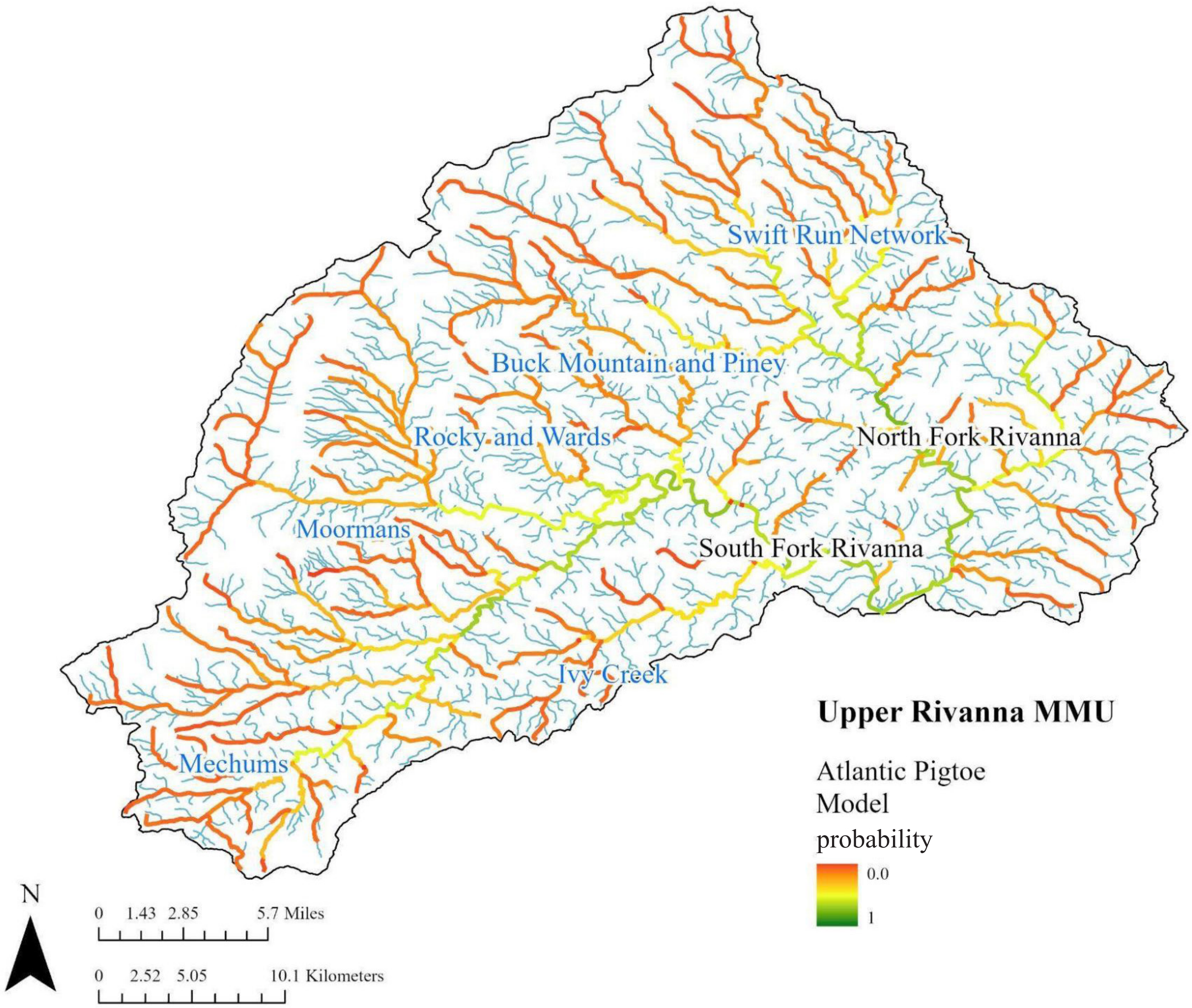


Figure 58. Models demonstrate some habitat suitability for Atlantic Pigtoe, with best scores in areas of higher vulnerability and impervious land use (Data source: Virginia Natural Heritage Program 2022c).

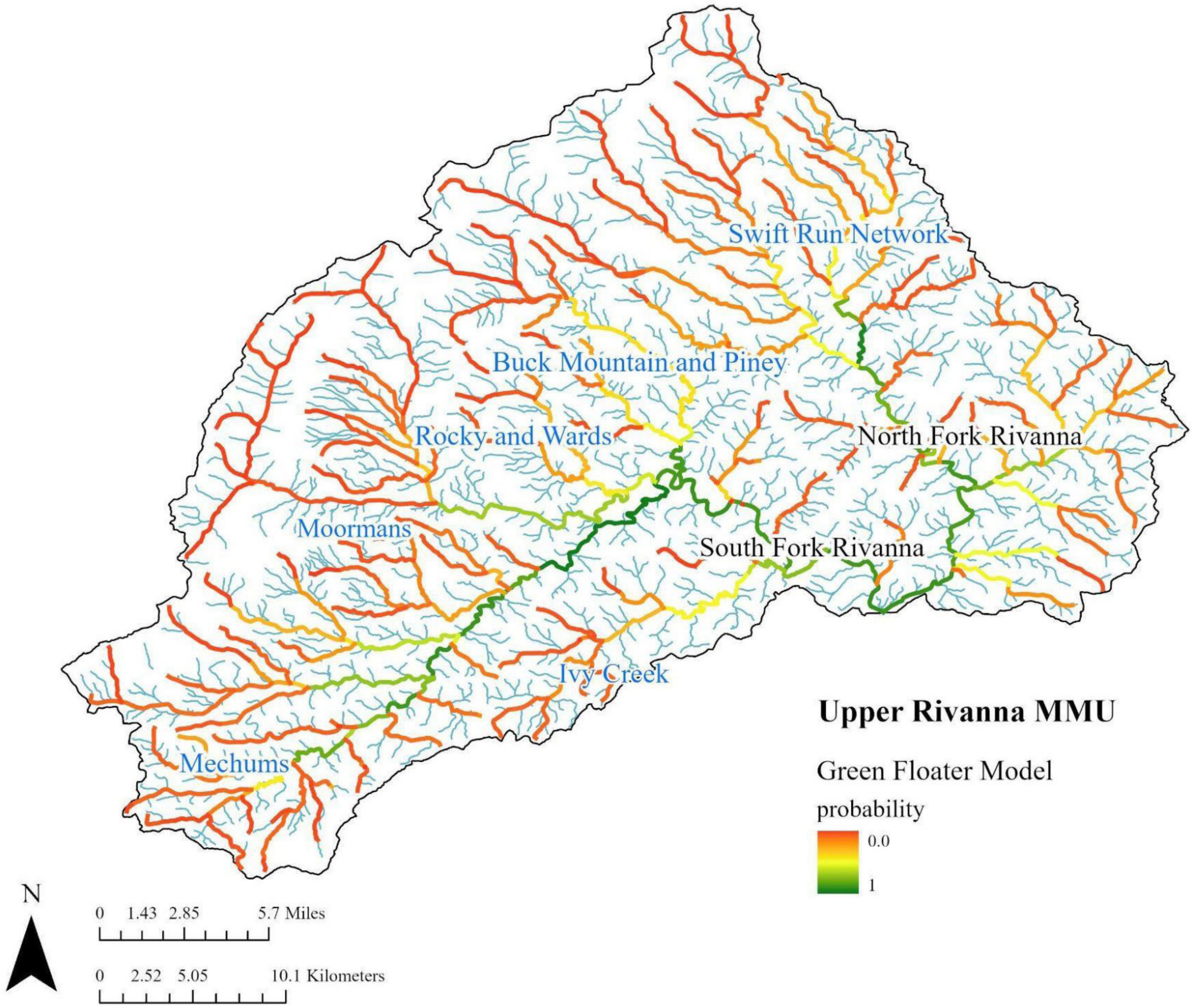


Figure 59. Mechums, South Fork Rivanna, and North Fork Rivanna demonstrate higher habitat suitability scores in the Rivanna MMU for Green Floater (Data source: Virginia Natural Heritage Program 2022d).

CRAIG

The stream network of this MMU drains parallel valleys of the Valley and Ridge physiographic province. This trellis network is a shared characteristic of many adjacent MMUs, including Jackson-Dunlap, Potts, Cowpasture, and Upper Maury (Figure 60). Like other adjacent MMUs, urban development is limited with total impervious cover in the watershed and riparian zone being 3.5% and 6.3%, respectively (Figure 61). Only one developed area exists in the Craig Creek MMU, that being New Castle. In addition, almost 90% of the total watershed and 83.6% of the riparian zones are forested. Large portions of the MMU are in National Forest. Many small tributaries start on these public lands with larger streams flowing through private lands (Figure 62). Compared to other MMUs, many reaches have been surveyed in the last 40 years, with particular focus on Craig Creek Virginia Department of Transportation (VDOT) fords and upper reaches of Johns Creek (Figure 63). Johns Creek, a major branch of Craig Creek, supports some of the most intact and robust mussel assemblages in the entire James River Basin. Its stream network may have the greatest number of James Spinymussel in the world, with other species considered common to relatively abundant, including Triangle Floater, Eastern Elliptio, Northern Lance, Eastern Floater, Creeper, and Notched Rainbow. Johns Creek is the only stream in the James River Basin where the federally threatened Yellow Lance is confirmed and known to persist and is designated critical habitat for the species (Orcutt 2021). It remains exceptionally rare. The Atlantic Pigtoe may persist in Johns Creek but there is limited evidence collected in the last 20 years despite sufficient sampling[18].

More than a decade of study has demonstrated the James Spinymussel population in Little Oregon, Dicks, and Johns creeks support the highest abundances of this species anywhere in its range. These occupied habitats are connected, with Little Oregon Creek flowing into Dicks Creek, and subsequently Johns Creek; therefore, this should be considered one metapopulation. This population currently serves as broodstock in the James River Basin[19].

Historically, the reach of Craig Creek downstream of New Castle supported a readily detectable population of James Spinymussel and Atlantic Pigtoe. Critical habitat for Atlantic Pigtoe is designated in Craig Creek. Studies in recent decades suggest severe decline of both species, with few individuals persisting at documented beds (Anderson and Carter fords, Figures 64-65). These fords have been studied because of VDOT maintenance. The five-year recovery plan for James Spinymussel covers this in depth (USFWS 2022c). A recent survey by Card (2022) confirmed rarity of both species in Craig Creek.

Models developed by DCR suggest variable habitat suitability for listed species, mostly limited to Johns Creek and Lower Craig Creek (Figures 66, 67, 68, 69, and 70). These models may be limited by confirmed detection so may not necessarily preclude work with species like Brook Floater.

The reach of Craig Creek upstream of Johns Creek is not explicitly addressed here due to limited detections. This reach has lower suitability scores compared to lower Craig Creek and Johns Creek. Though it has a record for James Spinymussel, Card (2022) only detected Creeper and Notched Rainbow in the reach. Mussels were not detected at most sites. Some habitats could be suitable for future work but other habitats of this MMU are clear priorities for immediate action.

Because assemblage conditions appear different in Johns Creek compared to lower Craig Creek, separate goals and actions have been developed for each.

[17] Atlantic Pigtoe was last detected in Johns Creek while collecting broodstock between 2008-2018 and only later identified and confirmed in a review of photographs, per. com. Brian Watson, 2/9/2024

[19] The other major brood stock is in Mill Creek of the Upper Maury MMU, see discussion in that section.

GOALS FOR JOHNS CREEK

1. Assemblages should include at least 5 species from the list below with the majority recruiting (>3 species).
    a. Triangle Floater
    b. Eastern Elliptio
    c. Northern Lance
    d. Yellow Lance
    e. James Spinymussel
    f. Eastern Floater
    g. Creeper
    h. Notched Rainbow
    i. Atlantic Pigtoe
    j. Alternative not historically documented
        i. Brook Floater
2. Augmentation should continue until mussels reach a density of 3 m^{-2} in well-defined suitable habitats[20]

ACTIONS FOR JOHNS CREEK

1. Select one site in Johns Creek to meet the assemblage and density goal
    a. Site 21 (Orcutt 2021) near VA Rte 311 bridge is a candidate
    b. Define the extent of suitable to optimal habitat at the selected site
2. Use propagation to meet density goals and increase species richness.
3. Translocate mussels from sites will augment populations elsewhere in MMU

GOALS FOR CRAIG CREEK BELOW NEW CASTLE

1. Overall Stream Assemblage with 5 species
    a. Evidence of recruitment of 3 species
    b. No one species making up more than 50% assemblage
2. Augmentation with propagated/translocated mussels until density of 2 m^{-2} in well-defined suitable habitat

ACTIONS FOR CRAIG CREEK BELOW NEW CASTLE

1. Select one site in Craig Creek around Oriskany to meet assemblage and density goal
    a. The mussel bed at Carter Ford is already defined so could be a strong candidate
    b. Propagated mussels have been released at an island upstream of the canoe launch at Oriskany, making this location another candidate
2. Use propagation and translocations to meet the density goal

[20] Density recommendation based on observations in Little Oregon Creek, where densities are generally between 2 and 4 m^{-2}

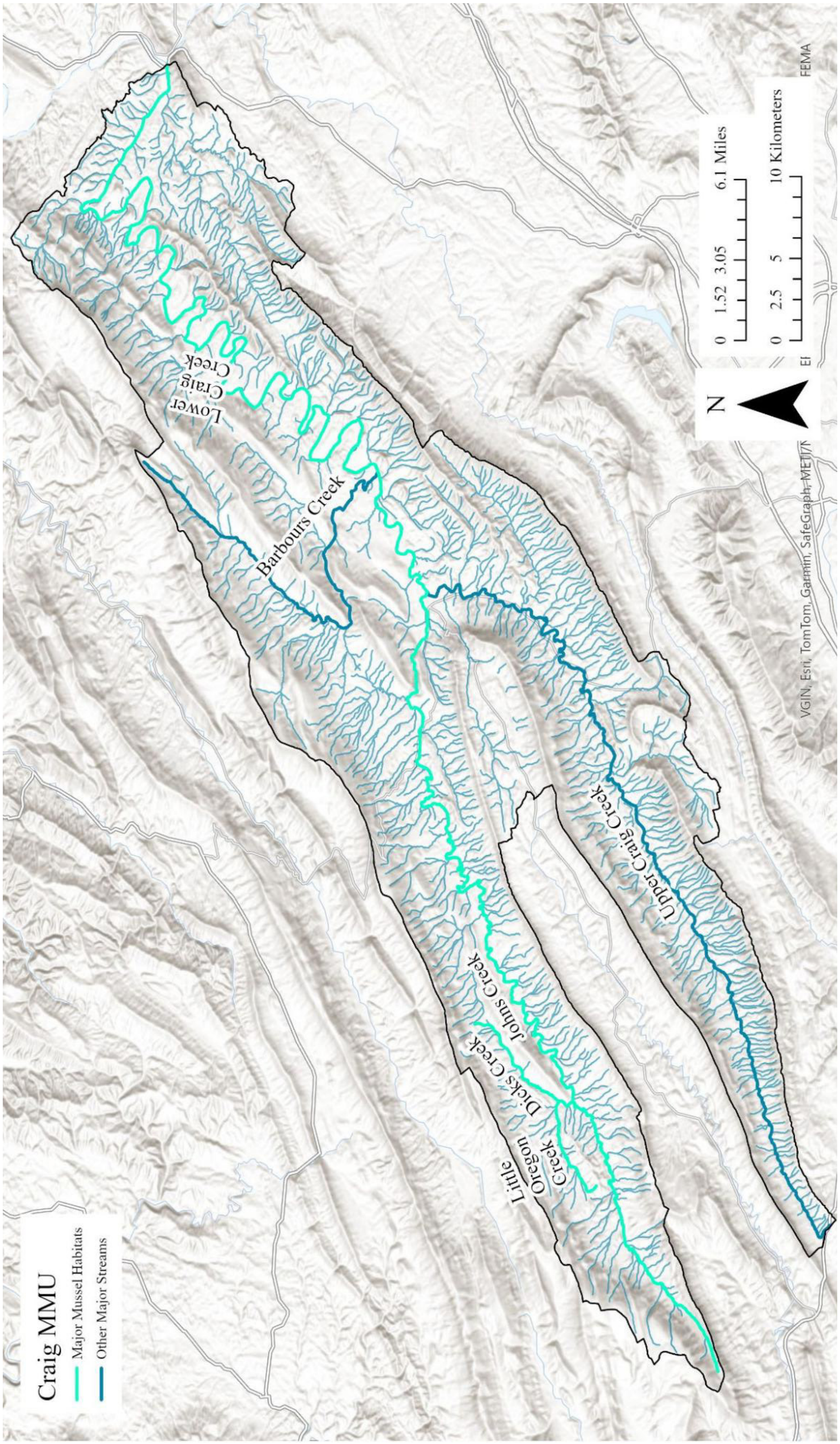


Figure 60. Major streams in the Craig Creek MMU.

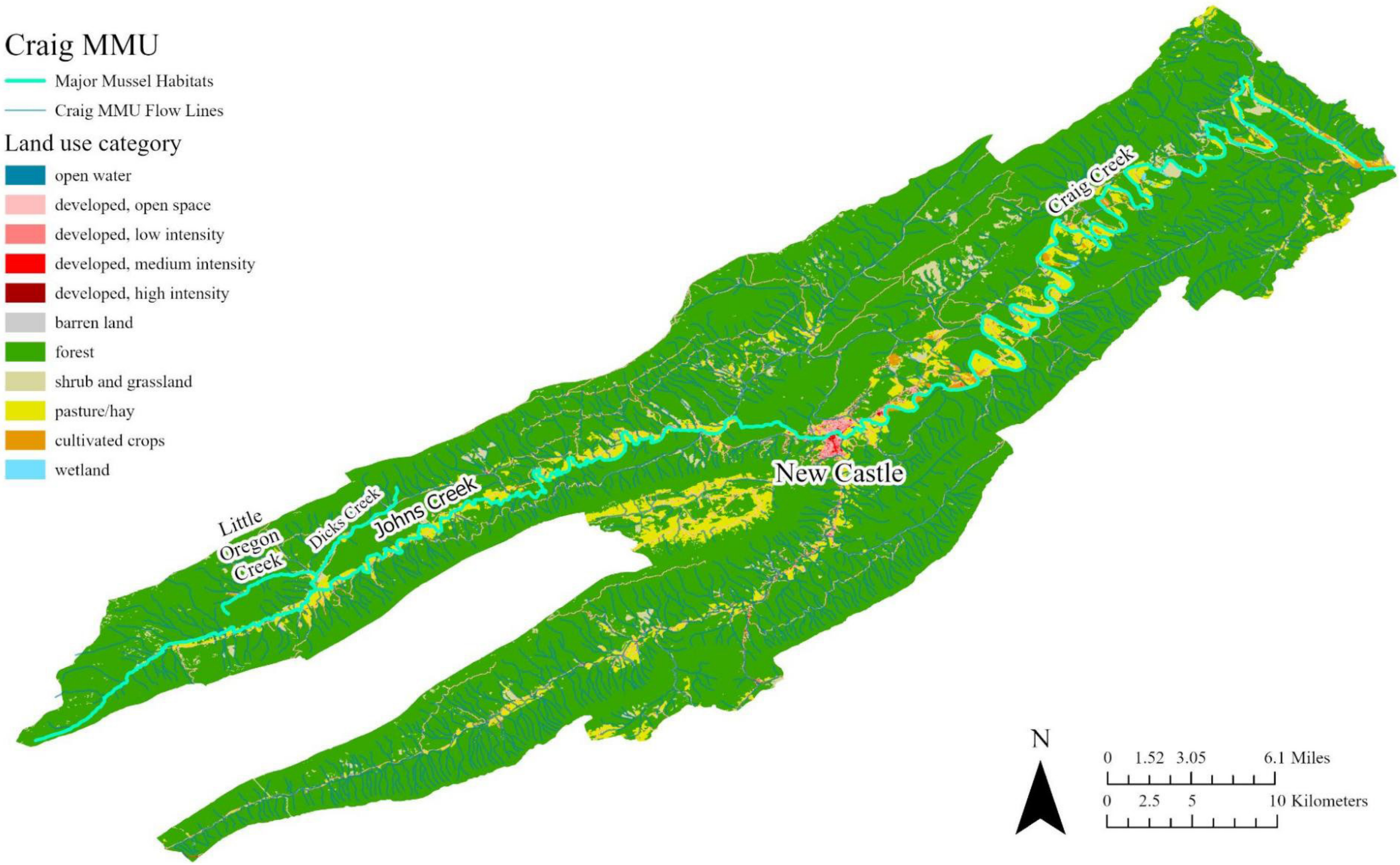


Figure 61. Land use in the Craig MMU is dominated by forest with pasture, hay fields, and some cultivated crops in valley bottoms and proximate to important mussel habitats. Only named reaches that should be the focus in the MMU are labeled and shown in light blue.

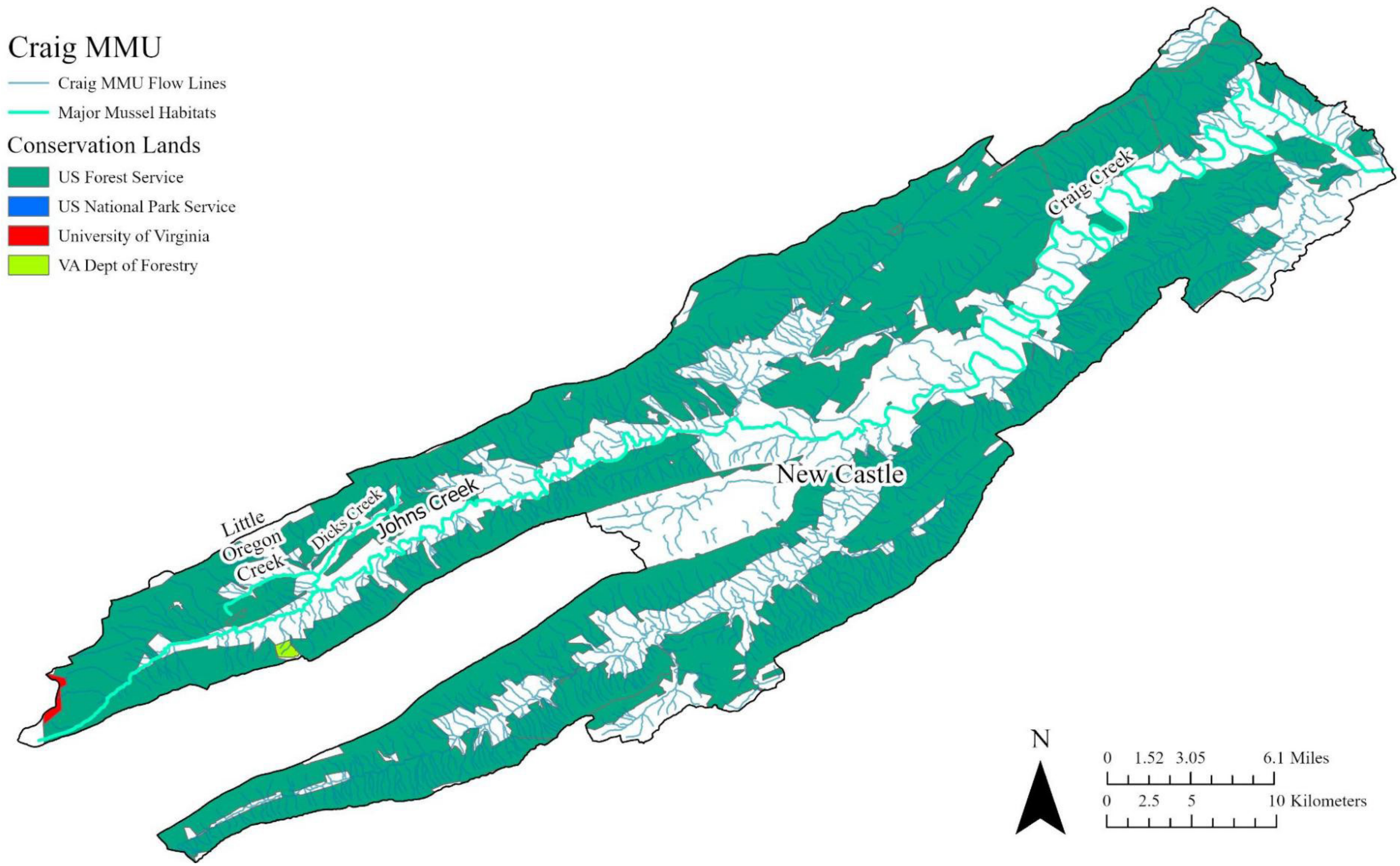


Figure 62. Large portions of the Craig MMU is U. S. Forest Service land. Only named reaches that should be the focus in the MMU are labeled and marked in light blue.

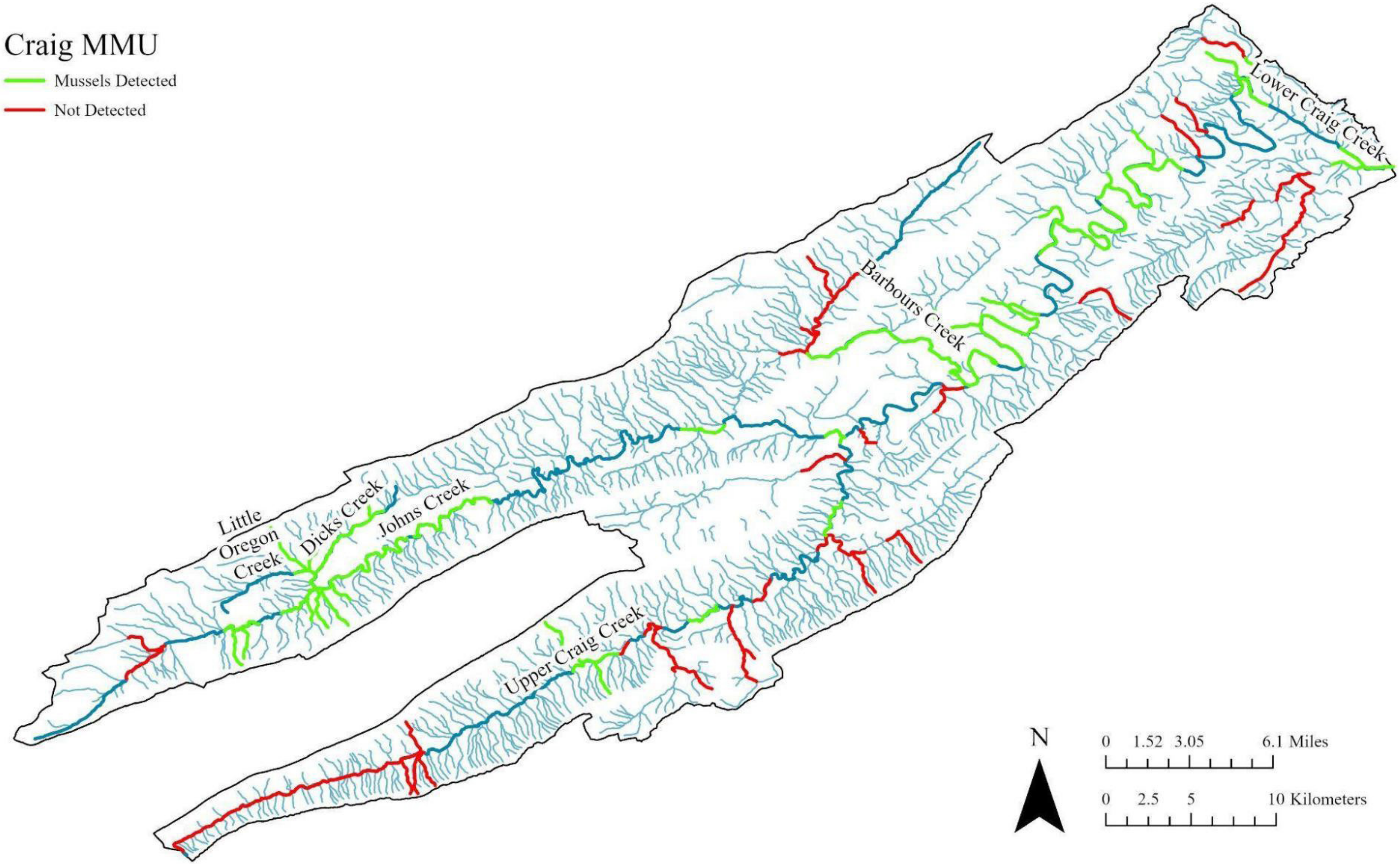


Figure 63. Surveyed reaches of Craig MMU. Stream reaches with no survey records since 1980 are blue. This data does not reflect more recent DCR surveys in Craig Creek (Card 2022).

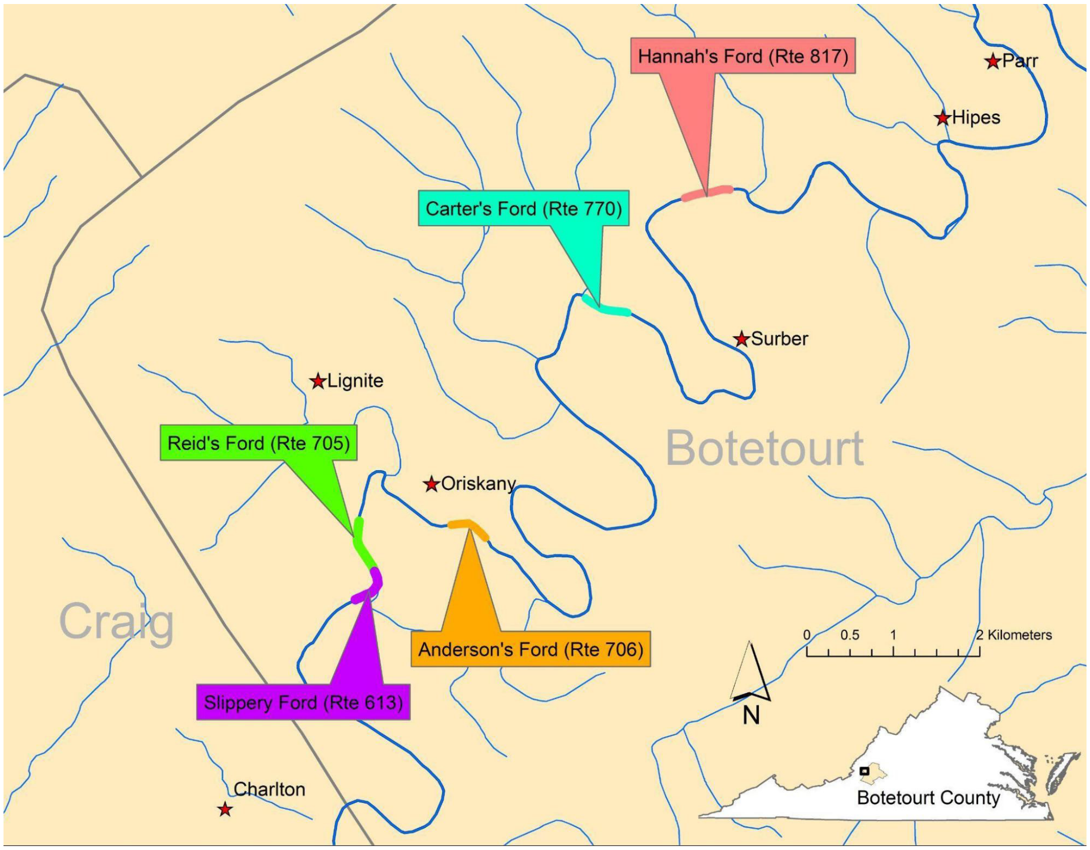


Figure 64. Ford locations occupied by listed species (Figure from Ostby and Neves 2010). Card detected several young James Spinymussel at Carter's Ford in 2022, these were propagated individuals.

Figure 65. Ford habitat in Craig Creek.

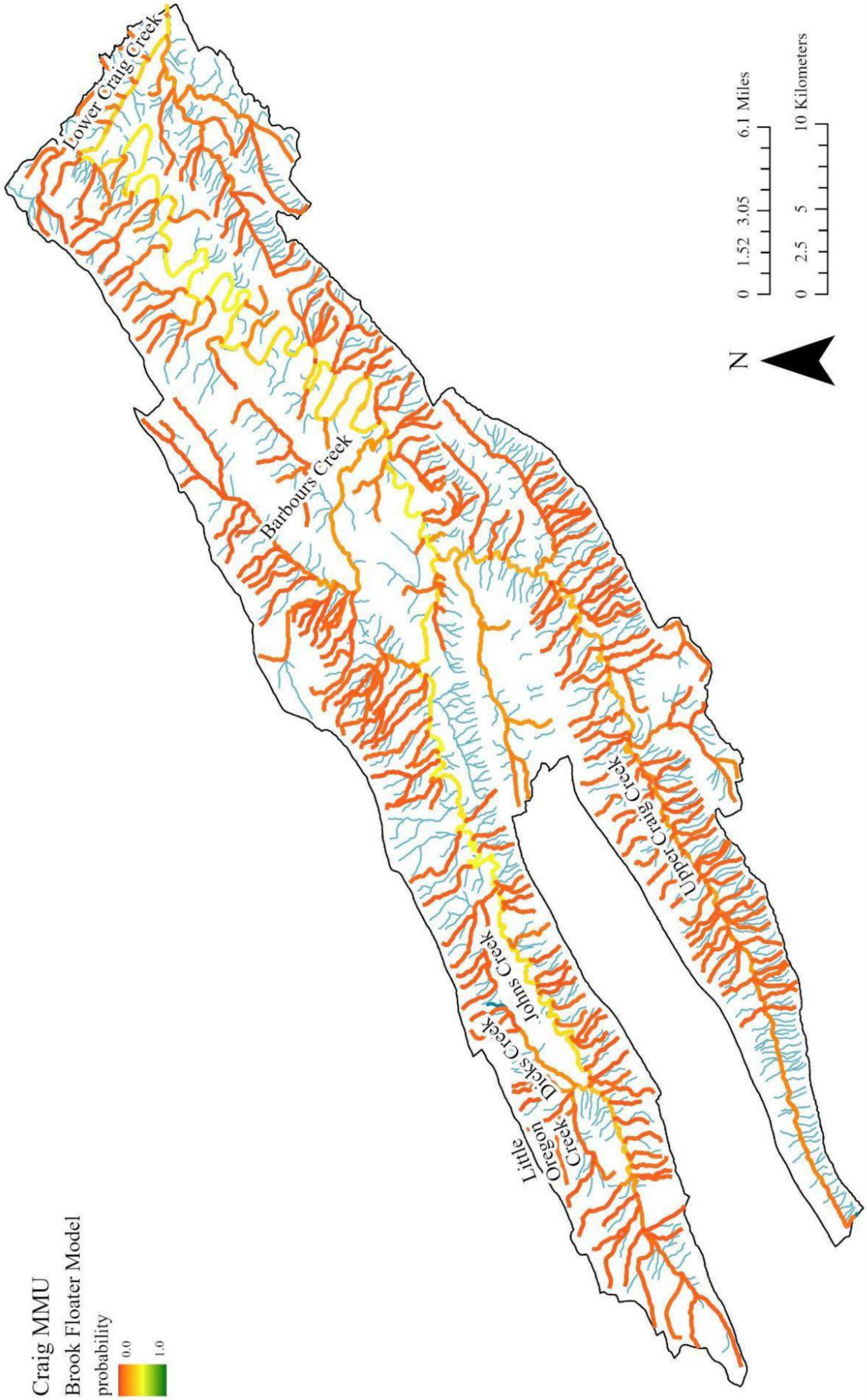


Figure 66. Johns Creek and lower Craig Creek have limited habitat suitability for Brook Floater according to DCR models (Data source: Virginia Natural Heritage Program 2022a).

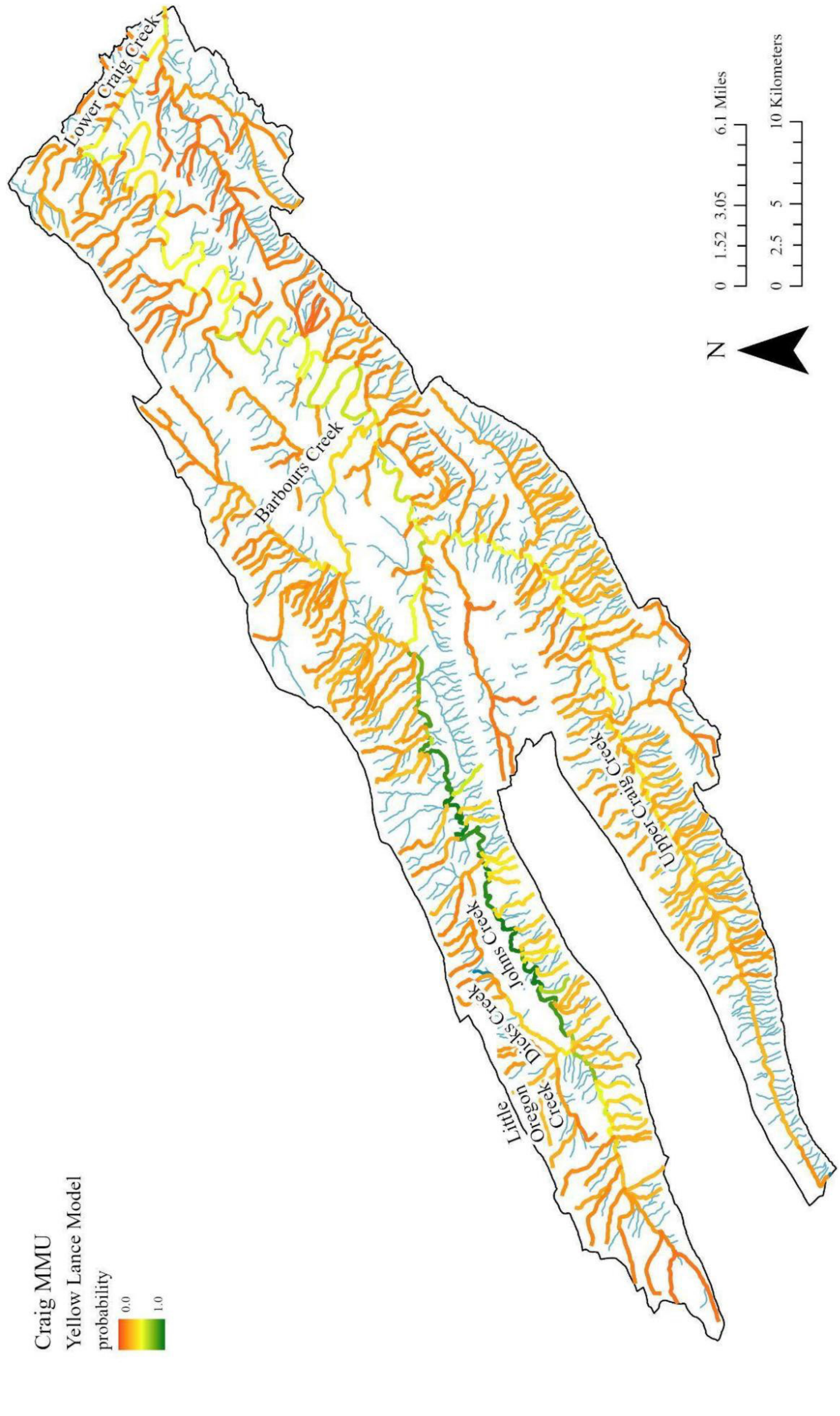


Figure 67. Johns Creek may provide some of the most suitable habitat for Yellow Lance in the entire James River Basin (Data source: Virginia Natural Heritage Program 2022b).

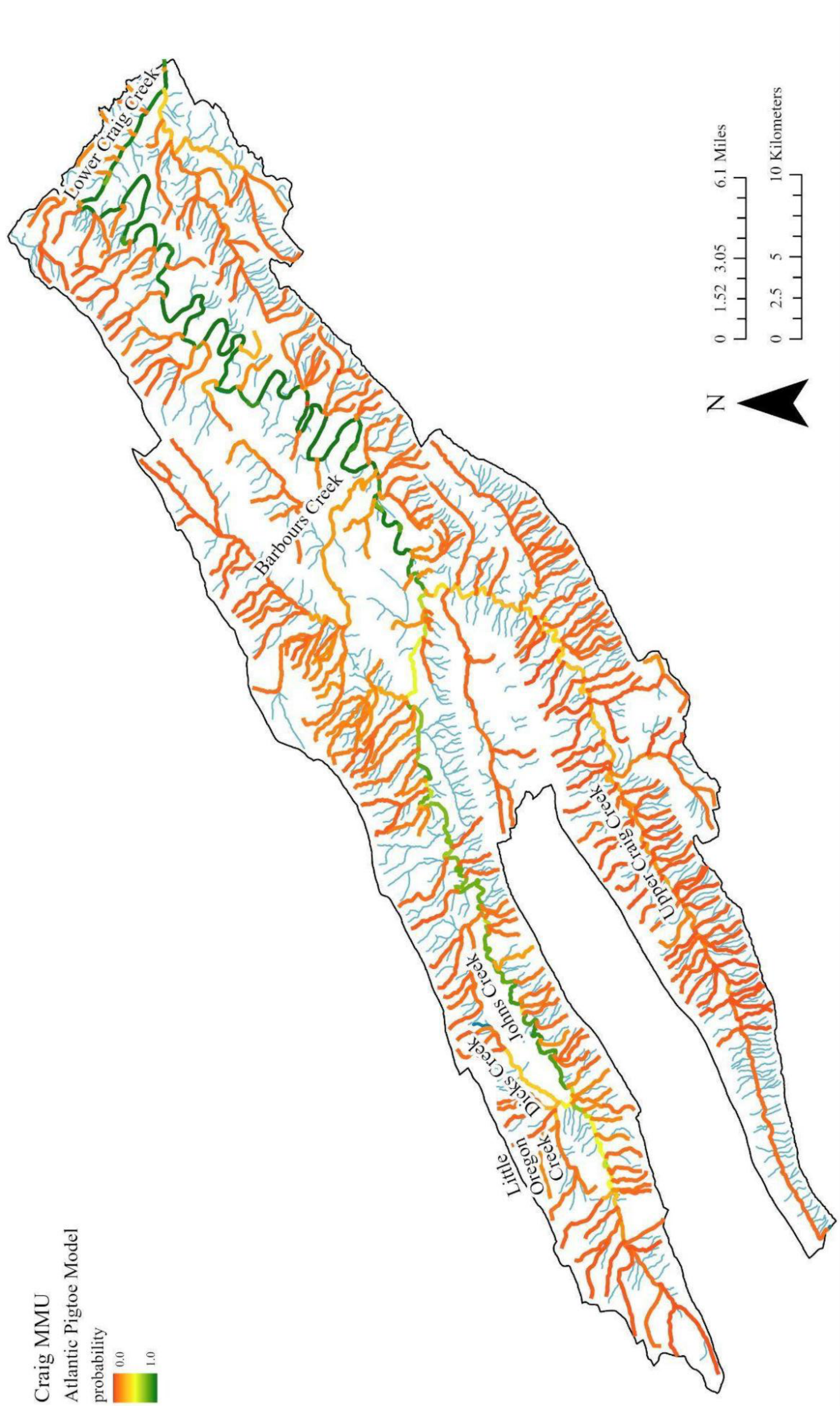


Figure 68. Most of lower Craig Creek is suitable habitat for Atlantic Pigtoe according to DCR models (Data source: Virginia Natural Heritage Program 2022c).

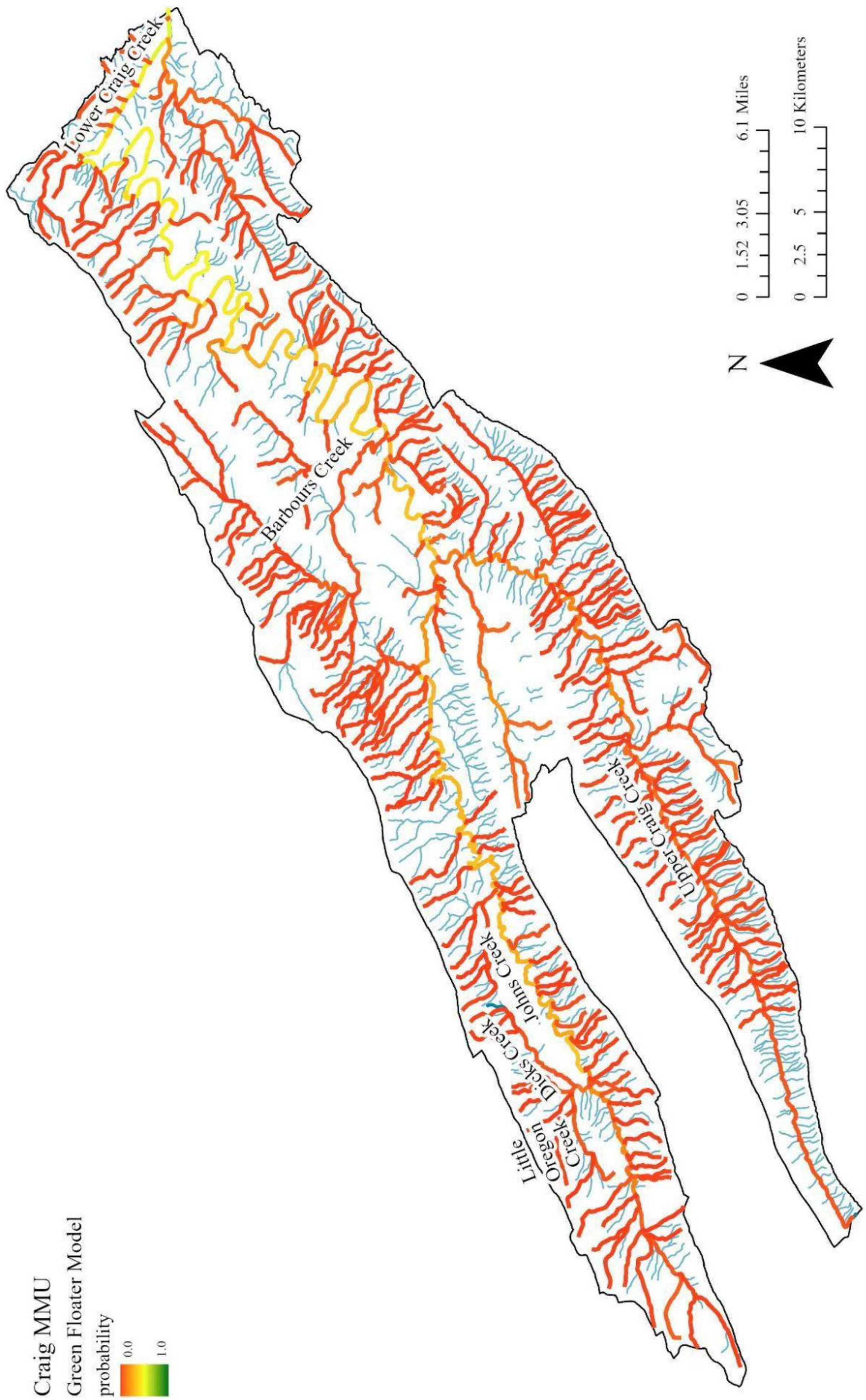


Figure 69. Lower reaches Craig Creek may provide marginal habitat for Green Floater (Data source: Virginia Natural Heritage Program 2022d).

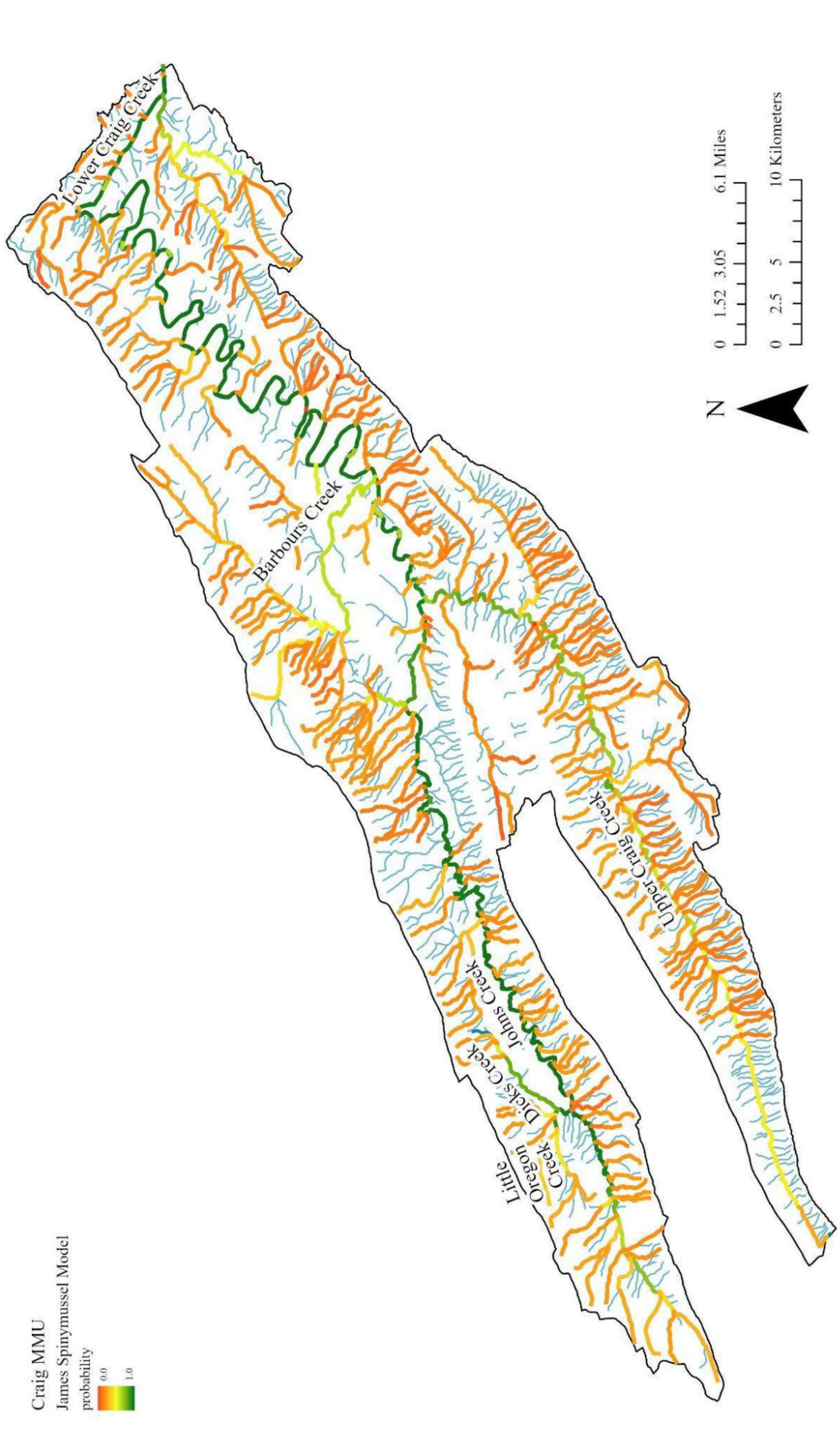


Figure 70. Most of lower Craig Creek and Johns Creek provide suitable habitat for James Spinymussel according to DCR models (Data source: Virginia Natural Heritage Program 2022e).

MAINSTREAM JAMES RIVER SCOTTSVILLE TO FALL LINE

This reach was originally proposed as extending from the mouth of the Rivanna River to the top of the fall line in Richmond. The extent of the MMU was increased to include Scottsville, which is an existing restoration/reintroduction site of considerable size, and Mayo Island, a restoration site for JRA (Figure 71).

There is no information about what a native assemblage should be in the James River itself. It is assumed that the assemblage includes nine to 10 extant species. Presently Eastern Elliptio (1) is the dominant species and, often, the only species present in a suitable habitat area. Northern Lance (2), Creeper (3), Notched Rainbow (4), Eastern Floater (5), Triangle Floater (6), and Green Floater (7) are rare. These species usually comprise <1% of an assemblage when present. The Paper Pondshell (8) has been collected mostly in or near impoundments. The Alewife Floater (9) has been documented near Hopewell, VA (per. com. Brian Watson 4/19/2024), and likely occurred historically around the fall line in Richmond. There are also records for the Tidewater Mucket downstream of the fall line (10). Models suggest suitable habitat for Brook Floater (Figure 72) and there is at least one potential record for this species (per. com. Brian Watson, 2/9/2024). Comparable large river habitats in the Potomac River are inhabited by Brook Floater (Ostby et al. 2006). In contrast, the James Spinymussel and Atlantic Pigtoe once inhabited the James River, with records from Botetourt County for James Spinymussel and Rockbridge County for Atlantic Pigtoe downstream to Goochland and Powhatan counties (USFWS 2021 and 2022c). DCR models suggest many suitable habitats for James Spinymussel (Figure 76). Based on nearby records from other Atlantic slope streams, Eastern Lampmussel, Yellow Lampmussel, and Eastern Pondmussel may have occupied these habitats. One relatively suitable habitat patch for Yellow Lance (Figure 73) has also been identified by DCR models, which provides general information to indicate potential suitable habitat. Much of the MMU may be suitable for Atlantic Pigtoe (Figure 74).

This Mainstream River MMU has defined shoal habitats isolated by miles of less suitable habitat. These separations likely create discrete population occurrences based on delineation guidance for freshwater mussels by NatureServe. They define occurrence separations as 2 km of unsuitable or 10 km of suitable habitat in lotic environments as different units (NatureServe website, accessed Nov. 18, 2023). Discussions about this reach resulted in the identification of four priority augmentation and reintroduction shoals. Some augmentation and reintroductions are ongoing at these locations. Land use and development vulnerability are unlikely to affect risk or habitat quality in this MMU because the scale is inappropriate. Factors shaping water quality and habitat are products of land use in dozens of watersheds upstream of this reach. Of particular note in this MMU, are the location of major outfalls that could contribute to local degradation of water quality. Figure 77 has mapped locations of major outfall permits from the VPDES database (Virginia DEQ; https://www.deq.virginia.gov/permits/water/surface-waters-vpdes), many other minor and unclassified permits are present but considered inconsequential due to volume of flow in the reach.

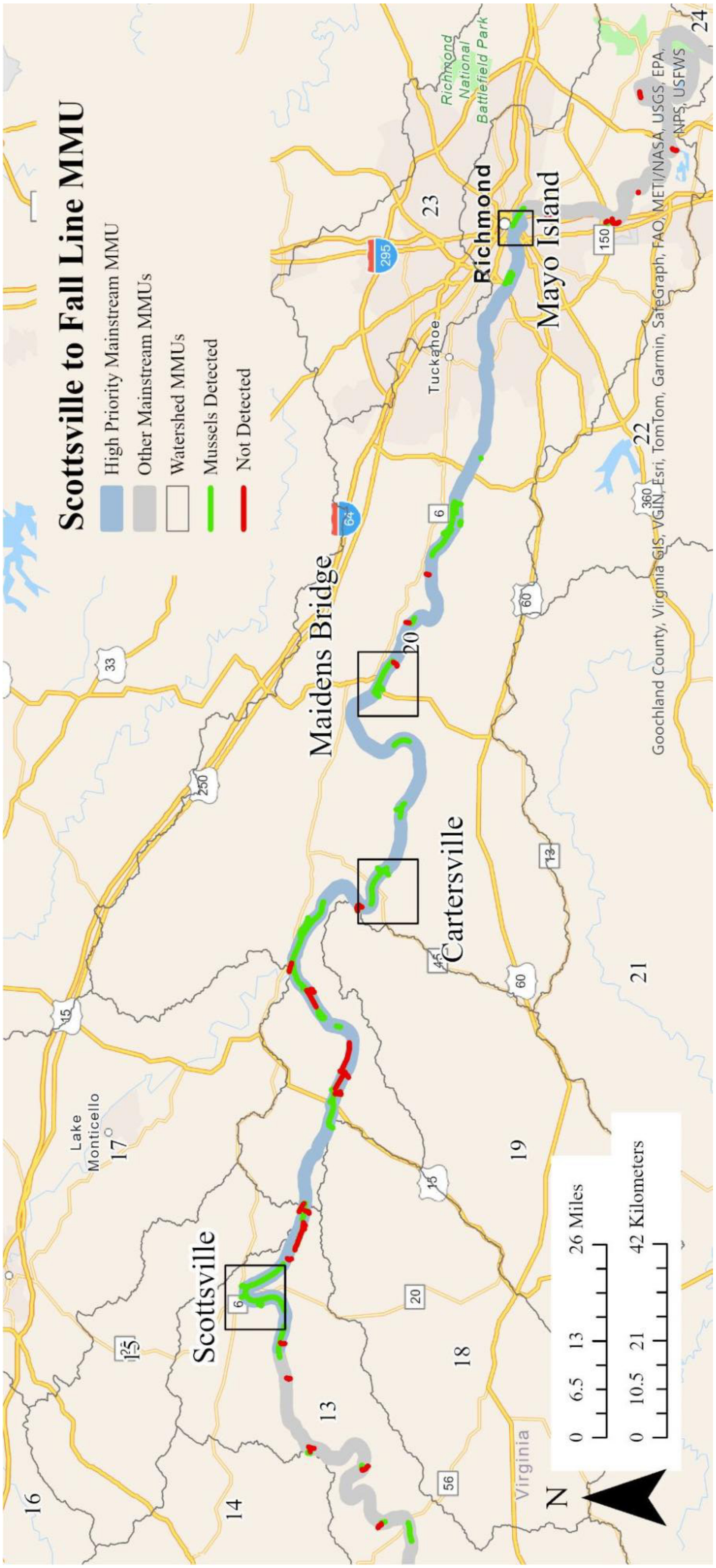


Figure 71. Reaches surveyed in the Scottsville to Fall Line MMU since 1980. Restoration sites are labeled.

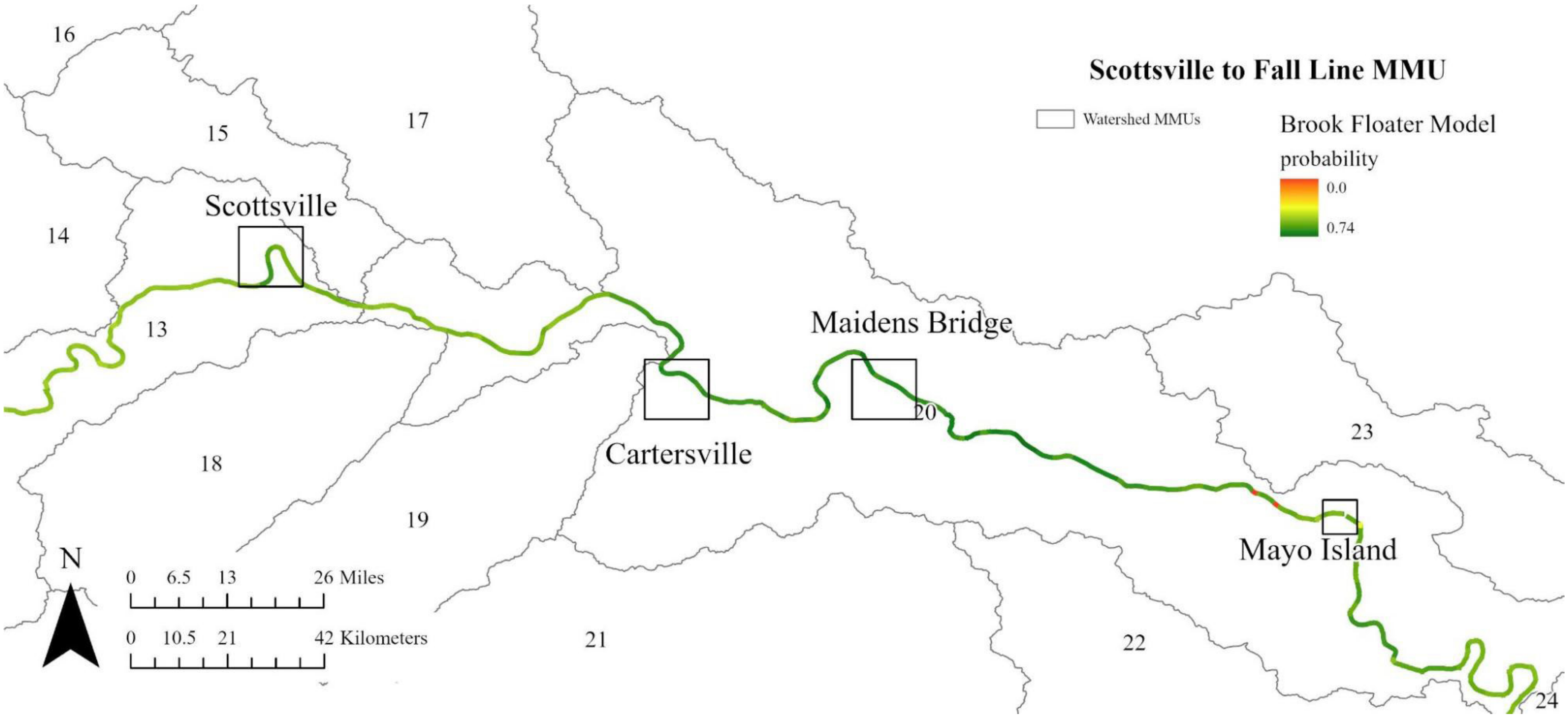


Figure 72. The DCR model suggests this mainstream MMU may provide relatively more suitable habitat for Brook Floater compared to other MMUs (Data source: Virginia Natural Heritage Program 2022a). Note the change in relative score, as the highest habitat suitability probability was 0.74, not 1.0 as in other comparable figures for this MMU.

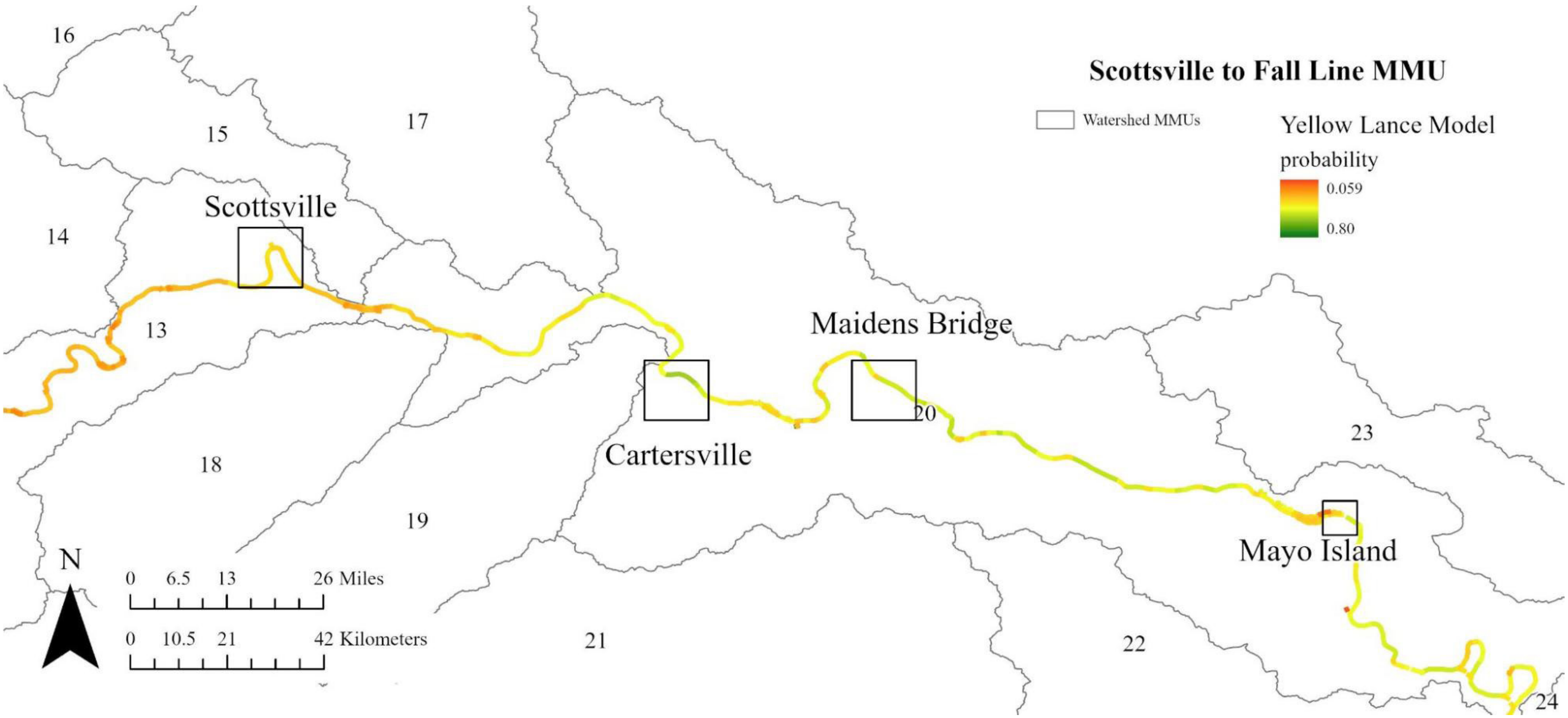


Figure 73. The DCR model suggests limited habitat suitability for Yellow Lance around Carterville and Maidens Bridge (Data source: Virginia Natural Heritage Program 2022b).

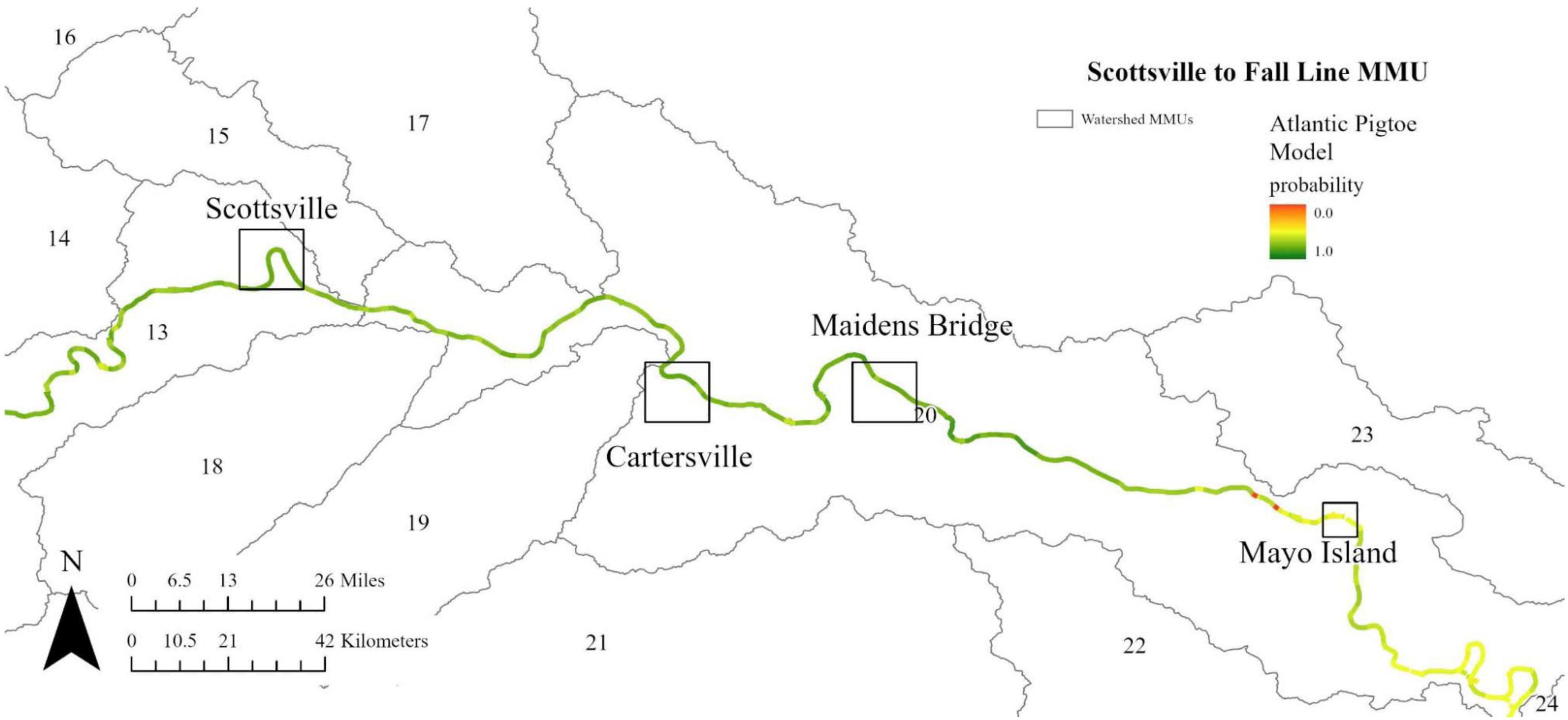


Figure 74. The DCR model suggests many habitats in this mainstream MMU are suitable for Atlantic Pigtoe, especially from Scottsville to downstream past Maidens Bridge (Data source: Virginia Natural Heritage Program 2022c).

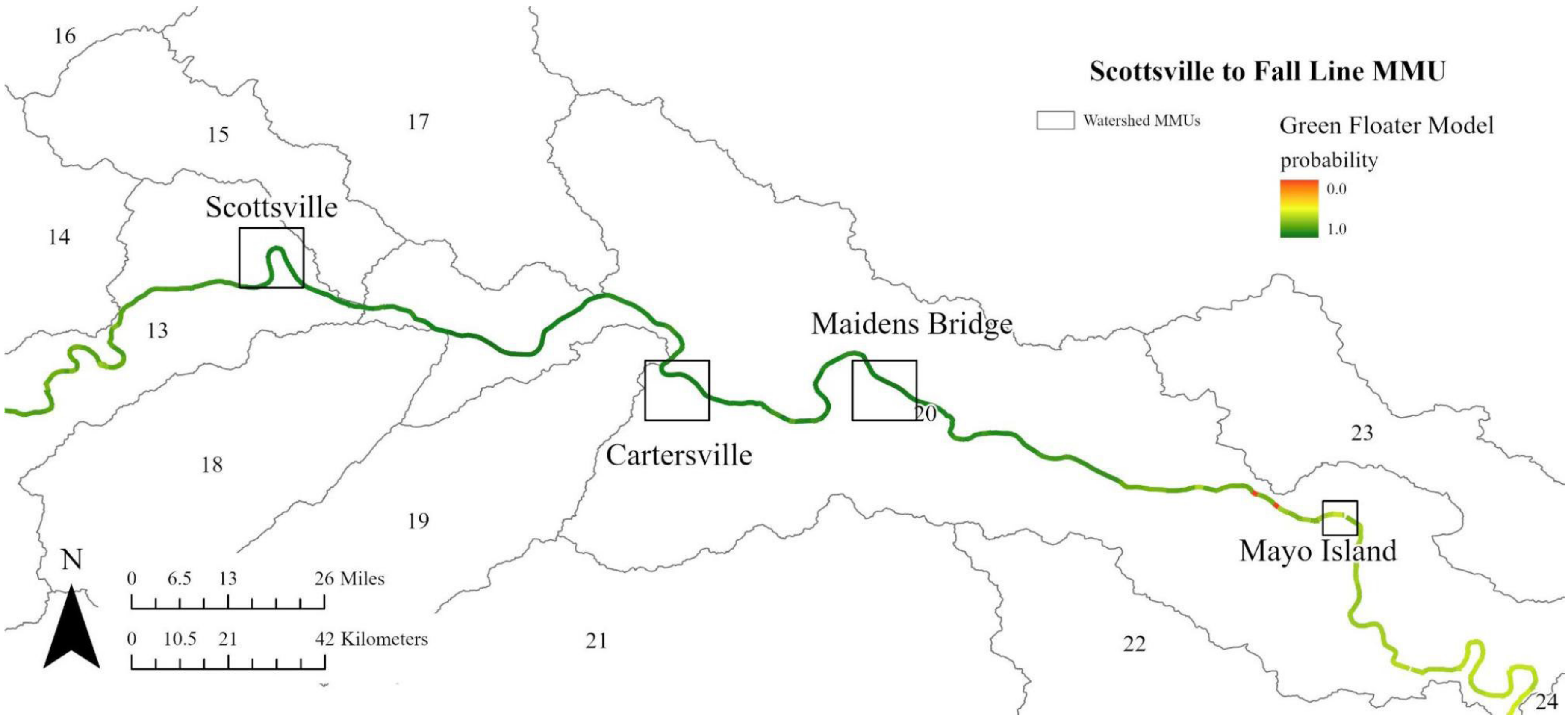


Figure 75. The DCR model suggests this MMU may provide many suitable habitats for Green Floater, especially in areas where restoration is ongoing: Scottsville, Cartersville, and Maidens Bridge (Data source: Virginia Natural Heritage Program 2022d).

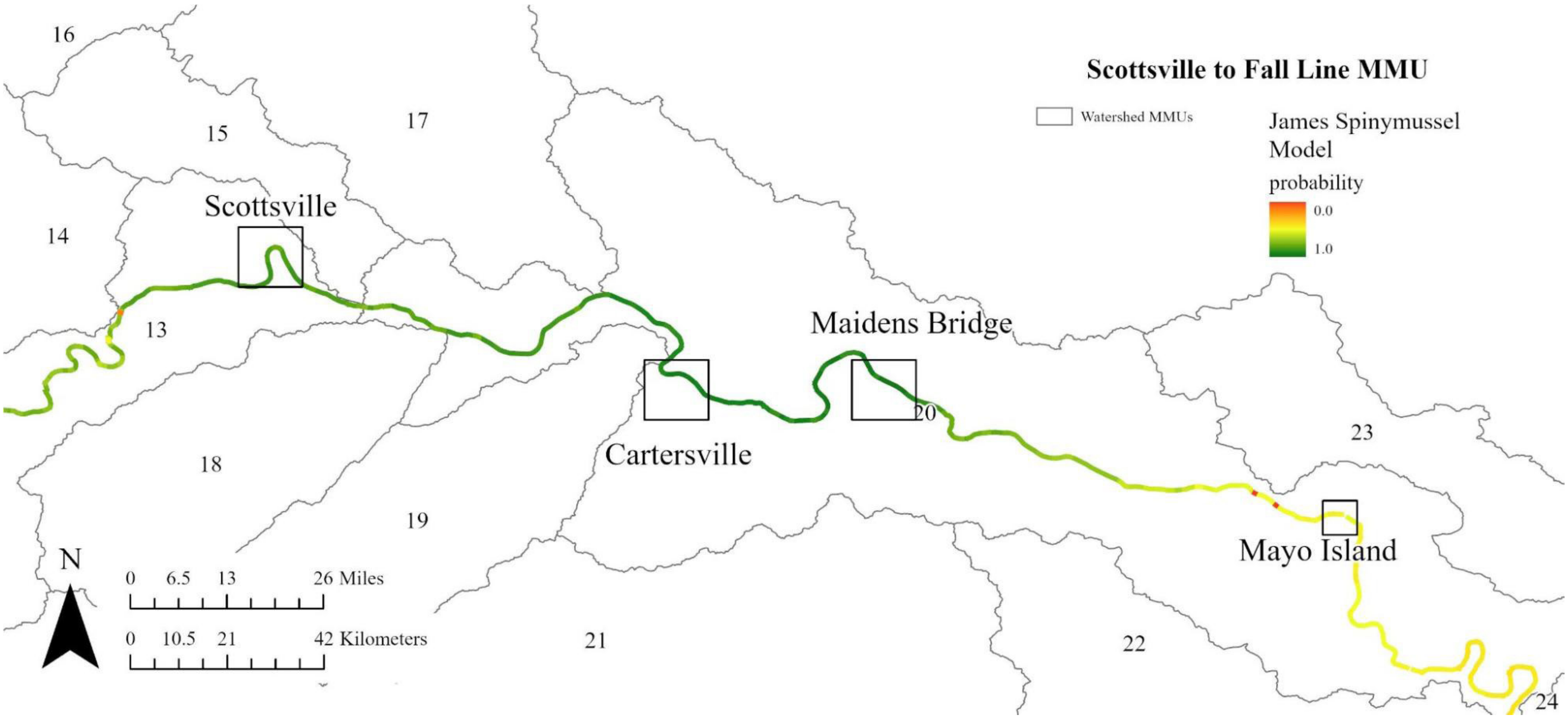


Figure 76. The DCR model suggests habitats from Scottsville to Maidens Bridge are suitable for James Spinymussel. Reaches near Richmond score much lower (Data source: Virginia Natural Heritage Program 2022e).

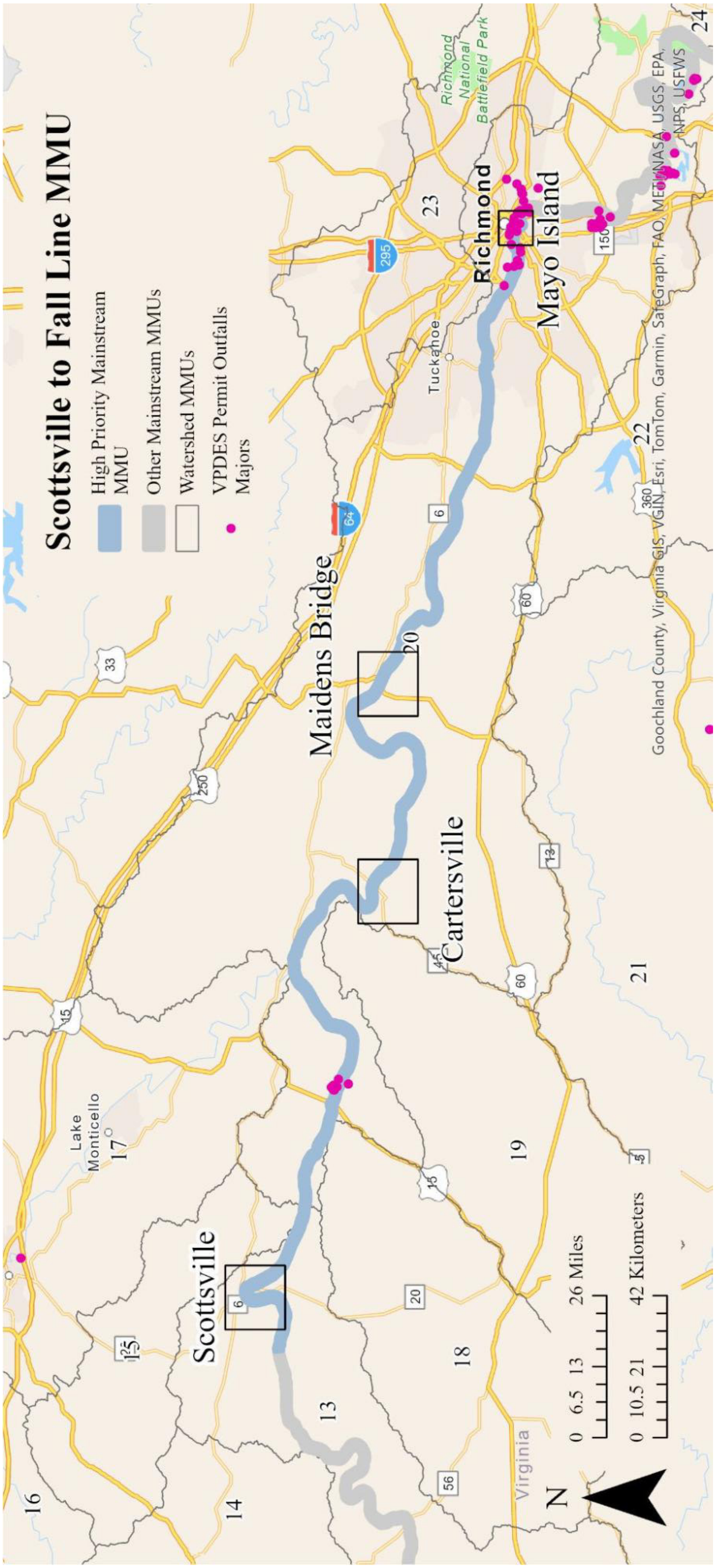


Figure 77. Threats from major permitted outfalls are present between Scottsville and Cartersvill, but most concentrated around Richmond and farther downstream.

GOALS FOR THE SCOTTSVILLE TO FALL LINE MMU

1. Assemblage with 7 species
    a. 80% Eastern Elliptio
    b. 20% comprised of the other 6 species; including any combination of the following species:
        i. All sites
            1. James Spinymussel
            2. Northern Lance
            3. Creeper
            4. Notched Rainbow
            5. Triangle Floater
            6. Atlantic Pigtoe
            7. Green Floater
            8. Yellow Lampmussel
            9. Eastern Lampmussel
            10. Brook Floater
        ii. Alewife Floater (augmentation/reintroduction is an option at the fall line site only)
2. Augmentation until mussel reach a density of 1 m^2 in well-defined suitable habitat
    a. This may need to include Eastern Elliptio to meet 1 m^2 (Chazal et al. 2012)
3. Augmentation and reintroduction of species to continue and expand until reaching the stated goals at the following locations:
    a. Scottsville
    b. Cartersville
    c. Maidens Bridge (Rte US 522)
    d. Fall Line (Mayo Island and other JRA planting sites)

ACTIONS FOR THE SCOTTSVILLE TO FALL LINE MMU

1. Define extent of optimal and suitable habitats
2. Establish bi-annual monitoring of density to guide augmentation/reintroduction efforts
3. Annual release of at least 10,000 juveniles of 3 propagated mussel species

ADDITIONAL SURVEYS

Expanding survey efforts have detected additional populations of rare species, especially James Spinymussel. In some parts of this plan specific survey needs have been detailed, such as those for the Upper Appomattox MMU, an area with great potential but little existing knowledge. Below is a list of MMUs that should be the focus of survey efforts in order of importance:

1. Cowpasture
2. Upper Appomattox
3. Under-sampled streams of the Upper Rivanna MMU: Mechums and Moormans Rivers
4. Upper Maury MMU outside of Mill Creek
5. Slate and Willis MMUs
6. Small Tidal Tributaries MMU, especially those streams threatened by sea level rise due to climate change
7. Chickahominy

OTHER PRIORITY MUSSEL MANAGEMENT UNITS

UPPER MAURY

This MMU contains one of the most substantial and isolated sites for mussels in the Valley and Ridge physiographic province of the James River Basin: Mill Creek (Figure 78). This tributary has been studied for well over a decade[21]. It supports a population of James Spinymussel in addition to several other species. The population will continue to be a source of broodstock for other nearby MMUs, most likely for the neighboring Cowpasture MMU. Mill Creek was also noted by Roderique (2018) as being a priority conservation area. This population is the most important factor elevating this MMU to a priority. Otherwise, the Upper Maury MMU is so similar to the Craig and Cowpasture MMUs, that inclusion as a high priority was considered redundant.

Beyond the reach of Mill Creek, streams in the Upper Maury and Lower Maury MMUs have excellent physical habitat but limited mussel resources. The Calfpasture (Upper Maury MMU), into which Mill Creek flows and whose headwaters follow a parallel path just east of Mill Creek, supports mussels, but has not received much attention in recent decades. The Little Calfpasture (Upper Maury MMU), which converges with the Calfpasture to form the Maury, also supports common species and has been sampled in the last 20 years. Other streams, including Hays Creek, may also support mussels but likewise have been undersampled. Historical records suggest the Lower Maury MMU, most notably the Maury River itself, supported detectable mussel assemblages and was inhabited by the James Spinymussel. This no longer appears to be the case, with recent surveys resulting in negative results for mussels. The Lower Maury MMU may have been more substantially disturbed by human activities, particularly industry around Lexington.

As mussels are thriving in at least one stream in the upper reaches of this watershed, there is potential for restoration for the entire stream network of both the Upper Maury and Lower Maury MMUs. Additional surveys are needed to understand distribution and status beyond Mill Creek in the Upper Maury MMU.

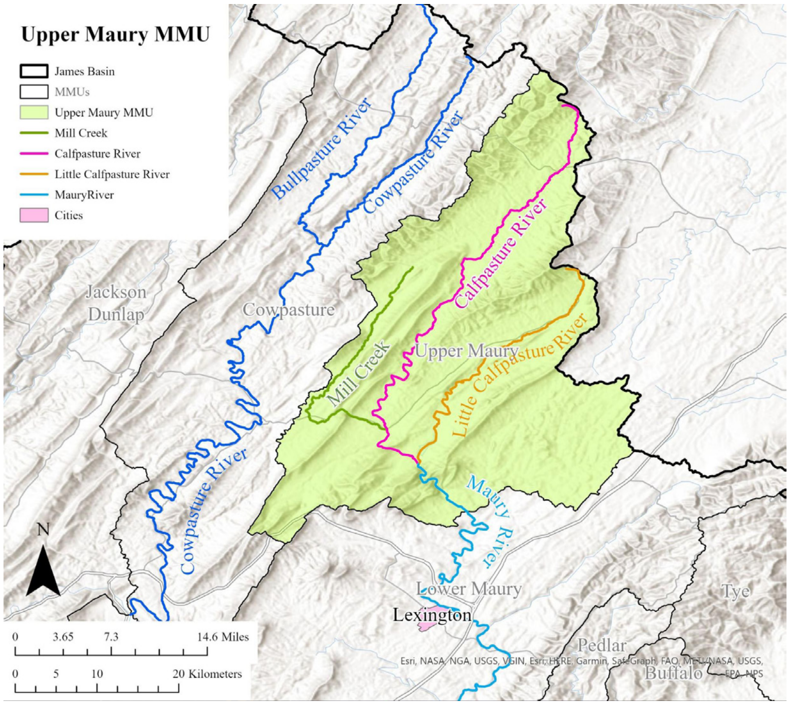


Figure 78. Mill Creek located in the Upper Maury MMU is an important freshwater mussel resource that can provide critical broodstock for neighboring MMUs. Other referenced streams are shown.

[21] Mill Creek has been part of the ongoing Capture-Mark-Recapture sampling program led by DWR (Ostby 2022a).

POTTS

The most important portion of this MMU lies in West Virginia. Surveys in the last 20 years demonstrate an unexpected decline in James Spinymussel detections in the Virginia portion of this MMU while the West Virginia populations (South Fork Potts) have remained stable (USFWS 2022c). There are several records from the Virginia portion in the 1980s but a comprehensive survey by Petty and Neves (2006) failed to detect James Spinymussel. The Virginia portion continues to support populations of Notched Rainbow, with other species apparently rare. The stream has minimal anthropogenic disturbance. Many feeding tributaries start on George Washington and Jefferson National Forest with the major stream, Potts Creek, meandering through pasture and often bordering forest lands. Petty and Neves (2006) hypothesized that cold water temperatures may limit James Spinymussel, as viable populations of the species persist in reaches of the South Fork Potts Creek that flow through pastures, where tree cover is limited and temperatures are presumed to be warmer. The stream network and land use in this MMU is similar to those of the Cowpasture, Craig, and Upper Maury MMUs.

The James Spinymussel population in the South Fork Potts Creek is the major reason this MMU is considered a priority. This population has remained fairly stable and also highly variable over the past 20 years (USFWS 2022c). Methodology used to monitor the population is suspected to underestimate populations (Kevin Eliason, per. comm.). No augmentation is proposed at this time but continued monitoring of this population is important. The USFWS and West Virginia DNR are the partners involved in periodic monitoring[22].

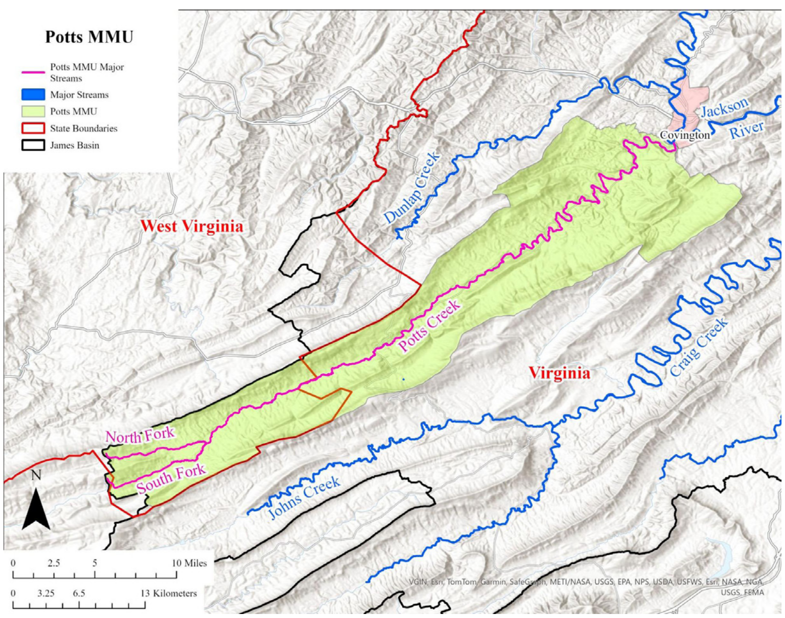


Figure 79. The West Virginia portion of Potts Creek located in the Potts MMU is an important freshwater mussel resource that can provide critical broodstock for neighboring MMUs. The West Virginia DNR monitors this population. Nearby streams are shown.

[22] The West Virginia Department of Natural Resources plans to monitor at least every 5 years with the next regularly scheduled monitoring in 2026 (K. Eliason, WVDNR)

PEDLAR

The Pedlar supports low density populations of James Spinymussel and Green Floater but seems to underperform given land use patterns. To its advantage, the MMU faces limited development pressure, has headwaters in George Washington and Jefferson National Forest, and is protected as a drinking water source for the City of Lynchburg (https://www.lynchburgva.gov/drinking-water-quality-report, 10/1/2023).

Periodic surveys of the Pedlar River should be conducted to understand the status of James Spinymussel and Green Floater populations. Mussels from this MMU could be used as broodstock for the James River itself.

Figure 80. James Spinymussel in Pedlar River.

TYE

This MMU is of particular interest due to the presence of Green Floater. It is the one MMU in the James River Basin where Green Floater is routinely detected. It also supports James Spinymussel, which was not known until the past decade. This population of James Spinymussel was augmented in 2019 with releases occurring at four sites. Otherwise, it supports a limited number of species, including Triangle Floater, Eastern Elliptio, Creeper, Paper Pondshell, and Notched Rainbow.

Biologists cited that one of its tributaries, Piney River, has substantial risks with outfalls, making it a risk for work. Review of VPDES found no major permits but a grouping of unclassified permits. This MMU may not support the assemblages and habitats it once did, as it was disproportionately affected by Hurricane Camille in 1969. The MMU may have experienced rainfall exceeding 25 inches in a day creating a catastrophic scour of the river channel. Resulting stream channel work to alleviate flooding, likely has led to long-term impacts through flow and substrate modifications (e.g, channel straightening).

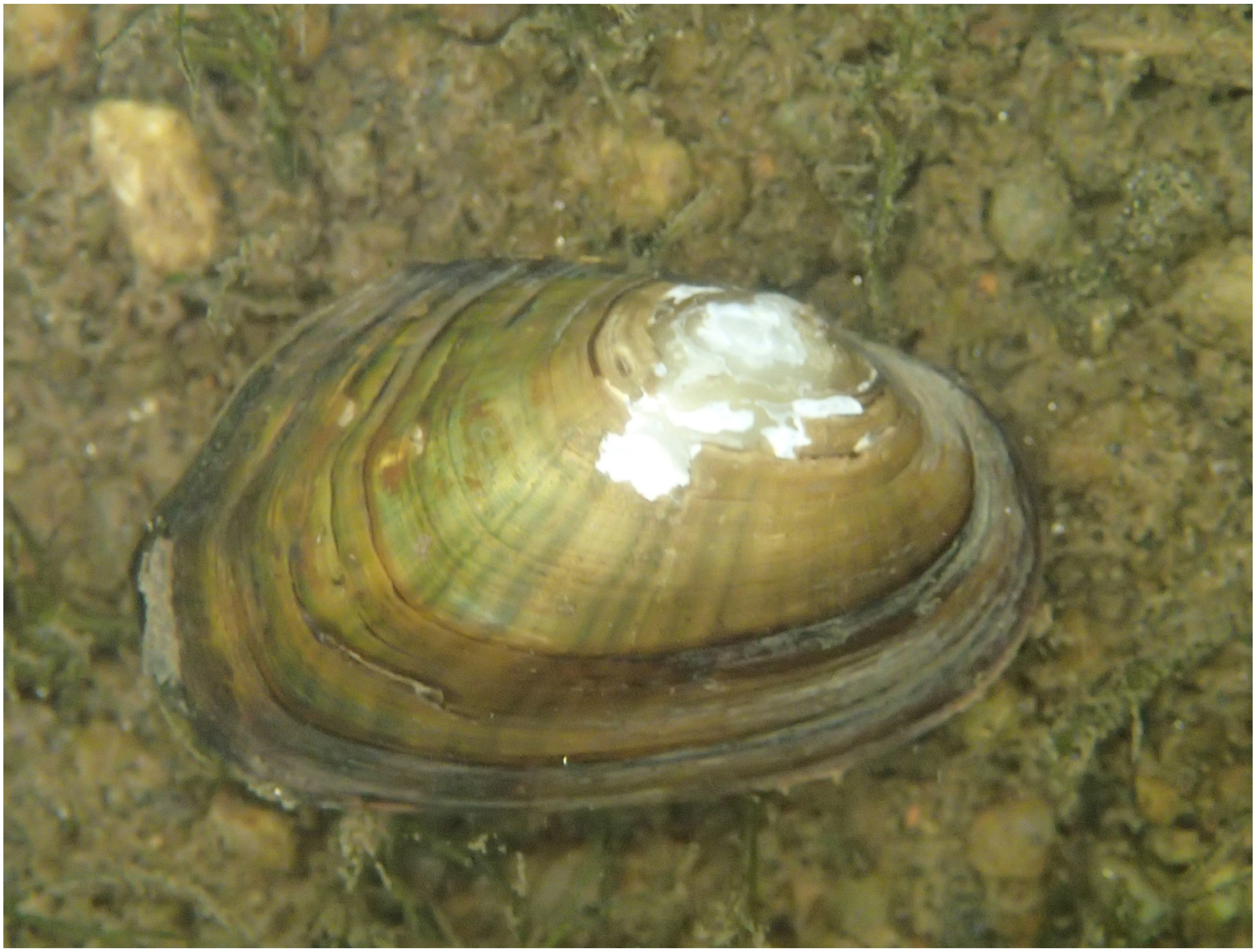


Figure 81. Green Floater.

CHICKAHOMINY

This MMU has a range of conditions, with its western headwaters starting in the Piedmont physiographic province, where its streams are affected by present and future urban expansion of the Richmond metropolitan area, and its mouth and downstream tributaries affected by tidal influences. Some species that are rare in the James River Basin have been documented in the Chickahominy MMU, including Tidewater Mucket and an additional *Elliptio* species[23]. There is also a historical record for Alewife Floater in the MMU. This MMU should receive more survey effort and contains habitats not otherwise represented among the high priority MMUs (mostly tidal influenced streams). Thus, it was listed as a priority.

Figure 82. The Chickahominy River near Bottoms Bridge.

[23] Records of Variable Spike (*E. incternia*) in the James River Basin are debated, with DWR having records but identification uncertain. This species was not included in Mussels of the James River Basin.

SMALL TIDAL TRIBUTARIES

In general, this MMU was not considered a high priority due to risks from rising sea levels as a consequence of climate change. That does not preclude restoration work targeting specific streams that benefit species not otherwise targeted[24]. This MMU has a limited amount of habitat due to tidal influence, but could support species not commonly prioritized, such as Alewife Floater and Tidewater Mucket. One tributary, Wards Creek, was identified as a stream that needs more study (Figure 83). Streams of this MMU could be easily stocked with Alewife Floater, with the goal to restore ecosystem integrity and augment a species persisting at apparent low abundances.

The James River Association has already started to augment populations in Wards Creek and Flowerdew Hundred Creek (Alewife Floater). Due to the relative ease of production, this activity should continue as resources allow, provided the work does not displace efforts on higher priority MMUs. Bukaveckas et al. (2023) suggest planting can be successful in rural streams of this MMU, with specific work in Herring Creek. Virginia Fisheries and Aquatic Wildlife Center at Harrison Lake National Fish Hatchery is located on Herring Creek, making this an easy investment.

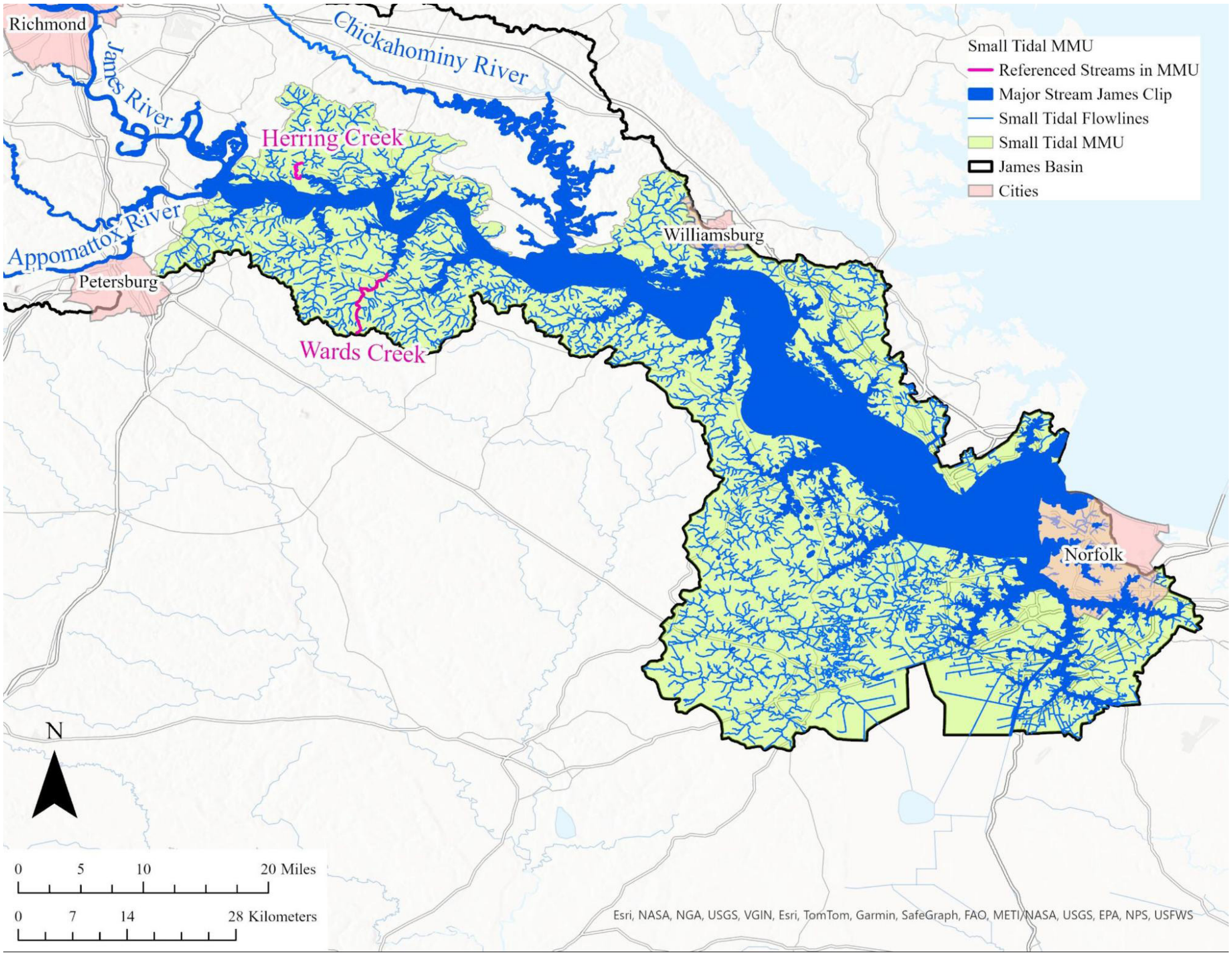


Figure 83. Wards Creek and Herring Creek are streams in the Small Tidal Tributaries MMU where mussel restoration work is ongoing. Virginia Fisheries and Aquatic Wildlife Center at Harrison Lake National Fish Hatchery is located on Herring Creek.

[24] This plan has underrepresented Coastal Plain streams. This acknowledged shortcoming was due to coincidence of risk with this physiographic province and greater occurrences of state and federally listed species in Valley and Ridge and Piedmont streams.

WILLIS AND SLATE MMUS

These neighboring MMUs are piedmont stream networks. These MMUs also contain large tracts of state forest and have little urban development, mostly constrained to road corridors. Both are relatively understudied, with recent surveys documenting greater richness in the Slate MMU (ESI 2016, Ostby 2021). Species documented in these neighboring MMUs include Triangle Floater, Eastern Elliptio, Northern Lance, and Creeper. The Eastern Floater, Notched Rainbow and Paper Pondshell were documented in either but not both MMUs. All should be considered members of the assemblages of both MMUs, with an assumed maximum assemblage richness of 7. No federally or state-listed species have been detected in these MMUs but the Slate watershed borders Rock Island Creek. A previously unknown population of James Spinymussel was detected in Rock Island Creek in 2011 (Chazal et al. 2012). These MMUs could also be occupied by Green Floater.

LYNCHBURG TO RIVANNA RIVERS

The 2011-2012 surveys (Chazal et al. 2012) detected James Spinymussel in Rock Island Creek and Totier Creek. The Rock Island Creek population was previously unknown. Rock Island Creek is a stream flowing directly into the James River, it is one of many similar streams in this MMU. Given positive survey results, streams in this MMU should be secondary priorities for future surveys and monitoring. James Spinymussel populations in this MMU are important redundancies and could be sources for natural restoration in the mainstream James River.

Using broodstock from Rock Island Creek, James Spinymussel was augmented from 2017-2019 at two long-term, Capture-Mark-Recapture (CMR) sites in this stream. One of these sites was significantly altered in 2018 by record rainfall and one particular flooding event, while the other site remains somewhat stable. CMR surveys should continue in Rock Island Creek as should monitoring of released James Spinymussel.

AROUND RICHMOND

The JRA has cooperated with DWR to release Alewife Floater in two streams around Richmond; Falling Creek and Turkey Island Creek. These tributaries flow directly into the James River. Opportunities for continued stocking of Alewife Floater should continue as resources are available. The status of mussels in these streams also warrants more assessment.

Figure 84. Hatchery raised mussels are often laser tagged prior to release, with a portion also marked with Passive Integrated Transponders (PIT tags), to facilitate recapturing and monitoring the mussels over time

GUIDANCE FOR PARTNERS

This plan focuses on population augmentation and reintroduction. These are not the only tools for protecting and restoring freshwater mussel assemblages. Other agencies (e.g. NRCS, USFWS, VDWR) and partners (e.g. JRA, Chesapeake Bay Foundation) are working in the basin to improve habitat and minimize human disturbances. Funding sources not directly tied to mussel restoration can be used to increase the probability that work planned in this document can succeed. It is hoped that partners will focus activities to MMUs and sites within that are priorities. However, it is acknowledged that work will proceed in non-priority MMUs based on other goals and priorities, or due to spatially explicit funding (such as work that can only happen in a county, watershed, or private parcel). It is not the intention for this plan to limit mussel restoration work to priority MMUs, but to focus limited resources to areas where positive outcomes are more likely. Work to improve habitat, water quality, and mussel populations is important and should be pursued throughout the James River Basin.

ADDITIONAL CONSERVATION PLANS FOR REFERENCE

There are other conservation planning documents and data available that may be useful for the reader, particularly when making the case for durable value in funding applications. Often, the outcomes of conservation efforts are most effective when multiple conservation problems are addressed and actions are taken. This is best done by multiple partners entering into cooperative efforts. However, the mussel population restoration work can only effectively occur in specific reaches of the James River Basin. This focus is critical for efficient use of limited resources and ecologically meaningful outcomes. Supportive activities could include land protection through fee simple purchase and easements, programs to improve water quality by reducing sediment and nutrients, adherence to development controls, and removing barriers such as dams and culverts.

The Virginia Department of Conservation and Recreation (DCR) Natural Heritage Program has drafted a broadly focused, and biotically encompassing, conservation plan titled ConservationVision. Data and WebMaps from this effort are available online at https://www.dcr.virginia.gov/natural-heritage/vaconvision. Data layers include watershed impacts, natural landscapes, agriculture, potential rare species richness, and forest conservation. As the reader can see, these aspects all complement and impact this plan's goals.

One priority of conservation investments is long term durability of the action's impacts. This requires an understanding of the landscape level and local threats to an ecosystem's ecological integrity. One upcoming analysis that addresses the landscape-scale aspect is the Resilient and Connected Freshwater Network analysis conducted by The Nature Conservancy Center for Resilient Conservation Science (due in 2024). This analysis is a good screening tool identifying stream and lake systems that could sustain representative aquatic biodiversity and are likely to retain ecological integrity as climate shifts occur. The analysis is based on physical landscape factors, stream system connected length, land use, and conservationally important biotic distributions. All 4 of the High Priority MMUs are totally or predominantly composed of HUC-12s identified as resilient in the current draft of this analysis. The lower portion of the Upper Appomattox MMU is the sole exception as an area with average or slightly above average resiliency.

The Chesapeake Bay Comprehensive Water Resources and Restoration Plan (CHESAPEAKE BAY COMPREHENSIVE WATER RESOURCES AND RESTORATION PLAN (arcgis.com), produced by the US Army Corps of Engineers (USCOE), is another useful framework for conservation. This analysis focuses on restoration needs and potential and has identified watershed stressors, restoration focal areas, and riparian restoration focal areas. Not surprisingly, the Craig Creek and Cowpasture River MMUs are identified as low stressor watersheds, the Upper Rivanna River MMU as mixed, and the Upper Appomattox River MMU as a moderately low stressor watershed. The Upper Appomattox River MMU and the North Fork Rivanna River are identified as stream restoration priorities. The riparian buffers layer also may help identify potential collaborations.

Collectively, these analyses and others may strengthen funding requests, help identify places where partners can support mussel restoration with other conservation activities, and help place the mussel restoration work identified in this plan into context basin-wide.

UNDERUTILIZED OPPORTUNITIES

Presently, USFWS and DWR use relocations as a mitigation tool when populations of native mussels are impacted by regulated activities, such as bank stabilizations and bridge construction. These relocations could be turned into translocations, with the goal of population augmentation or reintroduction. If the number of mussels to be moved from a specific site exceeds that which is needed to maintain abundances or insure persistence in a given stream or river reach, these individuals could be used to seed a reintroduction site elsewhere or to add a species to an established assemblage. Sites and streams mentioned in this plan should be priorities; however, regulatory agencies should encourage applicants to provide funding for biologists to find alternative sites when opportunities arise. These could be part of permit guidance or included in guidance documents. This may be particularly important for restoring populations of Eastern Elliptio, Northern Lance, and Notched Rainbow. These species often dominate relative abundances and occur at densities exceeding self-sustainability. For example, Eastern Elliptio could be restored to reaches of the James River where it has been apparently extirpated, such as the upper reaches of the Potts to Pedlar Mainstream MMU. Notched Rainbow is often limited to upstream habitats, such as small streams in the Upper Rivanna River MMU. This species could be moved to augment assemblages in Mainstream MMUs. To be effective, translocations would require large numbers of mussels, >1,000, and might need to be paired with releases of propagated mussels.

The Johns Creek James Spinymussel metapopulation is dynamic, with local abundances fluctuating greatly among years. When years of relatively high abundance are observed, dozens if not hundreds of mussels could be translocated to augment other populations in the Craig Creek MMU, especially at sites like Anderson and Carter fords, where this species persists at extremely low levels. Often during years of high abundance, James Spinymussel are preyed upon by raccoons, so removal from the source site might mimic a natural predation event. Careful monitoring would be required to validate no negative impact on the donor population dynamics.

The VFAWC can produce large numbers of Alewife Floater with relatively minimal effort (Pers. com. Rachel Mair, 1/27/23). These propagated mussels were reared from broodstock collected in other drainages, such as the Rappahannock. The JRA has already released this species in 4 sites; Wards Creek and Flowerdew Hundred Creek in the Tidal MMU, Turkey Island Creek and Falling Creek in the Small Direct Tributaries Rivanna to Richmond MMU (Pers. comm. Erin Reilly, 5/19/23). While this plan deprioritized many MMUs where Alewife Floater might be present, this may be an opportunity for non-profit partners or other groups to pursue. Results from Bukaveckas et al. (2023) suggest planting can be successful in rural streams of the Small Tidal MMU.

ENDANGERED SPECIES REGULATORY HURDLES

This plan relies heavily on propagation facilities. It is intended that propagated mussels will be the primary means of population augmentation, species reintroductions, and species establishments (see Propagation Facilities Working with James River Basin Species).

According to the Virginia Department of Wildlife Resources, **augmentation** is defined as the release of a species in a river reach where it currently exists. **Expansion** is the release of a species into suitable historical habitat in a river reach from which it has been extirpated, but where specimens currently survive upstream or downstream, and natural recolonization could occur. Release of species into such reaches that could be naturally colonized, but for which no records exist of the species' historical occurrence, would also be considered to be population expansions. **Reintroduction** is the release of a species into suitable historical habitat from which it has been extirpated, and where natural recolonization cannot reasonably be anticipated. **Establishment** is defined as the release of a species into suitable habitats in reaches for which no records exist of the species' historical occurrence, and where natural colonization cannot reasonably be anticipated. As detailed above, the historical assemblage for the entire basin was derived from records to the north and south of the James River Basin. The assumption that species such as Dwarf Wedgemussel and Brook Floater are members of the assemblage are biologically sound, with both habitat and fish hosts present. In the latter case, its presence may have been detected (Mainstream James River - Scottsville to Fall Line), and in the former case, its presence was documented in the 1800s in the Maury River, Lexington. These species, and others, are listed as potential establishments for specific MMUs. There are, however, regulatory hurdles to propagation and augmentation/expansion/reintroductions/establishments and also issues with the genetics of source populations. Both need to be addressed before execution of some actions in this plan.

These regulatory hurdles are appropriate given the risks to biodiversity and genetic diversity that reintroductions and augmentation can pose. There is also a more generalized risk of unintended ecosystem consequences. Nevertheless, recent analyses have demonstrated that risks from strategic translocations (e.g. reintroductions) have been greatly exaggerated (Novak et al. 2021). In a meta-analysis of 125 years of conservation translocations, Novak et al. (2021) found that such actions routinely yielded indeed benefits without causing harm, with ecological damage only occurring in cases where conservation practices and regulation were absent. Also surprising was the recent finding by Inoue et al. (2023), that propagated offspring from a single female mussel can retain high levels of population diversity. This was due to genetic material from multiple sires being present in the offspring from a single female.

In Virginia, both the USFWS and the DWR have joint authority to make decisions regarding propagation and establishment/reintroduction/augmentation/expansion of the Dwarf Wedgemussel, Yellow Lance, Atlantic Pigtoe, and James Spinymussel. These agencies have to be in agreement for any action to proceed. DWR permits are required and USFWS 10(a)(1)(A) recovery permits may be required. It is hoped this plan will facilitate those actions. The USFWS highly recommends developing propagation plans for federally listed species for approval by USFWS and DWR in accordance with the USFWS and NOAA's Policy Regarding Controlled Propagation of Species Listed Under the Endangered Species Act (65 FR 56916)[26]. Otherwise, DWR has primary authority on all other non-federally listed species. Both these agencies also coordinate with local government units (LGUs), such as County Boards of Supervisors, to approve projects[27]. Goals and actions in this plan are based on ecology and relative risk, not regulatory authority and agency priorities. This plan has provided justification for working with these species in the James River Basin and in some cases specific MMUs, which the USFWS can use in combination with SSA, Recovery Plans, and other reviews.

[26] USFWS 10(a)(1)(A) recovery permits and propagation plans are required under certain circumstances. Please contact USFWS for additional information.

[27] Code of Virginia, 29.1-103. Powers and duties of the Board, states "The Board is responsible for carrying out the purposes and provisions of this title and is authorized to: 6. Acquire and introduce any new species of game birds, game animals, or fish on the lands and within the waters of the Commonwealth, with the authorization and cooperation of the local government for the locality where the introduction occurs."

1. **Dwarf Wedgemussel**: The James River Basin is considered a historical location for the species (USFWS 1993) but was not discussed in the most recent 5-year review (USFWS 2019b). This needs to be addressed. This species has a considerably wide historic range being documented in basins to the north and south in Virginia, with an extant population in the Po River (Virginia) and at least 2 more in North Carolina. Many habitats in the James River Basin have favorable suitability based on DCR models. It is more likely that absence is due to a failure to detect, with most sampling possibly occurring after decline or extirpation, and disproportionately focused in habitats unlikely to support this species. The USFWS (2019b) review demonstrated that many populations have declined since listing and are considered extirpated. While there appears to be no limit to habitats where this species should be restored, the James River Basin should be considered for reintroduction.
2. **Yellow Lance**: Only the Craig Creek MMU has an extant Yellow Lance population. There is uncertainty of detection in the Cowpasture MMU. Given the apparent reductions in numbers and range for this species in the Rappahannock as documented in Carey and Ostby (2022), Yellow Lance recovery approaches should consider augmentation/expansion/reintroduction in the Craig Creek MMU, including potential use of broodstock from the Rappahannock basin.
3. **Atlantic Pigtoe**: Working with this species may require more aggressive efforts to collect individuals in the Craig Creek MMU for propagation. A single female may be sufficient to preserve genetic diversity. There are many historical records for this species in the James River Basin; reintroductions may be appropriate for the Upper Appomattox MMU. Individuals from the nearby Nottoway River may be the most appropriate broodstock for the Appomattox MMU. However, broodstock might need to be obtained from sites in NC as there are no known strongholds in the Nottoway River.
4. **James Spinymussel**: Propagation of this species has been relatively successful in Virginia. Propagation plans should be based on the best available genetic analysis and should prioritize broodstock from the nearest sources. Unlike any of the aforementioned federally listed species, there are several populations with ample broodstock.

There are MMUs and sites where DWR could start to work with Brook Floater and Green Floater. There are also opportunities for DWR to establish/reintroduce species that may have been part of the historical assemblage, including Yellow Lampmussel, Eastern Lampmussel and Eastern Pondshell. In fact, in conjunction with JRA, DWR has released Yellow Lampmussel in the James River in Richmond and in Lynchburg. With recent successes in propagating and rearing Brook Floater in Virginia, DWR should consider reintroductions to habitats already supporting associated species and with low relative risks.

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APPENDIX A: LIFE HISTORY STRATEGIES AND HOST FISH

Table A1. Host fish with citations referenced with numbered superscript. Based on Jenkins and Burkhead (1994), fish native to the James Basin are in Bold, introduced but present in orange, and with marine or estuary origins native or introduced in red. Preferred propagation species column is a list provided during planning meetings or notable information from reviewed sources.

Species	Specificity	Documented Fish Host Species	Preferred Propagation Species
Dwarf Wedgemussel	Cottidae[1] Percidae[1]	**Tessellated Darter** (*Etheostoma olmstedi*)[1] **Johnny Darter** (*Etheostoma nigrum*)[1] **Mottled Sculpin** (*Cottus bairdi*)[1]	
Traingle Floater	Generalist	**Blacknose Dace** (*Rhinichthys atratulus*)[2,4,5] **Longnose Dace** (*Rhinichthys cataractae*)[2,4] **Common Shiner** (*Luxilus cornutus*)[2,3,4] **Fallfish** (*Semotilus corporalis*)[4] **Central Stoneroller** (*Campostoma anomalum*)[3] **White Sucker** (*Catostomus commersonii*)[4] **Pumpkinseed** (*Lepomis gibbosus*)[3,4] **Northern Hogsucker** (*Hyprentelium nigricans*)[3] Fantail Darter (*Etheostoma flabellare*)[3] Slimy Sculpin (*Cottus cognatus*)[3,4] Largemouth Bass (*Micropterus salmoides*)[3,4] Blackside Darter (*Percina maculata*)[6] Rosyface Shiner (*Notropis rubellus*)[3] Spotfin Shiner (*Cyprinella spilotpera*)[6]	
Brook Floater	Generalist	**Brook Trout** (*Salvelinus fontinalis*)[7] **Longnose Dace** (*Rhinichthys cataractae*)[2] **Blacknose Dace** (*Rhinichthys atratulus*)[5] **Pumpkinseed** (*Lepomis gibbosus*)[5] Slimy Sculpin (*Cottus cognatus*)[5,7] **Margined Madtom** (*Noturus insignis*)[8] **Golden Shiner** (*Notemigonus crysoleucas*)[8] **Yellow Perch** (*Perca flavescens*)[8]	
Tidewater Mucket	Specialist (Moronidae)	White Perch (*Morone americana*)[9]	Additional hosts may be possible based on natural infestation studies[24]

Species	Specificity	Documented Fish Host Species	Preferred Propagation Species
Eastern Elliptio	Generalist in lab, speculated to work best on American Eel	**American Eel** (*Anguilla rostrata*)[10] Banded Killifish (*Fundulus diaphanus*)[11] Green Sunfish (*Lepomis cyanellus*)[11] Largemouth Bass (*Micropterus salmoides*)[11] Orangespotted Sunfish (*Lepomis humilis*)[11] White Crappie (*Pomoxis annularis*)[11] **Yellow Perch** (*Perca flavescens*)[12] Bluegill (*Lepomis macrochirus*)[13] **Pumpkinseed**(*Lepomis gibbosus*)[13] **Mottled Sculpin** (*Cottus bairdi*)[14] Slimy Sculpin (*Cottus cognatus*)[14] Lake Trout (*Salvelinus namaycush*)[14] **Brook Trout** (*Salvelinus fontinalis*)[14]	In vitro, Brook Trout/ Largemouth Bass (variable by lab)
Carolina Slabshell	Unknown	Unknown	
Nothern Lance	Generalist	**Johnny Darter** (*Etheostoma nigrum*)[15,16] Largemouth Bass (*Micropterus salmoides*)[15,16] Bluegill (*Lepomis macrochirus*)[15,16] White Shiner (*Luxilus albeolus*)[15,16] **Satinfin Shiner** (*Cyprinella analostana*)[16]	Ashton (2008) suggests additional host present in Maryland based on fish host study
Yellow Lance	Cyprinidae	White Shiner (Luxilus albeolus)17 Pinewoods Shiner (Lythrurus matuntinus)17	Identified fish host not in Virginia; In vitro (SSA)
Atlantic Pigtoe	Tending toward Cyprinidae	**Longnose Dace** (*Rhinichthys cataractae*)[18] **Creek Chub** (*Semotilus atromaculatus*)[18,19] Bluegill (*Lepomis macrochirus*)[15,16] **Shield Darter** (*Percina peltata*)[15,16] **Rosefin Shiner** (*Lythrurus ardens*)[18] **White Shiner** (*Luxilus albeolus*)[19] **Satinfin Shiner** (*Cyprinella analostana*)[19] **Bluehead Chub** (*Nocomis leptocephalus*)[19] **Rosyside Dace** (*Clinostomus funduloides*)[19] Pinewoods Shiner (*Lythrurus matuntinus*)[19] **Swallowtail Shiner** (*Notropis procne*)[19] **Mountain Redbelly Dace** (*Chrosomus oreas*)[19]	Wolf and Emrick (2011) suggest Longnose Dace & Creek Chub may be best hosts; Planning group listed White Shiner (not native to James)
Yellow Lampmussel	Species tolerant of higher salinity (Moronidae)	**Yellow Perch** (*Perca flavescens*)[9] White Perch (*Morone americana*)[9] Largemouth Bass (*Micropterus salmoides*)[20] White Bass (*Morone chrysops*)[21] Striped Bass (*Morone saxatilis*)[21] **Black Crappie** (*Pomoxis nigromaculatus*)[21]	Largemouth Bass Additional hosts may be possible based on natural infestation studies24

Species	Specificity	Documented Fish Host Species	Preferred Propagation Species
Eastern Lampmussel	Tending toward Centrarchidae	**Yellow Perch** (*Perca flavescens*)[21,22] Largemouth Bass (*Micropterus salmoides*)[21,22] **Black Crappie** (*Pomoxis nigromaculatus*)[22] **Pumpkinseed** (*Lepomis gibbosus*)[23] Rock Bass (*Ambloplites rupestris*)[23] Smallmouth Bass (*Micropterus dolomieu*)[22] White Perch (*Morone americana*)[22]	Lampsilis species tend to use Centrarchidae species
Green Floater	None needed	Metamorphosis in marsupium[25,26]	Black nose dace, mottled sculpin, rock bass, central stoneroller, margin madtom (JWJ)
James Spinymussel	Cyprinidae (nest associates)	**Bluehead Chub** (*Nocomis leptocephalus*)[27] **Rosyside Dace** (*Clinostomus funduloides*)[27] **Blacknose Dace** (*Rhinichthys atratulus*)[27] **Mountain Redbelly Dace** (*Phoxinus oreas*)[27] **Rosefin Shiner** (*Lythrurus ardens*)[27] **Satinfin Shiner** (*Cyprinella analostana*)[27] **Central Stoneroller** (*Campostoma anomalum*)[27] **Swallowtail Shiner** (*Notropis procne*)[27]	Rosyside Dace, Mountain Redbelly Dace highlighted by planning group
Eastern Floater		Common Carp (*Cyprinus carpio*)[12,28] **White Sucker** (*Catostomus commersonii*)[29,32] **Pumpkinseed** (*Lepomis gibbosus*)[30,32] Threespine Stickleback (*Gasterosteus aculeatus*)[31] Rock Bass (*Ambloplites rupestris*)[32]	Bluegill and yellow perch possible, referenced but unable to find original documentation
Eastern Pondmussel		**Yellow Perch** (*Perca flavescens*)[21] Bluegill (*Lepomis macrochirus*)[21] Largemouth Bass (*Micropterus salmoides*)[21] **Pumpkinseed** (*Lepomis gibbosus*)[21]	

Species	Specificity	Documented Fish Host Species	Preferred Propagation Species
Creeper	Extreme generalist; including amphibians	Susquehanna River list most relevant: Longnose Dace (*Rhinichthys cataractae*)[32,34,35] Common Shiner[32] Rock Bass[32] Yellow Perch[32] Largemouth Bass[32,33, 34] River Chub[32] Tessellated Darter[32] Slimy Sculpin[32,35] Blacknose Dace (*Rhinichthys atratulus*)[32,34] Brook Trout[32] Yellow Bullhead[32] Cental Stoneroller[32] River Chub[32] Rainbow Trout[32] Atlantic Sturgeon[32] Fallfish[35] Golden Shiner[35] Eastern Newt[32] Northern Two-lined Salamander[35] Creek Chub[33] Fathead Minnow (*Pimephales promelas*)[34] Brook Stickleback (*Pimephales promelas*)[34] Bluntnose Minnow (*Pimephales notatus*)[34] Slenderhead Darter (*Percina phoxocephala*)[34] Northern Redbelly Dace (*Chrosomus eos*)[34] Rainbow Darter (*Etheostoma caeruleum*)[34] Logperch (*Percina caprodes*)[34] Centeral Mudminnow (*Umbra limi*)[34] Blackside Darter (*Percina maculata*)[34] Creek Chub (*Semotilus atromaculatus*)[34] Iowa Darter (*Etheostam exile*)[34]	Planning group noted Blacknose dace, in vitro Extreme diversity in host matches extreme distribution, maybe population differences?
Paper Pondshell	Extreme generalist, possibly none needed[42]	Possibly unlimited Transformations on a range of non-native and native species[43]	Tests with wide variety of non-native fish available in international aquarium trade and amphibians can transform juveniles in laboratory settings [36] Dickenson and Seitman (2008) suggest no need for host

Species	Specificity	Documented Fish Host Species	Preferred Propagation Species
Alewife Floater	Anadromous fish	Alewife (*Alosa pseudoharengus*)[37,38] Blueback Herring (*Alosa aestivalis*)[39] American Shad (*Alosa sapidissima*)[39] White Perch (*Morone americana*)[38] **White Sucker** (*Catostomus commersonii*)[38] **Pumpkinseed** (*Lepomis gibbosus*)[38] Threespine Stickleback (*Gasterosteus aculeatus*)[29]	
Notched Rainbow	Darters[40] Centrarchidae secondary	**Fantail Darter** (*Etheostoma flabellare*)[40] Sand Shiner (*Notropis stramineus*)[41] **Central Stoneroller** (*Campostoma anomalum*)[41] Blackside Darter (*Percina maculata*)[41] **Tessellated Darter** (*Etheostoma olmstedi*)[41] Logperch (*Percina caprodes*)[41] **Yellow Perch** (*Perca flavescens*)[41] **Redbreast Sunfish** (*Lepomis auritus*)[41] Longear Sunfish (*Lepomis megalotis*)[41] Smallmouth Bass (*Micropterus dolomieu*)[41] Rock Bass (*Ambloplites rupestris*)[41]	Eads et al. (2006)[40] makes argument that darters maybe best choice, other transformations, including Centrarchidae but low juvenile production Watters (1999)[41] found transformation on non-native fish available in international aquarium trade

Table A2. Host fish references

#	Reference	Type and Note
1	Michaelson and Neves 1995	peer review published
2	Strayer and Jirka 1997	indirect references based on per. communications
3	Watters et al. 1998a	published
4	Nedeau et al. 2000	indirect references based on per. communications and gray literature
5	Fichtel, C. and D.G. Smith 1995	indirect references based on per. communications and gray literature
6	Watters et al. 1998b	from fish host database
7	Skorupa et al. 2022	published
8	Schultz and Marbain 1998	indirect references based on per. communications and gray literature
9	Wick 2006	thesis
10	Galbraith 2018	published
11	Young 1911	published
12	Lefevre and Curtis 1912	published
13	Watters et al. 2005	published gray
14	Lellis et al. 2013	published
15	Watters and O'Dee 1997b	published gray
16	O'Dee and Watters 2000	published gray

#	Reference	Type and Note
17	Eads and Levine 2009	report
18	Wolf and Emrick 2011	report
19	Eads and Levine 2011	report
20	Eads et al. 2007	report
21	Eads et al. 2015	published
22	Tedla and Ferando 1969	listed as natural infestation observations
23	Hanek and Fernado 1978	listed as natural infestation observations
24	Kneeland and Rhymer 2008	published natural infestation observations using DNA markers
25	Barfield and Watters 1998	published gray
26	Lellis and King 1998	published gray
27	Hove 1990	thesis initially, then published
28	Lefevre and Curtis 1910	published
29	Wiles 1975	published, natural infestation
30	Conner 1905	published, natural infestation
31	Threlfall 1986	published, natural infestation
32	van Snik Gray et al. 1999/Gray et al. 1999; van Snik Gray et al. 2002	published
33	Baker 1928	published
34	Cliff et al. 2011	published
35	Wicklow and Beisheim 1998	published gray
36	Watters and O'Dee 1997a	published gray
37	Johnson 1946	published
38	Davenport and Warmuth 1965	published
39	Nedeau 2008	published
40	Eads et al. 2006	published
41	Watters et al. 1999	published gray
42	Dickenson and Seitman 2008	published gray
43	Freshwater Mussel Host Database 2017	Database

Haag (2012) used life history information to group North America freshwater mussels into guilds according to reproductive strategies. The multivariate analysis underlying that work suggested guilds are imperfect but convenient groupings along a multidimensional continuum. These groupings provide a sound footing for better understanding population dynamics and moving forward with management decisions. The 3 guilds that Haag (2012) proposed were: equilibrium, periodic, and opportunistic. Equilibrium species demonstrate slow growth, late maturity and are long-lived (>30 years). They invest less in annual recruitment than do other guilds, resulting in low, but constant recruitment over time. These species tend to dominate medium to large-river habitats. Opportunistic species are extremely dynamic. They mature early, have high annual reproductive output, and short lifespans. They can colonize and dominate highly disturbed habitats, such as isolated backwaters, but have difficulty competing for resources in predictable, stable habitats. Periodic species represent an intermediate strategy. Haag (2012) suggested this compromise strategy is best suited for small stream habitats which have good years and bad years. These species live long enough to survive multiple years when conditions are less than favorable but have the reproductive potential to take advantage of favorable years.

APPENDIX B: PARTICIPANT LIST

Table B1. Workshop Attendees

Name	Affiliation
Erin Reilly	James River Association
Casey Johnson	James River Association
Braven Beaty	Daguna Consulting
Brett Ostby	Daguna Consulting
Caitlin Carey	Daguna Consulting/Virginia Tech
Brian Watson	Department of Wildlife Resources
Rachel Mair	USFWS - Harrison Lake Hatchery
Jaclyn Zelko	USFWS - Harrison Lake Hatchery
Jennifer Stanhope	USFWS - Virginia Ecological Services Field Office
Anne Chazal	DCR Natural Heritage Program
Brittany Bajo-Walker	Department of Wildlife Resources

Table B2. Review Team

Name	Affiliation
Erin Reilly	James River Association
Casey Johnson	James River Association
Jameson Brunkow	James River Association
Braven Beaty	Daguna Consulting
Brett Ostby	Daguna Consulting
Caitlin Carey	Daguna Consulting/Virginia Tech
Brian Watson	Department of Wildlife Resources
Rachel Mair	USFWS - Harrison Lake Hatchery
Jaclyn Zelko	USFWS - Harrison Lake Hatchery
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Anne Chazal	DCR Natural Heritage Program
Brittany Bajo-Walker	Department of Wildlife Resources
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Kevin M Eliason	West Virginia Department of Natural Resources
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James River

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