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Aquatic Habitat Mapping within the Obed Wild and Scenic River for Threatened and Endangered Species Habitat Delineation

Joseph Ross Candlish
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To the Graduate Council:

I am submitting herewith a thesis written by Joseph Ross Candlish entitled "Aquatic Habitat Mapping within the Obed Wild and Scenic River for Threatened and Endangered Species Habitat Delineation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Paul Ayers, Major Professor

We have read this thesis and recommend its acceptance:

Joanne Jogan, Larry Wilson

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Aquatic Habitat Mapping of the Obed Wild and Scenic River (OBRI) for Threatened and Endangered Species Habitat Delineation

A Thesis Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Joseph R. Candlish
May 2010

ABSTRACT

There is a need to define a more efficient and accurate approach to aquatic habitat mapping. Traditional approaches have focused on intense biological/non-biological sampling and observation analysis within specific and restrained scales. Therefore, an underwater video mapping system (UVMS) has been developed in efforts to identify federally protected aquatic species' habitats within the Obed Wild and Scenic River (OBRI). The UVMS kayak apparatus provides georeferenced video footage correlated with GPS (global positioning systems) for GIS (geographic information systems) mapping applications. Based on its fluvial and geomorphological trends, OBRI was dissected quantitatively and integrated into databases for species-specific GIS habitat queries. Substrate type, depth, above water river characteristics (pool/riffle/run), and substrate embeddedness were extracted to access specific habitats. To better pinpoint optimal microhabitat locations, a physical habitat suitability model was developed to rank preferred habitat locales. Rankings were sequentially broken into five categories: optimal, sub-optimal, marginal, sub-marginal, and poor habitat criteria.

Habitat suitability findings for the interested species habitats varied tremendously, favoring fish species. Spotfin chub, *Erimonax monacha,* optimal habitat was found to cover 22.14 km of river length within OBRI (30 % of OBRI's spatial extent). The blackside dace, *Phoxinus cumberlandensis,* (38.9 km) and the duskytail darter, *Etheostoma percnurum,* (50.9 km) met optimal habitat conditions that yielded 51% and 69% of OBRI's spatial extent, respectively.

In general, optimal habitats for the six mussels were sporadically distributed and had low occurrences. Primarily, these mussel species prefer highly embedded areas with very specific depths and pool/riffle/run conditions. Cumberland elktoe, *Alasmidonta atropurea*, optimal habitat ranges spanned across 4.32 km (6% of OBRI's spatial extent) with most of the habitat characteristics in OBRI being marginal. The purple bean, *Villosa perpurpurea*, optimal habitat was identified within 2.61 km of OBRI (3.5% of OBRI's spatial extent). Most of the physical conditions of OBRI supplied poor to sub-marginal habitat for the purple bean, at least from a thalweg perspective. Only 385 m coincided with optimal habitat for the cumberland bean, *Villosa trabalis*, (0.5% of OBRI's spatial extent) with most habitats in long sub-marginal reaches. Optimal habitats for the cumberlandian combshell, *Epioblasma brevidens*, the tan riffleshell, *Epioblasma florentina walkeri*, and the littlewing pearlymussel, *Pegias fibula*, were deficient, only occurring in 484 m, 276 m, and 252 m of OBRI, respectively (0.7%, 0.4%, and 0.3% of OBRI's spatial extent). Marginal to sub-marginal habitats dominated the park for these three mussel species.

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CHAPTER 1
INTRODUCTION

Due to the radical advancements of digital technology over the past three decades (e.g., flash memory, digital video recorders, GPS) the scientific spectrum has broadened to allow creative implementation toward biological research. Within a spatial framework via ArcGIS, new methods allow scientists to better investigate the many dynamics of observational data. As one of the most biologically diverse temperate zones on the planet and the most biologically diverse region in North America, the southern Appalachians have endured a brief yet intense landscape alteration since its settlements in the 1700's. This region's sensitive aquatic resources, or indicator species, have continuously suffered from land use change, wide-spread development, and impoundment installations.

There is a need to pinpoint aquatic species habitats within perennial rivers. As a part of the creation of the *Cumberland Habitat Conservation Plan (HCP)*, a new approach to habitat mapping is underway. Within the Obed Wild and Scenic River (OBRI) watershed, located in Morgan County, TN, and Cumberland County, TN, a method using an Underwater Video Mapping System (UVMS) correlates GPS information with geo-referenced video footage to exemplify river characteristics. Substrate type, depth, above water river dynamics, and embeddedness are the four main criteria in identifying critical microhabitat for federally protected endangered and threatened species.

The federally endangered and threatened species under the scope of this research include three fishes (the spotfin chub -*Erimonax monachus, b*lackside Dace- *Etheostoma percnurum,* and the duskytail darter- *Etheostoma percnurum*), and six mussels (the cumberland elktoe-*Alasmidonta tropurpurea,* purple bean-*Villosa perpurpurea, c*umberland bean- *Villosa trabalis, c*umberlandian combshell- *Epioblasma brevidens,* tan riffleshell- *Epioblasma florentina walkeri,* and the littlewing pearlymussel- *Pegias fibula*).

There are over 74 km (46 miles) of the Emory River watershed that are federally protected under the National Wild and Scenic Rivers Act of 1968. Within OBRI, three main Emory River tributaries were investigated. These sections are Clear Creek 30.9 km (19.2 miles), the Obed River 39.5 km (24.5 miles), Daddy's Creek 3.7 km (2.3 miles), and the Emory River 1.3 km (0.8 miles).

The purpose of this project was to develop habitat suitability maps customized for each species. To complement habitat locations, a mathematical habitat suitability model was implemented to rank preferred habitat locales. Rankings were dissected into five categories; optimal, sub-optimal, marginal, sub-marginal, and poor. Four criteria go into the index: pool/riffle/run sequences, substrate composition, depth, and embeddedness. Rankings and a template habitat suitability model was developed through a conglomeration of efforts of Tennessee Wildlife Resources Agency biologists, Tennessee Technological University biologists, and the Science Advisory Committee in charge of the development of the Cumberland Habitat Conservation Plan. These thematic habitat maps will assist the National Park Service in evaluating habitat conditions, determining species distribution, and recognize the feasibility of species reintroduction.

CHAPTER 2
LITERATURE REVIEW

2.1 The Obed Wild and Scenic River

The Obed Wild and Scenic River (OBRI) became part of the National Park system on October 12, 1976. Its remote and pristine setting straddles sections of Cumberland County and Morgan County within the Cumberland Plateau in Tennessee. There are three main tributaries of the Emory River that comprise the Wild and Scenic River: the Obed River, Clear Creek, and Daddy's Creek (Figure 1). The National Park system protects over 74 km (46 mi) under the National Wild and Scenic Rivers Act (Smith, 1990). Both federal and private land adjoins the 46 stream miles of which 2,093 ha (5,173 acres) fall within the park, and nearly 1,416 ha (3,500 acres) are federally owned. The remaining area (697 ha or 1,723 acres) are private land or state owned (West, 2002).

Before it was designated under the management of the Department of the Interior, many lobbying efforts by the Tennessee Wildlife Resources Agency and the Tennessee Citizens for Wilderness Planning were attempted to recognize the area as a rare and aesthetic commodity for the state. Eventually, the Catoosa Wildlife Management area (32,400 ha or 82,000 acres) was established under Tennessee's state land holdings.

OBRI is one of the most pristine areas in Tennessee and offers a variety of recreational opportunities for outdoor enthusiasts. As a predominant Cumberland Plateau system, OBRI encases rare qualities of archeological importance, immaculate wilderness, notable biodiversity, and a free flowing hydrological network (TDEC, 2000).

2.2 Hydrological Setting

2.2.1 Physiographic Setting & Geology of the Area

The Obed Wild and Scenic River lies within the Cumberland Plateau Physiographic Province of Tennessee. This extensive and distinct province spans over 60-100 km in width and is dispersed in a northeast-southwest alignment. Typical elevations range from 700-800 m. The topography of this section of the plateau holds gently sloping undulating hills interrupted by steep-sided river gorges (Schmalzer and DeSelm, 1982). These ravines are denoted by abrupt escarpments and large boulder colluvium deposits.

The Cumberland Plateau formed by erosion processes through broken strata uplifted in the Permian Period 250 million years ago. Most large fault lines indicate a slight northwestern uplifting. Geologically, the Plateau has a foundation comprised of Pennsylvania limestones, sandstones, shales, siltstones, and abundant coal deposits, although no exposed limestone is evident within the Obed Wild and Scenic River. Most exposed escarpments within OBRI's gorges reveal a sandstone-shale-sandstone sequence (Stearns, 1954). Atop this sits undisturbed sandstone and conglomerates (Sewanee Conglomerate in upper portion of Clear Creek) (Coker, 1965) which indicates these areas were deposited after the uplift event in Permian time. These ravines are denoted by abrupt escarpments and large boulder colluviums deposits. Most large fault lines indicate a slight northwestern uplifting. Geologically, the Plateau has a foundation comprised of Pennsylvania limestones, sandstones, shales, siltstones, and abundant coal deposits, although no exposedlimestone is evident within the Obed Wild and Scenic River. Most exposed escarpments within OBRI's gorges reveal a sandstone-shale-sandstone sequence (Stearns, 1954). Atop this sits undisturbed sandstone and conglomerates (Sewanee Conglomerate in upper portion of Clear Creek) (Coker, 1965) which indicates these areas were deposited after the uplift event in Permian time. The conglomerate strata also indicate a fast flowing freshwater depositional paleo-environment (Delcourt, 1979).

The USGS investigated the potential economic geology of the Obed Wild and Scenic River and surrounding area. Their results indicate that unexploited natural gas, oil, and natural gas liquids are present at levels of feasible exploration. Of these energy reserves, natural gas pockets proved to be the most prevalent and economically attractive resource to tap. Approximately 16.5 billion cubic feet of natural gas is estimated to be submerged in the geology between the Obed area and north to the Big South Fork National Recreation Area. Within the Obed Wild and Scenic River area, the USGS discovered approximately 10 thousand barrels of natural gas liquids and 0.6 thousand barrels of oil. Within the Big South Fork National Recreation Area, nearly 232 thousand barrels of natural natural gas liquids were estimated, along with 15 thousand barrels of oil (Schenk et *al.*, 2006) (Figure 2).

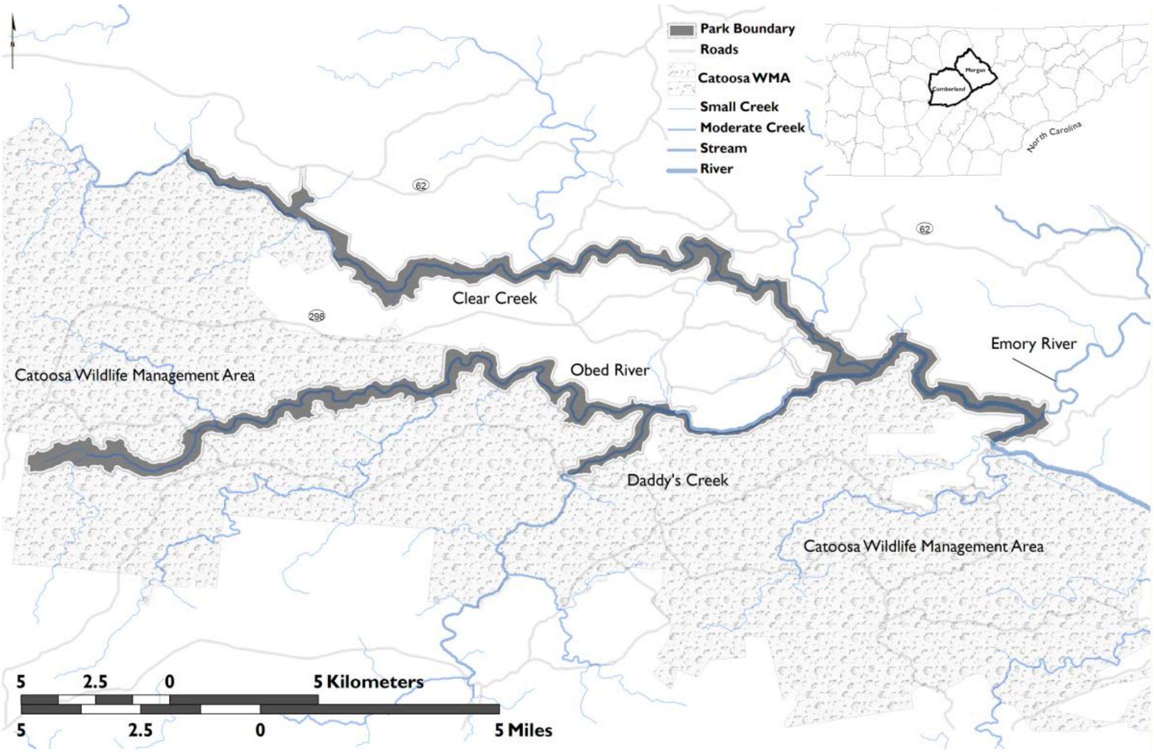


Figure 1: A location map of OBRI.

2.2.2 Vegetation

The current vegetation composition is somewhat different than the historical records indicate. After Europeans settled the Cumberland Plateau around 1800, much of the forests were cleared for subsistence agriculture and burned to improved cattle grazing pasture (Hacker, 1849 in O'Connell, 1970). This trend continued, along with logging efforts, during the construction of railroads from 1879-1900 (Bullard and Kreshniak, 1956). By 1945, all of the old-growth forests had been cut (Hibbert, 1966). During this time of degradation, forests were mesic deciduous taxa (Delcourt, 1979).

Current vegetation in this area of the Cumberland Plateau is characterized in the mixed mesophytic Forest Region. Upland forests are composed of oak, oak-pine, and/or oak-hickory forests dominate the canopy (Delcourt, 1979). More specifically, 12 community types thrive within the upland forests: river birch-holly, red maple, red maple-white oak-black gum, hemlock, white oak, mixed oak, shortleaf pine-white oak, chestnut oak, Virginia pine, scarlet oak, post oak-scarlet oak and blackjack oak types (Hinkle, 1978).

Plateau gorge forests, or riparian areas, are categorized into 12 types also. These include: river birch, beech, beech-tulip popular, hemlock, sugar maple-basswood-ash-buckeye, sugar maple-white oak, tulip poplar-shagbark hickory-northern red oak, northern red oak-sugar maple, white oak-northern red oak, white pine, mixed oak, and chestnut oak types. These communities are separated according to slope aspect and the influencing bedrock composition, which vary according to colluvium deposits and their affects on soil fertility (Hinkle, 1978). Frequent flood events in this area significantly affect the environment (Schmalzer and DeSelm, 1982).

2.2.3 Climate

The climate of the Obed Wild and Scenic River and its surroundings are categorized as mesothermal (Thornthwaite, 1948). Crossville, south of OBRI, averages 145 cm (57.1 in) of precipitation annually, with March (15.4 cm, 6.07in) having the most rain during the year (Crossville Living, 2009). Precipitation maximums occur during the winter and early spring; a secondary maximum

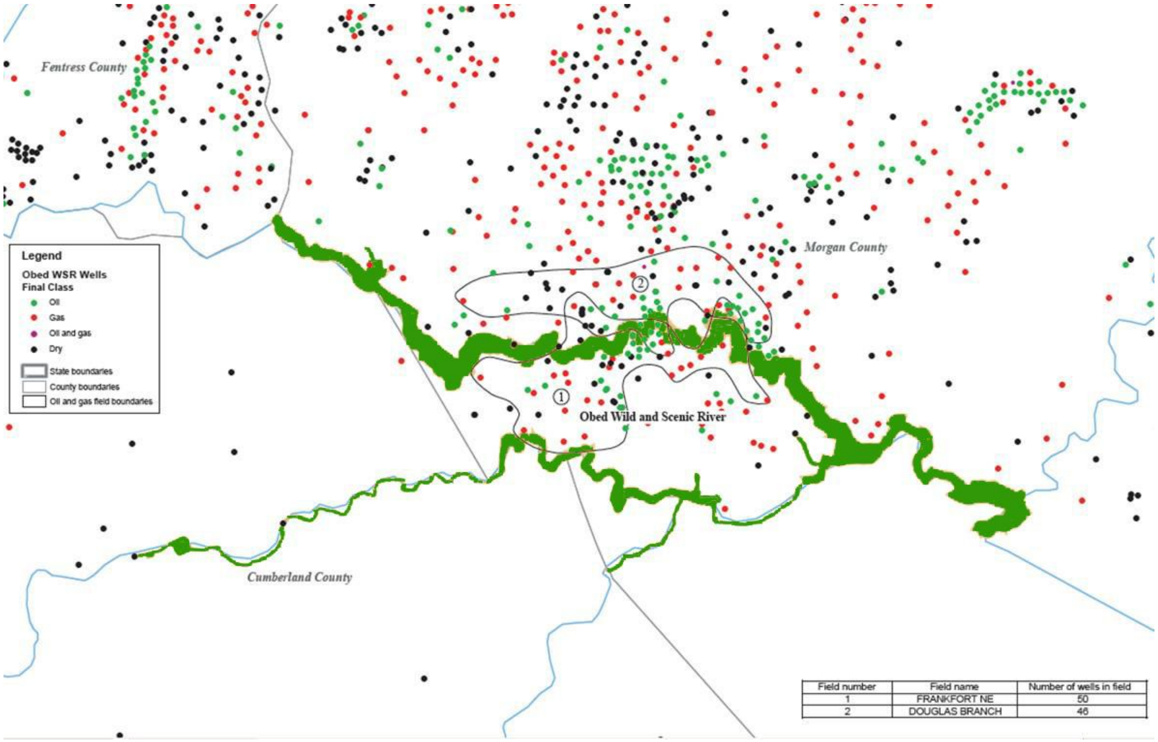


Figure 2: A map showing the number of natural resource wells adjacent to OBRI. Fields 1 and 2 are encroaching the Park and have the potential to be economical (Schenket *al*., 2006).

occurs during the summer months due to thunderstorm activity. The primary source of precipitation in this area is moist air originating in the Gulf of Mexico (Dickson, 1960). Fronts generally migrate from west to east across the state and are intercepted by the Cumberland Plateau, which is generally 300 m higher in elevation than the Highland Rim to the west. Tornados are rare on the Plateau, but severe thunderstorms are common during the summer months. Short term summer droughts are also common (Dickson, 1960; Vaiksnoras and Palmer, 1973). Crossville's annual temperature averages 13 °C or 55.5 °F with a July high of 29.2°C or 84.4°F and a low in January (-4.4°C or 24.0°F). Winters are generally mild and short lived. There are 180 freeze free days (Crossville Living, 2009).

2.2.4 Hydrology

The unregulated free-flowing hydrological network of OBRI is considered "flashy," meaning that discharge rates rise dramatically on a short time frame during rain events. Historical records indicate that flooding is frequent and peak flows during two year floods discharge at 1,300 m^3/s or (45,900 cfs), and there are records of 10 floods that have discharged over 1,980 m^3/s (70,000 cfs) from 1929-1977 (Schmalzer and DeSelm, 1982). An anomalous reading of over 2,970 m^3/s (105,000 cfs) occurred after the flood on May 27, 1973 (Wolfe et *al.,* 2006).

General characteristics of the Park indicated that baseflows are low and peak flows are high. The reasons why baseflows are low are explained by the surrounding geology. Most of the bedrock is impermeable, supplying minimal water to the groundwater aquifer. However, high peak flows result from a runoff regime. Once rain water permeates through the shallow upland soils, water hits the impermeable bedrock and migrates laterally into stream channels (Mayfield, 1980).

In terms of watershed size, the three large tributaries of OBRI generally hold similar characteristics. The average monthly discharge rates of Clear Creek and Daddy's Creek reveal this trend, while the Obed River captures higher peak flows (Figure 3). Flow Rates from Daddy's Creek are obtained from gauge 03539600), Clear Creek from gauge (03539778), and the Obed River from gauge (03539800) (Figure 4).

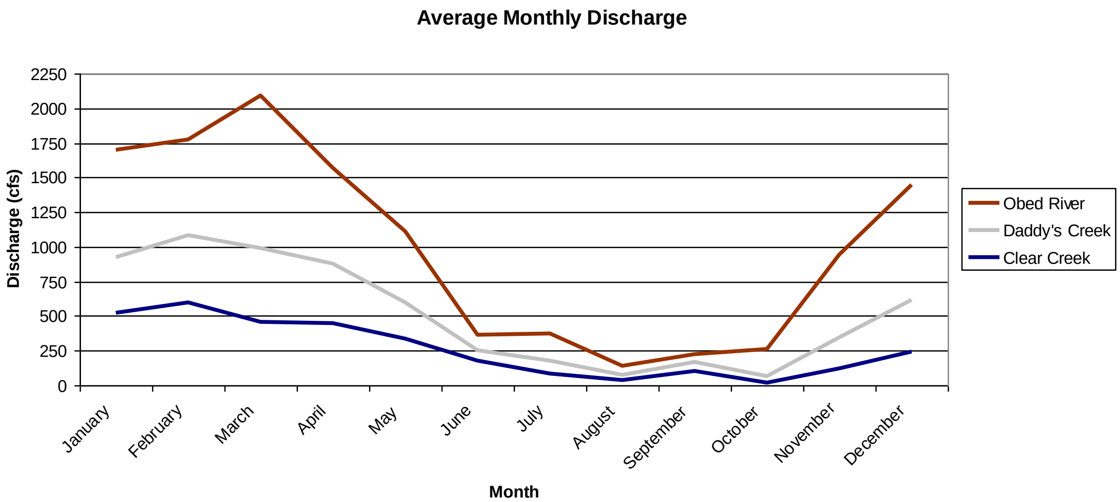


Figure 3: A graph showing the mean monthly discharges of the three main tributaries of OBRI. Obed River readings were subtracted from Clear Creek and Daddy's Creek to get an accurate discharge. Clear Creek means from March 1997-June 2006, Obed River mean readings from May 1957-September 2008, Daddy's Creek means from May 1957-September 2008 (USGS, 2009a).

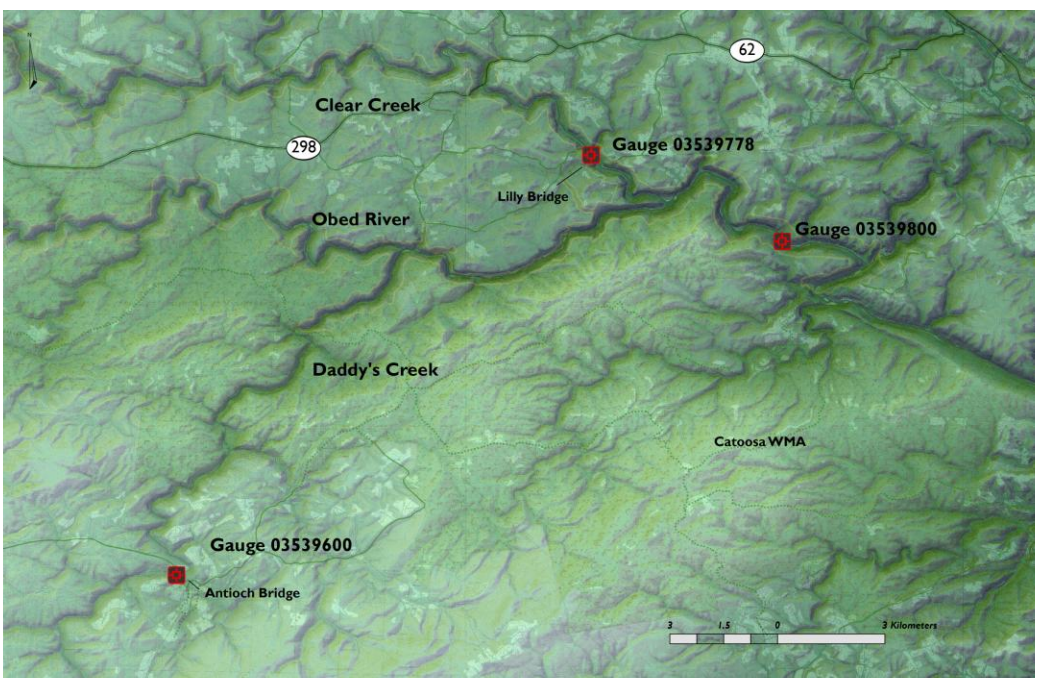


Figure 4: A map showing the locations of discharge gauges. Gauge 03539800 reads the accumulation of Clear Creek, Daddy's Creek and the Obed River.

2.3 Introduction to Freshwater Fishes

Freshwater fish in the United States have been impacted most in terms of diminishing numbers and habitat degradation. Currently, there are 115 freshwater fish species listed as endangered under the Endangered Species Act of 1973 (USFWS, 2006). Additionally, Tennessee has the richest freshwater fauna in the United States. In fact, there are 319 native and introduced species within the state. Four of Tennessee's native fish have become extinct, with many more on the verge (Etnier and Starnes, 1993).

Historically, freshwater fish became the first species type to go under federal protection. Spencer F. Baird, Federal Fish Commissioner from 1871-1887, pioneered management methodologies and propagation ideals that carried over into the 20th century (USFWS, 2009c). Within Tennessee, several pioneer ichthyologists deserve credit for discoveries and publications during the mid 1800's. Some of the most notable scientists were Edward D. Cope, D. H. Storer, Rafinesque, and Agassiz (Etnier and Starnes, 1993).

2.3.1 The Chubs, Genus (*Cyprinella) Erimonax*

Cyprinella has traditionally been treated as a sub-genus of *Notropis,* but it has recently been designated as its own genus, *Erimonax*. Within Tennessee, there are 10 species within this genus (Etnier and Starnes, 1993). At a national scale, only two *Cyprinella* species are listed as threatened and none are listed as endangered (USFWS, 2009a).

However, the spotfin chub *Erimonax monacha* is listed as endangered. This species' unique physiology has promoted controversy and confusion as to which genus it properly belongs. In 1985, the spotfin chub was moved from *Hybopsis* to the *Cyprinella* genus (Johnson, 2009), alleviating some physiological discrepancies. However, some biologists moved the Spotfin to *Erimystax* in 1989 (Johnson, 2009), further complicating its proper placement. Then in 2004, the final decision was made to place the Spotfin in its own genus, *Erimonax* (Nelson et *al.,* 2004).

2.3.2 The Redbelly Daces, Genus *Phoxinus*

Phoxinus contains unique species, especially when considering genetic anomalies. In some populations, these fish are "unisexual hybrid species." Clonal reproduction occurs by not incorporating sperm genetic information during ova development (Etnier and Starnes, 1993). Interestingly enough, a characteristic of hybrid genetic isolation sets this genus far apart from the other Tennessee native fish.

Within Tennessee, there are three *Phoxinus* species (blackside dace-*Phoxinus cumberlandensis*, the southern redbelly dace-*Phoxinus erythrogaster,* and the Tennessee dace-*Phoxinus tennesseensis*) (Etnier and Starnes, 1993). Of these, the blackside dace is federally listed as threatened (USFWS, 2009a), and the Tennessee dace is recognized as a species of concern by the Tennessee Heritage Program (Etnier and Starnes, 1993).

2.3.3 The Darters, Genus *Etheostoma*

Etheostoma is considered one of the richest genera in North American freshwater ecosystems. Currently, there are 69 species documented within Tennessee. In total, there are 119 darter species. It should be noted that "new discoveries" continue to be made since early biologists tended to overlook similar looking species (cryptic species). Due to the frequency of "new discoveries," *Etheostoma* may contain the most highly evolved species in the family Percidae (Etnier and Starnes, 1993).

Currently, there are a total of nine darter species in the genus *Etheostoma* that are endangered and three that are listed as threatened. Of these endangered and threatened species, four reside in Tennessee. The four species include: *Etheostoma boschungi* Slackwater darer (threatened), *Etheostoma percnurum d*uskytail darter, *Etheostoma* sp. Bluemask darter (endangered), and *Etheostoma wapiti* Boulder darter (endangered) (USFWS, 2009a).

2.4 Threatened and Endangered Fish of Interest

2.4.1 Spotfin chub, *Erimonax monacha*

Endemic to the Tennessee River drainage of Alabama, Georgia, North Carolina, Tennessee, and Virginia, the spotfin chub (*Erimonax monachus)* has been designated as a nationally threatened species since 1977 (Federal Register, 1977). Although threatened on a national scale, the Spotfin is denoted as endangered on a state level in Tennessee, Virginia, and North Carolina. It goes by many names, but the turquoise shiner, turquoise chub, and chub are most prevalent (Jenkins and Burkhead, 1984; Jenkins and Burkhead, 1993) (Figure 5).

Biologically, the Spotfin spawns from mid-May through mid-August (Jenkins and Burkhead, 1984), and females are noted to disperse their eggs into crevices of boulders or under slab rocks. During the breeding season, females often spawn multiple times and lay their eggs in several boulder crevices (Etnier and Starnes, 1993). One of the major disadvantages of the Spotfin during breeding is its physical appearance. Breeding males with their turquoise upper side become more attractive to finned predators as they tilt sideways to fertilize eggs. Females are also attractive to predators with their burnish-silver appearance (Jenkins and Burkhead, 1993). Generally, the Spotfin is most likely to spawn in areas that have a gently faster current, not allowing siltation and sedimentation to accumulate in crevices (Schmidt and Cook, 2007).

The Spotfin is found in rocky riffles and runs of small to medium sized rivers. Optimal adult habitats are isolated to swift currents, such as runs, with boulder/bedrock substrates (Jenkins and Burkhead, 1984; Russ, 2006). Juvenile habitats vary slightly, preferring moderate currents with small gravel substrate (Etnier and Starnes, 1993). The more highly populated areas are more localized to a small part of any riffle-run sequence (Jenkins and Burkhead, 1993). However, winter month habitats generally migrate to slower currents (Jenkins and Burkhead, 1984).

2.4.1.1 Historical and Current Distribution

Historically, the spotfin chub's distribution encapsulated most of the Tennessee River drainage. It thrived in four physiographic provinces: Blue-Ridge (French Broad River and Little Tennessee River), Ridge and Valley (Clinch River, Powel River, North and South Fork Holston Rivers, and Chickamauga Creek systems), Cumberland Plateau (Emory River and White Creek systems), and

Figure 5: A picture of a breeding male *Erimonax monachus*. Courtesy of Conservationfisheries.org

Interior Low Plateau (Shoal Creek, Little Bear Creek, and Duck River systems (USFWS, 1983).

Currently, the spotfin's ecogeography is fragmented and isolated. In Virginia, it only thrives in the North Fork of the Holston River. In North Carolina, it has been documented to only sustain a population in the Little Tennessee River between the Fontana Reservoir and Franklin, NC. Distributions are more wide-spread in Tennessee, ranging from the Emory River system and Holston River to the Buffalo River. In all, it survives in about 166 km spanning across these large tributaries to the Tennessee River (Jenkins and Burkhead, 1984; Etnier and Starnes, 1993). In general though, many of the southeastern rare fishes are being extirpated from their historical ranges (Shute et *al.,* 2005).

2.4.1.2 Reasons for Decline

There are many human induced stresses that have impacted or exterminated Spotfin populations. The most recognized culprits have been pollution from agriculture, direct chemical pollution, siltation from deforestation and coal mine sedimentation, impoundments, decreasing stream temperature from dam tailwater releases, and channelization (USFWS, 1983; Jenkins and Burkhead, 1984). In regards to pollution, the most recognized incident of chemical pollution occurred within Abrams Creek in the late 1950s in efforts to convert the creek into a trophy trout stream for recreational purposes (Lennon and Parker, 1959; Ayers, 2007). Massive amounts of ichthyocide extirpated 32 species, including the spotfin chub (USFWS, 1983; Ayers, 2007).

Biologically, the Spotfin is recognized as a non-aggressive feeder, and it is not opportunistic compared to other shiners (Jenkins and Burkhead, 1984). There are concerns of its future survival with its noncompetitive abilities in conjunction with anthropogenic stresses (USFWS, 1983). In fact, many surveys have indicated that recruitment into depleted populations is slight at best. Most occurrences of the species were within reaches with low to moderately diverse fish faunas, implying minimal recruitment for even non listed very common species (Jenkins and Burkhead, 1984).

2.4.2 Blackside Dace, *Phoxinus cumberlandensis*

The blackside dace (*Phoxinus cumberlandensis*) has been federally threatened since 1987 (USFWS, 1987; USFWS, 2009a). Its endemic distribution is limited to sections of Kentucky and northern Tennessee and is designated as endangered within Tennessee (Etnier and Starnes, 1993). More specifically, its range has been isolated to the Cumberland River system of Tennessee and Kentucky, primarily above Cumberland Falls. However, extensive surveys over the past decade have found specimens of the Dace within the Cumberland Plateau area (Eisenhour and Strange, 1998) (Figure 6). It should be noted that his species only occurs within 14 stream miles of 30 different streams (USFWS, 1987).

Biologically, the blackside dace spawns from April into July. Females commonly disperse over 1,500 eggs during the breeding season. Breeding males exude brilliant red and orange colors during the season. This species commonly spawns over stoneroller gravel nests, and generally utilize gravel areas under riffles when nesting (Etnier and Starnes, 1993).

The blackside dace is a specialist species that prefers small, cool, upland streams with moderate flow (USFWS, 1988). It thrives in bedrock and rubble substrates in clear water, flourishes well in covered canopy areas of trees and shrubs, and dwells within undercut banks and under boulders (Eisenhour and Strange, 1998).

It has been observed that the blackside dace occurs just downstream of riffles, where minimal silt (embeddedness) exists *(*USFWS, 1988). Additionally, riffle:pool ratios are important habitat considerations and it has been noted that this ratio should not exceed 60:40. A higher riffle:pool ratio usually indicates predominance of Creek chubs and Blacknose daces (Johnson et *al.,* 2009).

2.4.2.2 Historical and Current Distribution

The blackside dace's historical distribution is unknown, but records indicate that the species has been extirpated from at least 10 streams. Based upon its habitat requirements, biologists believe that the fish could have thrived in as many as 52 streams through the Cumberland Mountains and adjacent Plateau (USFWS, 1988).

Presently, this species is found within 30 different streams/tributaries in Tennessee and Kentucky (USFWS, 1987). They are restricted to the Cumberland Plateau region of the Cumberland drainage, both above and below Cumberland Falls (Etnier and Starnes, 1993). Occurrences are only within 22.4 km or 14 stream miles of these 30 streams (USFWS, 1987), which gives indication of its susceptibility to habitat degradation.

2.4.2.3 Reason for Decline

The physiological area of the blackside dace's range contains significant amounts of natural resources that are of economical importance, especially coal. This region of the Cumberland Plateau, near the Big South Fork National Recreation area, has been seriously altered by surface coal mining and forest harvests over previous decades, and many populations were probably extirpated well before their discovery (Etnier and Starnes, 1993). Other threatening factors that have impeded this species sustainability have been road construction and its associated runoff, agriculture, human development, and naturally low stream flows (USFWS, 1988).

Figure 6: A picture of a breeding male *Phoxinus cumberlandensis*. Courtesy of biology.eku.edu

2.4.3 Duskytail Darter, *Etheostoma percnurum*

The duskytail darter (*Etheostoma percnurum.*)(Figure 7), endangered since 1993 (USFWS, 2009a), is restricted to four known populations: Little River in Blount County, TN, lower section of Citico Creek in Monroe County, TN, Copper Creek in Scott County VA, and the in the Big South Fork in Scott County, TN (Jenkins and Burkhead, 1993; USFWS, 1993). All of these preferred waters range from tributaries to large rivers. The preliminary Recovery Plan was approved in 1993 (USFWS, 1993).

Biologically, duskytails spawn from late April through early June. Noted for their irregular breeding behavior, duskytail males clean nesting sites from silt and detritus with their caudal fins and wait to court females as they pass the preconditioned breeding site. Males usually court by erecting their fins, tail-wagging, and nipping female fins. Nesting females then turn upside down and press their abdomen up against a rock to lay their eggs. Males fertilize the eggs as

Figure 7: A picture of a breeding male *Etheostoma percnurum*. Courtesy of morehead-st.edu.

they exit the female. It has witnessed that females remain capsized for up to five hours (Etnier and Starnes, 1993). This is a remarkable timeframe to remain vulnerable to predation.

Although a specialist, the duskytail is not particularly picky on a single substrate type (Biggins and Shute, 1994); rather, they prefer substrates categorized as heterogeneous (Rakes et *al.,* 1992). Substrate mixtures of small gravel, large gravel, cobble, boulders and/or bedrock slabs are preferred. They are discriminatory about preferred microhabitat, thriving along the edges of shallow gently flowing pools 0.1 – 0.8 m (0.5 – 2.5 ft), eddy areas, and slow runs over heterogeneous substrates (Rakes et *al.,* 1992; Jenkins and Burkhead, 1993). During summer months, it commonly migrates under vegetation cover to escape heat, specifically riverweed (*Podostemum)*(Layman, 1991). The duskytail is rarely found in heavily silted areas or in areas where silt is present (Etnier and Starnes, 1993). As a result, distributions are commonly fragmented and patchy (Biggins and Shute, 1994).

2.4.3.1 Historical and Current Distribution

Historically, the duskytail thrived in the middle stretches of the Cumberland River and the upper reaches of the Tennessee River. Its distribution in these areas was relatively widespread. Recently however, its distribution has become very fragmented and isolated to only four known populations: Little River in Blount County, TN, lower section of Citico Creek in Monroe County, TN, Copper Creek in Scott County, VA, and in the Big South Fork in Scott County, TN (Jenkins and Burkhead, 1993; USFWS, 1993).

2.4.3.2 Reasons for Decline

The Little River has been impacted by extensive agricultural development in the lower sections of the watershed. Additionally, it is presumed that excessive residential development and water withdrawal has played a role in the depleting population (USFWS, 1993). Layman (1991) documented over 1,000 observations in a lower section of the Little River, but this same area was surveyed in 1993 during the same time of year as the 1984 survey and no occurrences were present (Shute et *al.,* 1993). It was noted that this survey site underwent significant substrate transformations, indicating an abundance of sedimentation had occurred (USFWS, 1993).

Citico Creek populations have endured evidence of stream side habitat destruction, or noticeable riparian disturbance. Duskytail populations here migrate through private lands. Destructed riparian areas and riparian erosion have also been documented in Copper Creek, but the population here has been impeded more by siltation from agricultural development and chemical pollution (USFWS, 1993). In the 1970s, Copper Creek had a very large and stable population of duskytails, but surveys in 1993 persuades the assumption of declining numbers, averaging only 0.4 duskytail observations per hour (Shute et *al.,* 1993).

Within the Big South Fork of the Cumberland River, aquatic life is protected from land use change. This area falls within the Big South Fork National Recreation Area and is managed by the National Park Service. However, runoff from coal mines in the upper watershed may impact the local duskytail population (USFWS, 1993).

2.5 Introduction to Freshwater Mussels

Freshwater mussels in the United States have endured the brunt of human negligence and aquatic regime transformations. Generally, they are the most sensitive organisms to habitat change and are the first to disappear in impaired waterways (Keller and Zam, 2009). Williams et *al.* (1993) state that mussel populations are 'declining precipitously.' In fact, historical records show that over 300 mussel species once thrived in the United States. North America alone is recognized for having the highest diversity of freshwater mussels in the world (USFWS, 2009b). Currently however, 10 % of these are extinct and an estimated 70 % are in threat of disappearing from the United States.

Freshwater mussel sensitivity to environmental degradation can be correlated to the statistics of other endangered species in the U.S. Over 70% of the mussels in the U.S. are extinct or imperiled, 16.5 % of mammalian species are extinct or imperiled, and 14.6 % of bird species are extinct or imperiled (USFWS, 2009b). Nationally, 72 mussel species are either threatened or endangered as under the Endangered Species Act of 1973 (Fiscor, 2005). Within the Obed Wild and Scenic River, two endangered mussel species thrive (purple bean-*Villosa perpurpurea,* and cumberland elktoe-*Alasmidonta atropurpurea*).

2.5.1 Reasons for Decline in Populations

Of the six endangered mussels of the study, most have adapted to live their lives in shoals of free-flowing rivers and streams. Anthropogenic factors like impoundments (not a significant factor for the cumberland elktoe and the Purple Bean), channelization, pollution (non-point and point source), sedimentation, and other influences have impeded their sustainability. More specifically, habitats are being impacted by an increasing flux of free flowing sediment from development and agriculture, which results in an increase in suspended solids (USFWS, 2004). Suspended solids are not a result of general development or agriculture, but the negligent "poor practice" of them, especially before extensive environmental research examined the impacts of sedimentation. Chemical pollutants from pesticides, fertilizers, and acid runoff from industrial mining have contributed considerably. Some of the other major influences of population decrease are gravel mining, reduced water quality below dams, and alien species.

It is important to note that already declining populations are more vulnerable to the detrimental effects of genetic isolation (USFWS, 2004).

2.6 The Endangered Freshwater Mussels of Interest

2.6.1 Cumberland Elktoe, *Alasmidonta atropurpurea*

The cumberland Elktoe, *Alasmidonta atropurpurea* (Rafinesque, 1831) has been listed as endangered since January 10, 1997 (USFWS, 2009a) (Figure 8). It is currently listed as endangered by the USFWS, TWRA, and KSNPC and the recovery plan was approved on May 4, 2004, by the USFWS. Its ecogeography is isolated to Tennessee and Kentucky. Historically, this species has not thrived within the Obed Wild and Scenic River (USFWS, 2004).

The Cumberland Elktoe thrives in medium-sized rivers and has occurrences in head waters of smaller tributaries where most other mussels are not present (Gordon and Layzer, 1989; Gordon, 1991). Its habitat niche is isolated to flats, glides, and, pools that lack significant contouring in the geomorphology (Gordon, 1991). It prefers sand and scattered cobble/boulder substrates at shallow depths in very slow moving current (USFWS, 2004).

2.6.2 Purple Bean, *Villosa perpurpurea*

The Purple Bean, *Villosa perpurpurea* (Lea, 1861), has been federally endangered since January 10, 1997 (USFWS, 2009a); and the recovery plan was approved on May 4, 2004, by the USFWS (Figure 9). Its distribution is endemic to the Tennessee River drainage basin of Northeast Tennessee and Southwest Virginia. This species does occur within the Emory River watershed (USFWS, 2004). This species thrives in small headwater streams to medium-sized rivers. It is found in moderate to fast-flowing riffles (Gordon, 1991; Neves, 1991 in USFWS, 2004). Studies have indicated that observations have been seen adjacent to the thalweg next to water-willow beds and under flat rocks (Ahlstedt 1991; Gordon 1991).

2.6.3 Cumberland Bean, *Villosa trabalis*

The cumberland bean, *Villosa trabalis* (Conrad, 1834), has been federally endangered since June 14, 1976 (Figure 10), and the recovery plan was approved on August 22, 1984, by the USFWS. At the state level, it is also listed as endangered by the TWRA and the KSNPC (Fiscor, 2005). This species does not occur within the Obed Wild and Scenic River, but it does thrive within an adjacent watershed, The Big South Fork National Recreation Area.

The cumberland bean habitat preference is somewhat atypical when compared to the other endangered species of Tennessee. It prefers small streams and rivers under fast moving current, typically riffles. Sand/gravel substrates are preferred (Parmalee and Bogan, 1998; Fiscor, 2005). This species does not occur within the Obed Wild and Scenic River, but it does thrive within its sister watershed, The Big South Fork National Recreation Area.

Figure 8: A picture of *Alasmidonta atropurpurea*. Courtesy of fws.gov

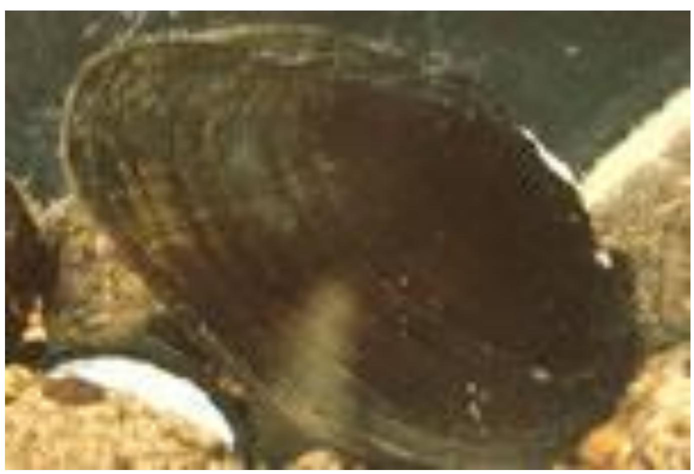


Figure 9: Picture of *Villosa perpurpurea*. Courtesy of fws.gov

Figure 10: A picture of *Villosa trabalis*. Courtesy of fws.gov

2.6.4 Cumberlandian Combshell, *Epioblasma brevidens*

The cumberlandian combshell, *Epioblasma brevidens,* has been federally endangered since January 10, 1997 (USFWS, 2009a) (Figure 11). As well as some of the other endangered mussels, the recovery plan was approved on May 4, 2004. This species only occurs within the Cumberland River drainage basin. By the 1980's, the cumberlandian combshell was considered "extremely rare" (USFWS, 2004). This species does not occur within the Obed Wild and Scenic River, but it does thrive within its sister watershed, The Big South Fork National Recreation Area of the Cumberland River drainage.

Habitat preferences have been studied extensively, indicating that the cumberlandian combshell prefers medium-sized to large rivers on riffles and

Figure 11: A picture of Epioblasma brevidens. Courtesy of fws.gov

shoals. Rarely does its range extend into higher elevation tributaries. It prefers coarse sands, gravel, cobble, and boulder substrates (Gordon, 1991).Depth preference has been somewhat subjective, indicating that it primarily thrives in depths less than three feet but occurrences are prevalent in deep water areas in sections of the Cumberland River (Gordon and Layzer, 1989 in USFWS, 2004).

2.6.5 Tan Riffleshell, *Epioblasma florentina walkeri*

The tan riffleshell, *Epioblasma florentina walkeri* (Wilson and Clark, 1914), has been federally endangered since August 23, 1977 (Figure 12); and the recovery plan was approved in 1984 by the USFWS. At the state level, this species is also endangered in Tennessee and Kentucky by the TWRA and KSNPC (Fiscor, 2005). This species does not occur within the Obed Wild and Scenic River, but it does thrive within its sister watershed, The Big South Fork National Recreation

Area.

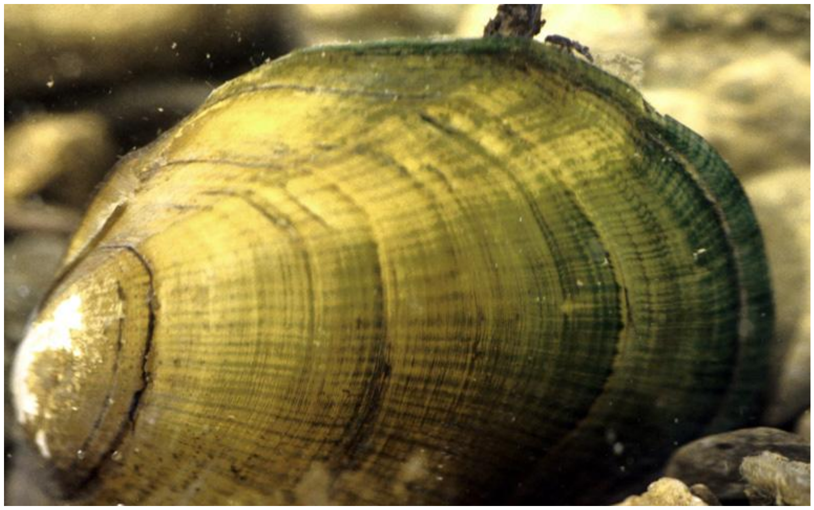


Figure 12: A picture of *Epioblasma florentina walkeri* (Fiscor, 2005)

The tan riffleshell prefers sand and gravel substrates with a heterogeneous mixture of silt. Typically, this species occurs in shallow depths, below 0.3 meters, in areas of moderate current (Parmalee and Bogan, 1998; Fiscor, 2005).

2.6.6 Littlewing Pearlymussel, *Pegias fibula*

The littlewing pearlymussel, *Pegias fabula* (Lea, 1838), has been federally endangered since November 14, 1988 (Figure 13). The littlewing pearlymussel's recovery plan was approved on September 22, 1989, by the USFWS. At the state level, this species is considered endangered in Tennessee and Kentucky by the TWRA and NSNPC. This species does not occur within the Obed Wild and Scenic River, but it does thrive within its sister watershed, The Big South Fork National Recreation Area (Fiscor, 2005). This species occurs in high-gradient streams.


Figure 13: A picture of *Pegias fibula*. Courtesy of fws.gov

It prefers cooler water with minimal turbidity. Typically, the littlewing pearlymussel thrives in the area just upstream of riffles in shallow water (15-25 cm) under or near sand and small gravel substrates. Observations have been recorded that indicate its occurrence within gravels underneath slabrock and boulders (Parmalee and Bogan, 1998; Fiscor, 2005).

2.7 Habitat Assessment Techniques

The past several decades have produced an abundance of habitat assessment protocols that rely on substrate attributes to monitor stream conditions. Methodologies have been criticized and claims have been made that identical approaches commonly yield different results, increasing the variation among data (Roper et *al.,* 2002). Other critiques indicate that there are inconsistencies in the proper protocol, lack of consistent training in this scientific niche, and difficulties in using stream attributes to detect change caused by management activity or human induced stream impacts (Hey and Thorne, 1983; Ralph et *al.,* 1992; Roper and Searnecchia, 1995; Wang et *al.,* 1996; Kondolf, 1997; Poole et *al.,* 1997; Bauer and Ralph, 2001). Regardless of the criticisms, aquatic ecosystems embrace variability and heterogeneity and this should be seriously considered when statistically analyzing natural conditions (Roper et *al.,* 2002).

There are many environmental factors that cohesively intertwine to make up a stream's integrity to sustain a variety of organisms. These factors include the physical habitat structure (focus of this research) biotic factors, chemical variables, flow regime, and considerations of energy sources (Karr et *al*., 1986; Newson and Newson, 2000). Together, these fluvial, biotic, and chemical interactions mold species specific habitats.

Respectively, habitat structure variables are composed of characteristics like the amount of siltation or sedimentation that has occurred, substrate composition, canopy cover or riparian vegetation type, channel morphology, and gradient (Karr et *al*., 1986). Another important consideration is the geomorphology and the frequency of such transitions that allow for multiple habitat locations. Biotic factors have a tremendous influence on stream integrity. Species sustainability can be broken down into two important criteria, natality rates and survival. Others biotic variables include feeding guild, disease, parasitism, predation, and competition (Karr et *al*., 1986; Schwartz, 2008).

Chemical variables play an important role in determining water quality. The most important considerations are pH, temperature, and chemical pollutants that deplete oxygen. Some of the major pollutants are from organic wastes, such as nitrogen and phosphorus, and acids from mining and industrial operations. Many standalone biotic factors may not be harmful to organisms, but may interact when in multitude with other chemicals to cause harmful effects. The pH of water often acts as a catalyst to drive such reactions, as in the case with increased pH that produces excess algae and plant growth which in turn produces high amounts of ammonia (Karr et *al.*, 1986; NRCS, 1998).

Flow regime and energy source factors also influence water resource integrity. Flow regime variables are composed of stream velocity and its associated high/low extremes during floods and drought, the amount of precipitation and runoff a stream captures, adjacent land use, and ground water characteristics. Energy source factors are natural occurring variables, such as seasonal cycles, sunlight, nutrient input, and production based on temperature (Karr et *al.*, 1986).

2.7.1 Hierarchy of Streams

Investigating habitat systems of streams occurs on various spatiotemporal scales. Properly delineating these scales would be subjective without a standard protocol. Watersheds, or stream systems, are broken down into successive lower categories. These categories include: the stream segment, reach, pool/riffle (or mesohabitat), and microhabitat (Figure 14). Essentially, a system at a higher level

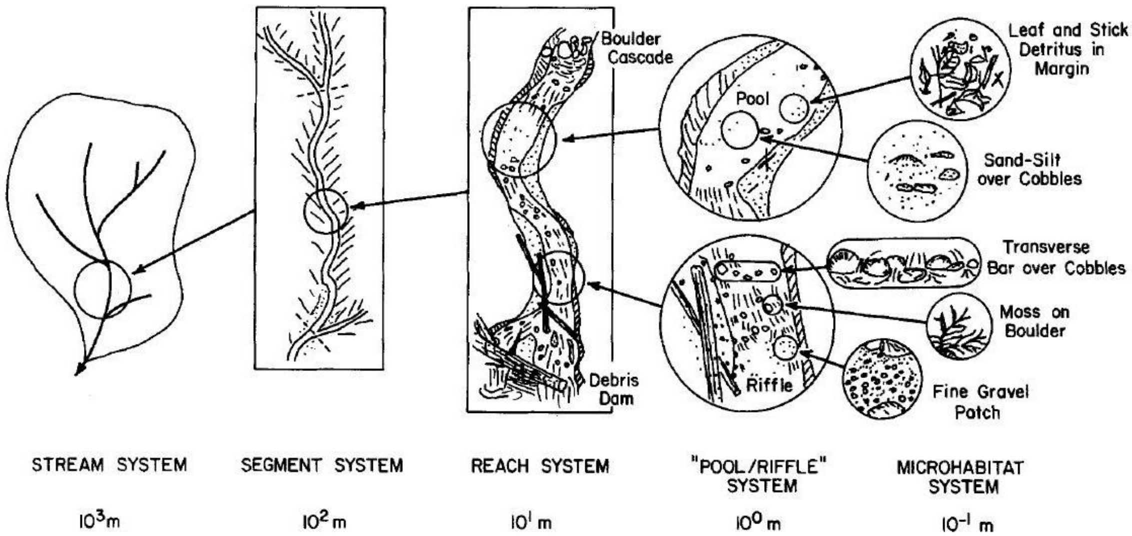


Figure 14: Hierarchical organization of a stream system and its habitat subsystems. Approximate linear spatial scale, appropriate to second or third order streams (Frissell, 1986).

forms the environment of its subsystems. Even though habitats are often correlated with a particular watershed, each subsystem plays a crucial structural and functional role for aquatic communities and exists in specific locations within the watershed (Frissell et *al.,* 1986).

Since subsystems are delineated according to scale, another aspect to consider is delineating the boundaries between these transitions. Table 2.14 identifies some spatial criteria to assist in defining these subsystem transitions. For example, geomorphic features alter the physical behavior of the stream channel. Also, differences can be seen in reaches in specific locations within the watershed (Montgomery and Bufferington, 1997). Locations vary and define boundaries such as: confluences, slope aspect, riparian vegetation variations, etc. Other criteria in evaluating subsystem transitions are vertical boundaries, longitudinal boundaries, and lateral boundaries (Table 1)(Frissell et *al.,* 1986). Also, it is evident that stream and reach differences occur according to effects of management and adjacent land use disturbance (Reeves et *al., 2004*).

2.7.2 'Top Down' Vs. 'Bottom Up' Approaches

There has been a dualism between freshwater ecologists and geomorphologists as to which is the best method of evaluating habitat patterns in stream channels. Traditionally, ecologist have taken the 'top down' approach, investigating biota availability as the keystone element in multivariate analysis to substrate topology (Holmes et *al*., 1998), also referred to as 'functional habitat' or 'mesohabitat'(Harper et *al*., 1995; Pardo and Armitage, 1997; Schwartz, 2008). Geomorphologists, however, have leaned towards using the 'bottom up' approach. Essentially, this approach tries to predict biotic patterns based on flow processes (Newson and Newson, 2000) controlled by substrate materials of a channel. This approach often refers to 'Ecohydraulic patterns' at a larger scale, commonly a reach scale (e.g., riffle-pool sequences).

Some scientists observe the hierarchical nature of stream geomorphology as a strong correlation of habitat in efforts to merge the two approaches. An example of this approach is a physical habitat simulation model called PHABSIM (Newson and Newson, 2000; Schwartz, 2008). This model computes estimates of useable habitat areas based on discharge and channel

Table 1: stream and reach differences occur according to effects of management and adjacent land use disturbance (Reeves et al., 2004).

Watershed	Stream System	Segment	Reach	Pool/riffle	Microhabitat
Biogeoclimatic region	Watershed class	Steam class	Segment class	Reach class	Pool/riffle class
Geography	Long profile	Channel flow	Bedrock relief,	Bed topography	Underlying
Geography	slope, shape	lithology	slope		substrate
Topography	Network structure	Channel floor slope	Morphogenic structure or process	Water surface slope	Overlying substrate
Soils		Position in drainage network	Channel pattern	Morphogenic structure or process	water depth, velocity
Climate		Valley sideslopes	Local sideslopes,	Substrates	Overhanging
Biota			floodplain	immovable in	cover
				<10 yr flood	
			Bank composition	Bank configuration	
Culture		Potential climax vegetation	Riparian vegetation		
		Soil associations	state		

morphologies (Rowntree and Wadeson, 1996; Bovee et *al.,* 1998). However, PHABISM has been criticized because its reliance on flow point measurements and studies have shown that fish use of certain habitat space is dependent on many abiotic and biotic factors, making them bound to areas that are mesohabitat scale (Jackson et *al.,* 2001; Parasiewicz, 2001; Rashleigh et *al.,* 2005 in Schwartz, 2008).

2.7.3 Ecohydraulic-based Mesohabitat Approach

This new method allows scientists and engineers to categorize habitat suitability for certain species based upon the interactions of 3D channel hydraulics, substrate morphology, and the biological needs of fish. This is a relatively new approach in assessing habitat quality. Areas of a stream are broken into 'eco-hydraulic mesohabitat units' and assigned a categorical value (Schwartz, 2008). A mesohabitat is defined as 'visually distinct units of habitat within the stream, recognizable from the bank with apparent physical uniformity' (Pardo and Armitage, 1997 in Newson and Newson, 2000). The ecological importance of the units is based on species relationships to feeding guild and their mesohabitat use patterns. By using hydraulic characteristics as a foundation for habitat variety, a more accurate classification can be determined when biotic resource needs is qualitatively characterized through the interactions of substrate morphology and hydraulic properties (Schwartz, 2008).

Nine mesohabitat units are categorized, including pool-front, -mid, and –rear units, scour pool, simple and complex riffles, glide, submerged point-bar, and channel expansion marginal deadwater. These units are further dissected by length, water depth, and bed slope and complexity (Schwartz, 2008). In order to properly identify which units a certain fish species prefers, electrofishing is commonly relied upon. As explained in previous sections, electrofishing devices yield significant inventory that encourages statistical analysis to determine abundance and species richness under specific river characteristics (Korman et *al.*, 2009).

2.8 Methods of Gathering Underwater Habitat Information

2.8.1 Traditional approaches

Some traditional methodologies to collect underwater habitat information are Remotely Operated Vehicles (ROV), which provide excellent data quality but are quite expensive, or a towed camera that is controlled hydraulically. Towed devices are economically attractive, but there are depth and operational limitations (Fiscor, 2005). Under ideal discharge rates, snorkeling is another approach. A more objectively systematic approach is the pebble count method. Also called the 'blind-toe-count' method, this protocol involves measuring particles on three separate axes to accurately categorize their substrate type and distribution (Rogers, 2007). Other methods are scuba surveys, grab sample surveys, mussel surveys, and electrofishing.

Self-Contained Underwater Breathing Apparatus (SCUBA) transects are very multidimensional in terms of methodologies. Time, however, is regimented according to various depths, so the longevity of a thorough survey is not feasible. On average, a diver can do one underwater survey per day at 5 m for 325 minutes, 10 m for 160 minutes, 20 m for 40 minutes and 25 m for 25 minutes (SSI Manual, 1995). A statistically sound approach that USGS used in the Virgin Islands is to randomly select 20 transects at 10 m length and video tape each of them, keeping the camera just above the substrate. To analyze the captured video, 30 unique frames were selected from each 10 m transect. Then, random dots were placed onto the images and substrates were identified at each dot location (Legoza, 2001).

Another SCUBA method is also used by the USGS along coral reefs in Molokai, Hawaii. Three people are involved, i.e., two that dive to actively survey, and one person is left on the boat to record GPS data over the divers. The two divers troll the bottom, one with a video camera and the other takes detailed scientific notes on the biodiversity, general biota, health of the reef, and the local geomorphology (Cochran et *al*., 2000).

2.8.2 Underwater Video Mapping System (UVMS)

The sit-on-top kayak used for the OBRI research is harnessed with a collection of electronics and sensors. The three essential components are video footage, depth sonar, and GPS. The general approach to this method is to kayak the stream through the thalweg and simultaneously record video footage and depth with its complementary GPS location. Due to the GPS receiver configuration output of 1 Hz, each second of video recorded has an associated location. Depth data from an acoustic shallow water depth transducer and GPS data are imported through a multiplexer to combine the two data sources into one data string at 1 Hz intervals (Legoza, 2002; Fiscor, 2005; Ayers, 2007). See Chapter 4 for more a more detailed description of the system.

Three digital video cameras are mounted throughout the apparatus. There is one waterproof camera mounted on the hull and used for above water river characteristics, and two cameras are mounted on the bottom of the kayak. One camera is mounted directly on the bottom underside of the kayak. This camera is used to interpret substrate type and embeddedness. The other underwater camera is mounted along the bottom left rear of the kayak used and is used to access substrate and embeddedness characteristics when the primary underwater bottom camera footage becomes impeded by air pockets, debris, temporary turbidity, or shallow depths.

Various UVMS design techniques have been used within the past ten years. The most common applications of video mapping technologies have included coral reef surveys for benthic habitat maps. Specifically, ecosystem mapping for coral reefs were used to delineate ecosystem sensitivity to human impediment or natural climatic alternations (Legoza, 2002).

A similar approach was taken for a perennial river within the Blue Ridge physiographic province of Tennessee. Within the Great Smokey Mountain National Park (GRSMNP), underwater GPS videography surveys were conducted on Abrams Creek to assist the evaluation of species recovery success. After a tragic outcome of applying rotenone (fish toxicant) in 1957 in efforts to convert Abrams Creek into a trophy trout fishery, 32 species were extirpated (Ayers, 2007). Habitat maps were created based on preferred habitat criteria for reintroduced endangered species. The resulting habitat locations allowed the National Park Service to focus their attention on precise locales for population monitoring and recovery success.

Mussel habitat mapping efforts have been conducted by Fiscor and Ayers (2005) at the Big South Fork National Recreation Area (BISO). This research utilized the UVMS approach as well but with a different apparatus. An Old Town canoe shuttled the UVMS equipment through various sections of the BISO, using a drop-down waterproof camera to investigate habitats in deeper waters. This research focused on identifying optimal habitat locations for the cumberland bean- *Villosa trabalis, c*umberlandian combshell- *Epioblasma brevidens***,** cumberland elktoe- *Alasmidonta atropurpurea,* littlewing pearlymussel- *Pegias fibula,* and the tan riffleshell- *Epioblasma florentina walkeri* (Fiscor, 2005).

Comparisons have been made between the accuracy of the traditional pebble count method and the UVMS approach in determining substrate type and distribution. Conclusions indicated that there were no statistically significant differences between measurements of particle size, diameter size class, and percent distribution among the UVMS method, pebble count method, and a control (PVC frame placed underwater) at $\alpha=0.15$ (Rogers, 2007).

The reliability of UVMS possesses many advantages over the pebble count method. Although both approaches are highly accurate, UVMS minimizes field work duration and allows collected datum to be post-processed in a controlled laboratory environment. This allows the scientist to investigate particles and environmental settings with no time constraints. Also, this method minimizes streambed disturbance, and allows the datum to be georeferenced for GIS applications (Rogers, 2007).

2.8.2.1 Physical Habitat Suitability Index

Habitat suitability index (HSI) models are generally presented in three formats: (1) graphic; (2) word; and (3) mathematical. HSI models describe, or hypothesize, the relationships of environmental factors (e.g., biota, stream flow, substrate type, canopy cover, water quality) and species needs that best represent suitable habitat. HSI models do not prove cause and effect relationships. Generally, these hypothesized models assist wildlife managers in decision making for management (USGS, 2009b).

In order to maximize the accuracy of aquatic habitat locations based on the UVMS criteria, a numerical habitat suitability index has been developed to quantify habitat ranges. This mathematical model considers the following criteria: (1) substrate composition, (2) depth, (3) macro habitat of pool/riffle/run, and (4) embeddedness (Figure 15). Trisha Johnson, head of the Cumberland HCP Science Advisory Committee, has collaborated with TWRA biologists, Tennessee Technological University biologists, and other wildlife experts to develop a quantifiable model. Based on a score from 0-34, these numerical values are equally divided to characterize habitat ranges of optimal, sub-optimal, marginal, sub-marginal, and unsuitable. On a per species basis, the sum of their quantitative classifications is mapped via GIS to thematically show habitat ranges throughout the OBRI Park.

The habitat suitability model only categories habitats through structural components, biological aspects are not considered.

Traditional procedures in developing a HSI model/index include defining the model variables, assigning a suitability index (0.0-1.0) to set conditions for each variable, and include the equation(s) for calculating the habitat suitability index. Field research is typically conducted to access the model variables.

HSI Score = (M) + (S) + (D) + (E)

Terms:

M = Macro habitat (pool/riffle/run setting)
S = Substrate type
D = Thalweg depth
E = Substrate embeddedness

Figure 15: An additive habitat suitability model used to delineate preferred habitat locations (Johnson, 2008).

Habitat units (HUs) and average annual habitat units (AAHUs) are calculated to be implemented into the HSI. Habitat units are values that result in multiplying the HSI by the size of habitat. The average annual habitat units are the total number of HUs that would be gained or lost as a result of the proposed objective (USFWS, 1981).

2.8.2.2 UVMS Relation to Quanitative Habitat Evaluation Index (QHEI)

A procedure has been developed that correlates stream potential with habitat integrity. This quantitative approach dissects major categories of biotic/abiotic factors that are crucial for habitat quality. The overall goal of this method is to minimize field measurements while minimizing the time spent collecting the data (Rankin, 1989).

The scoring system of the QHEI involves six categories (substrate, instream cover, channel quality, riparian erosion, pool riffle, gradient). Each category has a maximum score of 20 points, except for riparian erosion and gradient. They have a maximum score of 10 pts. Summing the categories produces a total score of 100 pts (Ohio EPA, 1989; Rankin, 1989).

In more detail, substrate is reduced to two categories: type and quality. Instream cover incorporates two themes: type and amount. Channel quality contains several components: sinuosity, development, channelization, and stability. Riparian vegetation includes width, floodplain quality, and bank erosion. The complexities of the pool/riffle environments have integrated six considerations. These include: max depth, current available, pool morphology, riffle/run depth, riffle substrate stability, and riffle embeddedness. Gradient is the last category of the QHEI (Ohio EPA, 1989; Rankin, 1989).

Of these seven categories, the underwater video mapping system (UVMS) already captures depth, substrate data, and pool/riffle/ data. In fact, the UVMS can be modified to capture real time observational data for the remaining QHEI factors: instream cover, channel quality, and riparian erosion. Large scale spatial thematic visualization could alleviate strenuous labor hours for workers and would be economical for the data hosting entity and data curator to track stream changes over time.

2.8.2.3 UVMS Point to Distance Relationship

Accurately estimating the distance that each GPS point represents correlated very well with the overall spatial distance of stream miles within OBRI. Within OBRI, there are nearly 74 km or 46 miles of stream. There was just over 75,000 GPS point within the OBRI database. Based on the average velocity of 1 m/s, a relationship exists that implies that each GPS point reasonably represents 1 meter of radial space. However, the Garmin 18 PC used for this research has a differential correction accuracy of 3 m (Garmin, 2004), which is sufficient for this research but deludes the overall accuracy of this point to distance relationship.

2.8.3 Hyperspectral Resolution Imagery (HSRH)

Researchers at the University of Oregon have utilized 1-m high spatial (128-band) hyperspectral resolution imagery (HSRH) to map in-stream habitats and depths within a fifth order stream in Yellowstone National Park (~6 km reach). This site was chosen simply because it had been studied extensively in the past on its physical components and fluvial morphology for various environmental projects. Therefore, ground truthing was documented and spatial variability could be minimized. Statistically, the overall observational accuracy of 85% for in-stream habitats (pools, riffles, glides, and eddy drop zones) in fifth order streams imply that this method could be valid in mapping large scale transitions in remote mountainous areas (Marcus et al., *2002*).

Depths were obtained by entering the field depth measurements into a step-wise multiple regression to determine the strength of the correlation between depth measurements in the field to the spectral reflectance of the photographs (captured by helicopter at ~600m altitude), and equations were developed to estimate depths throughout the stream. In-stream habitat classifications were used as a template to better identify depth ranges. Not surprising, depth recordings were variable and R^2 values ranged from 0.2 (for high-gradient riffles) to 0.99 (for glides) (Marcus et *al.,* 2002).

This approach alleviates the cost of ground-based surveys and is, in many cases, more accurate than classical survey methods (Marcus, 2001). Mapping in-stream habitats has widespread applications for fisheries and wildlife management, prediction of river change (Rosgen, 1996), inventory and assessment of channel change (Gilvear et al., 1995), and stratification of streams for environmental sampling (Ladd et *al*., 1998). Being able to provide physical evidence that depicts morphological change over time is another large advantage of aerial analysis, especially at watershed-scales. Such evidence could be used to help locate non-point source pollution areas (denoted by alluvial sediment deposition from poor agricultural practice or negligent land use change), and make recommendations for environmental planning or reclamation by accessing archived aerial photographs for reference. It should be noted, however, that this approach limits the ability for accurate substrate interpretation.

2.8.4 Acoustic Imaging

On the contrary, aerial photographs cannot be used to map areas of significant depth and turbidity. Therefore, acoustic imaging can be used as a method for habitat mapping. This approach is most commonly implemented for lentic and large lotic ecosystems. Specifically, acoustic sonar readings relay topological characteristics (typically 2 mosaic pixels depict 5 m horizontal accuracy) that are ground truthed by scuba divers and underwater video interpretations of the substrate to determined bed composition (Kendall et al., 2005). Further, side-scan sonar mosaics can provide information that helps identify beach erosion problem areas existing, and proposed channel dredging areas (Ojeda et al., 2003) that impede biotic sustainability within unique and potentially allopatric habitats.

Sonar mapping can comprehensively reveal natural sediment transport pathways that helps explain the physical processes acting upon continental shelves (Nittrouer and Wright, 1994). This approach provides continuous non-overlapping spatial data that is time efficient and covers a large spatial radius, whereas other methods like video-mapping and scuba surveys are somewhat subjective (biased video interpretations and scientific notes) or skewed from environmental factors (i.e., turbidity, daily climatic variation) and spatially fragmented. Even though side-scan sonar readings may be viewed as a subjective approach, observation interpretations are mainly descriptive and qualitative. Standardized techniques have been identified (Reed and Hussong, 1989), but further advances need to be made to standardize a quantitative approach that is implemented into accompanying analytical software.

CHAPTER 3

PROJECT JUSTIFICTION AND OBJECTIVES

3.1 Project Justification

The Obed Wild and Scenic River has been under federal protection since October 2, 1968. To date, 46 miles of the watershed are protected by the National Wild and Scenic Rivers Act (Smith, 1990). As one of Tennessee's most diverse and pristine river settings, the upper Emory River watershed possesses five rare fish species and numerous federally protected aquatic species. As a predominant Cumberland Plateau system, OBRI encases rare qualities of archeological importance, immaculate wilderness, notable biodiversity, and a free flowing hydrological network (TDEC, 2000). With the impact of pollutants and isolated by Watts Reservoir, the endemic spotfin chub (*Erimonax monachus)* is a staple example of the necessity for aquatic conservation (Schmidt and Cook, 2007). Although only found in the Tennessee drainage, the Spotfin has endured significant neglect over the last 120 years. The allopatric distributional pattern may have been nearly uninterrupted before excessive deforestation and impoundment (Jenkins and Burkhead, 1984). In order to promote the spotfin chubs' sustainability, wildlife managers need to compensate the negative biological offsets that this species has endured by human negligence.

There is a need to develop species specific habitat maps within the Obed Wild and Scenic River. Previous biological research has not focused on large scale watershed mapping. Most studies have concentrated focal points toward fragmented river sections with relatively easy access. One disadvantage of using a permanent site is that more effort is focused in fewer locations, so results may have limited applicability toward answering larger scale questions (Roper et al., 2002). This research focused on mapping the entire watershed within the nationally protected area. All river attributes are georeferenced to better target aquatic species optimal habitat locations.

There are many elements within a river that determine where species can thrive. The major advantage of this research is that a river's dynamics are dissected quantitatively and implemented visually via GIS format. As species' criteria change dynamically, GIS queries can also change, yielding accurate habitat locations. The EPA designated certain habitat descriptors that best encapsulate species' habitat criteria. Four of these descriptors will be applied to this project: river depth, substrate type, above water river characteristics (pool, riffle, and run), and substrate embeddedness (Barbour et *al.,* 1999).

Based upon habitat descriptors, there is a need to develop a habitat suitability index that will allow managers to numerically rank microhabitat preferences. Frequently, there are several analyzed habitat descriptors that do not fall within an optimal spectrum. It is common to get a mixture of these conditions (optimal, sub-optimal, marginal, and sub-marginal). A suitability index will better define the boundaries between these levels of preferable habitats and better assess the 'big picture'.

Although underwater video mapping (UVMS) technologies are in their pioneer stages for freshwater mapping, it serves as a viable tool for visualizing microhabitats encompassed within a large scale framework. This will assist biologists and wildlife managers in making imperative management decisions and, in turn, increase the probability of successful conservation efforts.

3.2 Project Objectives

The primary goal of this project was to develop habitat maps for federally endangered and threatened species by utilizing a GPS-underwater video mapping system (UVMS) and image georeferencing techniques. Habitats were delineated through a GIS database query. Database attributes were quantified into four critical habitat descriptors for accurately locating habitat. The four descriptors included: river characteristics (pool, riffle, and run), depth, substrate, and substrate embeddedness. Efforts were made to exhibit UVMS as a reliable management tool for georeferenced habitat mapping. Once habitat locations were determined, comparisons were made with previous habitat locales to investigate their correlations. Further, a habitat suitability index was constructed to quantitatively delimit habitat ranges into four categories. Sequentially, they are optimal, sub-optimal, marginal, and sub-marginal habitats.

Within OBRI, the investigated species habitats were for three fish (the spotfin chub -*Erimonax monachus*, blackside Dace, *Phoxinus cumberlandensis*, duskytail darter, *Etheostoma percnurum*), and six mussels (the cumberland elktoe-*Alasmidonta atropurpurea*, purple bean-*Villosa perpurpurea*, cumberland bean - *Villosa trabalis,* cumberlandian combshell -*Epioblasma brevidens*, tan riffleshell- *Epioblasma florentina walkeri*, and the littlewing pearlymussel- *Pegias fibula*).

CHAPTER 4

EQUIPMENT

4.1 Kayak Apparatus Overview

The kayak underwater video mapping system (UVMS) used for this research was a sit-on-top Wilderness Systems Tarpon 100 kayak. This kayak was equipped with a global positioning system (GPS), water proof video cameras, digital video recorders (DVRs), a depth transducer, and laser pointers to efficiently capture data on the environmental characteristics and components of the Obed Wild and Scenic River (OBRI) (Figure 16). The following sections delve into the electronics, specifications, and the engineering aspects of the UVMS.

4.2 VMS 200

The Video Mapping System 200 (VMS 200) served as the pinnacle component of this research. Its purpose was to encode-decode GPS data as it passes, converting the GPS data into and audio sound, then georeferences video footage at a predetermined PPS (one-pulse-per-second)(Figure 17). Essentially, the VMS 200 georeferences video footage through the audio port of the digital video recorders. Geo-tagging has traditionally been correlated with photography in Google Earth applications or used as a photographic hyperlink in ERSI mapping interfaces.

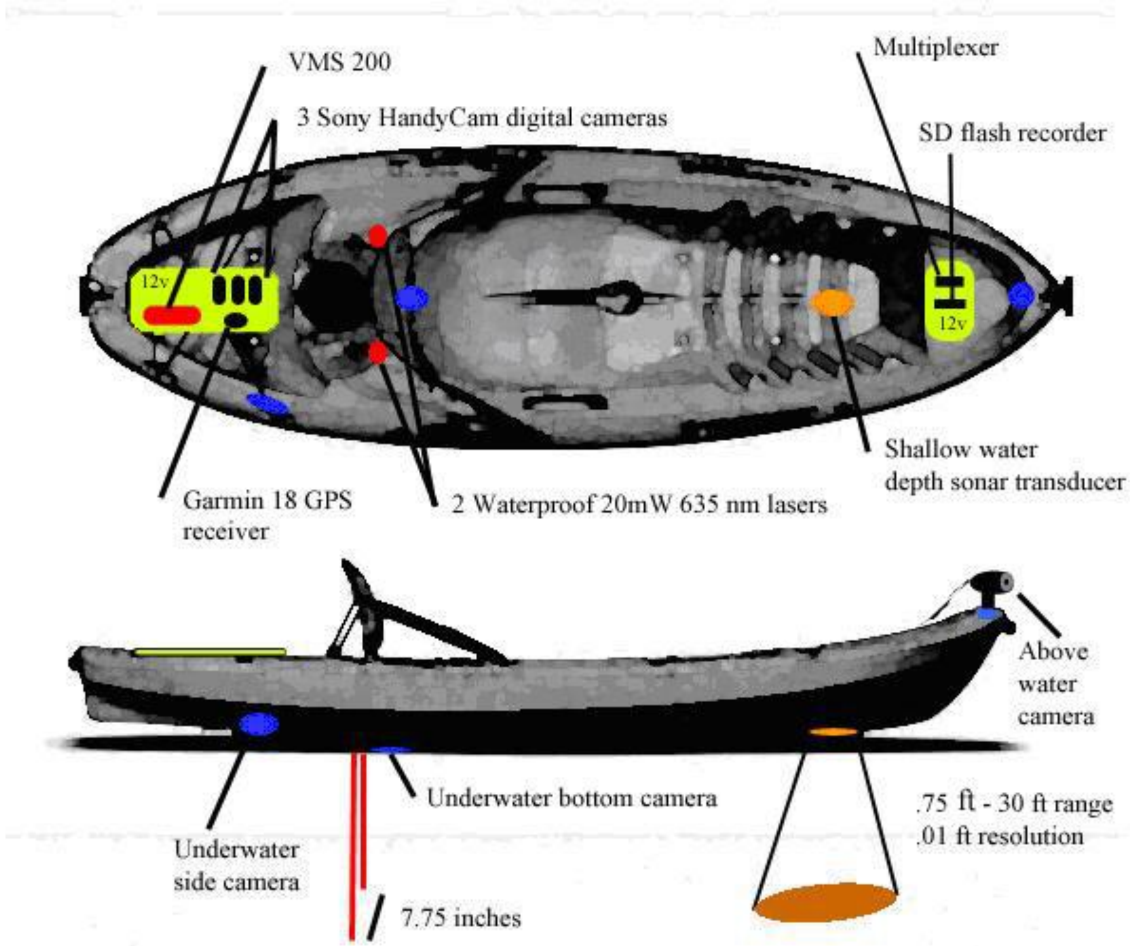


Figure 16: A schematic drawing that identifies the equipment layout of the UVMS.

Figure 17: A picture of the VMS 200

Figure 18: A picture of a Garmin 18 PC GPS Receiver.

4.3 GPS Receivers

4.3.1 Garmin 18 PC

This WAAS enabled Garmin 18 GPS receiver provided sufficient accuracy for its research application in the Obed Wild and Scenic River. Upon differential correction, real-time WAAS corrections yielded position errors of less than 3 meters (Garmin, 2004). The receiver can utilize up to 12 satellites simultaneously, but the topographic relief characteristics of the Cumberland Plateau impeded this receiver from optimizing its full capabilities (Figure 18).

4.3.2 Garmin V

Typically, a Garmin V handheld unit was used to record a tracklog during research. The Garmin GPS V was waterproof to IEC 529 IPX7 standards. This unit can store up to 500 waypoints with names and symbols, store up to 10 tracklogs, compute odometer readings, compute average and maximum speed, and provide navigation to waypoints. A 12-parallel channel GPS receiver, this unit can track and use up to 12 satellites under WAAS (Wide Area Augmentation System) enabled differential correction. Enabled differential correction can yield an accuracy from <15 m to <3 m (Garmin, 2004; Fiscor, 2005) (Figure 19).

4.4 Multiplexer

A NoLand NM42 National Marine Electronic Association (NMEA 0183) Multiplexer was used to combine multiple sources of data into one data string that would be stored simultaneously on a serial data recorder (Figure 20). This particular research utilized two multiplexer input ports (out of four), one for GPS signals and the other for depth sonar readings (Figure 20). Essentially, $GPRMC and $GPGGA NMEA 0183 sentences were combined with $SDDBT (depth) strings.

The voltage requirements of the multiplexer were 8-28 VDC at 50 mA. The serial output baud rate was 4,800-38,400 (selectable) via the RS-232 port. Status LEDs on the multiplexer indicated the status of the unit, and displayed when the multiplexer was receiving, retransmitting, or when there was an error in the transmission (Fiscor, 2005).

4.5 Depth Sonar Transducer

Two depth sonars were implemented throughout the tenure of this research project. From 2007-2008 research, a CruzPro depth transducer (model ATT120AT) provided a range of 0 to >135 m (0-450 ft). For 2009 research, customized depth sonar was installed on the kayak to obtain more accurate depth readings. This CruzPro ATU120ST shallow water depth sonar provided 3 mm (0.01 ft) resolution. Additionally, this sonar transducer was calibrated specifically for this research, set to read a range of depth from 15 cm – 13 m (0.50 – 44.00 ft) (Figure 21) Preset to 4800 baud, this sonar provided an output 1 Hz that coincided with the Garmin 18 output rate and presented its depth readings in NMEA 0183 data string format. Data sentences were imported through the NMEA multiplexer in the following $SDDBT structure: $SDDBT, 00.00, f, 00.00, M, 00.00, F*CS (where the number before "f", gave depths in feet)(CruzPro, 2009).

4.6 Underwater Video Cameras

There were three waterproof cameras mounted throughout the kayak to capture a diverse range of video footage. A Deep Blue camera was mounted on the bow to capture above water river footage to be analyzed for pool/riffle/run environments (Figure 22). Two Dropshot 20/20 video cameras were flush mounted within the hull of the kayak; one camera on the kayak bottom and the other mounted at an offset 30 degrees to capture side angle footage that can be analyzed when there are visibility issues with the bottom mounted camera (Figure 23). These threes cameras were connected to the auxiliary port of the Sony Handycam digital video recorders then recorded onto mini DVDs.

4.7 Lasers

Two 200mW 635nm waterproof lasers were used during this research to provide a consistent scale for substrate interpretations. These lasers operated on an 18650 lithium battery and were classified as Class III b (built for scientific research). To date, these Spyder II Pro lasers have been the most consistent waterproof lasers used for this research. They are durable, small in diameter, and very powerful (Figure 24).

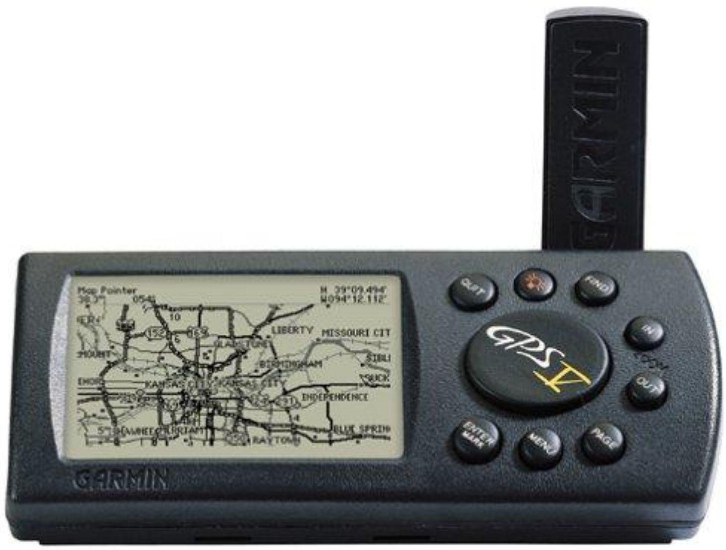


Figure 19: A picture of a Garmin V used to record a backup track log during field research.

Figure 20: A picture of a NMEA 0183 multiplexer used to combine depth data and GPS data into a single data string.

Figure 21: A photograph of an uninstalled hull mountable depth sonar. Cruzpro Model ATU120ST

Figure 212: A photo of the Deep Blue waterproof digital camera mounted on top of the kayak.

Figure 22: A photo of the dropshot waterproof camera mounted within the hull of the kayak.

Figure 24: A picture of the waterproof lasers used for this study.

CHAPTER 5

DATA ANALYSIS AND CLASSIFICATION

5.1 GPS Accuracy

In order to obtain a detailed understanding of the GPS attributes of OBRI river system, the final database was broken into three separate databases. Clear Creek, the Obed River, and Daddy's Creek possessed their own separate database, and GPS attributes were analyzed from each of the tributaries, as well as cumulatively (Figure 25).

5.1.1 Clear Creek

The GPS accuracy within Clear Creek yielded a 47.5% differential correction percentage (12,838/27,029 points). Given the remoteness of Clear Creek, the significant amount of vertical escarpments, and the various times of day research was conducted, a differential correction percentage of 47.5 % was sufficient for this research. Additionally, nearly half of all the data recorded in the field yielded accuracy greater than 3.0 meters (assumed with differential correction). This research did not rely on survey grade technologies. Rather, position readings near 3 meter accuracy provided general information as to what characteristics were present near that location (Table 2).

Other data of the Garmin 18 receiver were important to understand the environmental factors examined during this research. Within Clear Creek, the Garmin 18 utilized and average of seven satellites, with a maximum of 10 satellites used simultaneously and a minimum of zero satellites. There was a standard deviation of one satellite, which indicated that the Garmin 18 obtained data from 10 satellites a minimal proportion of the time. (Table 2)

Also within Clear Creek, the average dilution of precision (DOP) was 2.49, with a standard deviation of 1.95. Given that most of the data received during this research was within a bottleneck setting with the surrounding geology or covered by the riparian canopy, the Garmin 18 still had very good satellite geometry. As a thumb rule, DOP values ranging from 2-5 are good, and any readings below 2 are excellent (Table 2).

5.1.2 Obed River

Within the Obed River, the retained GPS data indicated that 42.0% of the data (over one third) was differentially corrected (18512/44056 points). There was a persuading percentage difference from Clear Creek in 2D/3D Fix correctional values with 5.5% (Table 2). Equally, pronounced bluff lines funnel the stream into a bottleneck, where colluvium was not present. There was one area of upper Obed that had GPS gaps. In all, nearly 760 meters of GPS gaps spanned across a section above Upper Potter's Ford. A topographic map of this surrounding area shows evidence of steep escarpments and narrow chutes.

Satellite information within the Obed River varied from the GPS attributes of Clear Creek. The average number of satellites in use was five satellites with a maximum of 9 satellites and a minimum of 0. The average DOP within the Obed River was 3.07. There was a standard deviation of 4.5. This high DOP standard deviation of 4.5 implied that the satellite geometry in this area was variable, but only in areas where there were two-three satellites in use (Table 2).

5.1.3 Daddy's Creek

Surprisingly, there was a 96.3% differential correction reception within the Daddy's Creek stretch from Devil's Breakfast Table to the Obed River confluence. Out of 3,922 GPS points, 3,779 of them were differentially corrected. This creek drains northward, which may have played a role in satellite reception and associated geometry (Table 5.1). This is due to the earth's orbital pattern as well the orbital patterns of GPS satellites.

On average, the Daddy's Creek data proved to utilize 8.5 satellites, with a maximum of using 10 satellites (158 points) and a minimum of five. There was a standard deviation of 0.78, which implied a consistent number of satellites used. Given that Daddy's Creek was kayaked in one day over a two hour time span, these GPS attributes were very consistent. A strongly correlated average DOP of 1.36 gave evidence towards highly precise data. Additionally, a narrow standard deviation of 0.38 supported this claim (Table 2).

5.2 Analysis of Spatial Video

This research investigated four criteria to assess habitats, with three derived from video footage and the other from a depth sonar transducer. The studied variables included: (1) above water river characteristics (macro- habitat), (2) substrate composition, (3) embeddedness, and (4) depth. Macro-habitat classifications were gathered from the above water camera on bow of the kayak. Macro-habitats were broken down into three categories: (1) pools, (2) riffles, and

(3) runs. These terms were also considered to define the above water river characteristics of flow regimes (NRCS, 1998).

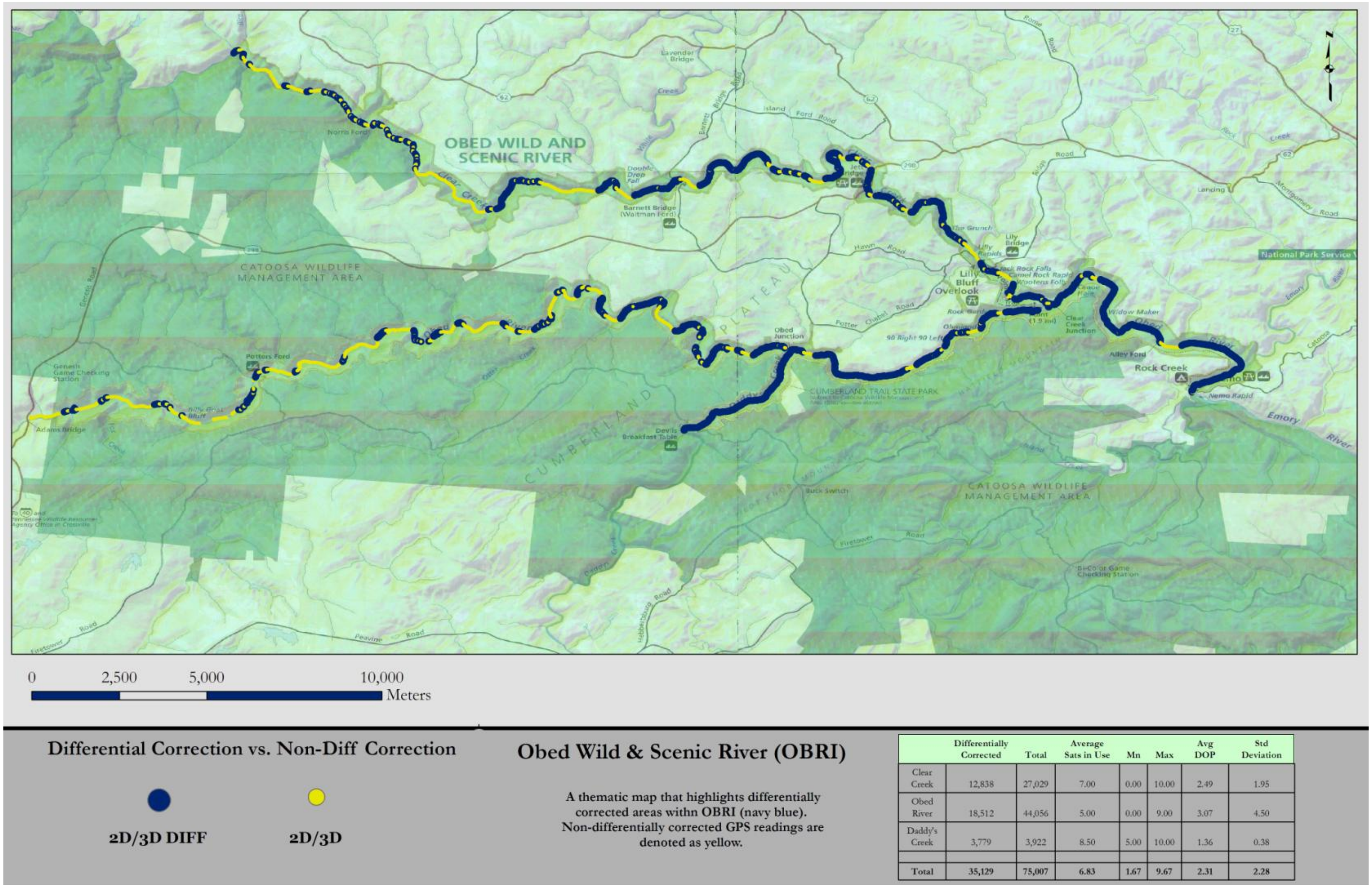
Substrate composition was determined from investigating underwater video footage from the bottom camera. Two 200mW 635 nm laser pointers were installed to reveal a scale within the video frame. This method was investigated by Rogers, (2005) (See Chapter 2.8.2). In all, there were seven categories for substrate: (1) fines, (2) small gravel, (3) large gravel, (4) cobble, (5) small boulder, (6) large boulder, and (7) bedrock. The following substrate section defines the adopted scale.

Embeddedness was also studied under the scope of this research. The underwater bottom camera also provided the platform to quantify the physical amount of sedimentation that had occurred to adjacent substrates. The following section defines the methodologies used to discern embeddedness ranges.

Depth was also used to better quantify habitat criteria throughout the OBRI. Throughout the tenure of this research, three depth measuring methods have been implemented. First, underwater lasers provided a sense of scale that could be used to generally estimate depths. This method was used in 2007 before depth sonars were implemented. Also, laser depth measurements were useful to capture when there were equipment problems. On 4-9-09, a small portion of Clear Creek had to be visually estimated for depth because of lost data from the depth sonar

The other two methods to obtain depth were the two different models of sonar transducers. A depth sonar resolution 0.1 and a range from 0.3 – 20 m was used during 2007 and 2008 research. Custom made shallow water depth sonar was installed for all 2009 field research. These data were generally more accurate since it had a resolution of 0.01 and range from .1 – 11 m.

The following table outlines the dates of conducted field research, the distance of that section, and the corresponding discharge rates for that day (Table 3, See Appendix).



	Differentially Corrected	Total	Average Sats in Use	Mn	Max	Avg DOP	Std Deviation
Clear Creek	12,838	27,029	7.00	0.00	10.00	2.49	1.95
Obed River	18,512	44,056	5.00	0.00	9.00	3.07	4.50
Daddy's Creek	3,779	3,922	8.50	5.00	10.00	1.36	0.38
Total	**35,129**	**75,007**	**6.83**	**1.67**	**9.67**	**2.31**	**2.28**

Figure 23: A thematic map of OBRI that shows differentially corrected GPS locations vs. non-differentially corrected locations.

Table 2: A table that expresses GPS attributes information within the three river stems of OBRI.

	Differentially Corrected	Total	Average Sats in Use	Min	Max	Avg DOP	Std Deviation
Clear Creek	12,838	27,029	7.00	0.00	10.00	2.49	1.95
Obed River	18,512	44,056	5.00	0.00	9.00	3.07	4.50
Daddy's Creek	3,779	3,922	8.50	5.00	10.00	1.36	0.38
Total	**35,129**	**75,007**	**6.83**	**1.67**	**9.67**	**2.31**	**2.28**

5.3 Classification of Above Water River Characteristics

Above water river characteristics were disseminated and identified throughout OBRI Characterizations were placed on pool/riffle/run transitions via GIS ArcMap 9.1-9.3. The definitions used to classify macro-habitats were based on the literature of Natural Resources Conservation Service, 1998 (Figure 26). There were a variety of macro-habitat trends throughout the Park, varying from other in park streams.

In all, 44.4% of OBRI contained runs, and were common throughout. Pools were more apparent in upper Clear Creek, from Bice Creek through Jett Bridge, and prevailed after Clear Creek confluence. Pools were less prevalent in the upper – mid Obed River. In all, pools composed 39.9% of the data. High frequencies of riffles were expected, as OBRI has world class white water rapids, and they contributed 23.5% of the data. Highly concentrated riffle areas were more noticeable in the upper Obed River (Upper Potters Ford – Lower Potters Ford), and were evident through the topography (Figure 27)(Table 4, See Appendix).

Flow Characteristics of the River		
Habitat Parameter	Description	Example
Pool	Areas characterized by smooth undisturbed surface, generally slow current, and deep enough to provide protective cover for fish (75 to 100% deeper than the prevailing stream depth).	
Run	Fast-moving section of a stream with defined thalweg and little surface agitation. Runs are deeper than a riffle and shallower than a pool.	
Riffle	Area characterized by broken water surface, rocky or firm substrate, moderate or swift current, and relatively shallow depth (usually less than 0.5 m). Shallow section in a stream where water is breaking over rocks, wood, or other partly submerged debris and producing agitation.	

Natural Resources Conservation Service, (1998).

Figure 24: Definitions and associated pictures of the criteria for macro-habitat classification (Fiscor, 2005).

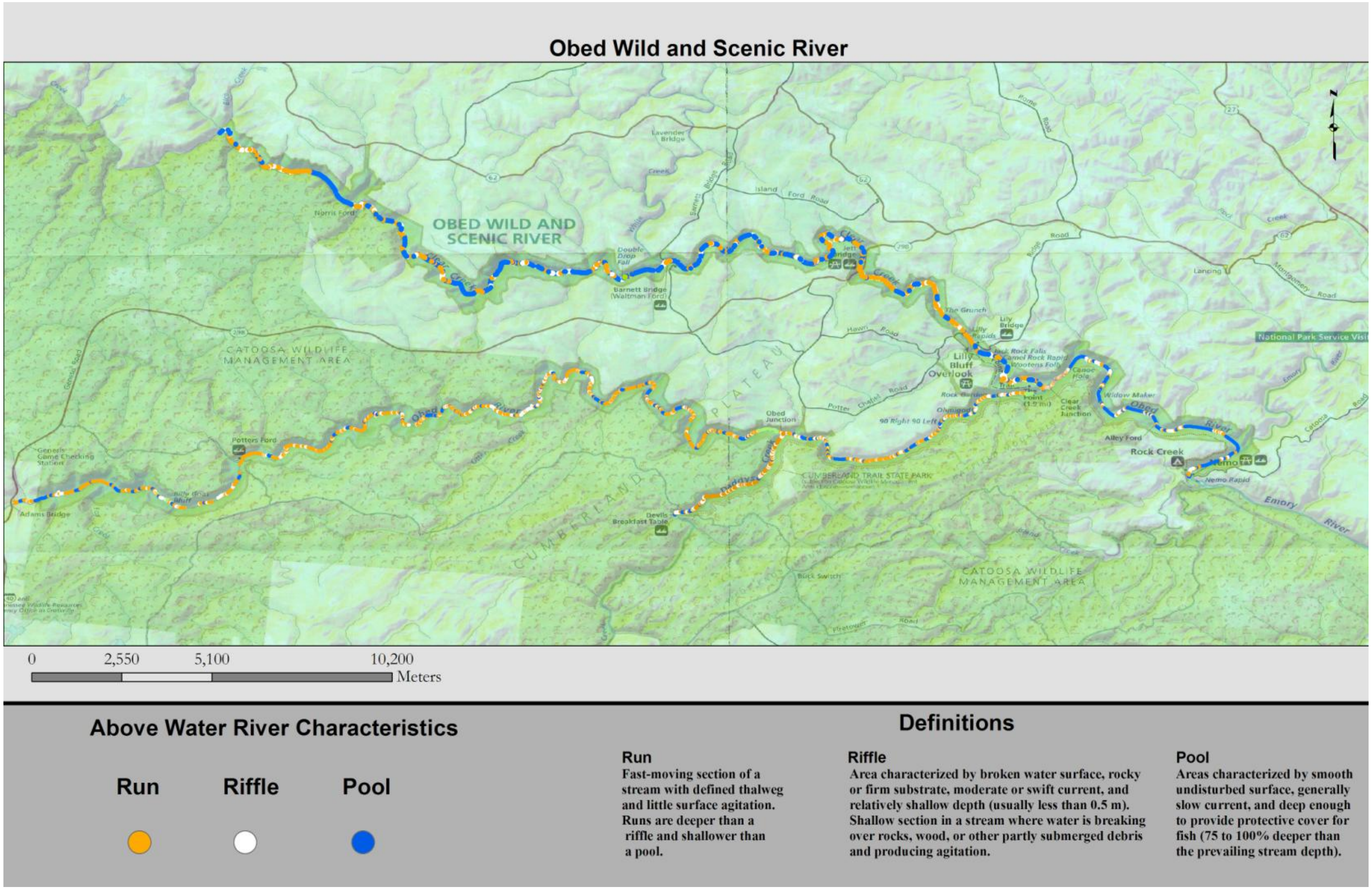


Figure 25: A thematic map that shows the pool/riffle/run transitions throughout the Park.

5.3.1 Clear Creek

Within Clear Creek, there was a total of 27,029 data points over a course of 27.2 km. The total number of pools was 11,465 points. This equates to 42.4 % of Clear Creek that has pools. There were 9,349 points as runs, which translates as 34.6%. As for riffles, 5,924 points yielded that 21.9% of Clear Creek contains riffles (Figure 28). For the sake of aquatic habitat, an overall run:riffle ratio was 8:5 (Figure 29).

5.3.2 Obed River

The Obed River data set comprised a total of 44,056 NMEA sentences. Of these, 48.0 % were runs (21,145/44,056). Riffles accounted for 25.1% of the Obed River (11,022/44,056) (Figure 28). Pools composed 22.4% of the Obed, distributed sporadically throughout the river (Figure 30). There was a run:riffle ratio of just under 2:1.

5.3.3 Daddy's Creek

Daddy's Creek supported 72.6% runs from the Devil's Breakfast Table to the Obed River confluence (2,848 points) (Figure 28). Riffles were evident in 18.0% of this reach, while pools were less common at 9.4% occurrence (705 points and 369 points, respectfully). There was a run:riffle ratio near 4:1 (Figure 31).

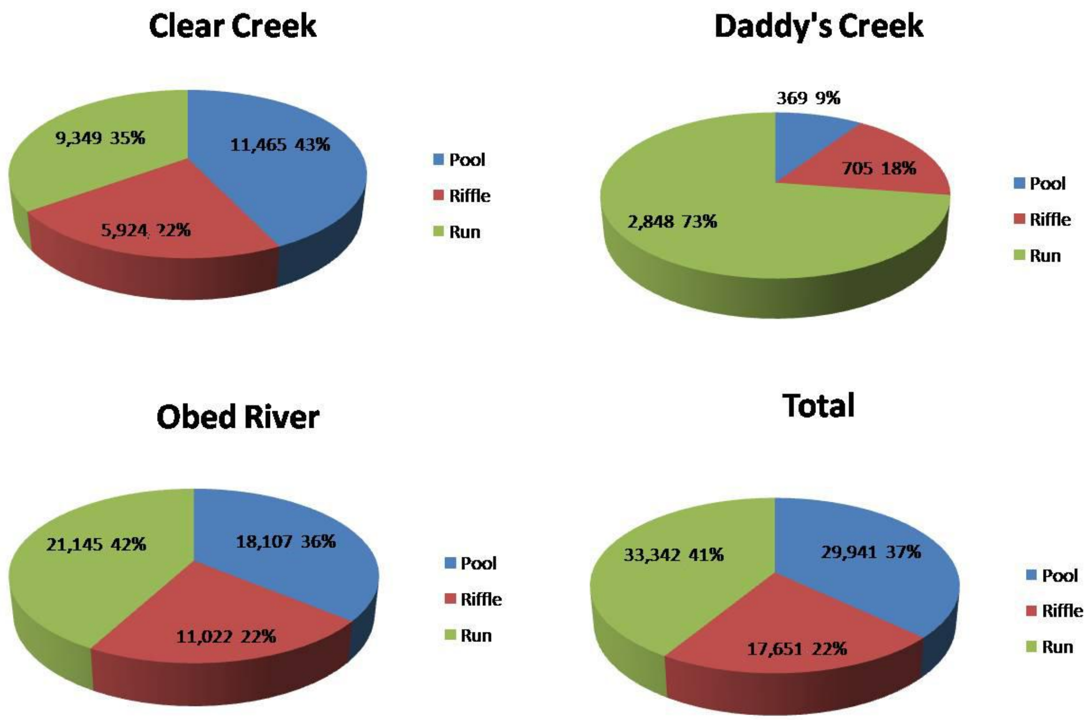


Figure 26: Pie charts that show the distribution of river characteristics throughout OBRI.

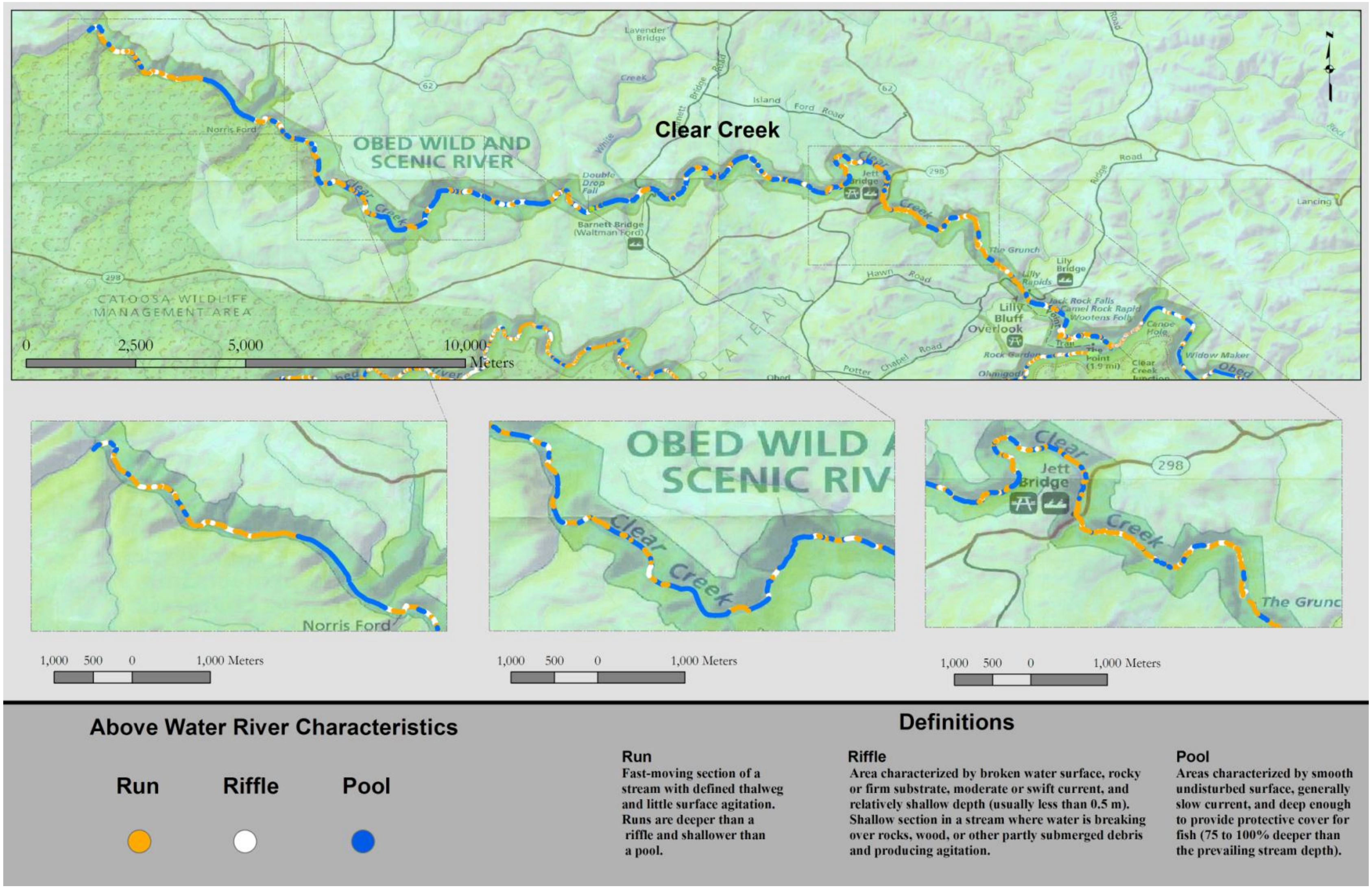


Figure 27: A thematic map that shows pool/riffle/run sequences throughout Clear Creek.

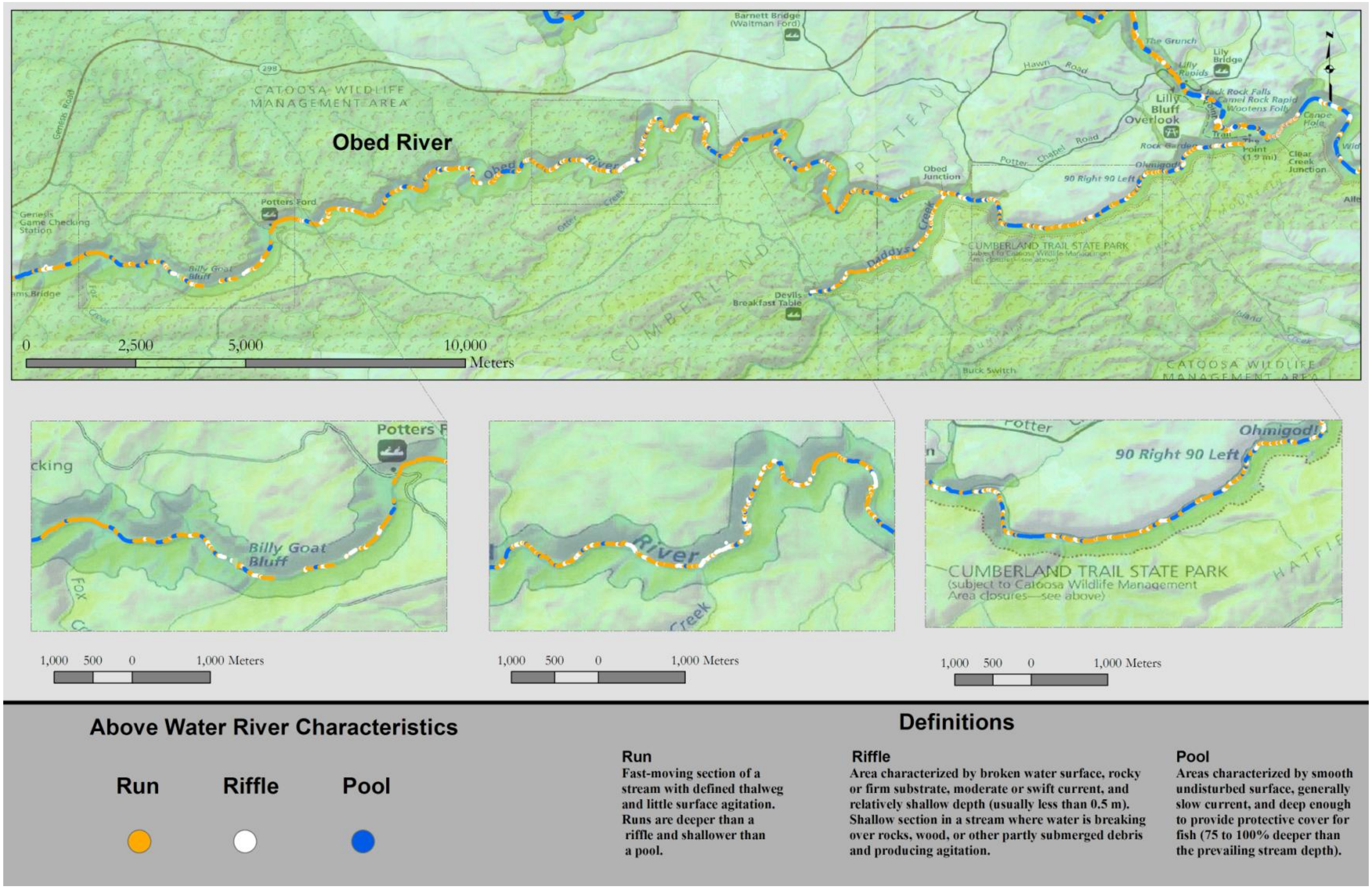


Figure 28: A thematic map of the Obed River that shows pool/riffle/run trends.

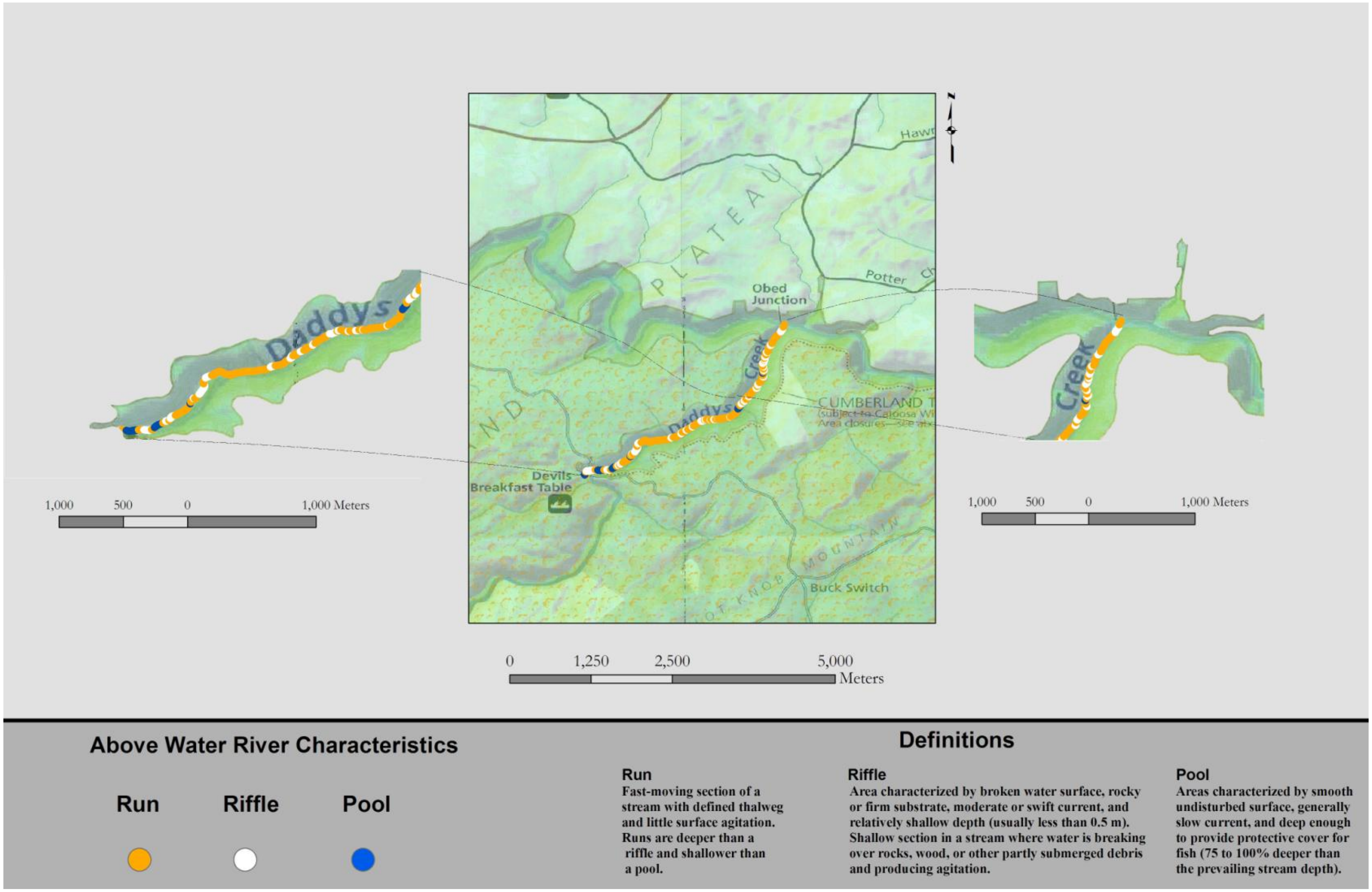


Figure 29: A thematic map that shows pool/riffle/run transitions within the lower section of Daddy's Creek.

5.4 Substrate Composition

The substrate scale used for this research was modified from the Wentworth Scale, which separated substrates into seven categories. These classifications included: fines, small gravel, large gravel, cobble, small boulder, large boulder, and bedrock (Figure 32) (Table 5). During video analysis of the underwater bottom camera, two lasers proved a constant scale to assist in accurate representations. These lasers were 20 cm (7.75 in) apart from each other, and were relatively consistent throughout the project.

Based on the georeferenced data, the OBRI's domain contains rivers composed of a high density of cobble and small bolder substrates. In fact, cobble was most abundant with 43.3% of the data. Small boulders were present 23.1% during field research. Bedrock raked third upon comparison of substrates, contributing 7.1 % of the data (Figure 33, Table 6).

Additionally, a table was constructed to better understand the relationships between pool/riffle/run sequences and the substrate composition within these macro-habitat transitions. According to the data, 23% of the collected data revealed that there was cobble substrate within a riffle environment. Small boulders were also evident within riffles (Figure 34, 35).

5.4.1 Clear Creek

The dominate substrate type for this creek was cobble, equating to nearly 40% (39.56%, 10,694 points). This stream is primarily composed of cobble and small boulders (21.2%, 5,732 points). Surprisingly, just over 11% of Clear Creek contained a bedrock substrate (11.25%, 3,041 points), which was higher than

Daddy's Creek and the Obed River. The other minority substrates included large boulders (1.7%, 464 points), gravels (4.9%, 1,323 points), and fines (5.5%, 1,470 points) (Figure 33, 36)(Table 6, See Appendix).

5.4.2 Obed River

The Obed's substrate characteristics varied slightly from Clear Creek's findings. Nearly 28% of the substrate composition in the thalweg was boulders (small and large) (12,307 points). Cobbles comprised 22.4% of the Obed. Together, boulders and cobbles accounted for over 50% of the substrate, which was comparable to Clear Creek. There was 5.2% bedrock and 8.5% gravel substrate (2,278 points and 3,739 points, respectfully). Fines were patchy and exhibited a 1.1% distribution (520 points)(Figure 33, 37)(Table 6, See Appendix).

5.4.3 Daddy's Creek

Cobble dominated the substrate composition within the lower section of Daddy's Creek (57.1%, 1,446 points) (Figure 33, 38). Boulders, especially small boulders, provided 36.9% of the substrate. Bedrock was not common, only supplying >1.0 % of the bed forms (40 points). There was no evidence of widely distributed fines, and gravel only supported 1.8% of the substrate (Table 6, See Appendix).

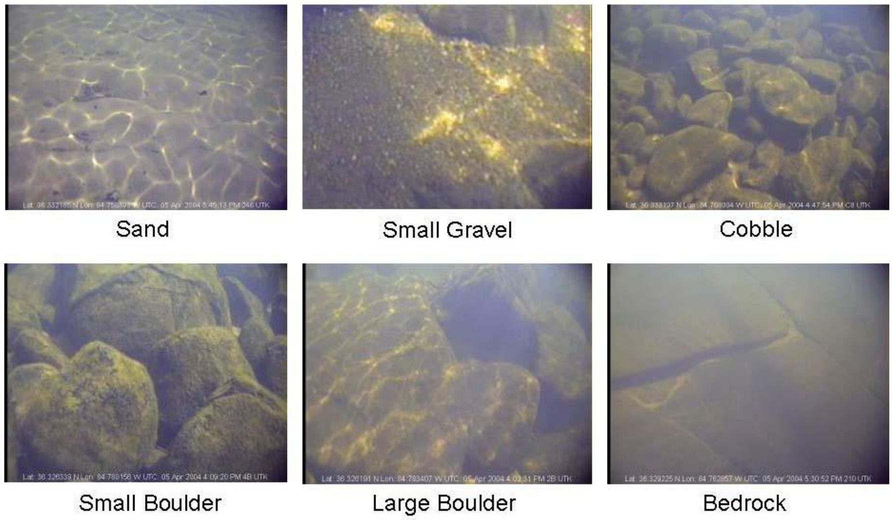


Figure 30: Photos of representative substrate types that are seen from underwater video cameras.

Table 3: Substrate scales used for this research. This scale was modified from an existing Wentworth Scale.

Substrate Type	**Size (metric)**	**Size (Customary)**
Fines	<2 mm	<0.1 in
Small Gravel	3 – 10 mm	0.1 – 0.4 in
Large Gravel	1 cm – 10 cm	0.4 – 4 in
Cobble	11 – 30 cm	4 – 12 in
Small Boulder	30 – 60 mm	12 – 24 in
Large Boulder	> 60 mm	>24 in
Bedrock	Unbroken Rock Surface	

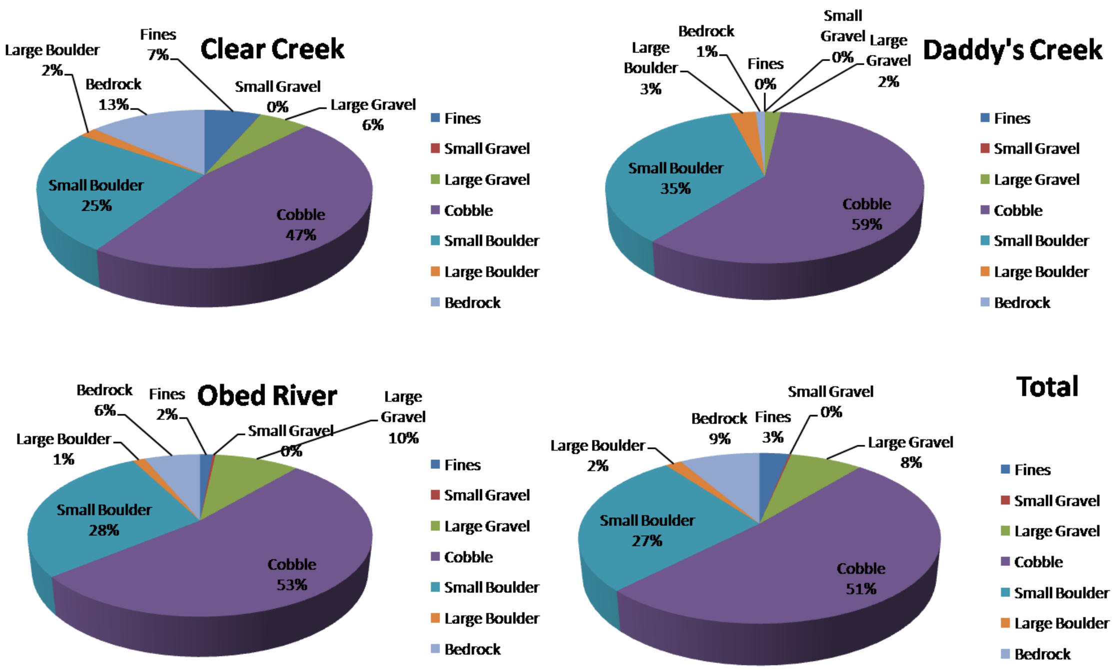


Figure 31: Pie charts that help visualize substrate compositions throughout OBRI.

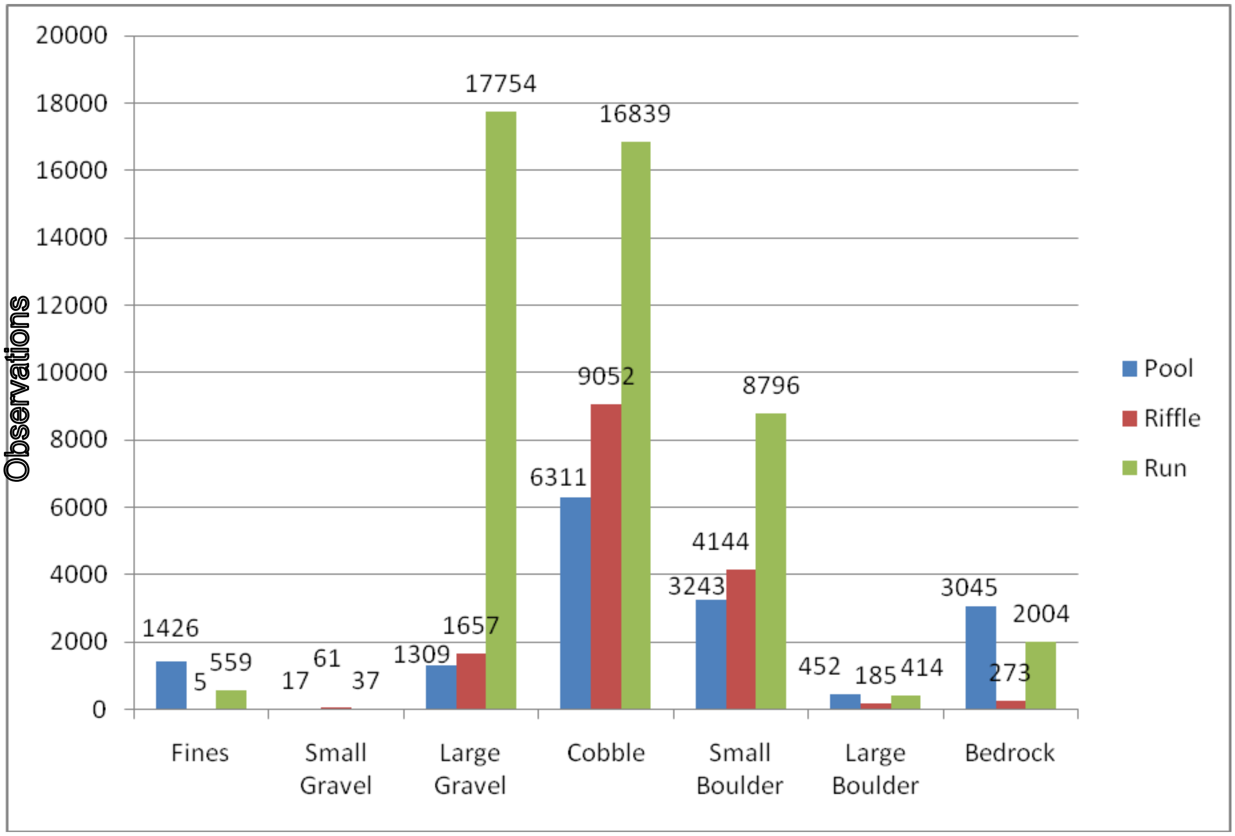


Figure 32: A chart that shows relationships between pool/riffle/run and substrate composition.

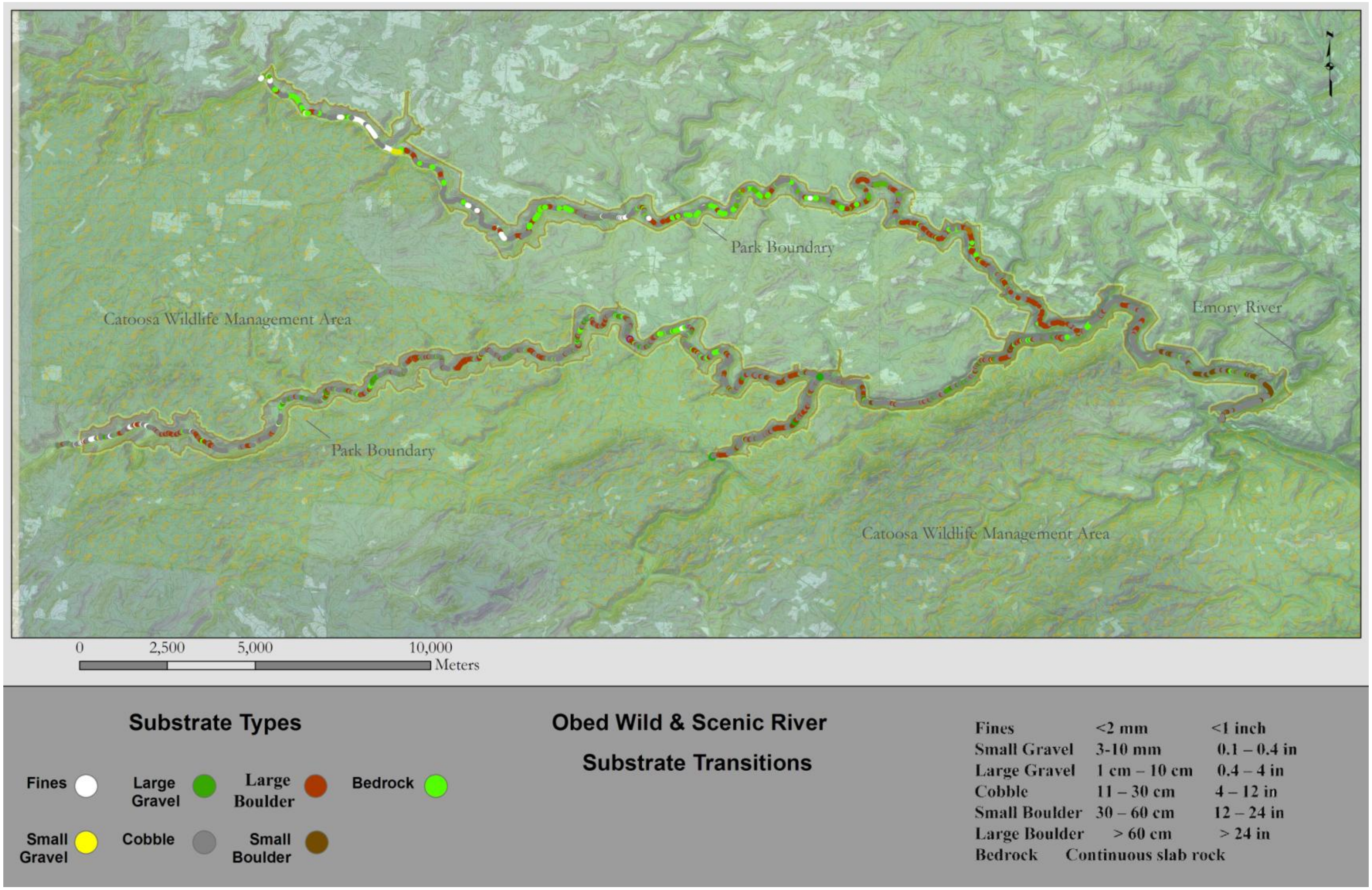


Figure 33: A thematic map of substrate transitions throughout the OBRI.

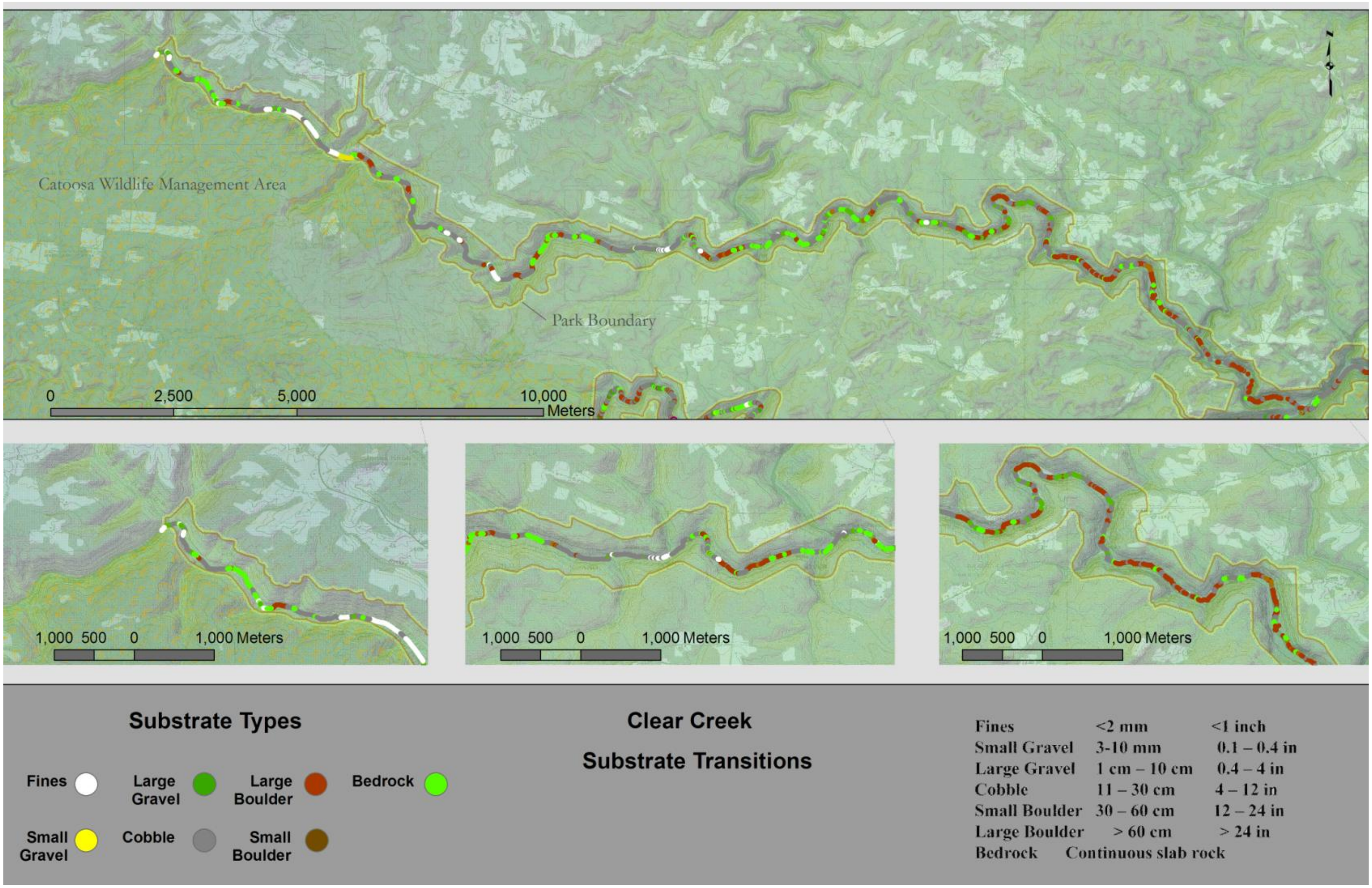


Figure 34: A thematic map that shows substrate trends within Clear Creek.

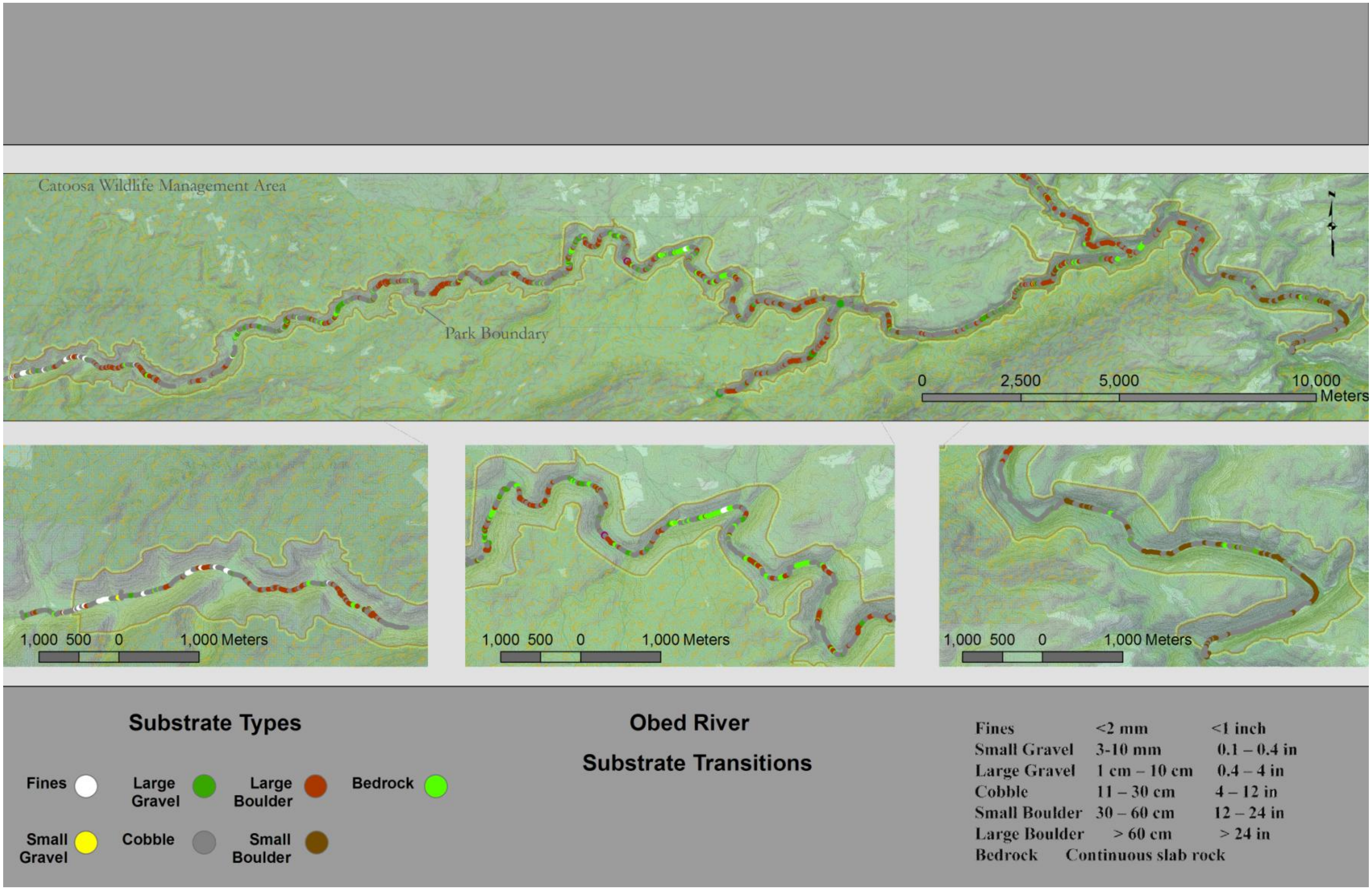


Figure 35: A thematic map that shows the substrate characteristics within the Obed River.

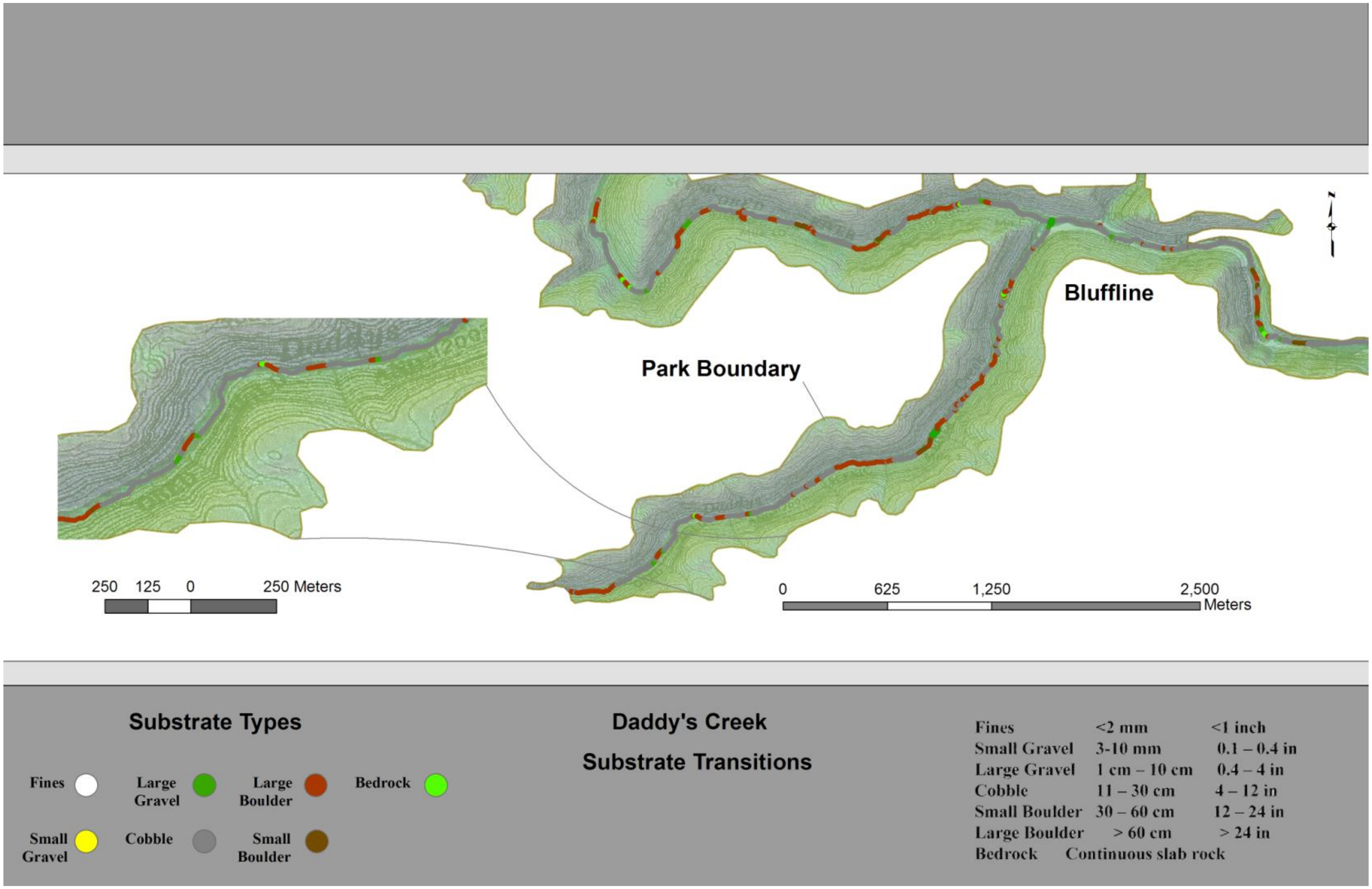


Figure 36: A thematic map that shows substrate transitions within the lower section of Daddy's Creek.

5.5 Depth Measurements

5.5.1 Clear Creek

Clear Creek averaged a depth of 1.4 m (4.3 ft) when excluding zero values from the database. When considering zero values, the depth transducer yielded an average depth of 1.1 m (3.5 ft). The maximum recorded depth was 8.7 m (26.5 ft) and a minimum of 0.17 m (0.5 ft) (Figure 38). A standard deviation of 1.2 helps explain the physical conditions of OBRI, at least a correlation at specific discharge rates (Table 7). Zero depth readings were significant within Clear Creek as shallow water was prevalent. The low flowing survey conditions within this creek probably impeded the transducer as many depths were more shallow than the transducer's range. There were 15.6% (4,233 points) of zero values for depth. Laser depths recordings were used to fill in areas that the depth sonar did not record, but there were still unknown values.

There were technical issues in the field that were worth mentioning. The loss of sonar data led to a depth data gap of approximately 2,500 m above double drop falls. Also, a lower section between Jett Bridge and Lilly Bridge (± 5,000 m) did not have sonar data. There were data captured in this area before the depth sonar was implemented. Depths were visually estimated from the underwater bottom video footage, and the consistency of the waterproof lasers was used to provide a general depth scale.

5.5.2 Obed River

The Obed River averaged a depth of 1.1m (3.4 ft), including all the zero data. But, this average would have been higher if zero depth sonar readings were omitted. In fact, there was an average depth of 0.9 m (2.7 ft). A standard deviation of 1.33 indicated fluctuations in depth readings (with zeros included). The minimum depth was 0.2 m (0.5 ft) and a maximum of 19.9 m (60.6 ft) (Table7). There were several depth readings over 16 m in a reach between Obed Junction and Canoe Hole (Figure 39).

In more detail, there was only one observation with a maximum depth of 19.9 m (60.6ft). Upon inveistigation, this area of the Obed River generally had deeper areas than the rest of the park, excluding the 19.9 m reading. In fact, there were two adjacent areas with a very large pool ~1,000 m below Daddy's Creek confluence that had numerous readings above 12.2 m (40 ft). Zero values were also present in this deep section which may be explained two ways: (1) there was large boulder/strata interference that impeded the depth transducer from attaining accurate depths, or (2) some of these areas were beyond the range of the transducer's calibration.

Future validation efforts will focus attention on this area of the Obed River to see if these analogous depth readings bear truth or if environmental interference yielded zero depth data.

5.5.3 Daddy's Creek

The average depth of Daddy's Creek was 0.8 m (2.4 ft), excluding zero depth values. Incorporated zero values yielded an average depth of 0.8 m (2.4 ft). Zero depth sonar readings were not common. In fact, a new depth sonar transducer was implemented for this kayak trip and others. This new transducer provided a range specified for shallow water application 0.2 – 9.8 m (0.5 ft – 30 ft), and resolution of 0.01 m. There was a standard deviation of 0.70 m, a minimum depth of 0.2 m (0.5 ft), and a maximum depth reading of 6.2 m (20.3 ft) (Figure 40) (Table 7).

5.5.4 Notes on Transducer Concerns

Even though there were many incidents where the depth sonar read zero for depth, this only occurred where the depth transducer was pinging depths outside of its range. The research conducted from 2007 and 2008 utilized a transducer with a range from 0.328 -20 m (1ft - +60ft), with a 0.1 resolution. This sonar reported zeros in nearly 48% of the Obed River data. The majority of these data were captured during 7/31/07, where flow rates were well below 2.9 m^3/s (100 cfs). So, there were non-expansive distances where the sonar was essentially scraping the substrate. Within Clear Creek, over 15% of the depth data gave zero values. Again, a large portion of this zero data was captured during 2007 where flow rates were near 2.9 m^3/s (100 cfs) or below.

Table 4: Depth attributes within Clear Creek, Obed River, and Daddy's Creek of OBRI.

	Depths of OBRI				
	Average	Min	Max	Avg w/ Zero Values	Std Dev
Clear Creek	1.42 m (4.33 ft)	0.17 m (0.51 ft)	8.69 m (26.5 ft)	1.14 m (3.46 ft)	1.18
Obed River	1.11m (3.39 ft)1	0.17 m (0.51 ft)	19.88 m (60.6 ft)	0.88 m (2.69 ft)	1.33
Daddy's Creek	0.77 m (2.35 ft)	0.17 m (0.51 ft)	6.66 m (20.31 ft)	of 0.77 m (2.36 ft)	0.7
Totals	**1.1 m (3.36 ft)**	**0.17 m (.051 ft)**	**19.88 m (60.6 ft)**	**0.93 m (2.83 ft)**	**1.07**

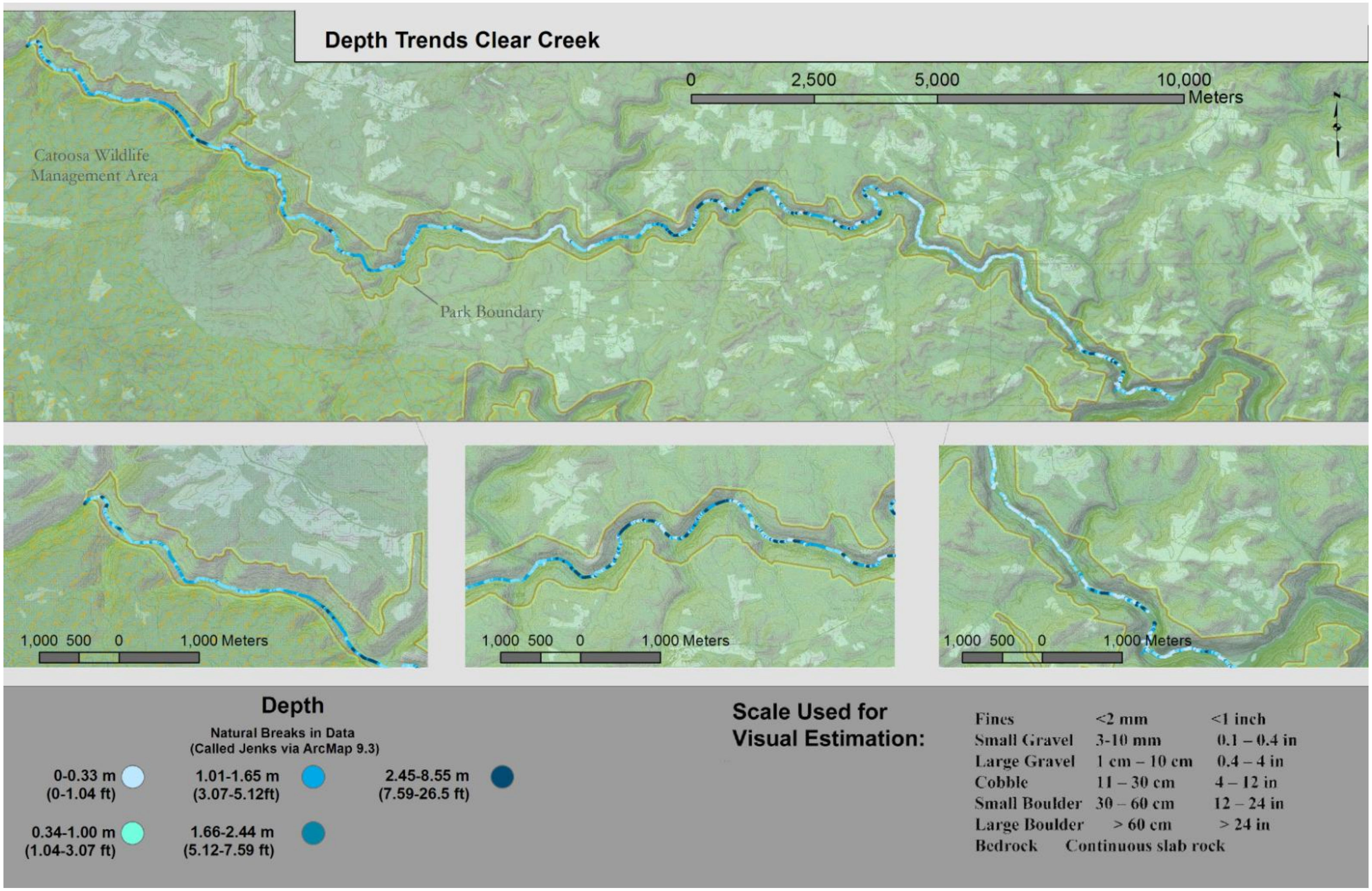


Figure 37: A thematic map that shows depth transitions throughout Clear Creek.

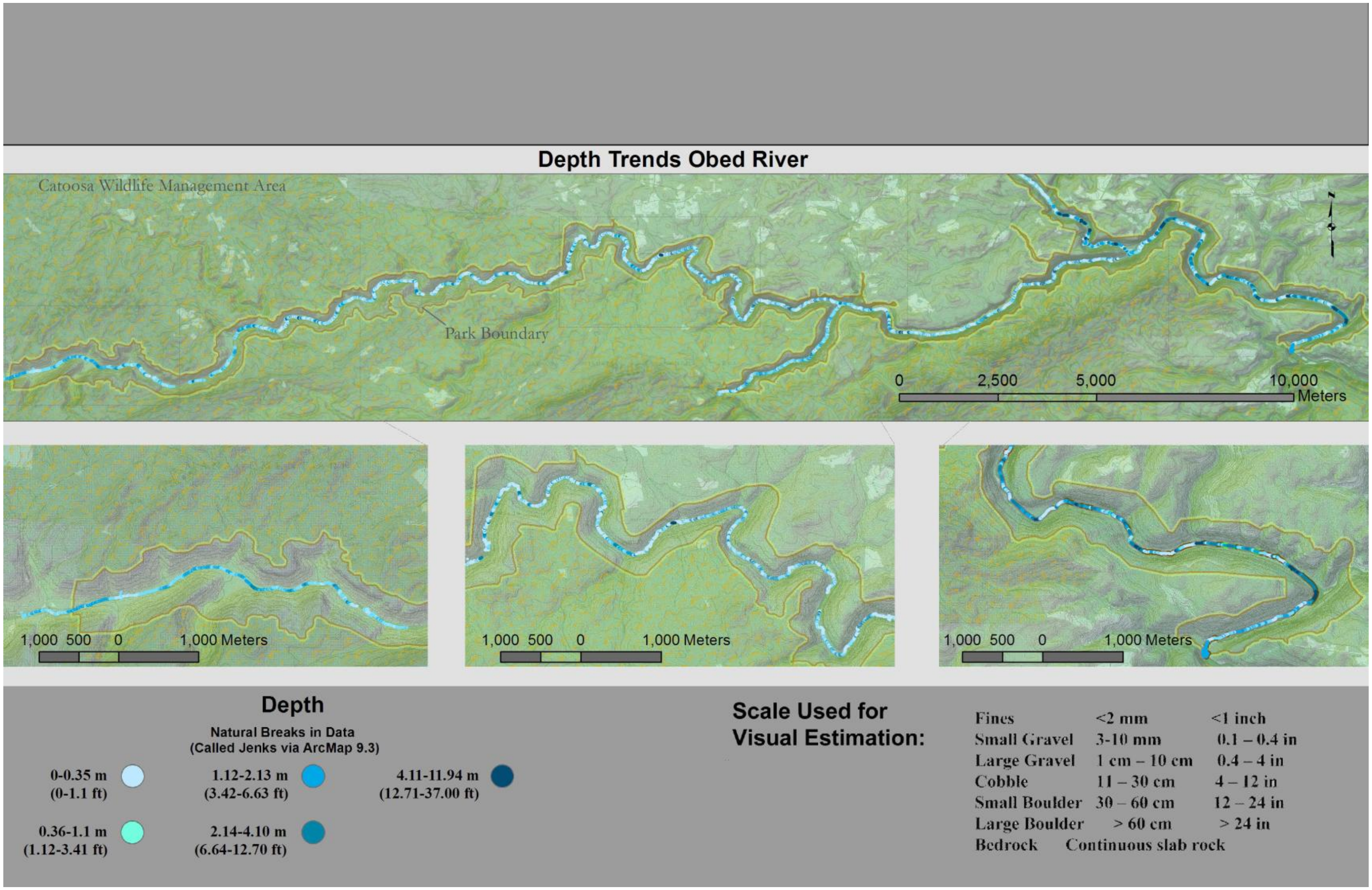


Figure 38: A thematic map of depth trends throughout the Obed River.

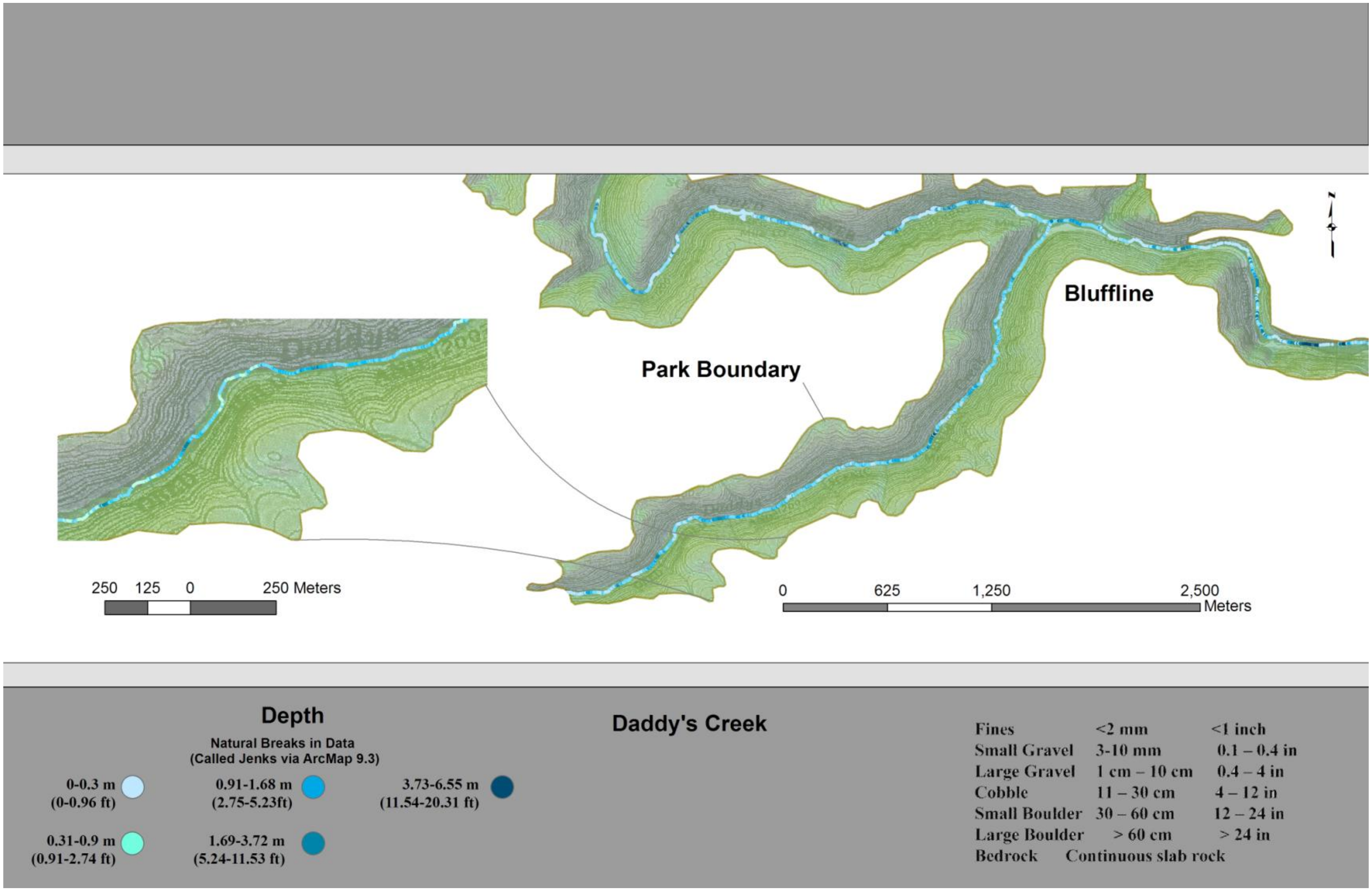


Figure 39: A thematic map of Daddy's Creek that shows depth transitions.

5.6 Embeddedness

Embeddedness values were based on Barbour et *al. (*1999) EPA protocol by estimating the physical amount of substrate that was surrounded by fine sediment. These values ranged from 0-20. The observer reduced this scale into four categories with only one number representing each category. A value of 20 implied that substrates are only surrounded by sediment by 0-25%. A value of 15 indicated that 25-50% sediment surrounds the adjacent substrate. Values of 10 and 5 designate 50-75% and >75% of the substrates are surrounded by fines (Barbour et *al.,* 1999) (Table 8).

5.6.1 Clear Creek

Even though only 4.9% of Clear Creek had areas of high embeddedness (EPA value of 5), the majority high embeddedness occurred just above Norris Ford (Figure 5.16). There were other locations with very high embeddedness, but distributions were periodic. Clear Creek was predominately clean, showing evidence of 72.7% of the thalweg had an EPA value of 20. However, there were intermittent patches of mild sedimentation. EPA values of 10 and 15 revealed 4.1% and 11.8% of selectable data throughout the course of Clear Creek (Figure 41, 42) (Table 9, See Appendix).

5.6.2 Obed River

Surprisingly, only 1.4% of the Obed River had an embeddedness value of 5, and most of these occurrences were below the Emory River confluence. Highly concentrated sediment was predominately observed within the upper sections of the Obed. Throughout the river, however, most of it was clean of sedimentation

(Figure 41, 43). In fact, 69.1% of the Obed River had a minimal embeddedness value of 20. Most of the embeddedness values of 10 did not span across long stretches, but were most common in the upper section above Upper Potter's Ford. Also, embeddedness values of 15, which might be a concern, were most often found above the confluence of Daddy's Creek (9.8%)(Table 9, See Appendix).

5.6.3 Daddy's Creek

Even with previous encroachment threats from development and recreational parks at the outskirts of Crossville, TN, Daddy's Creek exhibited very minimal embeddedness throughout its lower end course (Figure 41, 44). There were no EPA scores in the 5-10 range. Scores of 15 only contributed 2.6% to the data, with evidence of sedimentation just downstream of Devils Breakfast Table (not in great quantity). In general though, over 93% of this section was not associated with significant sediment deposits (Table 9, See Appendix).

Table 5: The embeddedness scoring criteria based on EPA protocols, and the customized scoring scale for OBRI research. Barbour et al., 1993).

Habitat Parameter	**Condition Category Embeddedness**			
OBRI Score	**5**	**10**	**15**	**20**
EPA Score	0 1 2 3 4 5	6 7 8 9 10	11 12 13 14 15	16 17 18 19 20
Embeddedness	Gravel, cobble, and boulder particles are more than 75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 50-75% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 25-50% surrounded by fine sediment.	Gravel, cobble, and boulder particles are 0-25% surrounded by fine sediment..

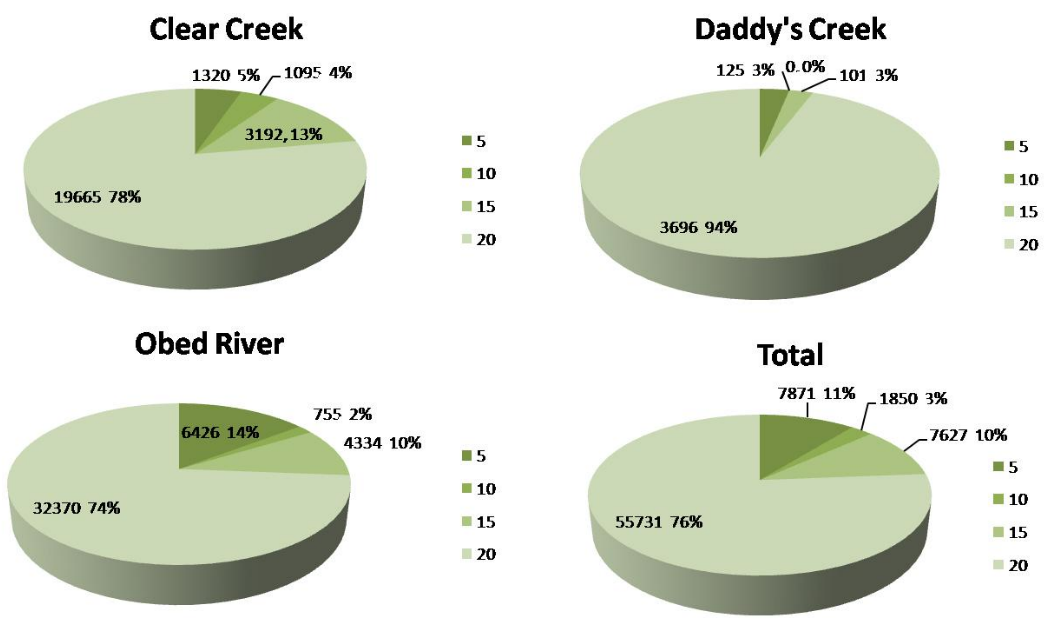


Figure 40: Pie charts that show the distribution of embeddedness within Clear Creek, Obed River, and Daddy's Creek.

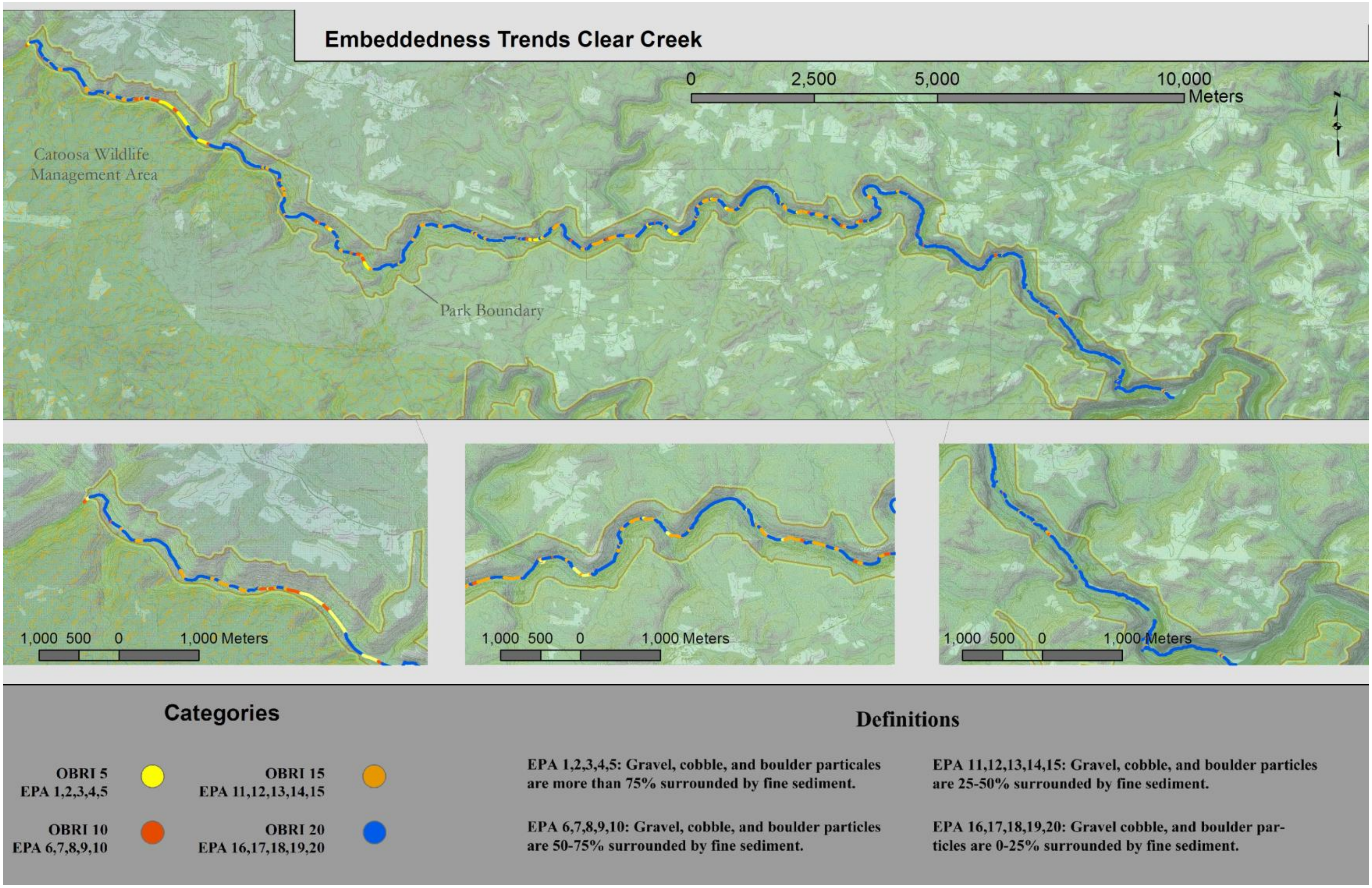


Figure 41: A thematic map showing embeddedness characteristics throughout Clear Creek.

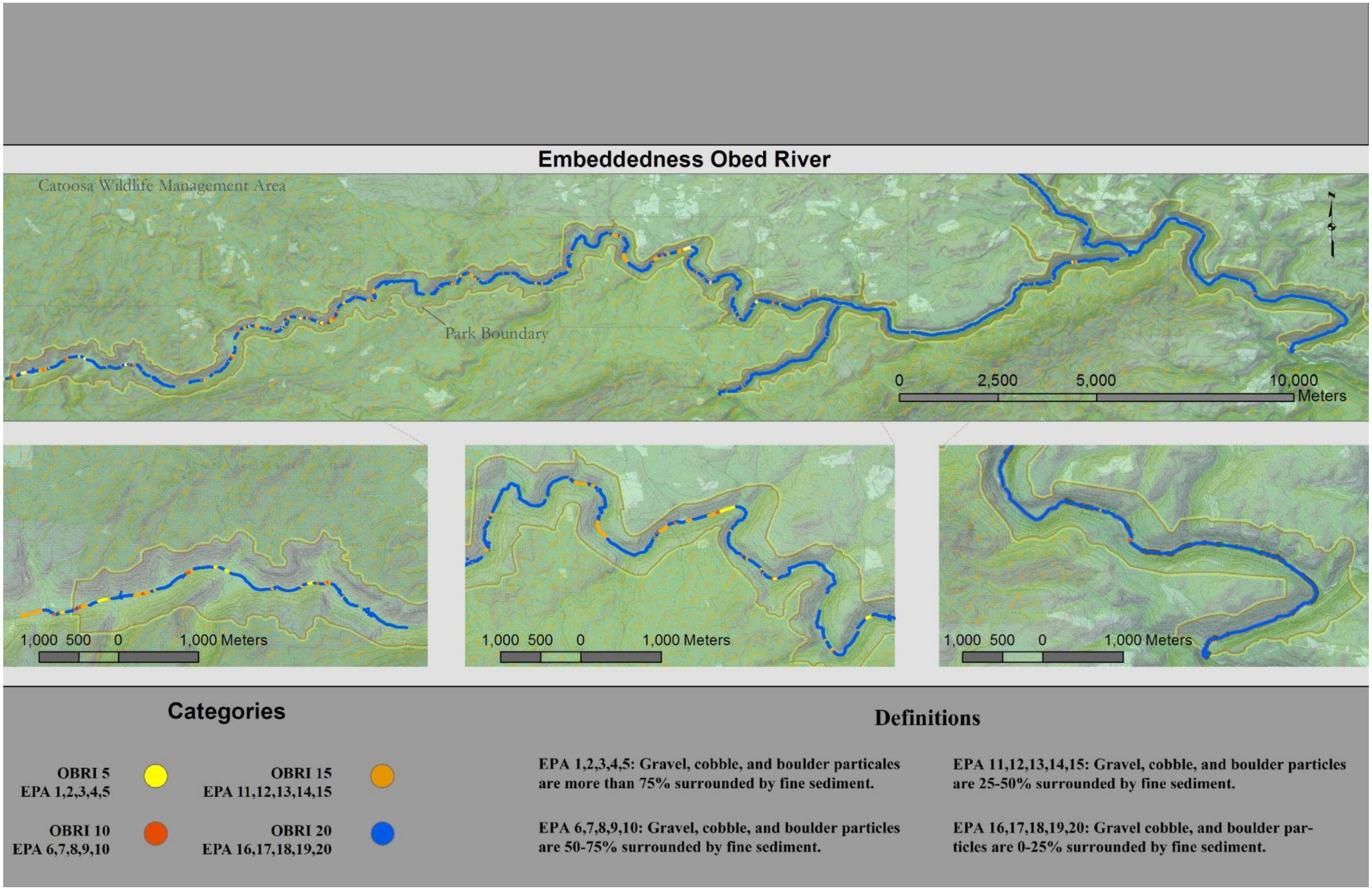


Figure 42: A thematic map showing embeddedness trends throughout the Obed River.

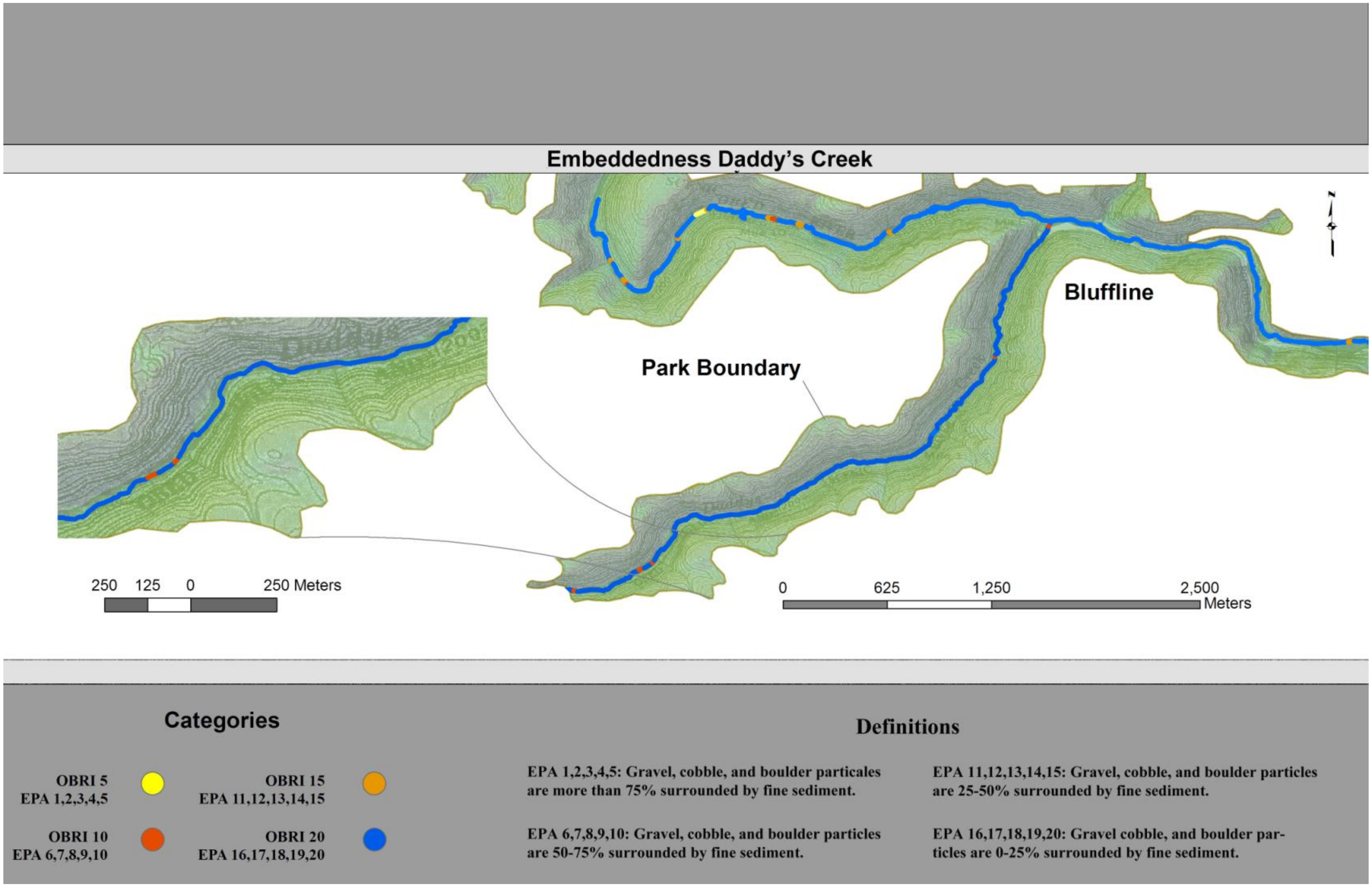


Figure 43: A thematic map showing embeddedness trends across the lower section of Daddy's Creek.

CHAPTER 6
HABITAT SUITABILITY FINDINGS

Employing a physical habitat suitability index outputted unique results for each of the species' habitat under the scope of this study. This index was specifically constructed to align with four habitat criteria: pool/riffle/run sequences, substrate type, depth, and embeddedness. This mathematically based model produced scores from the range of 0-34, correlating better habitat with higher number. Initially, this index was constructed by a conglomeration of United States Fish and Wildlife Service, Tennessee Wildlife Resources Agency, and Tennessee Technological University biologists for the purple bean. Treated as a template, the index was modified to fit the preferences of different species.

6.1 Spotfin chub

6.1.1 Habitat Suitability Criteria

The physical habitat suitability model was constructed based on literature findings of habitat preference and non-suitability. The spotfin is found in rocky riffles and runs of small- to medium-sized rivers. Optimal adult habitats are isolated to swift currents, such as runs, with boulder/bedrock substrates (Jenkins and Burkhead, 1984; Russ, 2006). Juvenile habitats vary slightly, preferring moderate currents with small gravel substrate (Etnier and Starnes, 1993). The more highly populated areas are more localized to a small part of any riffle-run sequence (Jenkins and Burkhead, 1993). However, the spotfin tends to prefer slower currents during the winter months (Jenkins and Burkhead, 1984). The index ranged scores from 0 – 34, indicating that summations greater than 27 indicated ideal habitat. Lower scores implied poorer habitat (Table 10).

6.1.2 Clear Creek

Within Clear Creek, there were significant optimal habitat findings for the spotfin chub (7,348 locations of HIS scores 27-34). Although most of Clear Creek did not have optimal habitat conditions, areas of potential optimal habitats were located in the upper portion of Clear Creek within the Park (near Bice Creek). The area just above Double Drop Falls depicted sufficient habitat conditions, as well as areas above and below Jett Bridge (Figure 46)(Table 11). In all, there was 10.9 km (15% of OBRI's spatial extent) of Clear Creek that supported optimal habitat.

6.1.3 Obed River

There were plentiful optimal locations throughout the Obed River. Overall, better habitat quality was prevalent upstream of the Daddy's Creek confluence. Much of the area near Obed Junction did not support optimal conditions. In all, roughly one-fourth of the Obed data supported optimal habitat conditions (11,924 pts out of 44,056 pts). More specifically, there was a 2,800m section of interchanging optimal and sub-optimal habitat just below Adam's Bridge. Also, there was a good reach of optimal habitat approximately 1,000 m just upstream from the Otter Creek confluence (Figure 47)(Table 11). Within the Obed River, 10.3 km (14 % of OBRI's spatial extent) supported optimal habitat.

6.1.4 Daddy's Creek

Out of 3,922 data points, 63% of the data held optimal habitat characteristics. In fact, over 90% of the lower stretch of Daddy's Creek provided optimal and sub-optimal habitat. Even though only 3.7 km (5% of OBRI's spatial extent) falls within the Park, this area provided notable habitat for this species.

More specifically, it was apparent that the lower 1,000 m of Daddy's Creek had a favorable optimal to sub-optimal habitat geomorphology (Figure 48)(Table 11). Within this lower section of Daddy's Creek, 882.1 m (1 % of OBRI's spatial extent) met optimal habitat criteria.

Table 6: The physical habitat suitability model for the spotfin chub. Values were derived from supporting evidence in the literature.

HSI 0 – 34	**Physical Habitat Suitability Model for Spotfin chub**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Runs	**6 = <1.6 ft**	**10 = Bedrock, Boulders**	**12 = 20**
	2 = Riffles	**4 = 1.61 – 2.6 ft**	**5 = Cobble**	**8 = 15**
	0 = Pools	**1 = 2.61 – 5.0 ft**	**1 = Gravels**	**4 = 10**
		0 = >5.01 ft	**0 = Fines**	**0 = 5**

Table 7: Habitat suitability results within Clear Creek, Obed River, and Daddy's Creek.

HSI 0 – 34	Physical Habitat Suitability Results – Spotfin chub – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	7,348 pts	**9,298 pts**	**5,487 pts**	**3,322 pts**	**1,574 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Spotfin chub – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	11,924 pts	**15,699 pts**	**10,139 pts**	**4,679 pts**	**1,615 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Spotfin chub – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	2,500 pts	**1,168pts**	**217 pts**	**37 pts**	**0 pts**

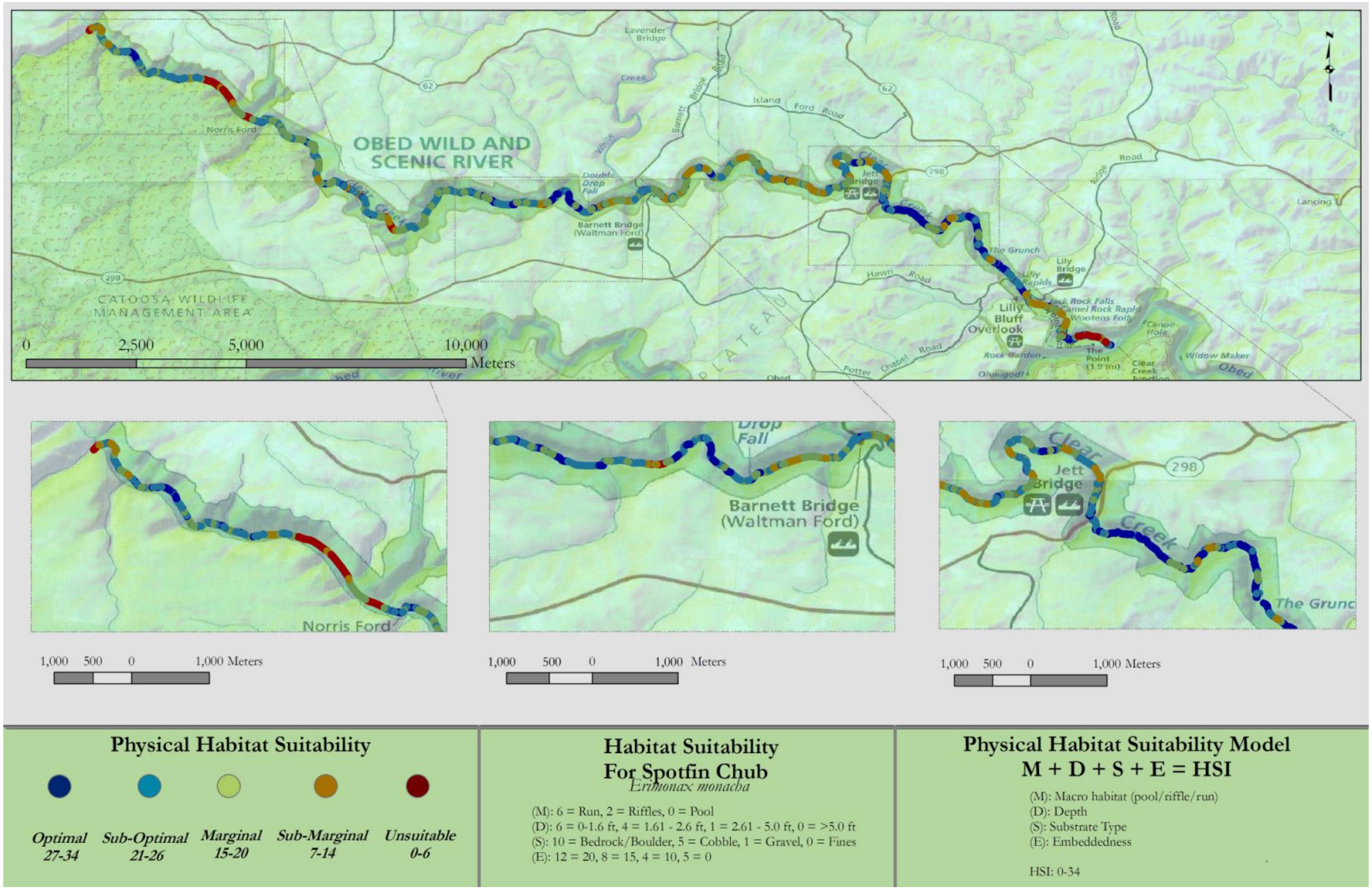


Figure 44: A map of Clear Creek that shows the habitat suitability for the spotfin chub within Clear Creek.

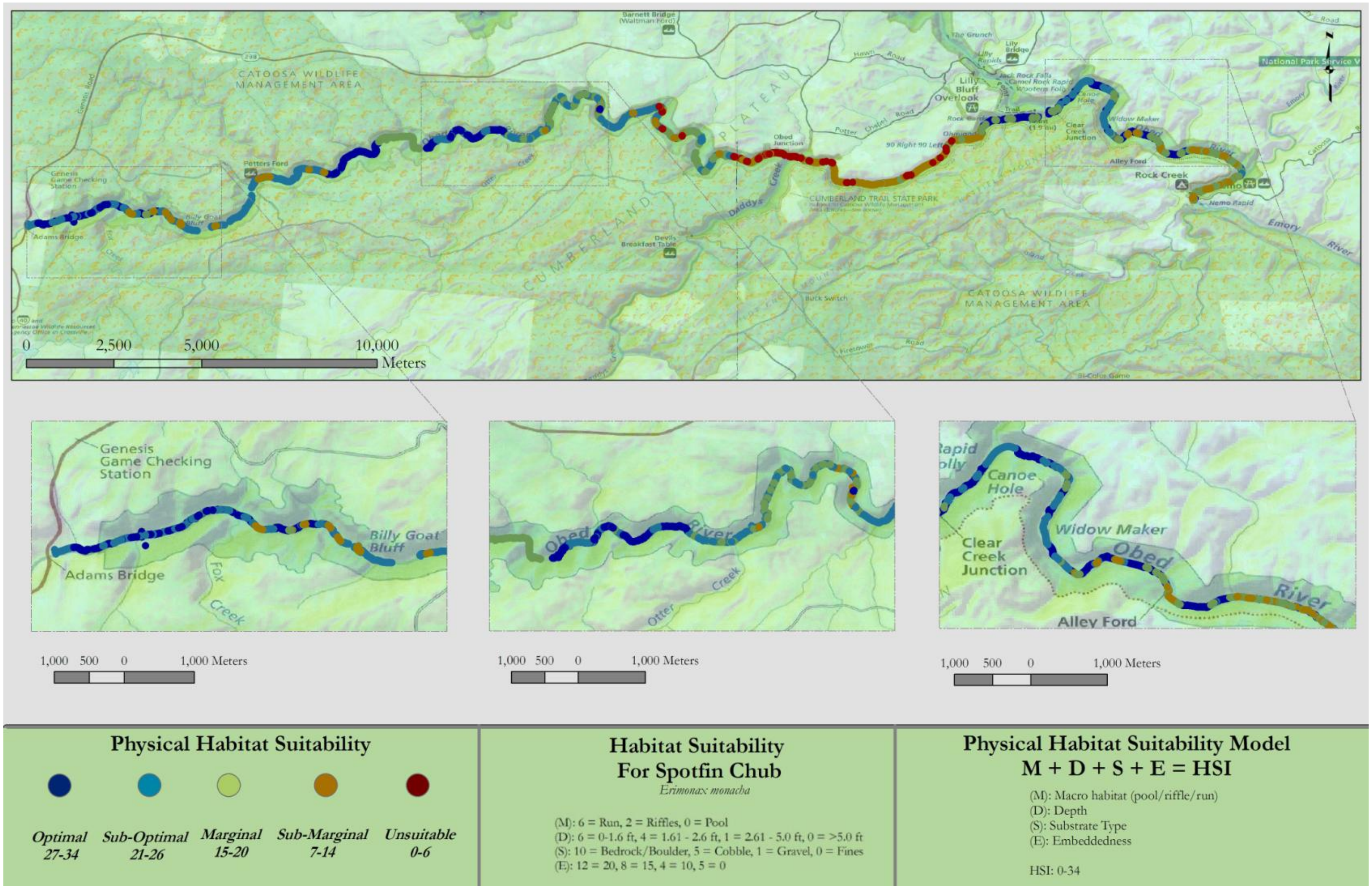


Figure 45: A map of the Obed River that shows the habitat suitability transitions within the Obed River.

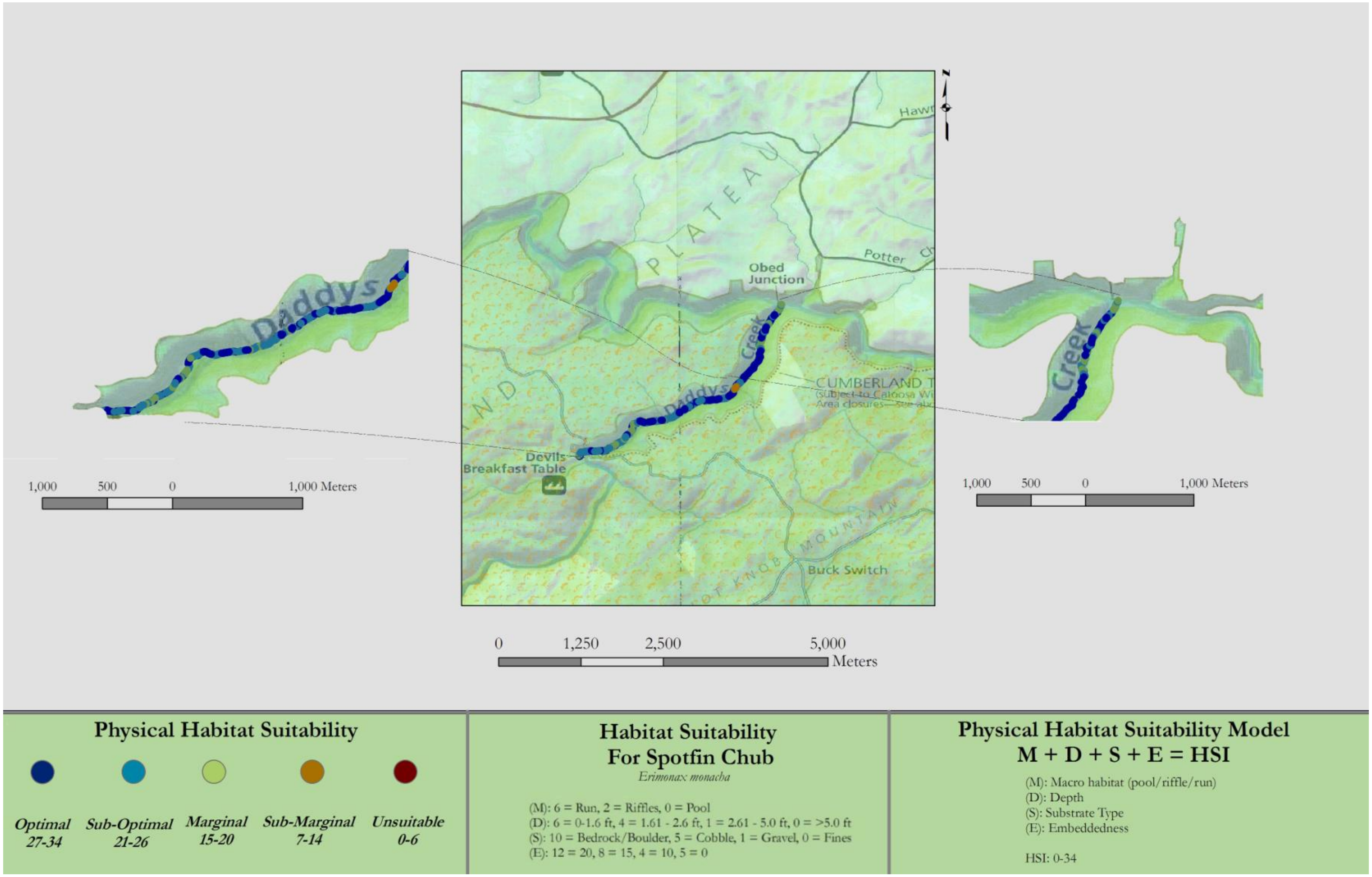


Figure 46: A map of Daddy's Creek that shows the habitat suitability transitions for the spotfin chub within Daddy's Creek.

6.2 Blackside Dace

6.2.1 Habitat Suitability Criteria

The physical habitat suitability model was built based on literature findings of habitat preference and non-suitability. The blackside dace thrives in bedrock and rubble substrates in clear water, flourishes well in covered canopy areas of trees and shrubs, and dwells within undercut banks and under boulders (Eisenhour and Strange, 1998). It has been observed that the blackside dace occurs just downstream of riffles, where minimal silt (embeddedness) exists (USFWS, 1988); it was noted that riffle:pool ratios are important habitat considerations, noted that this ratio should not exceed 60:40. A higher riffle:pool ratio usually indicates predominance of creek chubs and blacknose daces (Johnson et *al.,* 2009). The index ranged scores from 0–34, indicating summations greater than 27 implied ideal habitat. Lower scores recognized poorer habitat (Table 12).

6.2.2 Clear Creek

Optimal habitat conditions for the blackside dace were prevalent throughout Clear Creek (9,475 locations). Most notable optimal sections were above Norris Ford, above Barnett Bridge that spans across 2,500 m, and periodic locations above Lilly Bridge. In all, there was 13.2 km (18% of OBRI's spatial extent) of optimal habitat that ranged in scores from 27-34 (Figure 49)(Table 13).

6.2.3 Obed River

Color contrasts in the following habitat map signify a favoritism of optimal habitat characteristics of the blackside dace. More specifically, Upper Potter's Ford to Lower Potter's Ford, contained solid optimal habitat conditions with small pockets of sub-optimal habitat. This trend was generally evident from Adam's Bridge to the Daddy's Creek confluence (Figure 50). In all, there were over 16,000 data points that upheld optimal habitat conditions for this species. Additionally, there were over 14,000 sub-optimal points, and observations noticed that optimal and sub-optimal areas overlapped and intertwined within each other (Table 13). Within the Obed River, 22.0 km (30% of OBRI's spatial extent) met optimal habitat criteria.

6.2.4 Daddy's Creek

There were over 2,400 optimal data points throughout the lower end course. Similarly, most of the physical habitat conditions met optimal and sub-optimal categories. There were just 112 data points in poor habitat range. The habitat trends were not diverse. A thematic map showed that most of the lower end of Daddy's Creek supported optimal habitat in long passes, periodic sub-optimal stretches within optimal ranges, and the occasional poor habitat (Figure 51)(Table 13). Within this lower section of Daddy's Creek, 2.7 km (4% of OBRI's spatial extent) support optimal physical habitat components.

Table 8: Physical habitat suitability model for blackside dace. Supporting literature can be found in Chapter 2.4.2.

HSI 0 – 34	**Physical Habitat Suitability Model for Blackside Dace**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Runs	**6 = 2.0 – 6.0 ft**	**10 = Bedrock, Cobble**	**12 = 20**
	2 = Pools	**4 = >6.01 ft, <8.0 ft**	**5 = Boulders**	**8 = 15**
	0 = Riffles	**1 = >0.8 ft, <2.0 ft,**	**1 = Gravels**	**4 = 10**
		0 = <0.8 ft, >8.01 ft	**0 = Fines**	**0 = 5**

Table 9: Habitat suitability findings for the blackside dace within Clear Creek, Obed River, and Daddy's Creek.

HSI 0 – 34	Physical Habitat Suitability Results – Blackside dace – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	9,475 pts	**11,851 pts**	**6,787 pts**	**3,196 pts**	**1,574 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Blackside dace – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	16,334 pts	**14,222 pts**	**8,821 pts**	**4,614 pts**	**66 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Blackside dace – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	2,463 pts	**1,011 pts**	**321 pts**	**15 pts**	**112 pts**

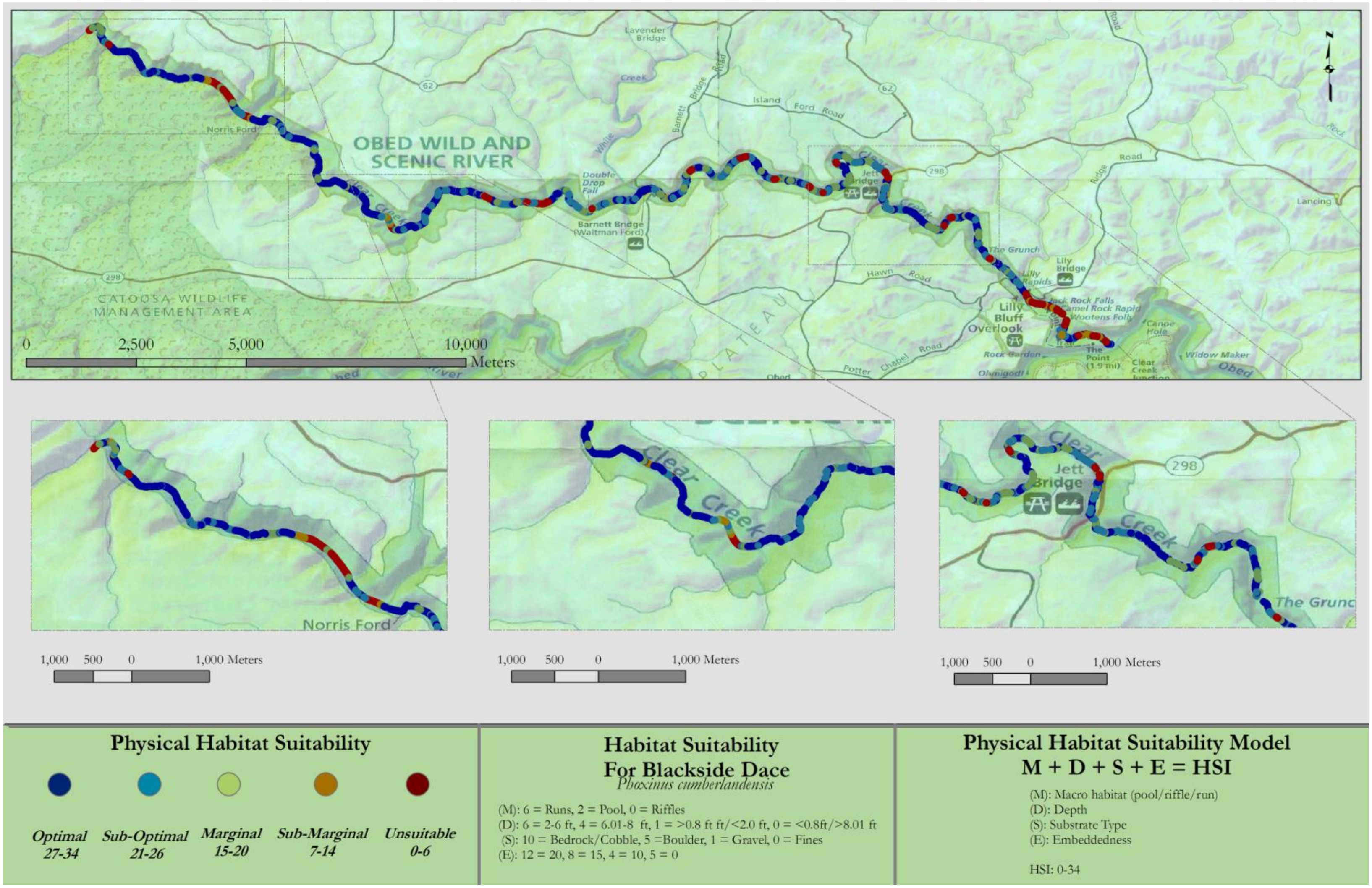


Figure 47: A thematic map that shows the habitat suitability of the blackside dace within Clear Creek.

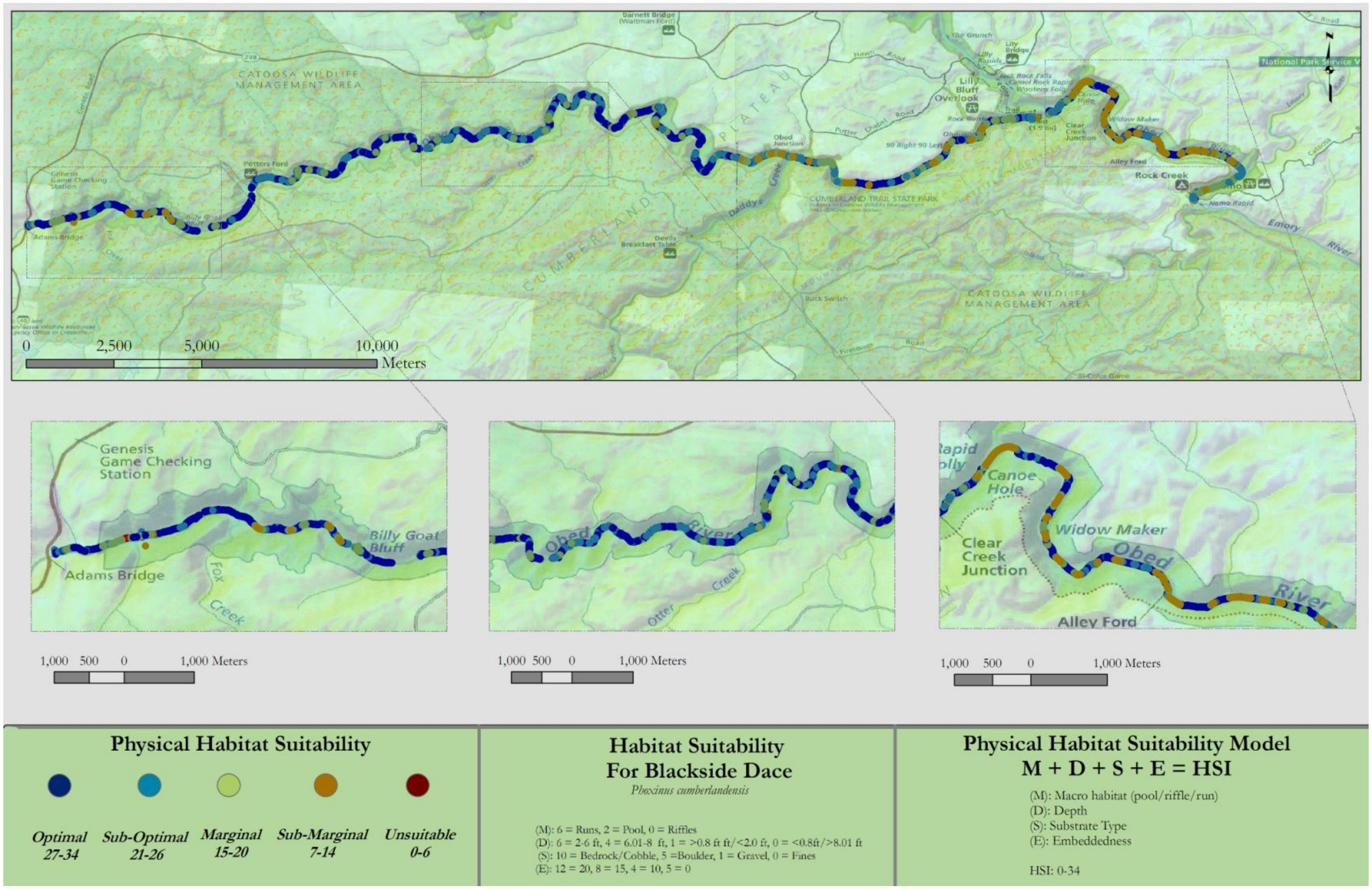


Figure 48: A thematic map that shows the habitat suitability of the blackside dace within the Obed River.

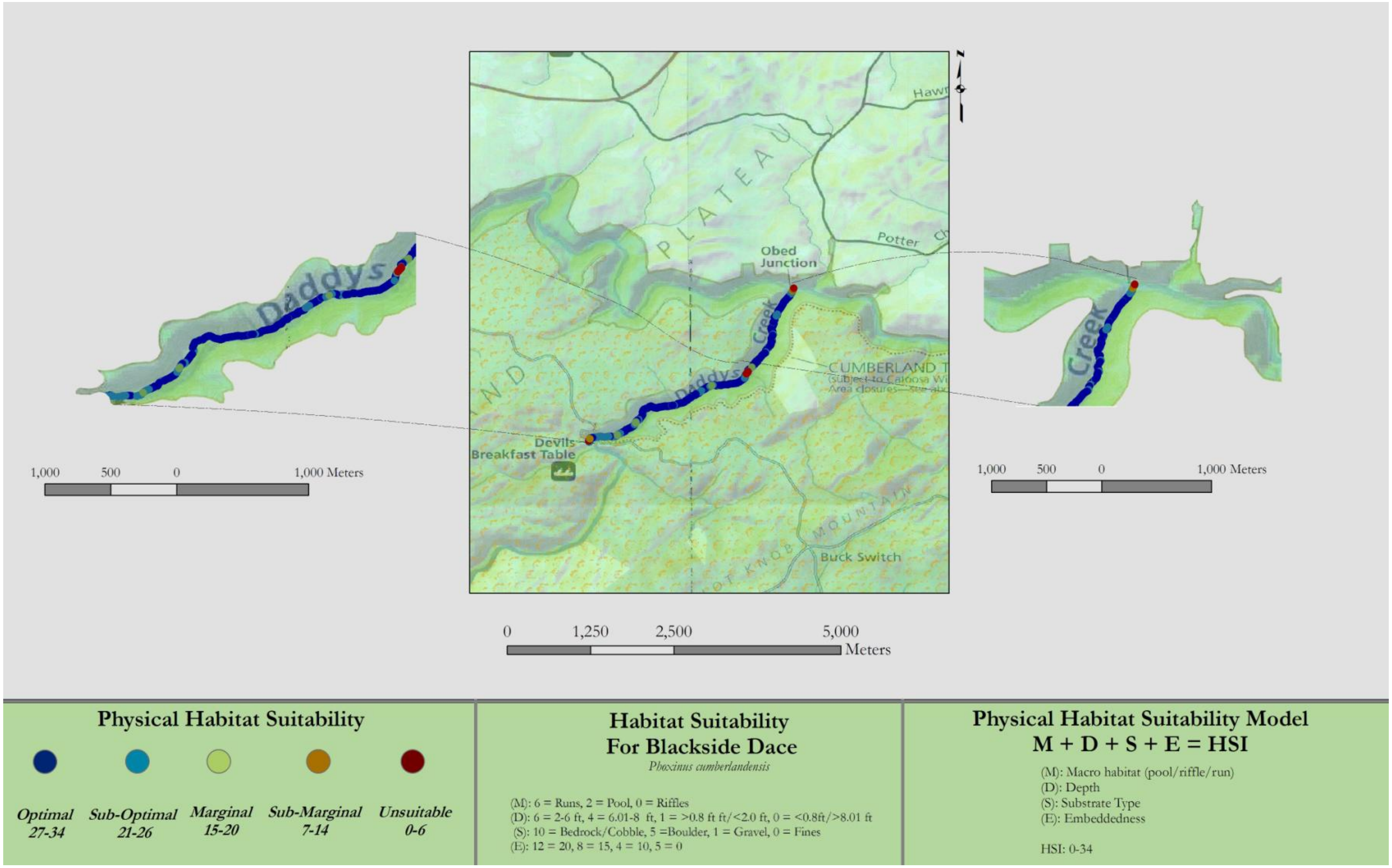


Figure 49: A thematic map that shows the habitat suitability of the blackside dace within Daddy's Creek.

6.3 Duskytail Darter

6.3.1 Habitat Suitability Criteria

The physical habitat suitability model was built based on literature findings of habitat preference and non-suitability. Although a specialist, the duskytail darter is not particularly picky on a single substrate type; rather, they prefer substrates categorized as heterogeneous (Rakes et *al.,* 1992). Substrate mixtures of small gravel, large gravel, cobble, boulders and/or bedrock slabs are preferred. They are discriminatory about preferred microhabitat, thriving along the edges of shallow gently flowing pools (0.5 – 2.5 ft), eddy areas, and slow runs over heterogeneous substrates (Rakes et *al.,* 1992; Jenkins and Burkhead, 1993). During summer months, it commonly migrates under vegetation cover to escape heat, specifically riverweed (*Podostemum)*(Layman, 1991). The duskytail is rarely found in heavily silted areas or in areas where silt is present (Etnier and Starnes, 1993). As a result, distributions are commonly fragmented and patchy (Table 14).

6.3.2 Clear Creek

Even though there is no current scientific evidence that the duskytail darter thrives in the Emory River watershed, specifically the OBRI, there are areas within Clear Creek that qualify as optimal habitat. There were 16,245 locations that classify as optimal habitat based on physical components (> 5.9 km, 8% of OBRI). More specifically, optimal ranges were evident below Norris Ford, above and below Barnett Bridge, and downstream of Jett Bridge (Figure 52)(Table 15). In all within Clear Creek, over 18.7 km (25% of OBRI's spatial extent) met optimal habitat criteria for duskytail darter habitat preference.

6.3.3 Obed River

Even though the duskytail dater's ecogeography has not included the Emory River watershed, optimal habitat for this species was noticeable, at least given from a structure perspective. Similar to the other two fishes, Upper Potter's Ford to Lower Potter's Ford possessed a significant portion of optimal ranges (Figure 53). The upper Obed River contained notable habitat as well. There were nearly 28,000 specific locations of optimal structural components (Table 15). Below Adam's Bridge, there were 400-500 m optimal sections with periodic interruptions of sub-optimal habitat. About 1000 m below this area was another sequence of optimal habitat disrupted by pattern like periods of very poor habitat. Evidence supports the determination that some of these optimal habitat zones were invaded by high frequencies of embeddedness. In all, 29.8 km (40% of OBRI's spatial extent) of the Obed River supported optimal habitat criteria.

6.3.4 Daddy's Creek

Even though its distribution is limited to the Cumberland River drainage, there was a surprising amount of optimal habitat. In all, there were 3,272 locations which equate to well over 3 km of this lower end. (Figure 54)(Table 15). Additionally, there were only 561 points that indicated marginal to poor physical habitat. However, over 2.4 km (3% of OBRI's spatial extent) met optimal habitat conditions.

Table 10: The habitat suitability model for the duskytail darter.

HSI=M+D+S+E 0 – 34	**Physical Habitat Suitability Model for Duskytail darter**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Pools	**6 = < 2.5 ft**	**10 = Gravel, Cobble, Small Boulder**	**12 = 20**
	2 = Runs	**4 = 2.51 – 4.3 ft**	**5 = Large Boulders**	**8 = 15**
	0 = Riffles	**1 = 4.31 – 8.0 ft**	**1 = Bedrock**	**4 = 10**
		0 = <2.5 ft, >8.01 ft	**0 = Fines**	**0 = 5**

Table 11: Physical habitat suitability findings for the duskytail darter.

HSI 0 – 34	Physical Habitat Suitability Results – Duskytail darter – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	16,245 pts	**4,700 pts**	**2,723 pts**	**2,017 pts**	**1,318 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Duskytail darter – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	27,917 pts	**8,223 pts**	**2,234 pts**	**3,060 pts**	**3,522 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Duskytail darter – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	3,272 pts	**101 pts**	**546 pts**	**15 pts**	**0 pts**

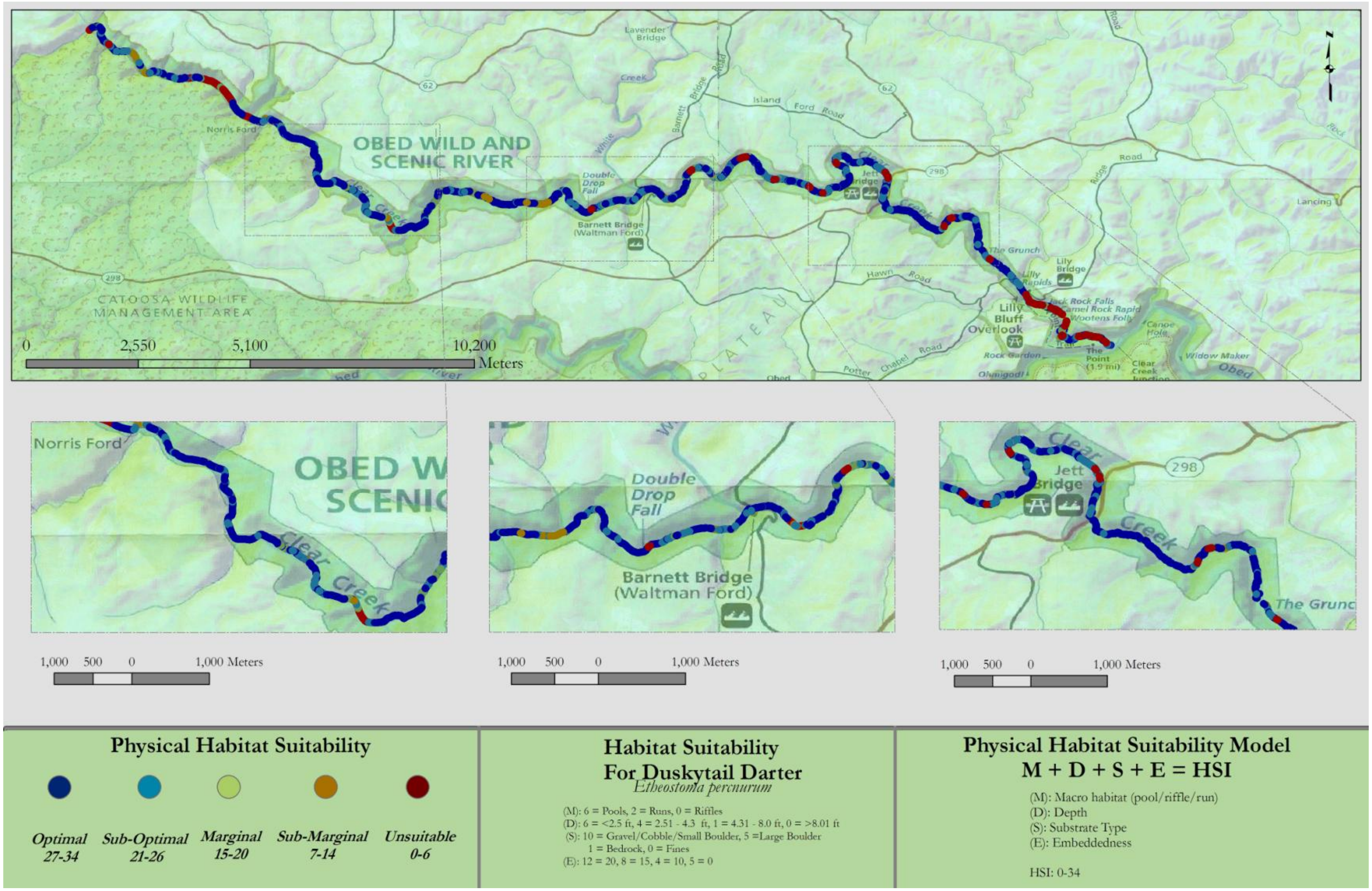


Figure 50: A thematic map showing habitat suitability transitions for the duskytail darter throughout Clear Creek.

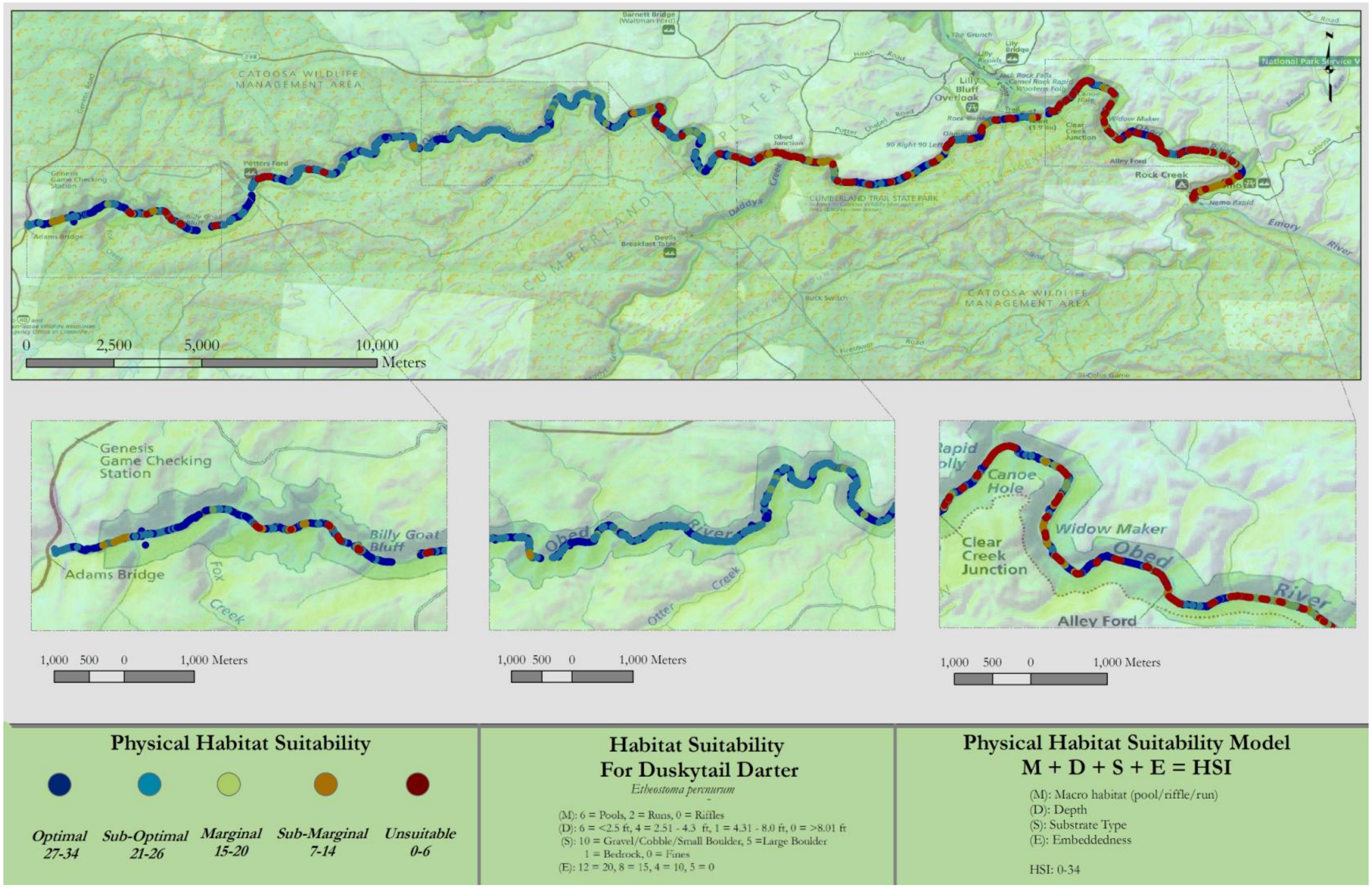


Figure 51: A thematic map showing HSI transitions for the duskytail darter throughout the Obed River.

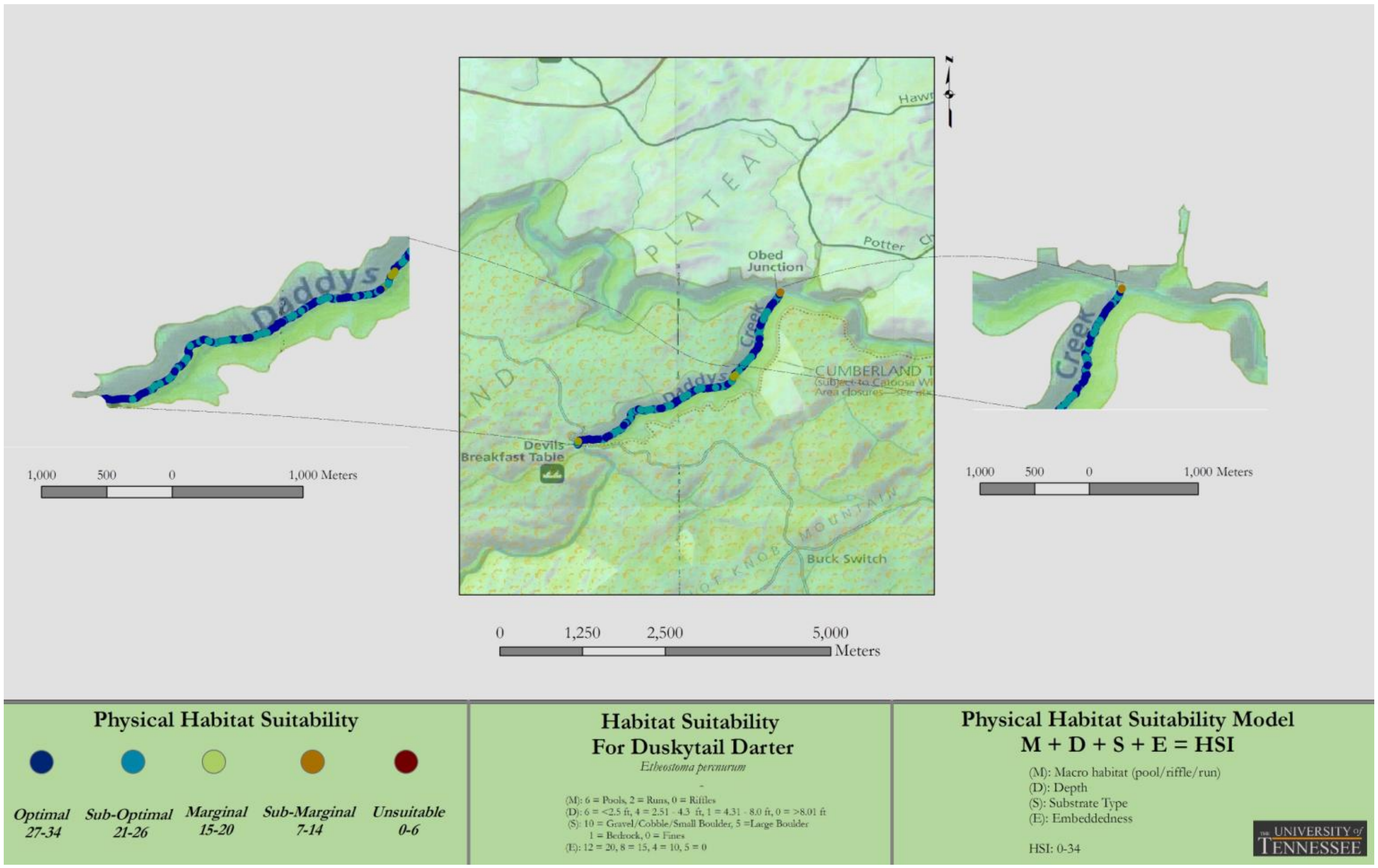


Figure 52: A thematic map showing the habitat suitability transitions for the duskytail darter within Daddy's Creek.

6.4 Cumberland Elktoe

6.4.1 Habitat Suitability Criteria

The physical habitat suitability model was constructed on the evidence of literature findings of habitat preference and non-suitability. The cumberland elktoe thrives in medium-sized rivers and has occurrences in head waters of smaller tributaries where most other mussels are not present (Gordon and Layzer, 1989; Gordon, 1991). Its habitat niche is isolated to flats, glides, and, pools that lack significant contouring in the geomorphology (Gordon, 1991). It prefers scattered cobble/boulder substrates at shallow depths in very slow moving current (USFWS, 2004). The habitat index indicated habitat preference based on highest to lowest values in each category (Table 16).

6.4.2 Clear Creek

The cumberland elktoe did not have an outstanding amount of optimal habitat within Clear Creek. Areas that did fit the criteria were found above Norris Ford and upstream of Barnett Bridge. In all there were 1,739 points that met optimal conditions and fell within an optimal range of 26-34. This comprised to over 2.5 km (3% of OBRI's spatial extent)of optimal habitat conditions within Clear Creek (Figure 55)(Table 17).

6.4.3 Obed River

Optimal habitat characteristics were commonly associated with gradual to sharp river meanders throughout the Plateau. Ideal conditions were widespread from below Adam's Bridge, below Upper Potter's Ford, and ~2,000 m upstream of the Daddy's Creek Confluence (Figure 56). In all, there were only 333 optimal habitat points (Table 17). Optimal habitat locations contributed a patchy 1.8 km (2% of OBRI's spatial extent).

6.4.4 Daddy's Creek

Cumberland elktoe habitat throughout the lower section of Daddy's Creek was just marginal. In fact, there were >800 data points outside marginal habitat. The thalweg tracklog showed a thematic trend of fragmented sub-marginal habitat within long continuous marginal sections. (Figure 57)(Table 17). Within this lower section of Daddy's Creek, no optimal habitat locations were evident.

Table 12: Physical habitat suitability model for the cumberland elktoe.

HSI 0 – 34	Physical Habitat Suitability Model for Cumberland Elktoe			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Pools	**6 = 0 - 2.5 ft**	**10 Fines, Gravel, Cobble**	**12 = 5**
	2 = Runs	**4 = 2.52 – 4.3 ft**	**5 = Small Boulder**	**8 = 10**
	0 = Riffles	**1 = 4.31 – 8.0 ft**	**1 = Large Boulder**	**4 = 15**
		0 = >8.01 ft	**0 = Bedrock**	**0 = 20**

Table 13: Habitat suitability findings for the cumberland elktoe.

HSI 0 – 34	Physical Habitat Suitability Results – Cumberland elktoe – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	1,305 pts	**3,292 pts**	**15,147 pts**	**5,077 pts**	**2,208 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Cumberland elktoe – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	333 pts	**3,281 pts**	**24,154 pts**	**11,571 pts**	**4,717 pts**
HSI 0 – 34	Physical Habitat Suitability Results– Cumberland elktoe – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**201 pts**	**3,084 pts**	**585 pts**	**52 pts**

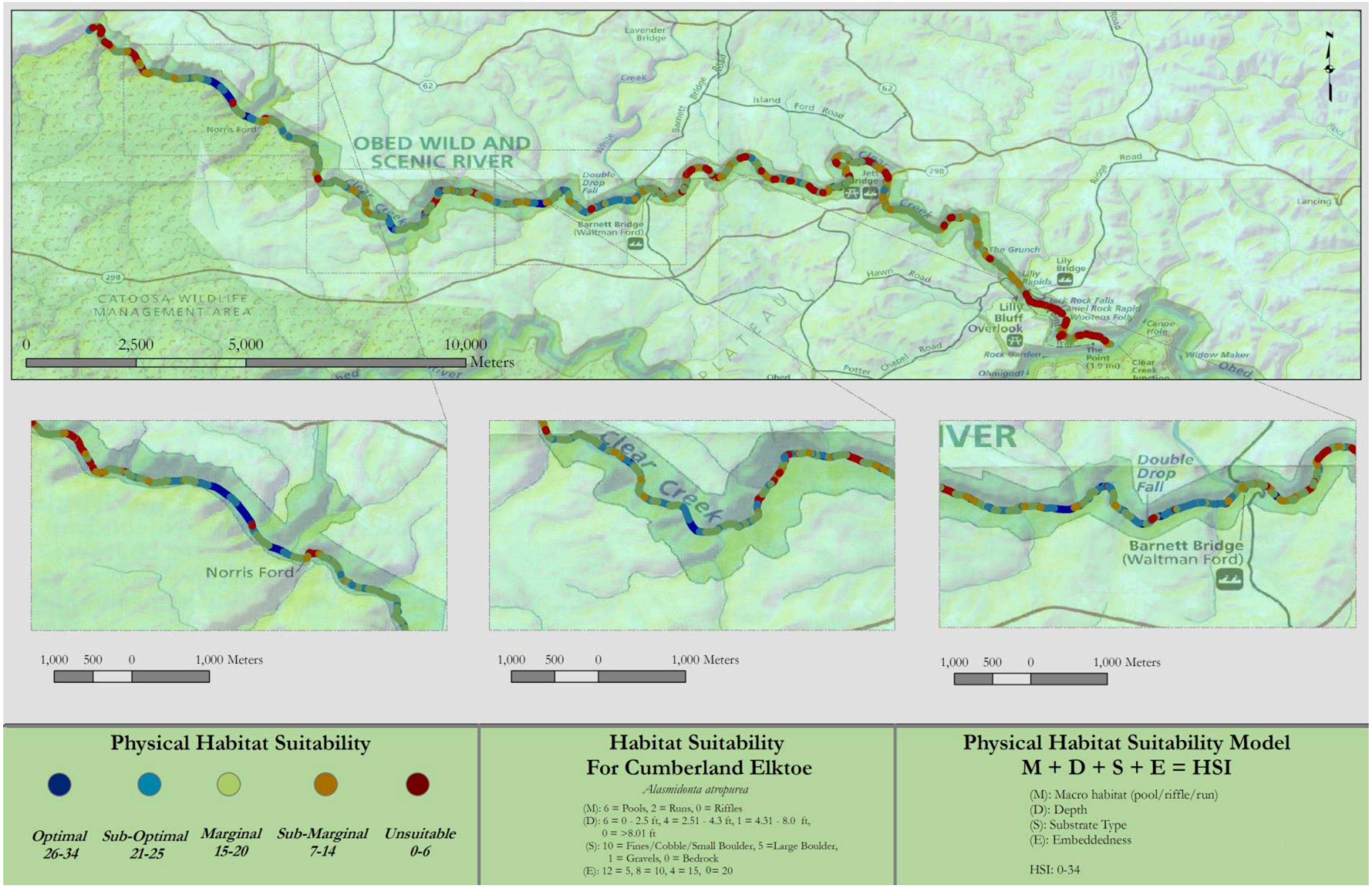


Figure 53: A thematic map that shows the habitat suitability trends for the cumberland elktoe within Clear Creek.

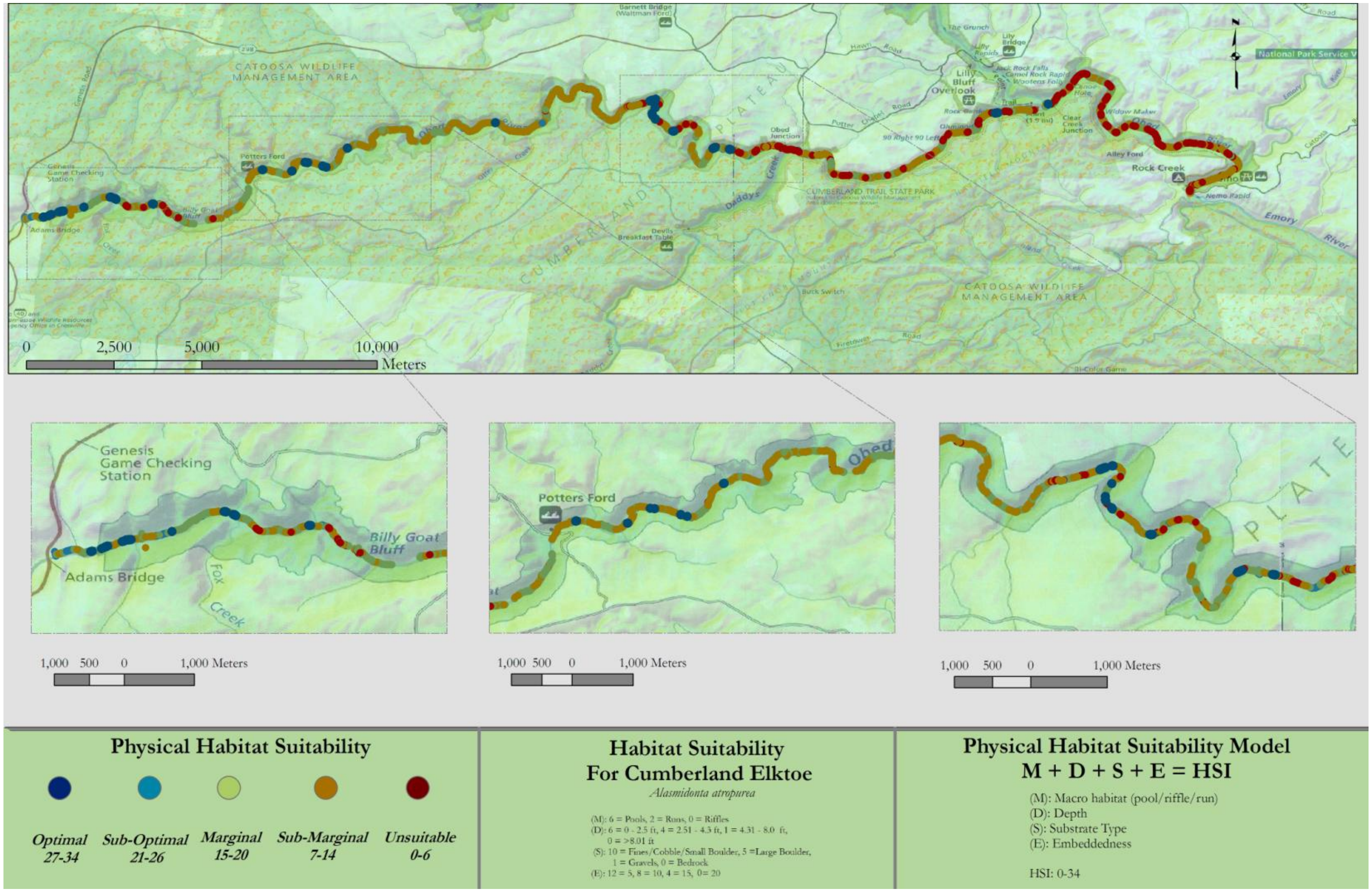


Figure 54: A thematic map that reveals habitat suitability trends for the cumberland elktoe throughout the Obed River.

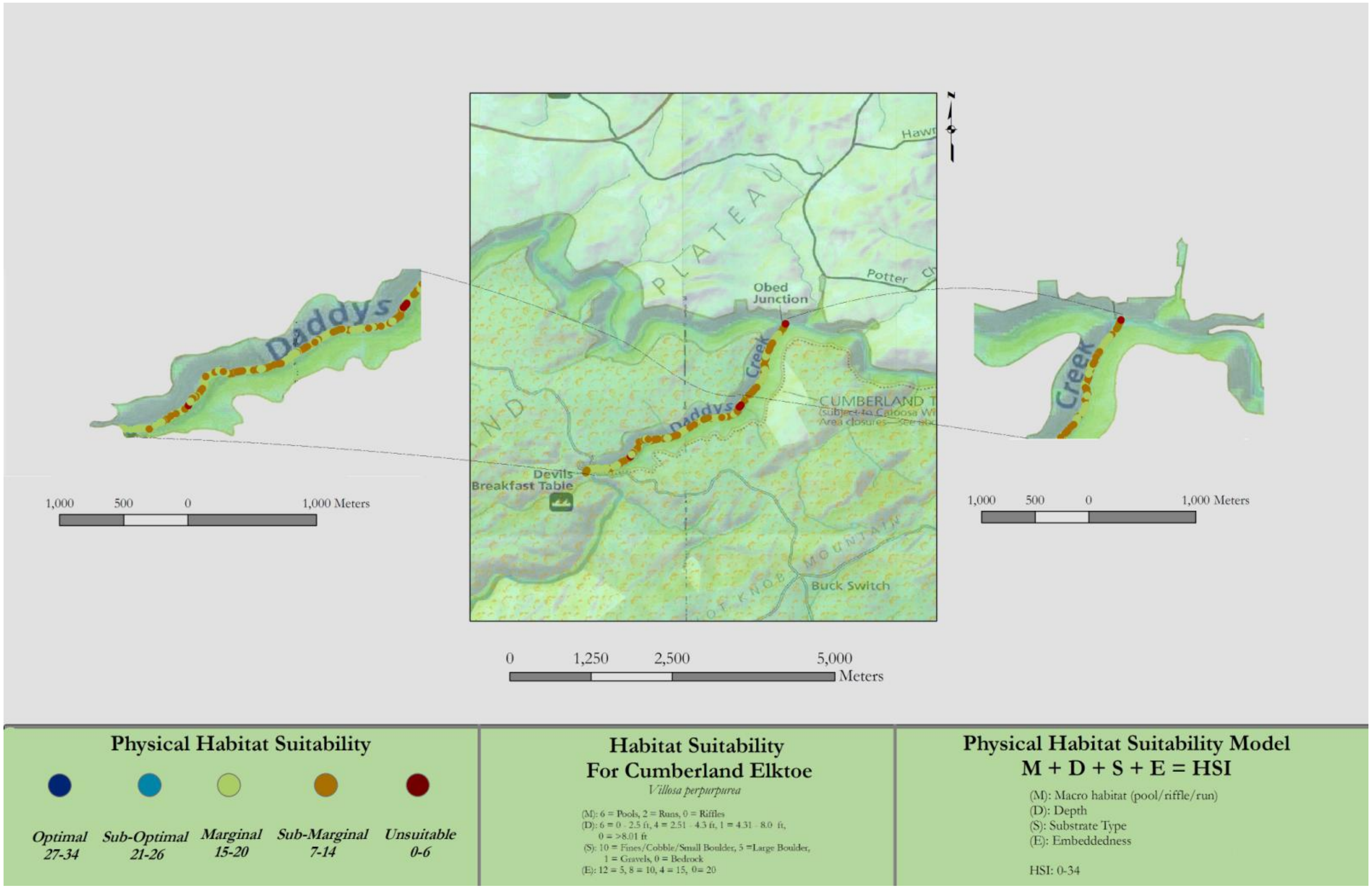


Figure 55: A thematic map that shows habitat suitability trends for the cumberland elktoe throughout the lower section of Daddy's Creek within OBRI.

6.5 Purple Bean

6.5.1 Habitat Suitability Criteria

The physical habitat suitability model was fabricated based on literature findings of habitat preference and non-suitability. This species thrives in small headwater streams to medium-sized rivers. It is found in moderate to fast-flowing riffles (Gordon, 1991; Neves, 1991 in USFWS, 2004). Previous studies have indicated that observations have been seen adjacent to the thalweg next to water-willow beds and under flat rocks (Ahlstedt 1991; Gordon 1991 in USFWS, 2004). The habitat index indicated habitat preferences were based on highest to lowest values (Table 18).

6.5.2 Clear Creek

Optimal habitat stretches for the Purple bean were very limited. In fact, most ideal habitat conditions occurred upstream of Barnett Bridge. The largest continuous stream reach was evident above Norris Ford, stretching approximately 550 m. In all there were 1,002 optimal locations with an EPA score ranging from 27-34 (1.5 km, 2% of OBRI's spatial extent)(Figure 58) (Table 19).

6.5.3 Obed River

Optimal habitat was not abundant. Only 176 pts located optimal range (Table 19). Those areas that met preferred habitat conditions were above Upper Potters Ford. The Clear Creek confluence possessed these conditions, as well as a small section above Daddy's Creek confluence (Figure 59). In all, the Obed River supplied 589.3 m (<1% of OBRI's spatial extent) of optimal habitat for this species.

6.5.4 Daddy's Creek

Over 98% of Daddy's Creek habitat delineations were either sub-marginal or worse (Table 19). Most of the data revealed transitions in a short sub-marginal stretches to longer poor areas (Figure 60). Generally though, this area did not have an abundance of optimal habitat here. Cumulatively, there were 525 m (<1% of OBRI's spatial extent) of optimal habitat.

Table 14: Physical habitat suitability mathematical model for the Purple Bean.

HSI 0 – 34	**Physical Habitat Suitability Model for Purple Bean**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Pools	**6 = 2.5 – 3.5 ft**	**10 Fines**	**12 = 5**
	2 = Runs	**4 = 3.5 – 4.0 ft**	**5 = Cobble**	**8 = 10**
	0 = Riffles	**1 = 1.0 – 2.49 ft**	**1 = Gravel**	**4 = 15**
		0 = <1.0 ft, >5.0 ft	**0 = Boulders, Bedrock**	**0 = 20**

Table 15: Habitat suitability findings of the Purple Bean.

HSI 0 – 34	Physical Habitat Suitability Results – Purple Bean – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	1,001 pts	**647 pts**	**3,006 pts**	**9,771 pts**	**12,604 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Purple Bean – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	176 pts	**444 pts**	**2,375 pts**	**11,714 pts**	**32,157 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Purple Bean – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**28 pts**	**546 pts**	**2,146 pts**	**1,748 pts**

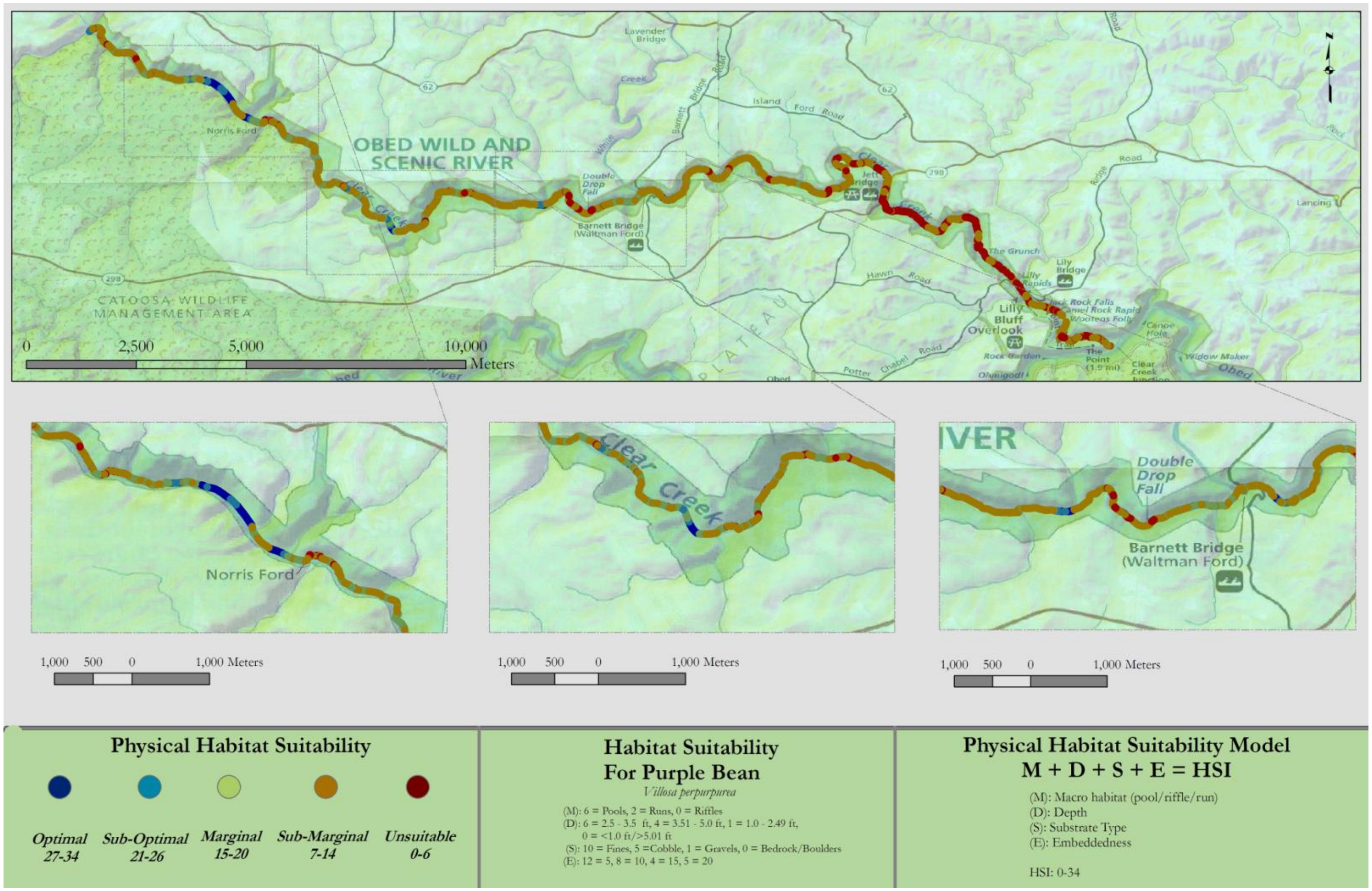


Figure 56: A thematic map that denotes purple bean habitat suitability transitions throughout Clear Creek.

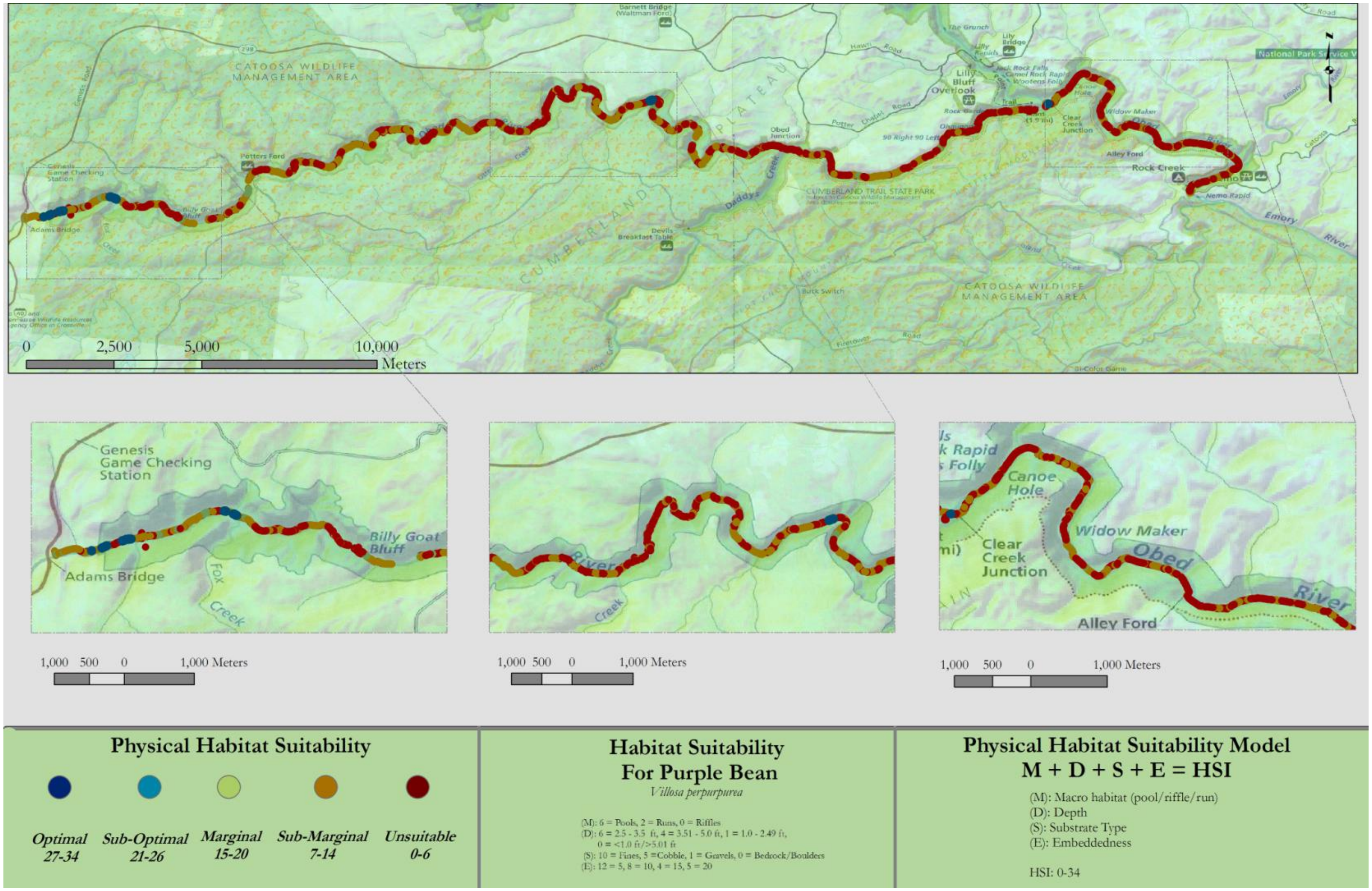


Figure 57: A thematic map that shows habitat suitability transitions for the purple bean throughout the Obed River.

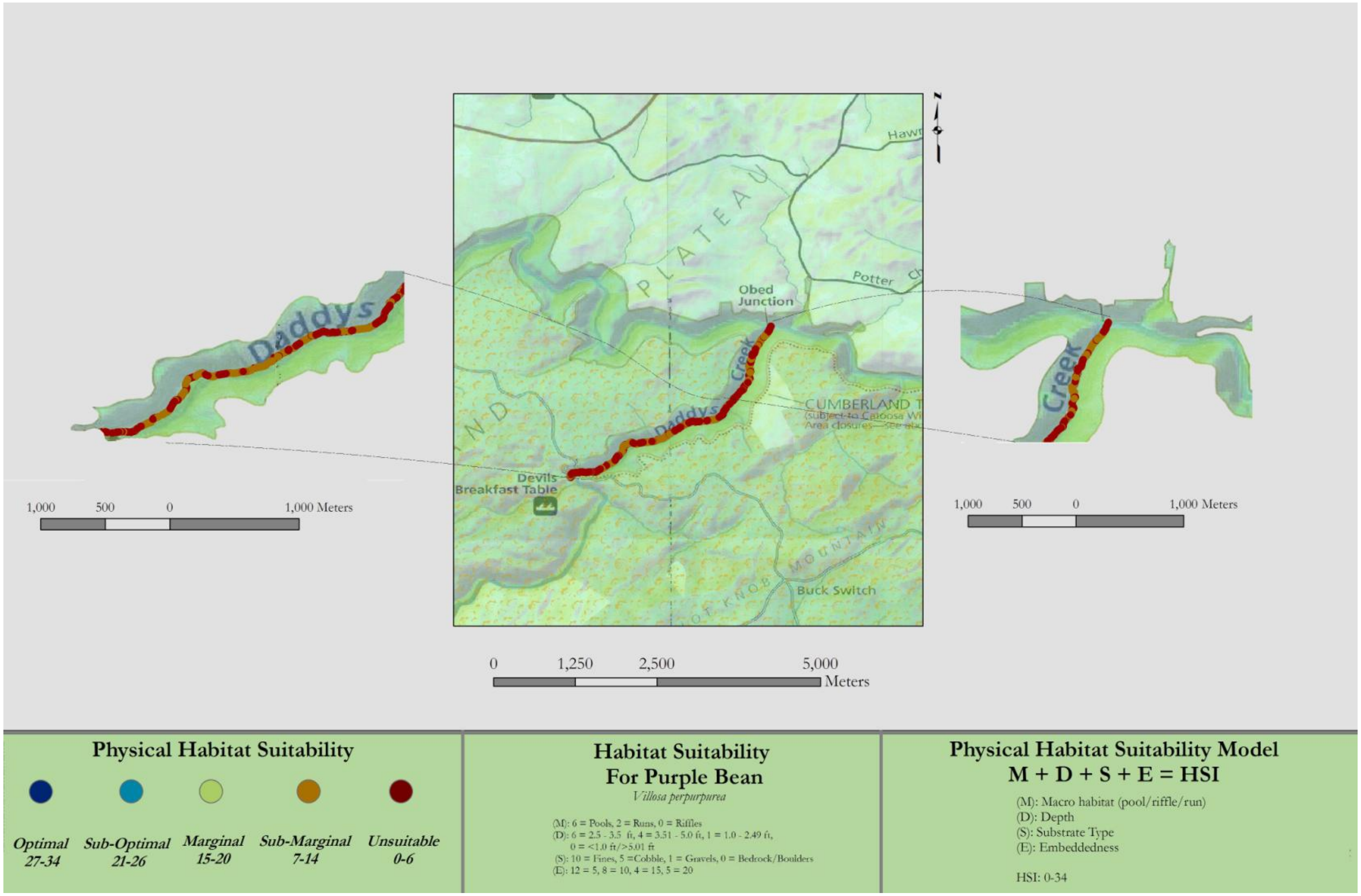


Figure 58: A thematic map of Daddy’s Creek that shows habitat suitability trends for the purple bean within the lower section of Daddy’s Creek.

6.6 Cumberland Bean

6.6.1 Habitat Suitability Criteria

The physical habitat suitability model was fabricated based on literature findings of habitat preference and non-suitability. The cumberland bean habitat preference is somewhat atypical when compared to the other endangered species of Tennessee. It prefers small streams and rivers under fast moving current, typically riffles. Sand/gravel substrates are preferred (Parmalee and Bogan, 1998; Fiscor, 2005). This species does not occur within the Obed Wild and Scenic River, but it does thrive within its sister watershed, The Big South Fork National Recreation Area. The physical habitat suitability index indicated habitat preferences were based on highest to lowest values (Table 20).

6.6.2 Clear Creek

Cumberland bean habitat within Clear Creek of OBRI was generally poor. Only 164 points revealed an HSI score within 27-34 (~200 m). Optimal findings were noticed near Barnett Bridge and upstream of Jett Bridge. However, There was a substantial patch of sub-optimal habitat upstream of Norris Ford (>700 m) with a HIS score of 21-26 (Figure 61)(Table 21).

6.6.3 Obed River

There were only 86 locations that supported cumberland bean optimal habitat conditions (Table 21). However, there were a substantial number of sub-optimal areas that intertwine very poor habitat areas. Evidence of optimal habitats ranged was below of Adam's Bridge (fragmented) and down from Upper Potter's Ford (Figure 62). In all, only 185 m (<1% of OBRI's spatial extent) of the Obed supplied optimal habitat criteria for the cumberland bean.

6.6.4 Daddy's Creek

Continuous sub-marginal habitat prevailed for the cumberland bean. There were no records of optimal and sub-optimal habitat within this section of Daddy's Creek. Periodic highlights of marginal habitat were observed towards the confluence (Figure 63)(Table 21). There were no optimal habitat occurrences within this section of Daddy's Creek.

Table 16: Habitat suitability model for the cumberland bean.

HSI 0 – 34	Physical Habitat Suitability Model for Cumberland Bean			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Riffles	**6 = 0 - 2.5 ft**	**10 Fines, Gravel**	**12 = 5**
	2 = Runs	**4 = 2.52 – 4.3 ft**	**5 =Cobble**	**8 = 10**
	0 = Pools	**1 = 4.31 – 8.0 ft**	**1 = Boulder**	**4 = 15**
		0 = >8.01 ft	**0 = Bedrock**	**0 = 20**

Table 17: Physical habitat suitability findings within OBRI of the cumberland bean.

HSI 0 – 34	Physical Habitat Suitability Results – Cumberland bean – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	164 pts	**1,466 pts**	**4,444 pts**	**14,160 pts**	**6,795 pts**
HSI 0 – 34	Physical Habitat Suitability Results– Cumberland bean – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	86 pts	**2,602 pts**	**9,160 pts**	**22,390 pts**	**9,818 pts**
HSI 0 – 34	Physical Habitat Suitability Results– Cumberland bean – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**0 pts**	**548 pts**	**2,998 pts**	**376 pts**

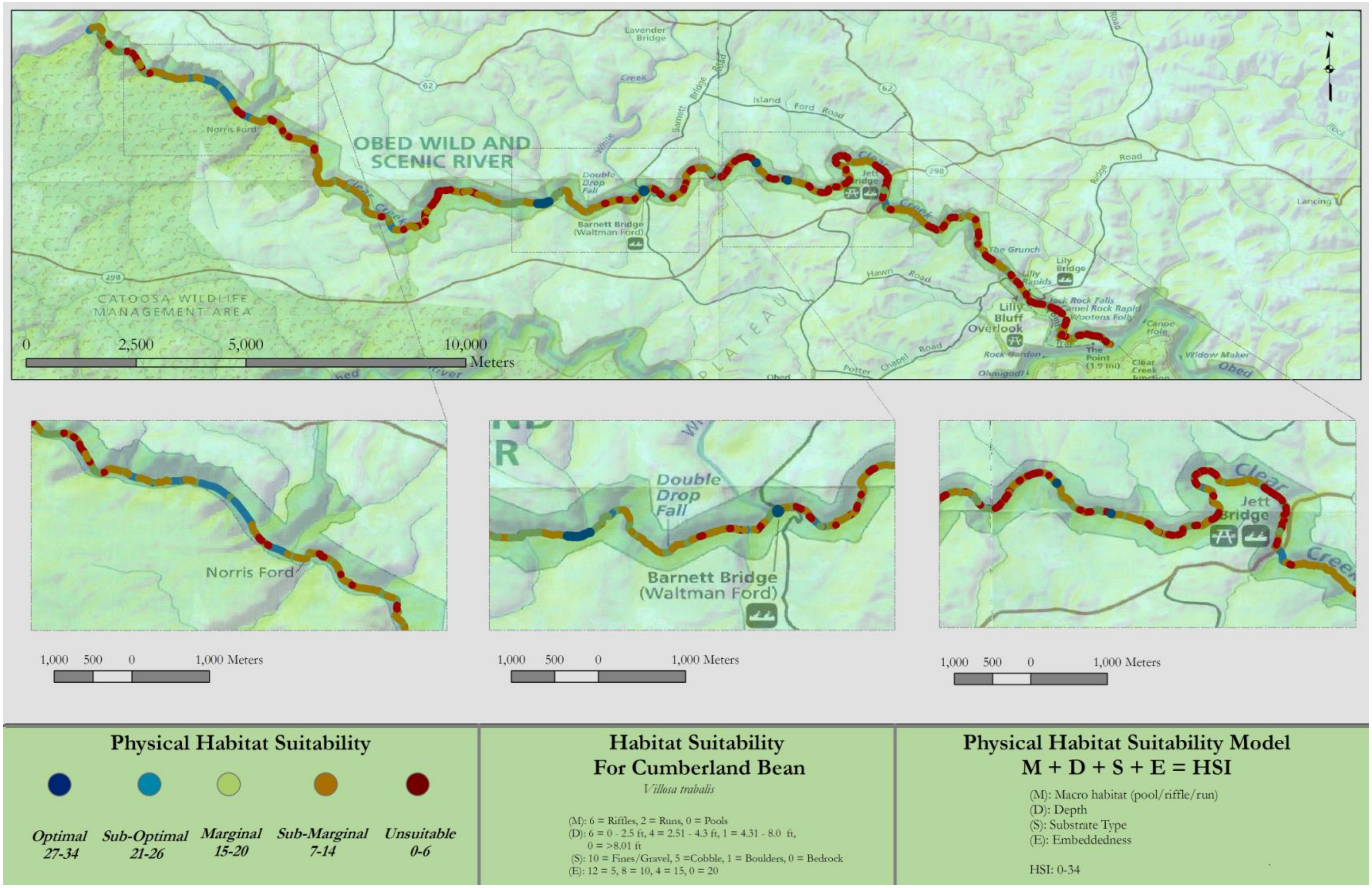


Figure 59: A thematic map that shows habitat suitability trends for the cumberland bean throughout Clear Creek.

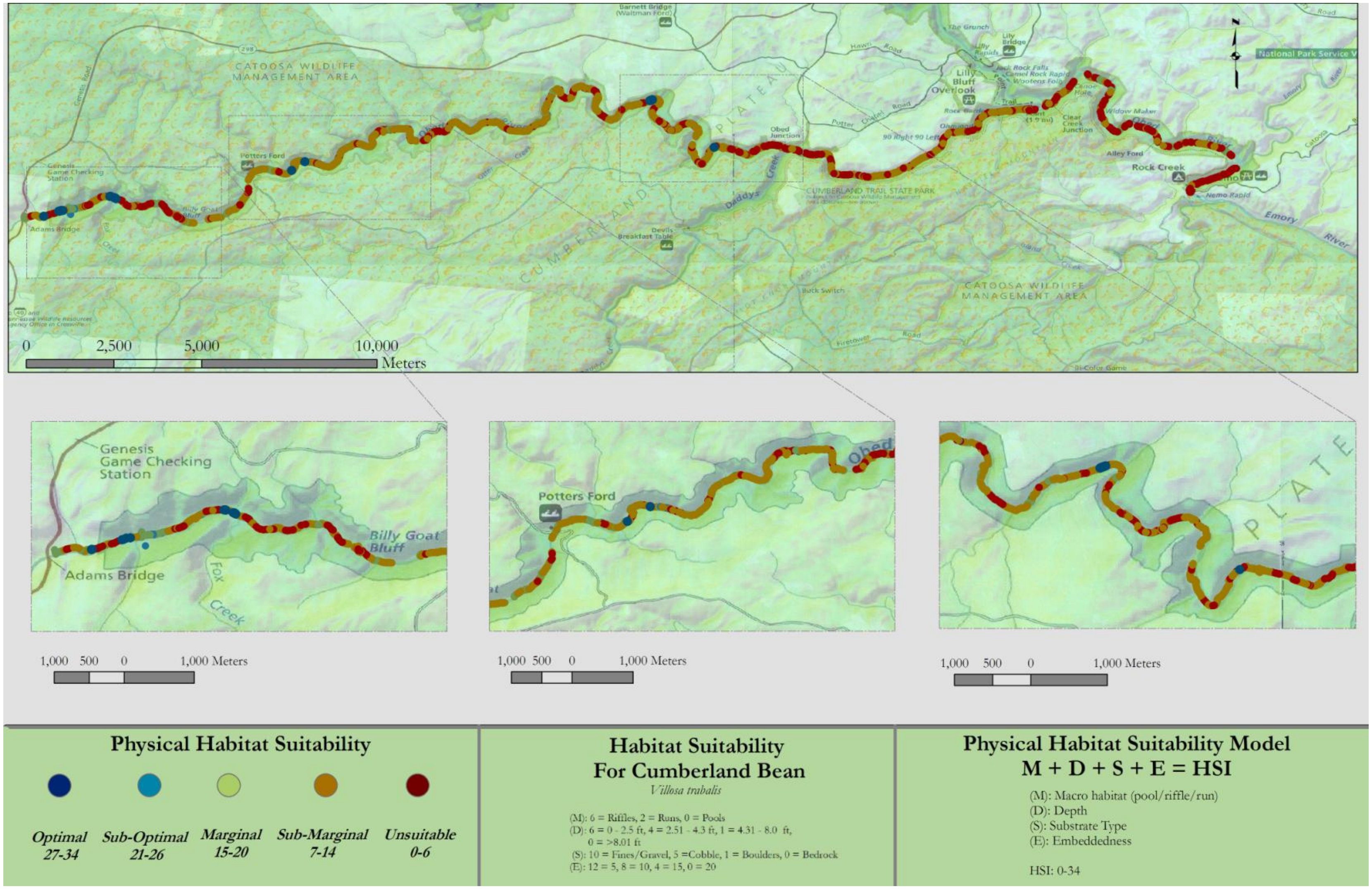


Figure 60: A thematic map of the cumberland bean's habitat suitability throughout the Obed River.

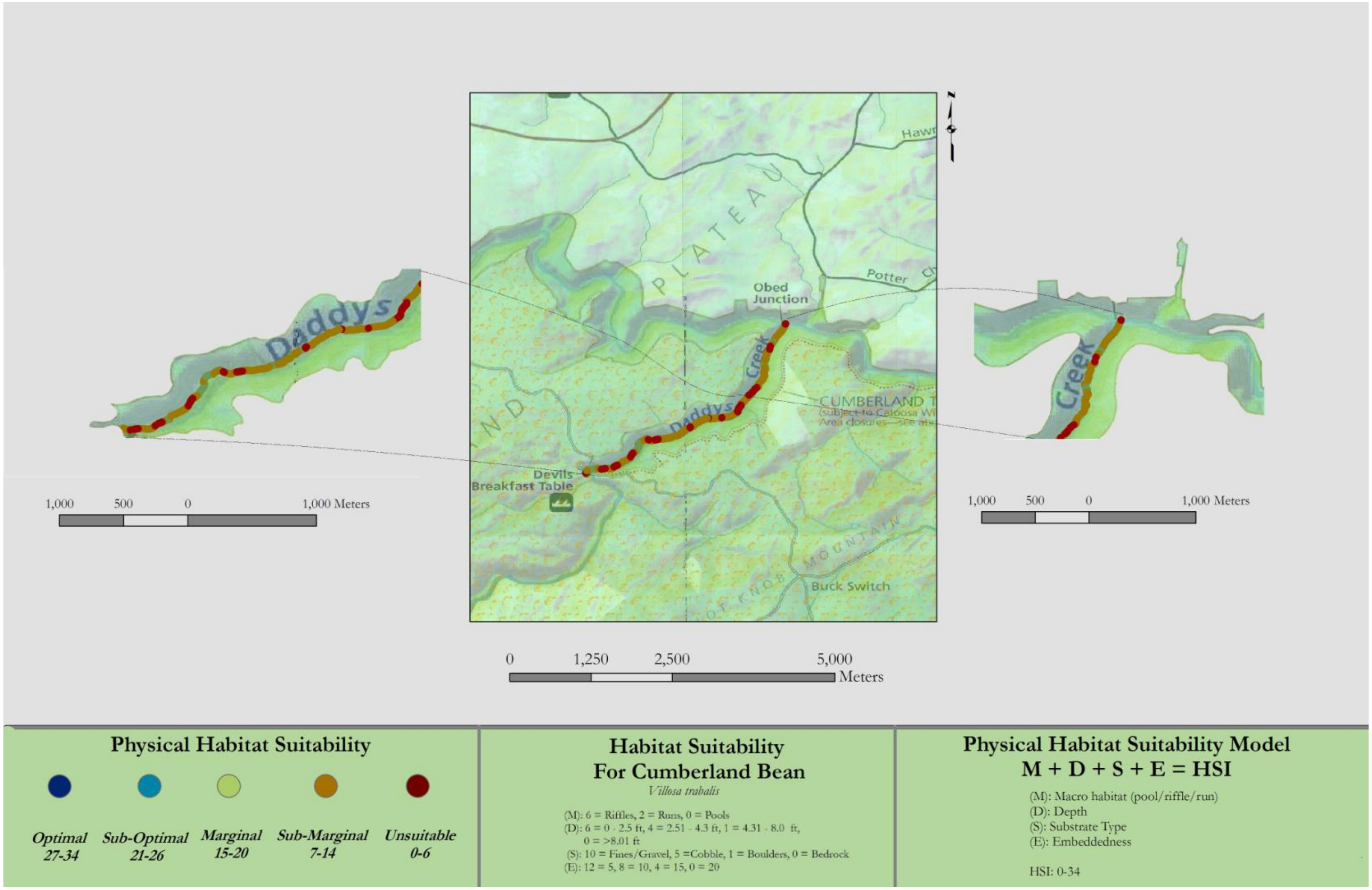


Figure 61: A thematic map of habitat suitability for the cumberland bean throughout the lower section of Daddy's Creek.

6.7 Cumberlandian Combshell

6.7.1 Habitat Suitability Criteria

The physical habitat suitability model was fabricated based on literature findings of habitat preference and non-suitability Habitat preferences have been studied extensively, indicating that the cumberlandian combshell prefers medium-sized to large rivers on riffles and shoals. Rarely does its range extend into higher elevation tributaries. It prefers coarse sands, gravel, cobble, and boulder substrates (Gordon, 1991). Depth preference has been somewhat subjective, indicating that it primarily thrives in depths less than three feet but occurrences are prevalent in deep water areas in sections of the Cumberland River (Gordon and Layzer, 1989 in USFWS 2004). The habitat suitability index indicated habitat preferences were based on highest to lowest values in each category (Table 22).

6.7.2 Clear Creek

As with the case of other mussel habitat within Clear Creek, most of the optimal ranges of 27-34 were found sporadically. In total, there were 386 locations within optimal range (484 m, <1% of OBRI's spatial extent). Most optimal occurrences were noticeable near Norris Ford and upstream and downstream of Barnett Bridge (Figure 64)(Table 23).

6.7.3 Obed River

Primarily, there were marginal and sub-marginal habits throughout the Obed River. Optimal and sub-optimal habitats were not present. Most of the marginal habitats were evenly distributed between sub-marginal habitats (Figure 65)(Table 23).

6.7.4 Daddy's Creek

The vast majority of this section of Daddy's Creek supplied sub-marginal structural habitat interactive components. There was a concentrated poor habitat area just below Devil's Breakfast Table (Figure 66)(Table 23). No optimal and only 20 sub-optimal locations were identified.

Table 18: The physical habitat suitability model for the cumberlandian combshell.

HSI 0 – 34	**Physical Habitat Suitability Model for Cumberlandian Combshell**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Riffles	**6 = <3.0 ft, >8.0 ft**	**10 Fines, Gravel**	**12 = 5**
	2 = Runs	**4 = 3.01 – 4.3 ft**	**5 =Cobble, Small Boulder**	**8 = 10**
	0 = Pools	**1 = 4.31 – 8.0 ft**	**1 = Large Boulder**	**4 = 15**
			0 = Bedrock	**0 = 20**

Table 19: Habitat suitability findings for the cumberlandian combshell.

HSI 0 – 34	Physical Habitat Suitability Results – Cumberlandian combshell – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	386 pts	**1,532 pts**	**7,811 pts**	**12,104 pts**	**5,196 pts**
HSI 0 – 34	Physical Habitat Suitability Results– Cumberlandian combshell – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**0 pts**	**19,357 pts**	**21,037 pts**	**3,662 pts**
HSI 0 – 34	Physical Habitat Suitability Results– Cumberlandian combshell – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**20 pts**	**807 pts**	**2,932 pts**	**163 pts**

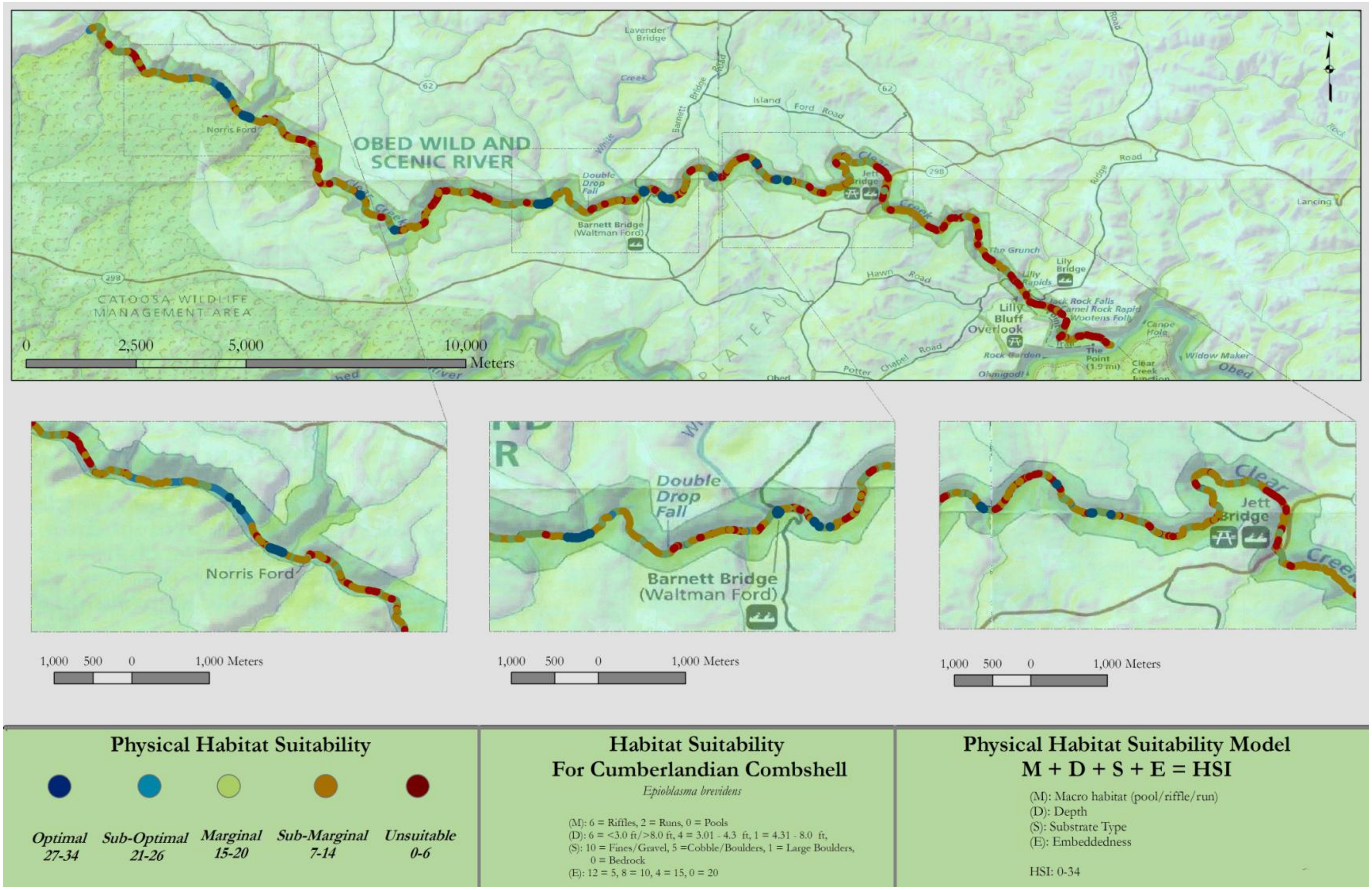


Figure 62: A thematic map that shows the habitat suitability transitions for the cumberlandian combshell throughout Clear Creek.

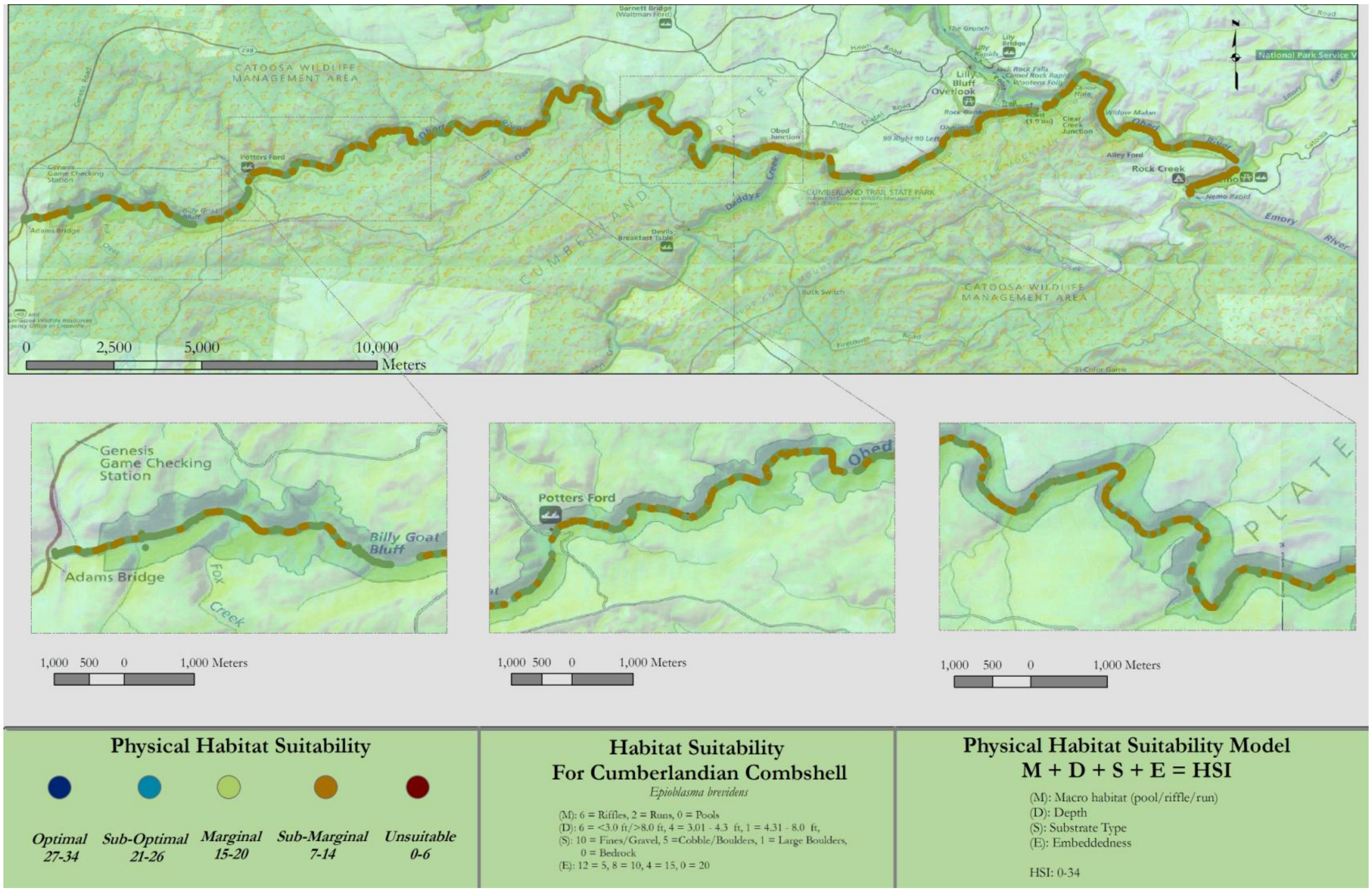


Figure 63: A thematic map that reveals habitat suitability transitions for the cumberlandian combshell within the Obed River.

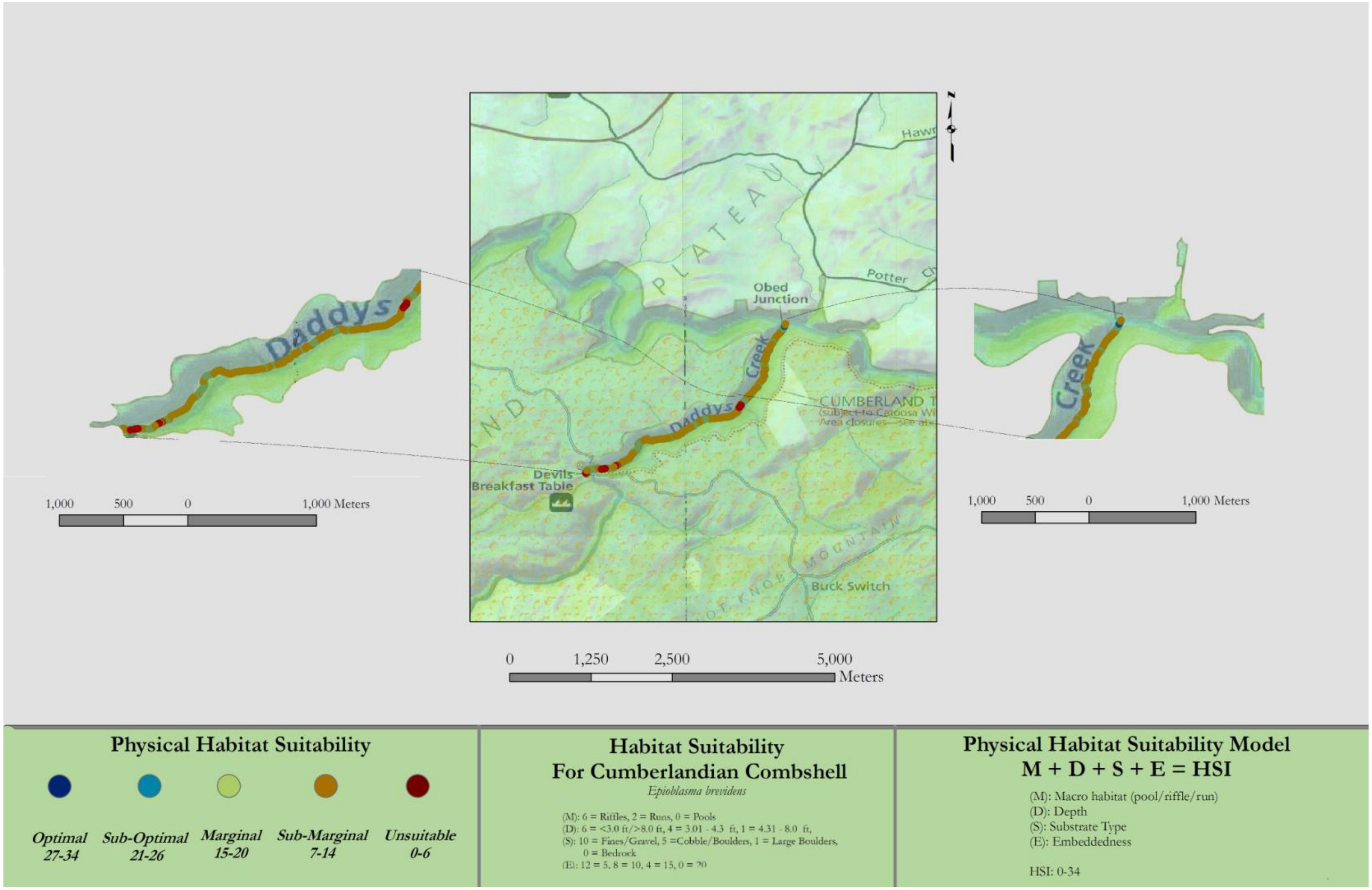


Figure 64: A thematic map that show habitat suitability for the cumberlandian combshell within the lower section of Daddy's Creek.

6.8 Tan Riffleshell

6.8.1 Habitat Suitability Criteria

The physical habitat suitability model was fabricated based on literature findings of habitat preference and non-suitability. The tan riffleshell prefers sand and gravel substrates with a heterogeneous mixture of silt. Typically, this species occurs in shallow depths, below 0.3 m, in areas of moderate current (Parmalee and Bogan, 1998; Fiscor, 2005). The habitat index indicated habitat preferences were based on highest to lowest values in each category (Table 24).

6.8.2 Clear Creek

Throughout Clear Creek, there were only 216 locations that met optima habitat criteria. More specifically, the few optimal locations were noticed above Norris Ford, ~2,000 m up gradient of Barnett Bridge, and a few periodic sections between Barnett Bridge and Jett Bridge (Figure 67)(Table 25). In all, there were only 276 m (<1% of OBRI's spatial extent) of optimal habitat that stretched throughout Clear Creek.

6.8.3 Obed River

The overall habitat quality in the Obed River was, generally, sub-marginal with over 84% of the habitat data falling in this range. There were no optimal and sub-optimal habitat locations found within the thalweg. Additionally, there were not any poor habitats (Figure 68)(Table 25).

6.8.4 Daddy's Creek

Similar to other mussels under this study, this section of Daddy's Creek upheld sub-marginal habit for the tan riffleshell. Even though there were some decent habitat stretches, poor habitat areas were periodic throughout this section (Figure 69)(Table25). Highly embedded shallow runs were not typical conditions.

Table 20: Physical habitat suitability model for the tan riffleshell.

HSI 0 – 34	**Physical Habitat Suitability Model for Tan Riffleshell**			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Runs	**6 = < 1.5 ft**	**10 Fines, Gravel**	**12 = 5**
	2 = Riffles	**4 = 1.51 – 4.3 ft**	**5 =Cobble**	**8 = 10**
	0 = Pools	**1 = 4.31 – 8.0 ft**	**1 = Boulder**	**4 = 15**
		0 = >8.01 ft	**0 = Bedrock**	**0 = 20**

Table 21: Habitat suitability findings for the tan riffleshell within OBRI.

HSI 0 – 34	Physical Habitat Suitability Results – Tan riffleshell – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	216 pts	**1,528 pts**	**5,087 pts**	**14,127 pts**	**6,071 pts**
HSI 0 – 34	Physical Habitat Suitability Results –Tan riffleshell – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**0 pts**	**6,924 pts**	**37,132 pts**	**0 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Tan riffleshell – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**41 pts**	**1,615 pts**	**2,020 pts**	**246 pts**

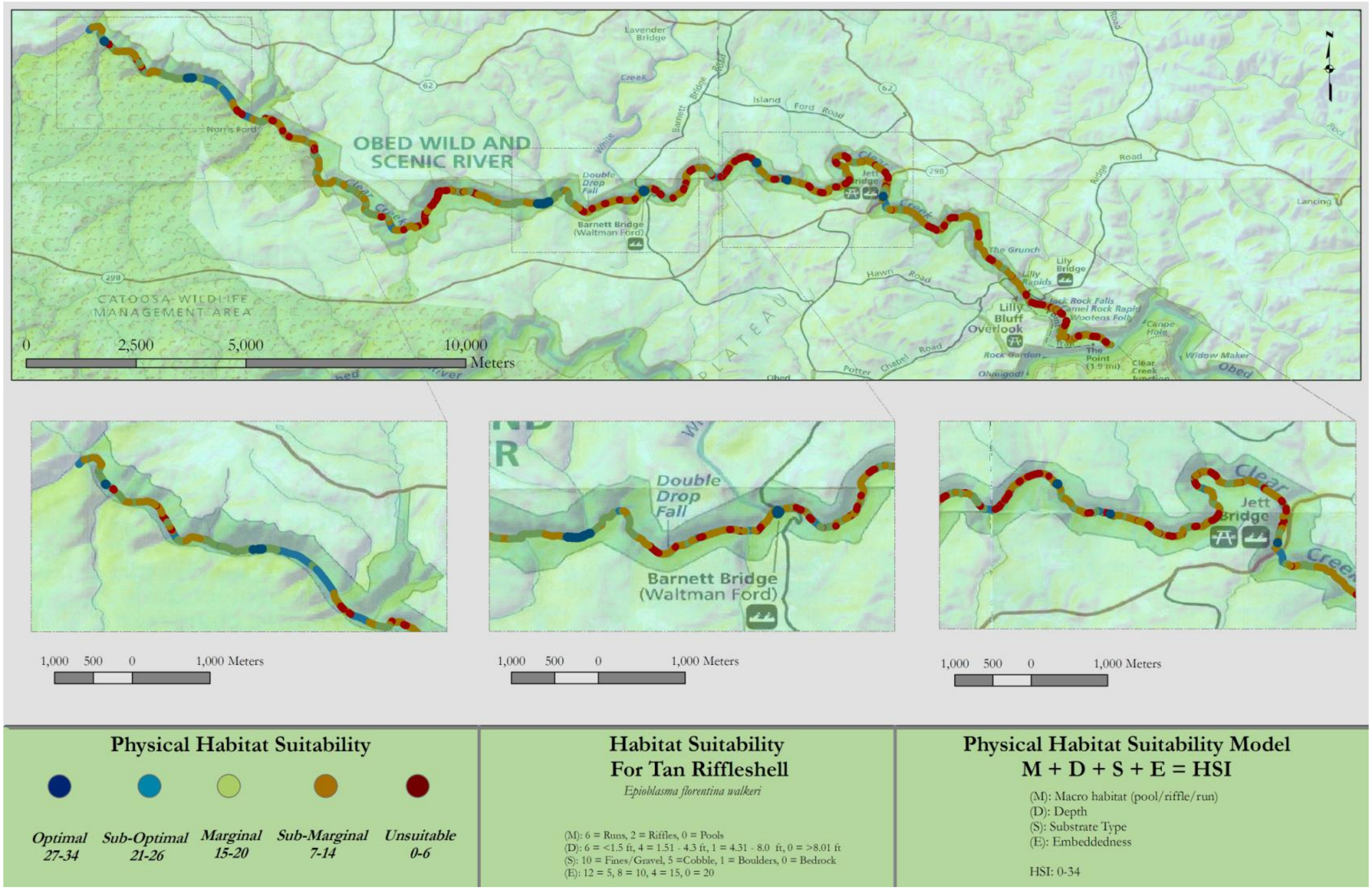


Figure 65: A thematic map that shows habitat suitability trends for the tan riffleshell throughout Clear Creek.

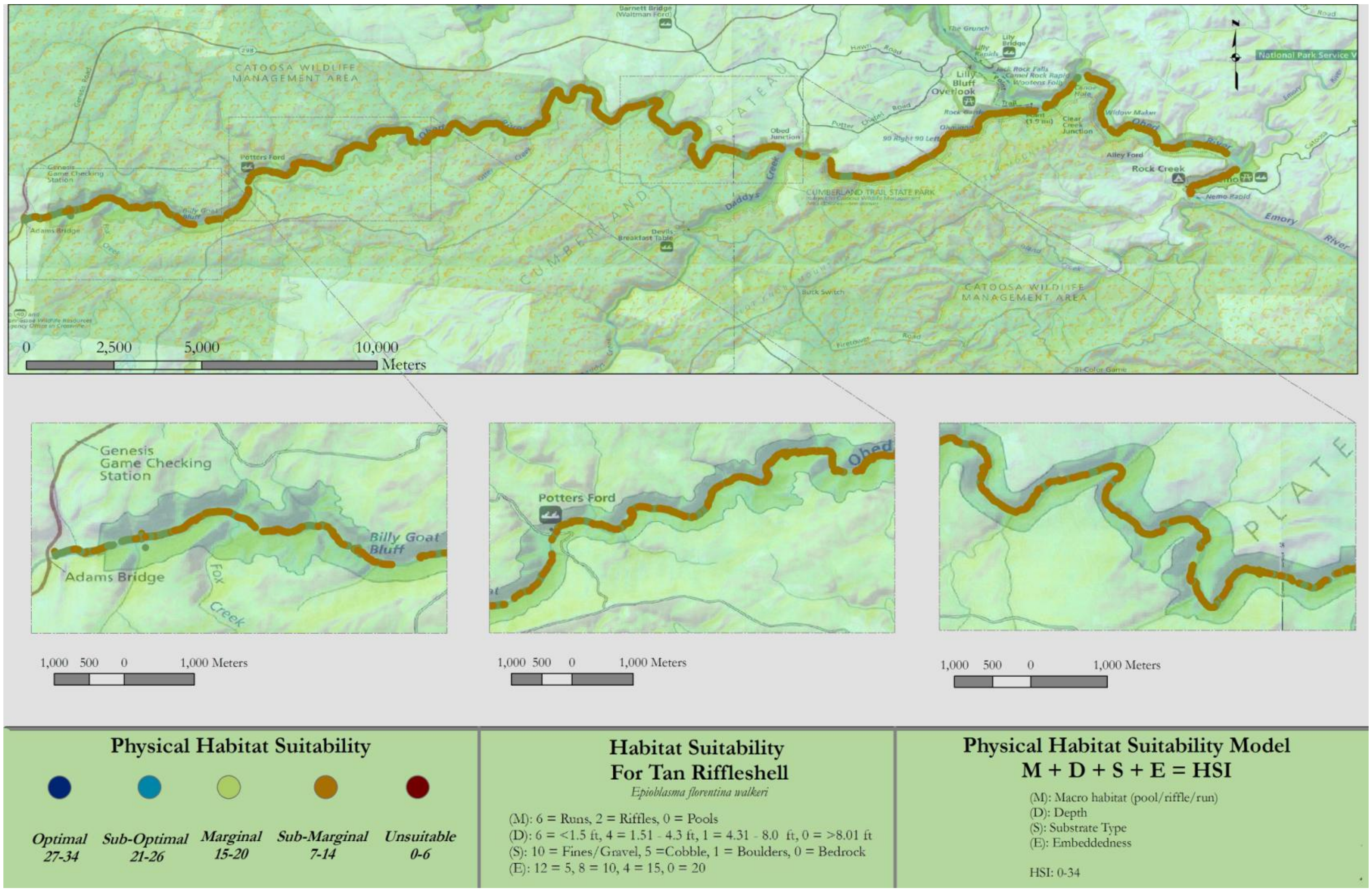


Figure 66: A thematic map that reveals habitat suitability trends for the tan riffleshell throughout the Obed River.

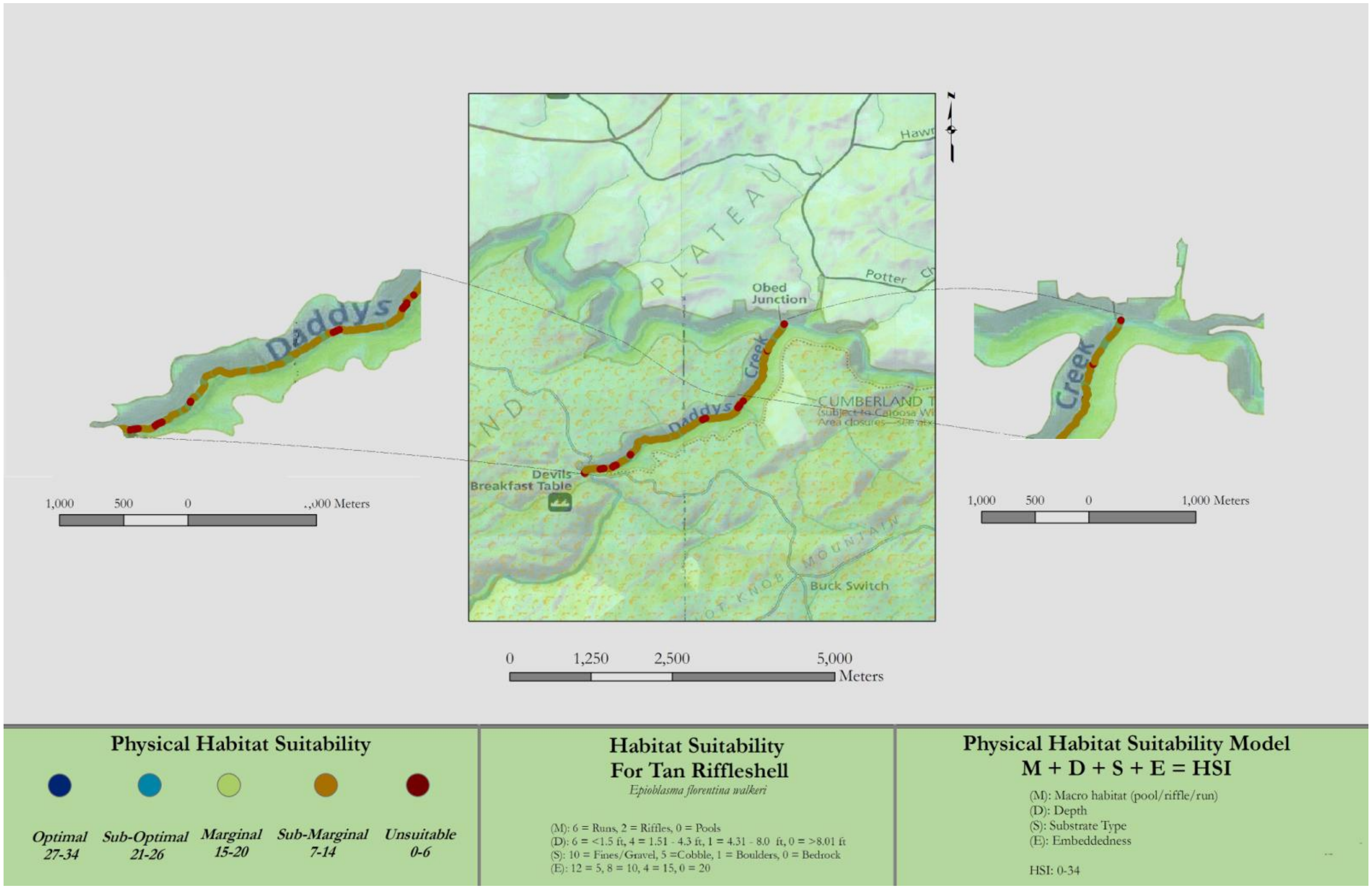


Figure 67: A thematic map that shows habitat suitability transitions for the tan riffleshell through the lower end of Daddy's Creek within OBRI.

6.9 Littlewing Pearlymussel

6.9.1 Habitat Suitability Criteria

The physical habitat suitability model was fabricated based on literature findings of habitat preference and non-suitability. This species occurs in moderate to high-gradient streams. It prefers cooler water with minimal turbidity. Typically, the littlewing pearlymussel thrives in the area just upstream of riffles in shallow water (15-25 cm) under or near sand and small gravel substrates. Observations have been recorded that indicated its occurrence within gravels underneath slabrock and boulders (Parmalee and Bogan, 1998; Fiscor, 2005). The habitat index indicated habitat preferences were based on highest to lowest values. Scores ranged from 0-34 (Table 26).

6.9.2 Clear Creek

There were only 208 point locations that met optimal habitat criteria within Clear Creek. As with many previous mussel habitat locations, upstream of Norris Ford and near Barnett Bridge and Jett Bridge hold ideal conditions for this species to thrive, at least from a physical component perspective (Figure 70) (Table 27). In all, 252 m (<1% of OBRI's spatial extent) of optimal habitat existed within Clear Creek.

6.9.3 Obed River

There was no evidence of supporting optimal littlewing pearlymussel habitat within the Obed River. Most habitat conditions were sub-marginal, indicating that its unique habitat preferences did not occur. At best, marginal habitat was located among 7,867 location points (Figure 71)(Table 27). There were no optimal locales within the Obed River.

6.9.4 Daddy's Creek

Habitat for the littlewing pearlymussel was >68% sub-marginal. There was considerable deviation from sub-marginal to occasionally marginal and poor habitat (Figure 72)(Table 27). Optimal habitat of runs with fine sediment substrates did not occur.

Table 22: Physical habitat suitability mathematical model for the littlewing pearlymussel.

HSI 0 – 34	Physical Habitat Suitability Model for Littlewing Pearlymussel			
	(M)	**(D)**	**(S)**	**(E)**
	6 = Runs	**6 = < 1.5 ft**	**10 Fines, Gravel**	**12 = 5**
	2 = Riffles	**4 = 1.51 – 4.3 ft**	**5 =Boulder**	**8 = 10**
	0 = Pools	**1 = 4.31 – 8.0 ft**	**1 = Cobble**	**4 = 15**
		0 = >8.01 ft	**0 = Bedrock**	**0 = 20**

Table 23: Habitat suitability findings for the littlewing pearlymussel within OBRI.

HSI 0 – 34	Physical Habitat Suitability Results – Littlewing pearlymussel – Clear Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	208 pts	**1,292 pts**	**4,588 pts**	**14,216 pts**	**6,725 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Littlewing pearlymussel – Obed River				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**0 pts**	**7, 867 pts**	**36, 180 pts**	**0 pts**
HSI 0 – 34	Physical Habitat Suitability Results – Littlewing pearlymussel – Daddy's Creek				
	Optimal (27 - 34)	**Sub Optimal (21 – 26)**	**Marginal (15 – 20)**	**Sub Marginal (7 – 14)**	**Poor (0 -6)**
	0 pts	**35 pts**	**982 pts**	**2,683 pts**	**222pts**

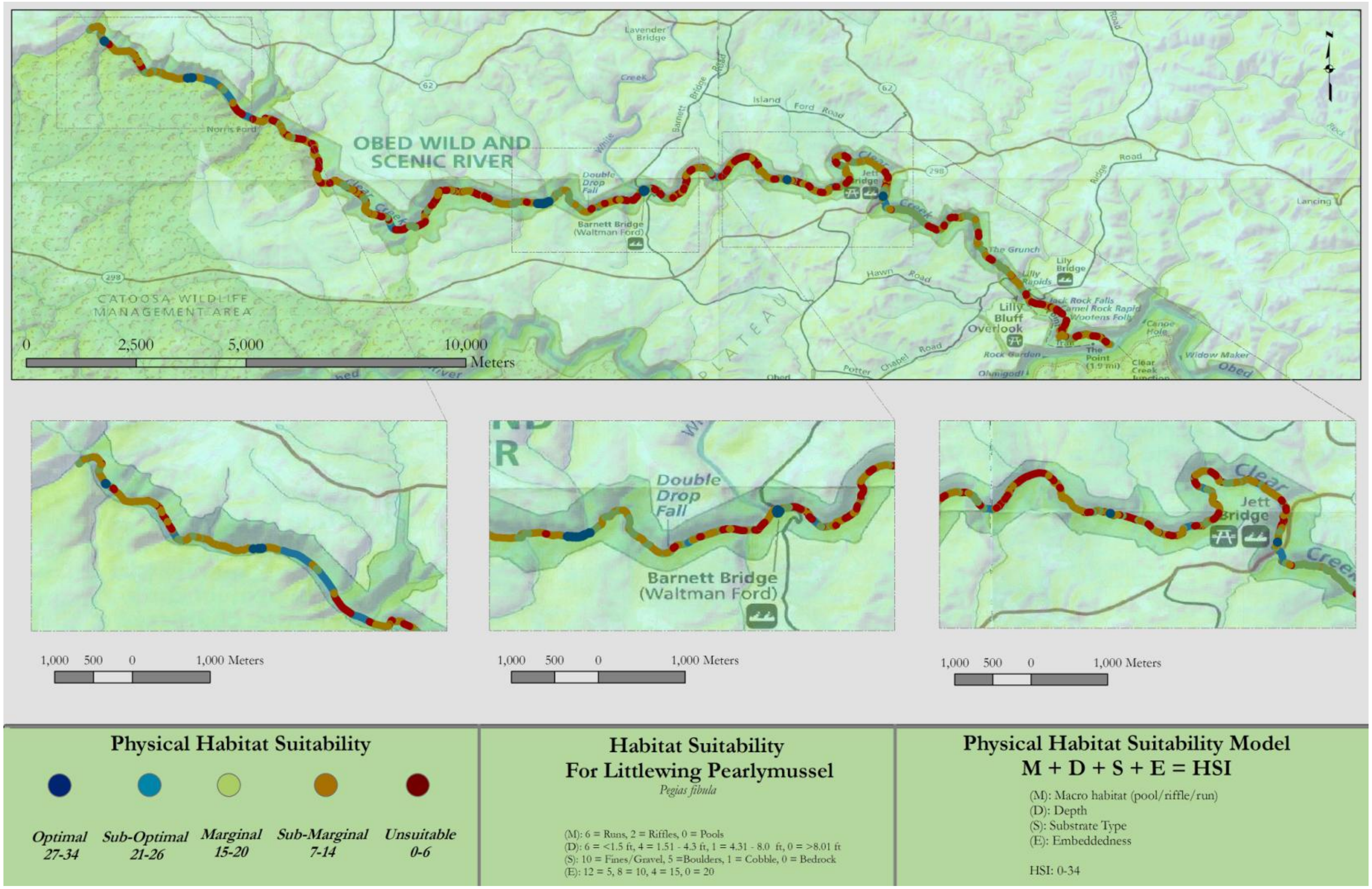


Figure 68: A thematic map shows habitat suitability transitions for the littlewing pearlymussel throughout Clear Creek.

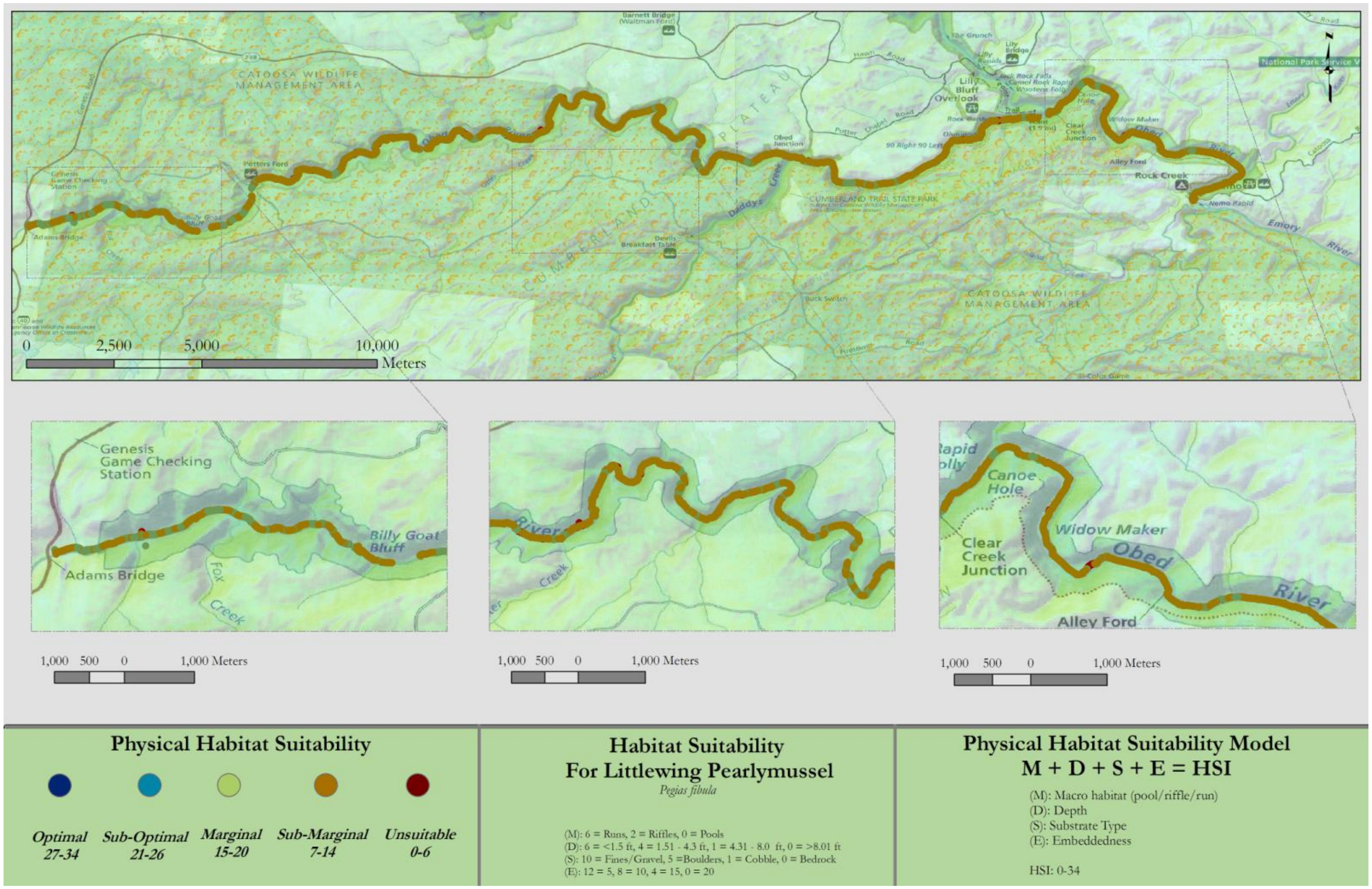


Figure 69: A thematic map that reveals habitat suitability trends for the littlewing pearlymussel throughout the Obed River.

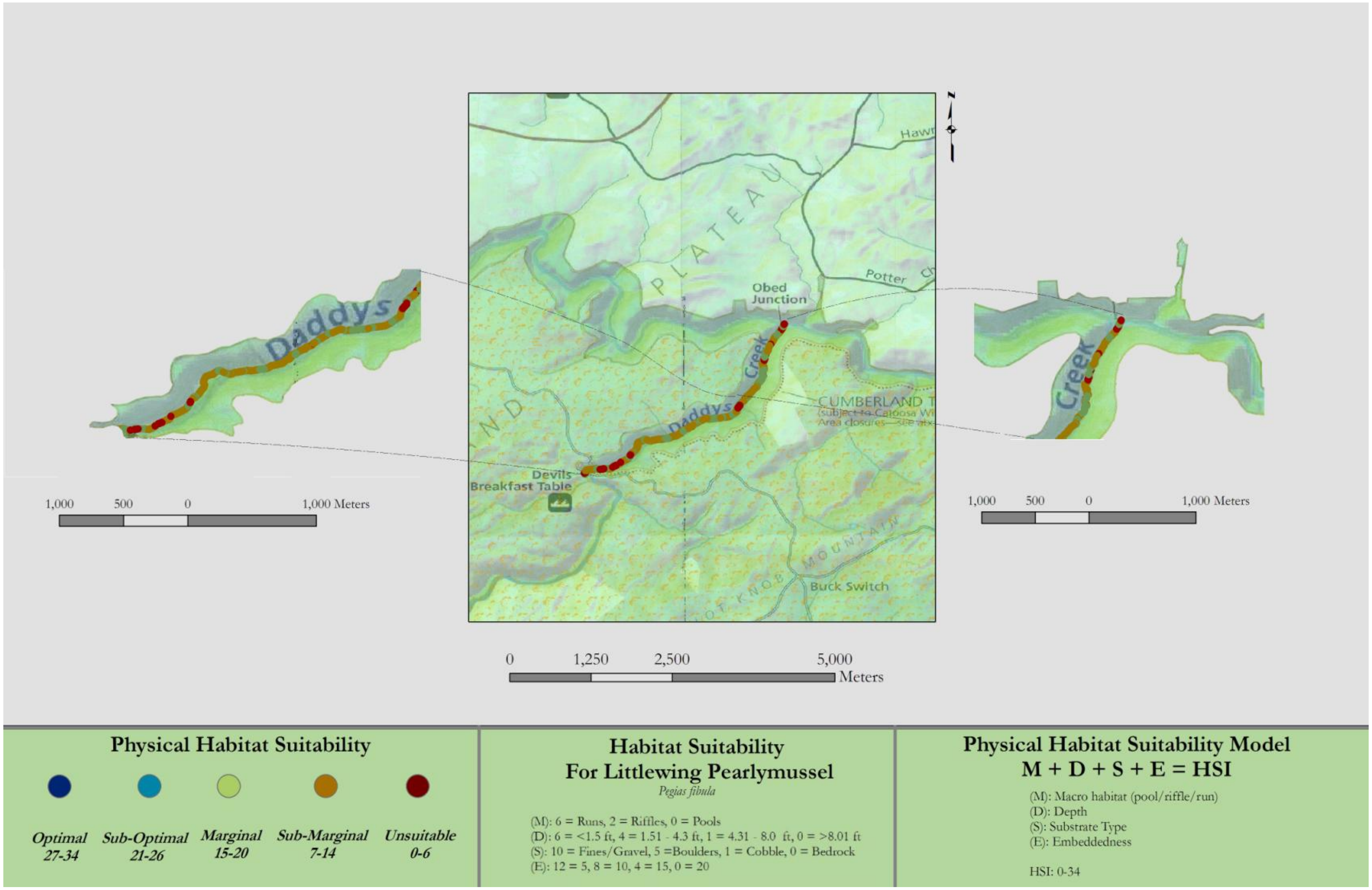


Figure 70: A thematic maps that shows the habitat suitability trends for the littlewing pearlymussel within the lower section of Daddy's Creek within OBRI.

6.10 Optimal Habitat Summary

Optimal habitat locations throughout the Obed Wild and Scenic River varied tremendously for the investigated species criteria. The three fish species (spotfin chub, blackside dace, and the duskytail darter) had far more optimal habitat locations than the six mussel species cumberland elktoe, purple bean, cumberland bean, cumberlandian combshell, tan riffleshell, and the littlewing pearlymussel).

Duskytail darter preferred habitat occurred most frequently, covering 50.87 km throughout the Park. Although this species does not thrive in OBRI, optimal habitat locations were very prevalent. Similarly, optimal habitat for the blackside dace was also very wide-spread, spanning across 37.89 km of the Park. To date, this species does not occur within the Emory watershed. However, the spotfin chub has historically thrived within the upper Emory River watershed, with extensive fish surveys that are currently ongoing. Even though its current range has been impeded and continues to diminish as survey efforts focus downstream, optimal habitat exists in many locations throughout the Park. In fact, over 22 km of OBRI supports optimal conditions (Table 28, 29).

The mussels, however, had limited optimal habitat distribution. Of the six mussels, the cumberland elktoe had the most optimal habitat areas, spreading across 4.32 km randomly throughout the Park. As in the case with most of the other mussels, optimal habitat locales were sporadic and fragmented in continuous distribution. The Purple Bean, historically thrived here, had 2.61 km of optimal habitat to sustain. The other species' habitat (cumberland bean, cumberlandian combshell, tan riffleshell, and the littlewing pearlymussel) were very patchy and limited in distribution. Since high embeddedness was not a predominant habitat feature, isolated pockets of optimal conditions existed (Table 28, 29).

6.11 Preliminary Validation Efforts

Russ (2006) conducted an electrofishing survey the spring months over the course of two years (2004-2005) to find evidence of sustainable spotfin chub populations within OBRI. Of the 10 locations surveyed, two locations produced the most spotfin inventory (OBRI's boundary that cuts across the Emory River, and ~50 m upstream of the Emory River confluence, 7 and 20 observations, respectively)(Figure 73).

The optimal habitat scores for the spotfin chub were mapped to better understand the correlation among the UVMS data and Russ (2006). The area above the Emory River junction yielded the highest number of occurrences, and this research captured optimal spotfin criteria closely adjacent to Russ' (2006) survey location (Figure 73). There were other survey sites that also matched the UVMS optimal habitat data, but the inventories gathered above Canoe Hole were very low, and may have been coincidental.

Table 24: Optimal habitat conditions that were met for each species.

Species	Percent Occurrence	Distance km
Spotfin chub	30%	22.1 km
Blackside dace	51%	37.9 km
Duskytail darter	69%	50.9 km
Cumberland elktoe	6%	4.3 km
Purple bean	4%	2.6km
Cumberland bean	0.5%	0.4 km
Cumberlandian combshell	0.6%	0.5 km
Tan riffleshell	0.4%	0.3 km
Littlewing pearlymussel	0.4%	0.3 km

Table 25: Optimal habitat conditions that were met within Clear Creek, Obed River, and Daddy's Creek.

Species	Clear Creek	Obed River	Daddy's Creek
Spotfin chub	10.9 km	10.3 km	0.9 km
Blackside dace	13.2 km	22 km	2.7 km
duskytail darter	18.7 km	29.8 km	2.4 km
Cumberland elktoe	2.5 km	1.8 km	0 km
Purple bean	1.5 km	0.6 km	0.5 km
Cumberland bean	0.2 km	0.2 km	0 km
Cumberlandian combshell	0.5 km	0 km	0 km
Tan riffleshell	0.3 km	0 km	0 km
Littlewing pearlymussel	0.3 km	0 km	0 km

Figure 73: A validation map for optimal habitat for the spotfin chub (Russ, 2006).

CHAPTER 7
CONCLUSIONS

Previous underwater video mapping (UVMS) research used underwater technology on a canoe or outboard boat, so the customized kayak UVMS apparatus was more compact and environmentally adept to harsh river conditions. Overall, the equipped kayak hulled and protected sensitive equipment very effectively. This system proved its durability and navigational preciseness in shallow narrow channels and swift water.

The primary goals of this project were to develop habitat maps for federally endangered and threatened species by utilizing a GPS-underwater video mapping system (UVMS) and image georeferencing techniques. Habitats were delineated through a GIS database query. Database attributes are quantified into four critical habitat descriptors for accurately locating habitat. The four descriptors include: river characteristics (pool, riffle, and run), depth, substrate, and substrate embeddedness. Efforts were made to exhibit UVMS as a reliable management tool for georeferenced habitat mapping. Once habitat locations are determined, comparisons are made with previous habitat locales to investigate their correlations. Further, a habitat suitability index was constructed to quantitatively delimit habitat ranges into four categories. Sequentially they are: optimal, sub-optimal, marginal, and sub-marginal habitats.

The captured GPS data were reliable and accurate with an average DOP of 2.3 and 47% of GPS locations were differentially corrected. The Garmin 18 PC receiver provided sufficient reception, even with pronounced geologic escarpments and narrow cannons. In fact, the Garmin 18 PC read an average of seven to eight satellites throughout the tenure of this research. There were areas of no reception that resulted in data gaps, but these areas were minimal in the grand scheme of OBRI. There were many occurrences of utilizing nine and ten satellites, which also supported commendable satellite geometry.

The above water camera effectively captured video footage of pool/riffle/run transitions. Runs comprised most of the rivers morphology, but there were common occurrences of violent riffles and significantly deep pools. Deep pools were evident in sections throughout Clear Creek and below the confluence with the Obed River (Clear Creek Junction).

Substrate components of the Park were dominated by cobble and small boulders, 43% and 23%, respectively. The UVMS approach to capture bed morphology was effectively demonstrated, but there were environmental factors that limited visibility. Air pockets clouded the lenses, deep pools, turbidity, and occasional technical issues impeded video resolution. Overall though, this method was very effective in understanding geomorphology in shallow to average depths, especially with the assistance of lasers that provided a constant scale.

Depth measurements were gathered over three methods. Prior to 2009, all depths were recorded from a CruzPro ATT120AT depth transducer with a 0.1 resolutions and range of 0-144m (0-450 ft). Although this sonar provided reliable depth data, there were many zero readings in areas <0.3 m (<1.0 ft). Therefore, a shallow water customized depth sonar (CruzPro ATU120ST) was installed for 2009 research. This depth transducer was ideal for OBRI, capturing shallow depth readings as well as depth to >9 m (30 ft). There were areas where depth sonar data did not exist, and manual depth interpretations were conducted from the underwater bottom cameras.

According to the physical habitat suitability model constructed for this research, fish habitats were widely favored over the mussels. Preferred habitat of the spotfin chub was evident throughout 22.1 km of OBRI. Optimal habitats for the blackside dace and the duskytail darter contributed 37.9 km and 50.9 km, respectively.

High embeddedness was fragmentally distributed throughout OBRI. Primarily, this watershed did not yield significant amounts of sedimentation. As a result, mussel habitats were also sporadic and isolated in relatively short stream reaches.

Preferred optimal habitats for the mussel species were not so widely disbursed. Even though there were optimal habitat conditions within the Obed River, most of the optimal locales were evident throughout Clear Creek. Of the investigated mussel habitats, cumberland elktoe and purple bean optimal habitats were most abundant. Preferred habitat for these species, although sporadic, had significant continuous stretches of ideal physical conditions. These locations contributed to 4.3 km and 2.6 km, respectfully. The remaining unique mussel habitats were isolated to small sections and chaotic dispersions throughout the Park. Ideal habitats for the cumberland bean (0.4 km), cumberlandian combshell (0.5 km), tan riffleshell (0.3 km), and the littlewing pearlymussel (0.3 km) were not high in frequency.

Habitat mapping has become an effective tool in contribution to aquatic conservation and management. Compared to traditional river surveying methodologies, the UVMS invites management awareness and recommendations for large framework with zoom in capabilities to assess habitat within a microhabitat environment.

CHAPTER 8
RECOMMENDATIONS

8.1 Recommendations for UVMS Data Collection Process

Even though the current kayak UVMS recorded spatial data with mini DVDs, the Sony Handycam DVRs were sensitive to extensive vibration. One recommendation to resolve this issue would be to utilize a recording platform with flash memory. There are varieties of DVRs that record video in specified formats, so one that records MPEG 2 is recommended. Other formats often compress video and audio, distorting the GPS audio. As a result, GPS locations cannot be extracted from video files.

8.2 Recommendations Related to Data Analysis

Data analysis was a crucial aspect of this research. Commonly, various people review and interpret spatial video. This often results in varying subjectivity and can result in inaccurate interpretations. It is important to limit the number of reviewers in efforts to provide consistency in interpreted data.

Substrate interpretations were somewhat subjective due to heterogeneity and some limited visibility. However, and objective approach was taken to bypass confusion. A "five second rule" was implemented for substrate classification. This rule implies that a dominant substrate must be prevalent for five seconds to be classified.

8.3 Recommendations Related to Study Methodology

It would be beneficial to validate the UVMS data in certain areas of the Park. More specifically, it would be useful to ground truth optimal habitat areas for the aquatic species under the scope of this research. If natural occurrences of these species thrived within the specified optimal locations, then validated findings could persuade aquatic biologists to become dependent on implementing large scale awareness approaches.

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APPENDIX

Table 26: A table that relays survey dates, river reach, flow, and data captured.

Date	Section	System	Distance km	Distance Mi	Discharge m^3/s	Discharge cfs	Data Acquired
7/19/2007	Barnett to Jett	Kayak	1.48	4.6	0.74	26	AW,UWB,UWS
7/31/2007	Upper Potter Fd to Lower Potter Fd	Kayak	3.06	9.5	1.19	42	AW,UWB,UWS, w/ Depth
5/19/2008	Lower Potter Fd to Obed Jxn	Kayak	0.64	2	4.47	158	AW,UWB,UWS, w/ Depth
5/21/2008	Obed Jxn to Canoe Hole	Kayak	1.71	5.3	3.62	128	AW,UWB,UWS, w/ Depth
7/27/2007	Lilly Bridge to Nemo	Kayak	2.42	7.5	5.24	185	AW, w/ Depth
5/23/2008	Lilly Bridge to Nemo	Kayak	2.42	7.5	5.38	190	AW, w/ Depth
7/3/2009	Upstream of CC Jxn	Tube*	<0. 3	<1	0.37	13	AW
4/9/2009	Upper CC to Barnett Bridge	Kayak	3.12	9.7	8.21	290	AW,UWB,UWS, w/ Depth
6/17/2009	Adam's Bridge - Upper Potters Ford	Kayak	1.32	4.1	3.57	126	AW,UWB,UWS, w/ Depth
5/21/2009	Deveil's Bfast Table - Obed Jxn	Kayak	0.74	2.3	2.89	102	AW,UWB,UWS, w/ Depth

Table 27: A table that expresses macro-habitat observations within each river reaches within OBRI.

Macro Habitat Findings				
	Pool	Riffle	Run	Total
Clear Creek	11,465	5,924	9,349	27,029
Obed River	18,107	11,022	21,145	44,056
Daddy's Creek	369	705	2,848	3,922
Total	**29,941**	**17,651**	**33,342**	**75,007**

Table 28: A table that displays the quantified substrate compositions throughout the major tributaries of OBRI.

	Number of Locations -Substrate Attributes within OBRI						
	Fines	Small Gravel	Large Gravel	Cobble	Small Boulder	Large Boulder	Bedrock
Clear Creek	1,470	7	1,316	10,694	5,732	464	3,041
Obed River	520	108	3,451	19,222	10,310	500	2,278
Daddy's Creek	0	0	71	2,240	1,331	115	40
Total	**1,990**	**115**	**4,838**	**32,516**	**17,373**	**1,079**	**5,359**

Table 29: Embeddedness scoring results within Clear Creek, Obed River, and Daddy's Creek of OBRI.

Habitat Parameter **OBRI Score**	**Condition Category Embeddedness**			
	5	**10**	**15**	**20**
Clear Creek	1,320	1,095	3,192	19,665
Obed River	6,426	755	4,334	32,370
Daddy's Creek	125	0	101	3,696
Totals	**7,871**	**1,850**	**7,627**	**55,731**

VITA

J. R. Candlish graduated from Sewanee: The University of the South in May 2006 with a B.S. in Environmental Studies: Natural Resources. During his tenure at Sewanee, J. R. interned with the Tennessee Wildlife Resources Agency (TWRA) to assist Region IV in their coldwater fisheries management program.

After graduating from Sewanee, J. R. worked in Atlanta, Georgia for one year as an erosion inspector for Alpha Environmental Management Corporation investigating residential/commercial construction sites around the Atlanta metro area. During this time, J.R. got accepted to the graduate school at the University of Tennessee at Knoxville with an interest from Paul Ayers in the Department of Biosystems Engineering and Soil Sciences.

J. R. began his master's of science coursework and field efforts in January 2008, with the pursuit if earning his M.S. in Biosystems Engineering Technology. In April 2009, J. R. also dedicated several months to intern with the Oak Ridge National Laboratory (ORNL). This internship focused exclusively on GIS applications for the long-term benefit of the meteorology program at ORNL.

In January 2010, J. R. accepted a technical assistant position with Information International Associates, Inc. in Oak Ridge, Tennessee.