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Operational Draft Regional Guidebook for the Functional Assessment of High-Gradient Headwater Streams and Low-Gradient Perennial Streams in Appalachia

Elizabeth A. Summers, Chris V. Noble, Jacob F. Berkowitz,
and Frank J. Spilker

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Abstract

The HGM Approach is a method for developing functional indices and the protocols used to apply these indices to the assessment of ecosystem functions at a site-specific scale.

This report uses the HGM Approach to develop a Regional Guidebook to: (a) characterize high-gradient (greater than four percent channel slope) ephemeral and intermittent streams, known collectively as headwater streams, and wadeable, shadeable perennial streams with less than four percent slope, known as perennial streams, in the Appalachian region; (b) provide the rationale used to select functions for the headwater and perennial stream subclasses; (c) provide the rationale used to select assessment variables at the stream, riparian/buffer zone and watershed levels;(d) provide the rationale used to develop assessment equations; (e) provide data from reference streams and document their use in calibrating variables and assessment equations; and (f) outline the necessary protocols for applying the functional indices to the assessment of stream functions. The rapid assessments provided in this guidebook utilize structural components of streams and their watershed and can be used in conjunction with assessment of water quality and biotic communities if desired.

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Preface

This work was performed by the U.S. Army Corps of Engineers (USACE) Army Engineer Research and Development Center (ERDC) in cooperation with USACE District office in Huntington, West Virginia. Funding was provided through the Wetlands Regulatory Assistance Program (WRAP).

This guidebook was developed in cooperation with a team of experts familiar with streams in the Appalachian region. The following people made major contributions to the development of this guidebook: James Spence, Mike Hatten, and Noah Kennedy, Huntington District, USACE; and Greg Pond, U.S. Environmental Protection Agency (USEPA).

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COL Bryan S. Green was Commander of ERDC. Dr. Jeffery P. Holland was Director.

1 Characterization of Stream Ecosystems in the Appalachian Mountain Region

Introduction

This guidebook was developed to assess the ecological functions of: (a) high-gradient headwater streams and (b) perennial streams within the reference domain described below. This guidebook meets the requirements for assessment methods that include: (1) classification, (2) reference data including reference standards, (3) equations describing the functions being assessed, and (4) a protocol for data collection necessary for functional assessment (Berkowitz 2014). This guidebook was developed with the input of a multi-agency, interdisciplinary team. This guidebook provides updated information relating to the assessment of headwater streams and is intended to replace the "*Operational draft regional guidebook for the functional assessment of high-gradient ephemeral and intermittent headwater streams in western West Virginia and eastern Kentucky*" (Noble et al. 2010).

Information about wetland classification and how guidebooks are developed can be found in the following documents:

- *A hydrogeomorphic classification for wetlands* (Brinson 1993). http://el.erdc.usace.army.mil/elpubs/pdf/wrpde4.pdf
- *Hydrogeomorphic (HGM) Approach to assessing wetland functions: Guidelines for developing guidebooks (Version 2)* (Smith et al. 2013). http://el.erdc.usace.army.mil/elpubs/pdf/trel13-11.pdf
- *Framework for the data-driven geographical expansion of rapid ecological assessment methods*. (Berkowitz et al. 2014). http://el.erdc.usace.army.mil/elpubs/pdf/tnwrap14-1.pdf

Reference Domain

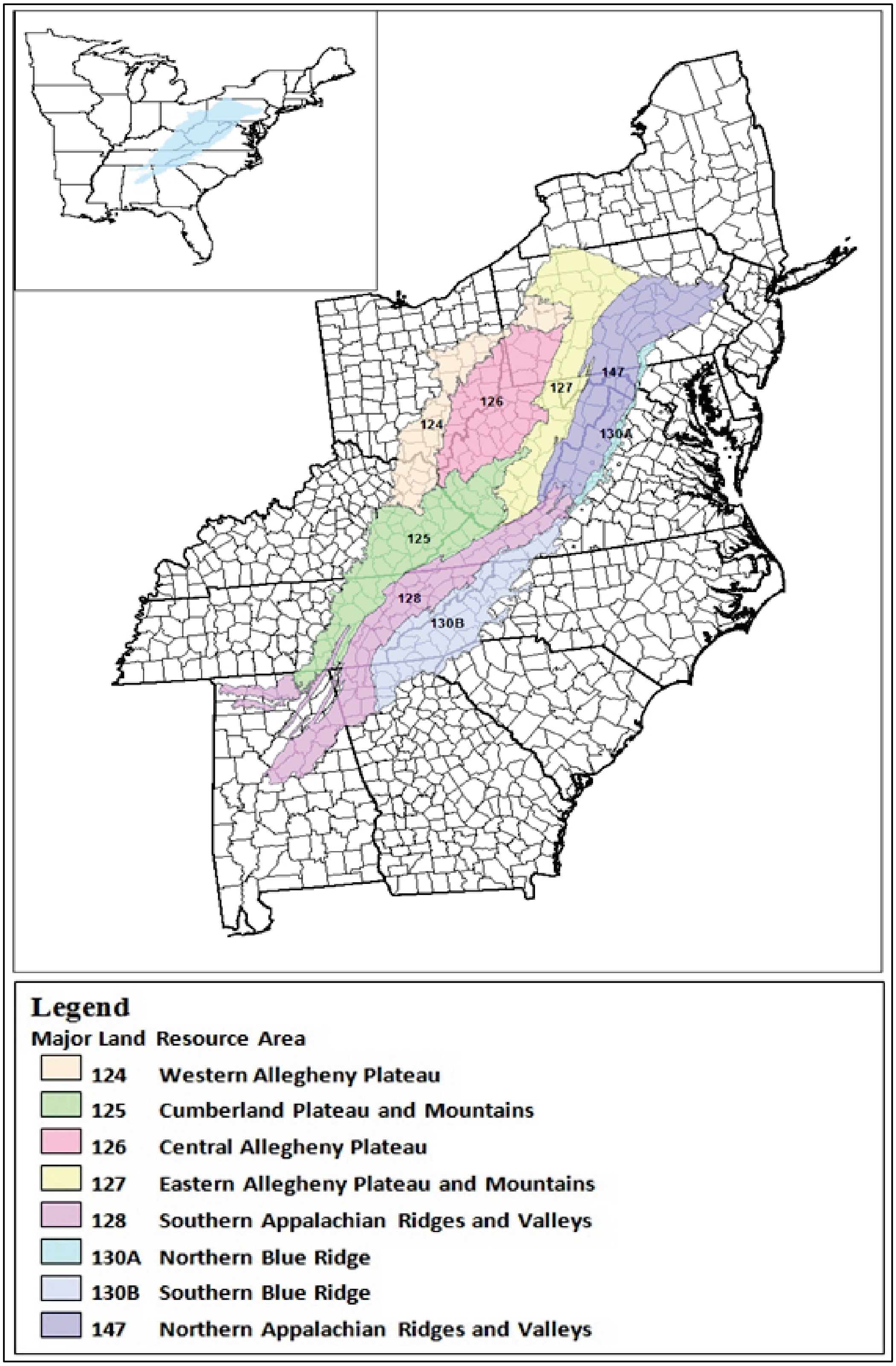
Development of this guidebook was initiated, in part, to meet the need of federal and state agencies for a procedure to assess potential impacts and mitigation needs for stream reaches in eastern Kentucky and western West Virginia. Following initial assessment development and calibration using data from reference streams in eastern Kentucky and western West Virginia, headwater and perennial stream assessments were successfully applied to an expanded reference domain including much of the Appalachian Plateau within Tennessee, Ohio, Pennsylvania, and Virginia. The original reference domain used for assessment development includes Major Land Resource Areas (MLRA) 125 – Cumberland Plateau and Mountains, 126 – Central Allegheny Plateau, and 127 – Eastern Allegheny Plateau and Mountains (Figure 1) (NRCS 2006). The expanded reference domain includes MLRA 124 – Western Allegheny Plateau, 128 – Southern Appalachian Ridges and Valleys, 130A – Northern Blue Ridge, 130B – Southern Blue Ridge, and 147 – Northern Appalachian Ridges and Valleys (Figure 1).

Physiography and Geology

The reference domain is a region of hilly to mountainous terrain, ranging from 330 ft (101 m) in elevation in the Northern Appalachian Ridges and Valleys area to about 6,600 ft (2012 m) in the Smoky Mountains of Tennessee. The region has diverse topography, with local relief ranging from 15 to 980 ft (5 to 300 m). The Cumberland Plateau and Mountains area consists of long, steep side slopes between narrow ridgetops and narrow stream floodplains. Narrow level valleys and narrow sloping ridgetops, separated by long, steep side slopes, characterize the Central Allegheny Plateau area. Steep slopes dominate the Eastern Allegheny Plateau and Mountains area, with gently rolling plateau remnants in the northern part. Parallel ridges characterize the Southern Appalachian Ridges and Valleys area, with narrow intervening valleys, as well as areas of low hills. The Northern Blue Ridge area consists of rugged mountains with steep slopes, sharp crests, and narrow valleys; and the Southern Blue Ridge area consists primarily of mountains and intermountain basins. The Northern Appalachian Ridges and Valleys area is a folded area of steep, parallel ridges. (NRCS 2006)

The geology of the Cumberland Plateau and Mountains, the Central Allegheny Plateau, and the Eastern Allegheny Plateau and Mountains areas consists of sandstone, siltstone, clay, shale, and coal, with unconsolidated deposits of silt, sand, and gravel in the major river valleys. The Southern Appalachian Ridges and Valleys area is composed of alternating beds of limestone, dolomite, shale, and sandstone. The Northern Blue Ridge area contains linear ridges composed of chlorite-actinolite schist, schistose metabasalt, siliceous metabreccia, laminated metasedimentary gneiss, quartzite, phyllitic, and rhyolitic layers in northern Virginia, and a series of

Figure 1. Map of the reference domain for headwater and perennial streams in the Appalachian Region (NRCS 2006). The original reference domain used for assessment development includes MLRAs 125, 126, and 127. The expanded reference domain includes MLRAs 124, 128, 130A, 130B, and 147.



upthrust crystalline shingle blocks of resistant granite, augen gneiss, or quartzite where narrow fault valleys are underlain by less resistant mylonitic gneiss and schist units in southern Virginia. The Southern Blue Ridge area consists of Precambrian metamorphic rock formations including gneiss, schist, amphibolites, metasandstone, slate, phyllite, metasiltstone, and meta-conglomerate, with a few small bodies and windows of igneous and sedimentary rocks. The Northern Appalachian Ridges and Valleys area is composed of ridge crests made up of resistant sandstones and conglomerate bedrock, and valleys underlain by less resistant shales and limestone (NRCS 2006).

Climate

The climate within the reference domain is seasonal, characterized by warm summers and cold winters (Bailey 1995). Average annual temperatures range from 43 to 63 °F (6 to 17 °C) and precipitation averages 31 to 60 in. (79 to 152 cm) annually and increases with elevation, with up to 199 in. (505 cm) at higher elevations in the Southern Blue Ridge (NRCS 2006). In much of the reference domain, the highest rainfall amounts occur in midsummer, and the lowest occurs in autumn and early winter. Rainfall often occurs as high-intensity thunderstorms in summer. Overall, this climate provides a water surplus in the reference domain, with precipitation exceeding potential evapotranspiration for much of the year. However, water deficits (i.e., when evapotranspiration exceeds precipitation) usually occur in summer (June - August). Snowfall occurs annually in areas of high elevation and in the northern part of the reference domain, and may exceed 50 in. (127 cm) (NRCS 2006).

Anthropogenic Alterations

Most of the watersheds within the reference domain were cleared of trees prior to 1900 (Petranka et al. 1993). Since that time, many areas have been allowed to regenerate, so they are currently dominated by native hardwood trees, while other areas in the adjacent upland landscape have undergone additional forest clearing for agricultural production or pasture (Yarnell 1998). Other common land uses that directly or indirectly impact streams in the reference domain include the construction of county, state, and interstate highways, logging access roads and bridges, urban development, and excavating and filling as part of the coal mining process. Anthropogenic alteration led to changes in stream structure including channelization, downcutting, erosion, and sedimentation. These changes alter stream hydrologic, biogeochemical, and habitat functioning.

Regional Subclasses

Headwater Stream Subclass

For the purpose of this guidebook, high-gradient ephemeral and intermittent streams are known collectively as headwater streams. Headwater streams, as defined in this guidebook, have greater than four percent channel slope and are typically first- or second-order streams. Ephemeral streams have flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral streambeds are located above the water table year-around. Groundwater is not a significant source of water for the stream. Runoff from rainfall provides the primary source of water for stream flow (Federal Register 2007). Ephemeral channels often lack a readily discernible floodplain (Figure 2). In contrast, intermittent streams receive inputs from both surface runoff and groundwater. As a result, intermittent streams may have flowing water during dry periods (Federal Register 2007).

Figure 2. A typical headwater stream reach within the reference domain. Note the absence of a well-defined flood plain associated with the headwater stream channel.

Perennial Stream Subclass

Perennial streams, as defined in this guidebook, typically occur as second- or third-order streams that (1) have less than four percent channel slope, (2) remain shallow enough that a person can safely wade across during normal flow conditions, and (3) are narrow enough that the potential exists for full tree canopy closure over the channel (i.e., measurements of 100 percent canopy cover are possible when the riparian/buffer zone is forested) (Figure 3). The perennial stream subclass spans the continuum ranging from streams with less than four percent, located immediately down-gradient of headwater streams, to low-gradient streams that are shallow enough to remain wadeable and narrow enough to have the potential for full canopy closure from surrounding trees and other vegetation. In general, streams within the perennial subclass have flowing water year-round during years with normal precipitation; but, as flow regime is difficult to determine without continuous monitoring, slope, depth, and width can be used as on-site indicators to define the perennial stream subclass. Perennial streams, as defined in this guidebook, typically occur as second- or third-order streams.

Figure 3. A photo illustrating a representative perennial stream within the reference domain.

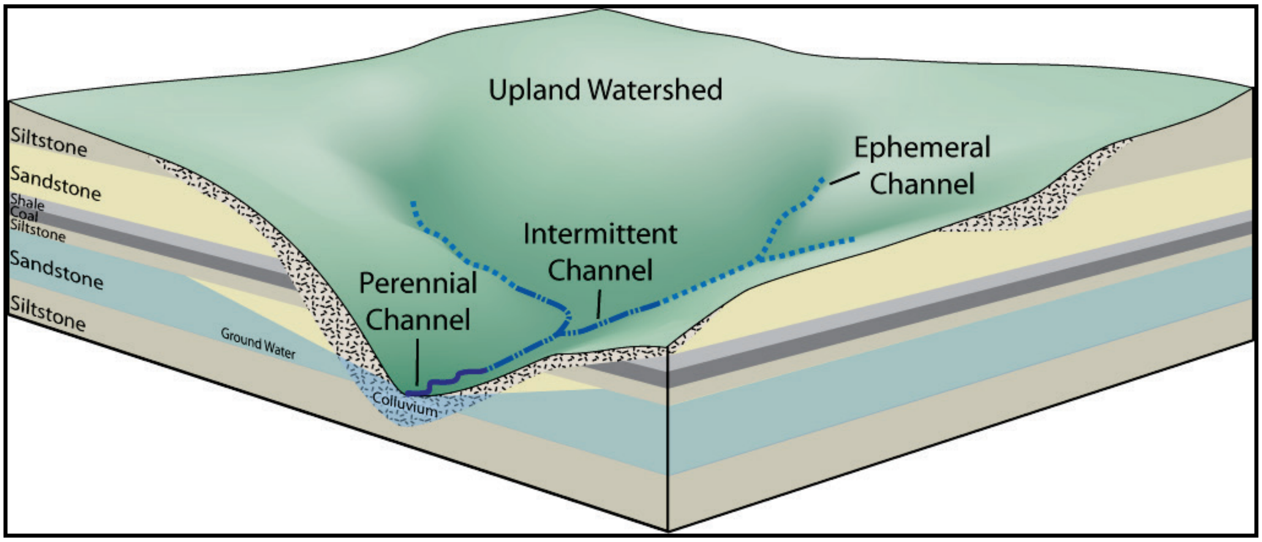
Characterization of streams

Geomorphic Setting

Headwater Stream Subclass

Within the reference domain, headwater streams occur primarily as linear drainages within steep to very steep upland landscapes (Figure 4). For the purpose of this guidebook, headwater streams are defined as streams in the upper portions of the drainage basin that have channel slopes greater than four percent and whose hydrologic inputs include precipitation and overland flow, with potential groundwater contributions. Although stream channels have low sinuosity, they may contain many step pools and would therefore classify as A or Aa+ channels consisting of gravel- or cobble-controlled channels within Type I valleys (Rosgen 1996). This guidebook is not intended to assess streams that are dominated by a bedrock substrate (e.g., greater than 50 percent of the stream reach composed of exposed bedrock substrate). The surrounding drainage basins contributing to the channels are typically forested with hardwood trees and woody shrubs on moderately steep to very steep slopes (NRCS 2006). Within the reference domain, drainage basins can be small (1 acre), and many stream channels do not appear on standard 1:24,000 USGS topographic maps.

Figure 4. Illustration of ephemeral, intermittent, and perennial channels within a typical landscape setting found in the reference domain.



Perennial Stream Subclass

Perennial streams receive inputs from headwater channels in the watershed (Figure 4) and, to a lesser degree, from groundwater seepage at toe slopes.

For the purpose of this guidebook, perennial streams are defined as streams that have an average slope less than four percent. Unimpacted streams within the subclass tend to display sinuosities greater than 1.2, moderate width to depth ratios greater than 12, and would classify as B2, B3, B4, and B5 channels according to Rosgen (1996). Bankfull widths within the reference domain commonly range from 2.9 and 16.6 m. The surrounding drainage basin contributing to the channels are typically forested with hardwood trees and shrubs in narrow, alluvial valleys surrounded by moderately steep to very steep slopes (NRCS 2006). Watershed sizes for stream reaches within the reference domain commonly range from 90 to 4900 hectares (ha). Perennial streams are generally associated with floodplains of varying dimensions and limited extent, depending on depending on stream reach gradient and degree of confinement. In many cases, perennial stream channels within the reference domain abut a steep valley wall on one side, often due to anthropogenic impacts (e.g., stream channel straightening and relocation) within the riparian/buffer zone (Figure 5).

Figure 5. A perennial stream with a steep valley wall on one side of the channel.

Hydrologic Regime

Headwater Stream Subclass

Flow rates in headwater streams are commonly less than 0.01 cubic ft per second (cfs) (0.0003 cubic m per second (cms)); however, after rain events, flow rates often exceed 30 cfs (0.85 cms) (Noble et al. 2014). Typically, ephemeral streams grade into intermittent streams; however, they can flow directly into perennial streams, which have flowing water nearly all year in most years. The addition of groundwater typically increases the duration of flow in intermittent streams to several months each year, but they are usually dry during the driest months of the year (Figure 6). Intermittent streams typically flow into perennial streams. In this region, ephemeral streams are nearly always first-order streams, whereas intermittent streams often occur as first- or second-order streams (Strahler 1952).

Perennial Stream Subclass

Flow rates in perennial streams within the reference domain commonly range from 0.05 to 0.8 cfs (0.001 to 0.02 cms). During drought periods, perennial streams sometimes exhibit low to no flow. Hydrologic inputs include groundwater, precipitation, overland flow, and influx from intermittent streams. Perennial streams, as defined in this guidebook, tend to be second- and third-order streams.

Soils

Soils in the drainage basins surrounding headwater and perennial streams are extremely variable, ranging from shallow to very deep, excessively drained to somewhat poorly drained, and skeletal to clayey in texture (NRCS 2006). The most current soils information for the reference domain can be found on the Web Soil Survey at http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx.

Figure 6. A typical view of a headwater stream channel without flowing water during dry periods.

Flora

In unaltered headwater and perennial streams, riparian zone communities are characterized by deciduous forest vegetation that is dominated by tall, broadleaf trees (Bailey 1995). Common forest species across the reference domain include: white oak (*Quercus alba*), northern red oak (*Quercus rubra*), scarlet oak (*Quercus coccinea*), red maple (*Acer rubrum*), sugar maple (*Acer saccharum*), mockernut hickory (*Carya tomentosa*), pignut hickory (*Carya glabra)*, American beech (*Fagus grandifolia*), chestnut oak (*Quercus montana*), black oak (*Quercus velutina*), American basswood (*Tilia americana*), eastern hemlock (*Tsuga canadensis*), shagbark hickory (*Carya ovata*), yellow birch (*Betula alleghaniensis)*, black birch (*Betula lenta*), tuliptree (*Liriodendron tulipifera*), blackgum (*Nyssa sylvatica*), white ash (*Fraxinus americana*), eastern sycamore (*Platanus occidentalis*), Fraser magnolia (*Magnolia fraseri)*, black cherry (*Prunus serotina*), and sweetgum (*Liquidambar styraciflua*) (Strausbaugh and Core 1978; USDA 2009).

Common shrub species associated with headwater and perennial stream riparian/buffer zones include, but are not limited to: northern spicebush (*Lindera benzoin*), American witchhazel (*Hamamelis virginiana*), pawpaw (*Asimina triloba*), wild hydrangea (*Hydrangea arborescens*), flowering dogwood (*Cornus florida*), alternate-leaf dogwood (*Cornus alternifolia*), possumhaw (*Ilex decidua*), southern arrowwood (*Viburnum dentatum*), hobblebush (*Viburnum lantanoides*), mountain laurel (*Kalmia latifolia*), and great laurel (*Rhododendron maximum*) (Strausbaugh and Core 1978; USDA 2009).

Herbaceous species that are commonly found in the understory of headwater and perennial stream drainage basins are: Yellow trout-lily (*Erythronium americanum*), jack in the pulpit (*Arisaema triphyllum*), white fawnlily (*Erythronium albidum*), largeflower bellwort (*Uvularia grandiflora*), white clintonia (*Clintonia umbellulata*), Canadian may-lily (*Maianthemum canadense*), feathery false lily-of-the-valley (*Maianthemum racemosum*), Indian cucumber (*Medeola virginiana*), smooth Solomon’s seal (*Polygonatum biflorum*), mayapple (*Podophyllum peltatum*), bloodroot (*Sanguinaria canadensis*), Virginia wildrye (*Elymus virginicus*), rattlesnake plantain (*Goodyera pubescens*), eastern hay-scented fern (*Dennstaedtia punctilobula*), marginal woodfern (*Dryopteris marginalis*), Christmas fern (*Polystichum acrostichoides*), asplenium ladyfern (*Athyrium asplenioides*), and northern maidenhair (*Adiantum pedatum*) (Strausbaugh and Core 1978; USDA 2009).

Fauna

Headwater Stream Subclass

Headwater streams provide habitat for a diverse community of macroinvertebrate and amphibian species that require water or moist soils to complete at least a portion of their life cycles. Over 300 species of insects have been identified in headwater streams within the reference domain (Pond and McMurray 2002). Stoneflies (Plecoptera), mayflies (Ephemeroptera), dragonflies (Odonata), beetles (Coleoptera), caddisflies (Trichoptera), moths (Lepidoptera), true flies (Diptera), and alderflies (Megaloptera) are insect orders that have been found in headwater streams within the reference domain (Lee and Samuel 1976).

Salamanders often replace fish as the primary vertebrate predators in headwater streams (Jung et al. 2004). Salamanders commonly associated with headwater streams within the reference domain include: the northern two-lined (*Eurycea b. bislineata*), southern two-lined (*E. cirrigera*), Allegheny mountain dusky (*Desmognathus ochrophaeus*), spring (*Gyrinophilus p. porphyriticus*), red (*Pseudotriton r. ruber*), long-tailed (*E. longicauda*), northern dusky (*Desmognathus f. fuscus*), seal (*D. monticola*), black-bellied (*D. quadramaculatus*), streamside (*Ambystoma barbouri*), seepage (*D. aeneus*), imitator (*D. imitator*), ocoee (*D. ocoee*), spotted dusky (*D. conanti*), Carolina mountain dusky (*D. carolininsis*), Blue Ridge dusky (*D. orestes*), pygmy (*D. wrighti),* Blue Ridge two-lined (*E. wilderae*), Junaluska (*E. junaluska*), and mud (*Pseudotriton montanus*) salamanders (Mitchell and Gibbons 2010; Petranka 2010; Rocco and Brooks 2000; Russell et. al 2004). Detailed information on salamanders can be found in Petranka (2010).

Perennial Stream Subclass

Perennial streams provide habitat to a diverse community of macroinvertebrate, fish, and amphibian species that require water or moist soils to complete at least a portion of their life cycles. Macroinvertebrate taxa found in perennial streams within the reference domain include: mayflies (Ephemeroptera), stoneflies (Plecoptera), caddisflies (Trichoptera), dragonflies (Odonata), alderflies (Megaloptera), true flies (Diptera), midges (Chironomidae), and aquatic worms (Oligochaeta) (Tetra Tech 2000).

As the dominant predators in perennial streams, fish exert a controlling influence on trophic structure (Forrester et al. 1999). Fish species that utilize perennial streams within the reference domain include: creek chub (*Semotilus atromaculatus*), brook trout (*Salvelinus fontinalis*), central stoneroller (*Campostoma anomalum*), Cumberland arrow darter (*Etheostoma sagitta*), Johnny darter (*Etheostoma nigrum*), fantail darter (*Etheostoma flabellare*), rainbow darter (*Etheostoma caeruleum*), northern hogsucker (*Hypentelium nigricans*), white sucker (*Catostomus commersoni*), and southern redbelly dace (*Chrosomus erythrogaster*) (Etnier and Starnes 1993; Lotrich 1973).

In general, there is a shift towards more aquatic salamander species as stream permanence increases. Salamanders commonly associated with perennial streams within the reference domain include: the red (*Pseudotriton r. ruber*), northern dusky (*Desmognathus f. fuscus*), black-bellied (*D. quadramaculatus*), shovel-nosed (*D. marmoratus*), black mountain (*D. welteri*), spring (*Gyrinophilus p. porphyriticus*), and Blue Ridge two-lined (*Eurycea wilderae*) salamanders, the mudpuppy (*Necturus maculosus*), and the hellbender (*Cryptobranchus alleganiensis*) (Mitchell and Gibbons 2010; Petranka 2010; Russell et. al 2004).

Numerous bird and mammal species utilize the riparian zones of perennial streams. Mammals commonly associated with streams and their riparian areas include raccoon (*Procyon lotor*) and mink (*Neovision vison*). Birds that use stream riparian areas include the Louisiana waterthrush (*Parkesia motacilla*) and the hooded warbler (*Setophaga citrina*).

2 Assessment Variables and Functions

Data for this guidebook were collected on 201 headwater Stream Assessment Reaches (SARs) and 151 perennial SARs within the reference domain. Thirty-nine headwater SARs and eight perennial SARs were identified as reference standard reaches, representing the least disturbed, most functional SARs in the dataset.

The first section of this chapter describes the assessment approach and presents the scaling applied to each assessment variable. Each variable is assigned a subindex value from 0.0 to 1.0 based on the conditions observed in the reference domain. When the condition of a variable is within the range of conditions exhibited by reference standard sites or reaches, a variable subindex of 1.0 is assigned. As the condition deviates from the reference standard condition (i.e., the range of conditions within which the variable occurs in reference standard sites or reaches), the variable subindex is assigned based on the defined relationship between variable condition and functional capacity. As the condition of a variable deviates from the conditions exhibited in reference standard sites or reaches, it receives a progressively lower subindex, reflecting its decreasing contribution to functional capacity. In some cases, the variable subindex drops to zero. All variable values reported in this chapter are based on data collected in West Virginia and Kentucky and do not represent data from the expanded reference domain (Berkowitz et al. 2014).

The second portion of the chapter explains each assessed function and describes the assessment equation associated with each stream function. Variables are combined in an assessment equation to produce a Functional Capacity Index (FCI) that ranges from 0.0 to 1.0. The FCI is a measure of the functional capacity of an SAR relative to reference standard reaches in the reference domain. SARs with an FCI of 1.0 perform the function at a level characteristic of reference standard reaches within the same subclass. As the FCI decreases, it indicates that the capacity of the SAR to perform the function is less than that of reference standard reaches.

Throughout the text, headwater stream assessment variables are described first, followed by perennial stream variables. Each function is described first for headwater streams, and then for perennial streams. Subindex curves for headwater stream variables are shown with a yellow background, and subindex curves for perennial stream variables are shown with a blue background. Procedures for measuring each variable in the field, including site layout and sampling plot sizes, can be found in Chapter 3. A list of assessment variables and applicable ecological functions for headwater and perennial stream subclasses is provided in appendix B (Table B1).

Assessment Variables

The following variables are used for the functional assessment of headwater streams in the Appalachia region:

1. Channel Canopy Cover ($V_{CCANOPY}$)
2. Channel Substrate Embeddedness (V_{EMBED})
3. Channel Substrate Size ($V_{SUBSTRATE}$)
4. Channel Bank Erosion ($V_{EROSION}$)
5. Large Woody Debris (V_{LWD})
6. Riparian/Buffer Zone Tree Diameter (V_{TDBH})
7. Riparian/Buffer Zone Snag Density (V_{SNAG})
8. Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})
9. Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH})
10. Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)
11. Riparian/Buffer Zone Herbaceous Cover (V_{HERB})
12. Watershed Land-use (V_{WLUSE})

The following variables are used for the functional assessment of perennial streams in the Appalachian region:

1. Channel Canopy Cover ($V_{CCANOPY}$)
2. Channel Substrate Embeddedness (V_{EMBED})
3. Channel Substrate Size ($V_{SUBSTRATE}$)
4. Streambank Stability ($V_{BANKSTAB}$)
5. Large Woody Debris (V_{LWD})
6. Riparian/Buffer Zone Tree Diameter (V_{TDBH})
7. Riparian/Buffer Zone Tree Density (V_{TDEN})
8. Coefficient of Conservatism (V_{CVALUE})
9. Watershed Forest Cover (V_{FOREST})

Channel Canopy Cover ($V_{CCANOPY}$)

$V_{CCANOPY}$ variable is the average percent cover of woody vegetation (e.g., trees, saplings, or shrubs) over the stream channel. Stream canopy cover is determined using a visual estimate. The use of comparison charts

(Figures B1 and B2) can be helpful in making visual estimates of percent canopy cover. $V_{CCANOPY}$ applies to the Habitat function for both headwater streams and perennial streams, and the Biogeochemistry function for perennial streams.

Channel Canopy Cover shades the stream and affects the temperature, nutrient cycling, and habitat of riparian and stream ecosystems. Canopy coverage is inversely related to daytime surface temperature (Todd and Rothermel 2006) and water temperature (Studinski et al. 2012). Reduced canopy coverage can accelerate desiccation and lead to mortality in amphibians (Rothermel and Luhring 2005), and increased surface temperature accelerates detrital decomposition, thus altering amphibian habitat. Changes in canopy cover and composition affect the quality of stream inputs from the riparian zone (Wipfli et al. 2007) and the flow of biomass from headwaters to downstream reaches. Stemflow and canopy leaching are additional sources of nutrients to riparian and aquatic systems (Mulholland 1992). Riparian plant communities provide habitat for wildlife and are affected by canopy shading, with shade-tolerant species germinating below a full canopy, and early successional species dominating in areas where a canopy is absent (Moorhead and Coder 1994).

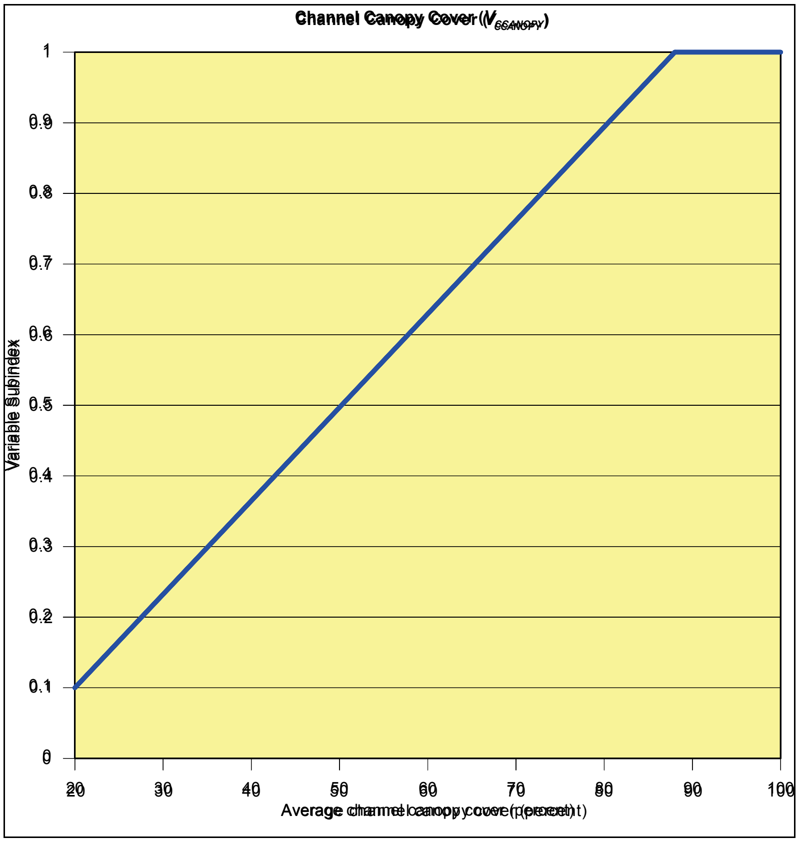
In headwater reference standard reaches, stream canopy cover values were at least 88 percent. Figure 7 shows a channel with greater than 90 percent canopy cover. For headwater streams, if $V_{CCANOPY}$ is less than 20 percent (Figure 8), then neither Riparian/Buffer Zone Tree Diameter (V_{TDBH}) nor Channel Canopy Cover ($V_{CCANOPY}$) is used to determine assessment and riparian/buffer Sapling/Shrub Density (V_{SSD}) and Riparian/Buffer Herbaceous Cover (V_{HERB}) are used instead.

Channel Canopy Cover in headwater streams within the reference domain ranged from 0 to 100 percent. Based on data collected at reference standard reaches, Channel Canopy Cover values of at least 88 percent are assigned a variable score of 1.0. SARs with Channel Canopy Cover of 20 percent are assigned a subindex of 0.1. At 20 percent canopy cover, trees still provide some shade and temperature moderation to the channel, but at a much reduced level, reflected in the subindex score of 0.1. For headwater streams below 20 percent canopy cover, trees are not measured, and shrubs and herbaceous cover become the primary influence on the function of the stream channel. The subindex score increases linearly as Channel Canopy Cover increases from 0.1 at 20 percent canopy cover to 1.0 at 88 percent canopy cover (Figure 9).

Figure 7. Headwater SAR exhibiting greater than 90 percent canopy cover over the stream channel.

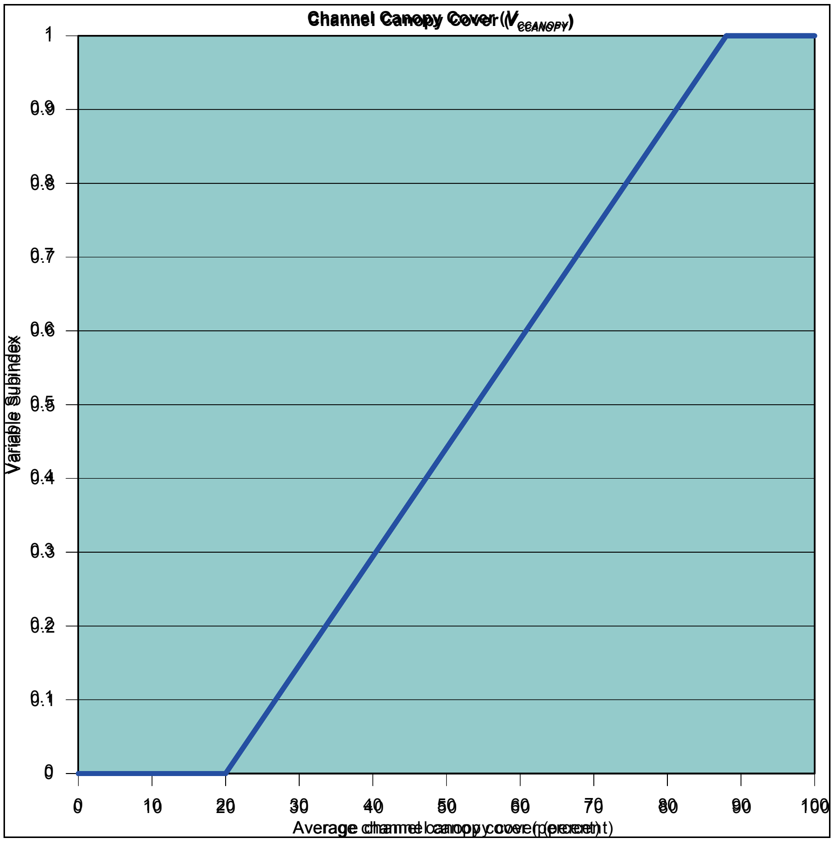
Figure 8. SAR exhibiting zero canopy cover over the stream channel after clear cutting.

Figure 9. Relationship between average percent Channel Canopy Cover ($V_{CCANOPY}$) and functional capacity for headwater streams.



For perennial streams, Channel Canopy Cover within the reference domain ranged from 1 to 99 percent. Very few streams within the reference domain displayed average Channel Canopy Cover of 20 percent or less due to the presence of shrubs and other small woody vegetation overhanging stream banks at even the most altered sites. Based on data collected at reference standard reaches, Channel Canopy Cover values of at least 88 percent are assigned a variable subindex score of 1.0. SARs with Channel Canopy Cover values less than 20 percent are assigned a subindex of 0.0. The subindex score increases linearly from 0.0 at 20 percent canopy cover to 1.0 at 88 percent canopy cover (Figure 10). The mean for data collected within the reference domain was 70 percent. Unlike headwater streams, Channel Canopy Cover for perennial streams is measured for all streams, even those with less than 20 percent canopy cover.

Figure 10. Relationship between average percent Channel Canopy Cover ($V_{CCANOPY}$) and functional capacity for perennial streams.



Channel Substrate Embeddedness (V_{EMBED})

This variable represents the average embeddedness of the stream substrate. Channel Substrate Embeddedness is defined as an index based on the percentage of fine soil particles (e.g., sand, silt, and clay) that surround coarse substrate materials (e.g., gravel, cobble, and boulder) (Table 1). Embeddedness measurements provide an indication of the quantity of fine soil particles delivered to the stream channel from erosion of the surrounding drainage basin and persisting in the stream channel (Chang 2006).

Channel Substrate Embeddedness is important to stream function. As the spaces around large particles (Figures 11 and B3) become filled with fine particles (e.g., sand and silt), streambed roughness is reduced, which in turn reduces energy dissipation (Wilcock 1998). The reduction of voids limits the available cover for macroinvertebrates and salamanders and can result in changes to fish community composition, such as a decrease in the number of riffle-spawning fish (Berkman and Rabeni 1987; Merrit et al. 2008; Sutherland et al. 2002). Low Channel Substrate Embeddedness ratings correspond to lower macroinvertebrate numbers and species diversity (Snyder et al. 2003). For both headwater streams and perennial streams, V_{EMBED} applies to the Hydrology, Biogeochemistry, and Habitat functions.

Table 1. Embeddedness ratings for gravel, cobble, and boulder particles (rescaled from Platts et al. 1983).

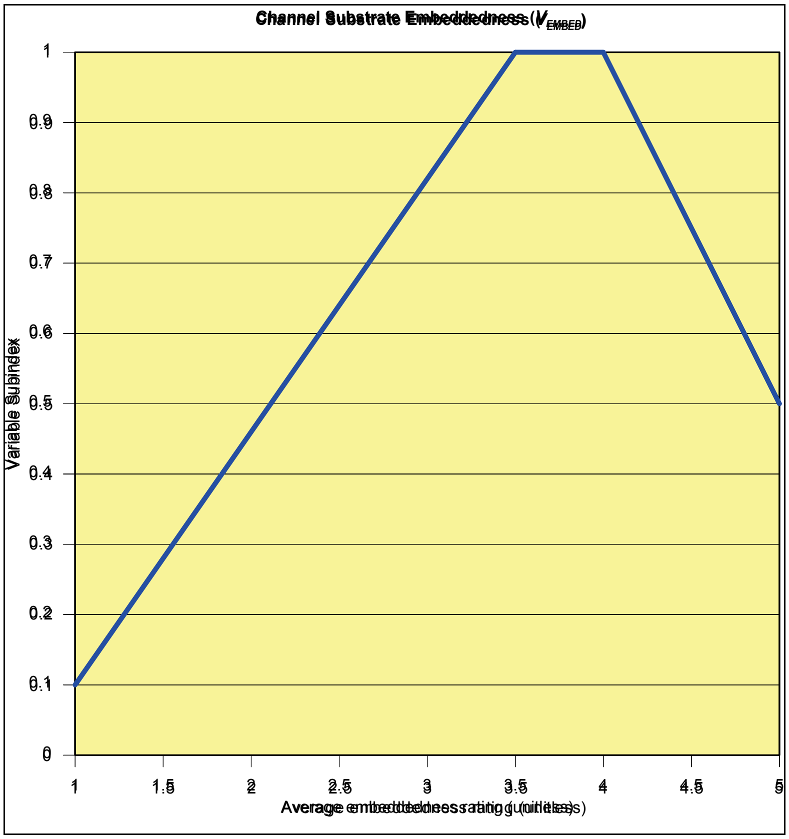
Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment (or bedrock)
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment (or artificial substrate)

Figure 11. Headwater stream channel with an embeddedness rating of 1 (>75 percent of the surface covered by fine sediments).

In headwater streams within the reference domain, all reference standard reaches had average embeddedness ratings of 3.5 to 4. An embeddedness rating of four corresponds to particle surfaces that are an average of 5 to 25 percent covered, buried, or surrounded by fine sediments (Table 1, Figure 12). An average embeddedness rating less than 3.5 reduces cover for macroinvertebrates and amphibians outside of the range observed under reference standard conditions. On the other hand, average embeddedness ratings greater than four (no more than 25 percent embeddedness), found in constructed channels, receive a reduced subindex score (Figure 13).

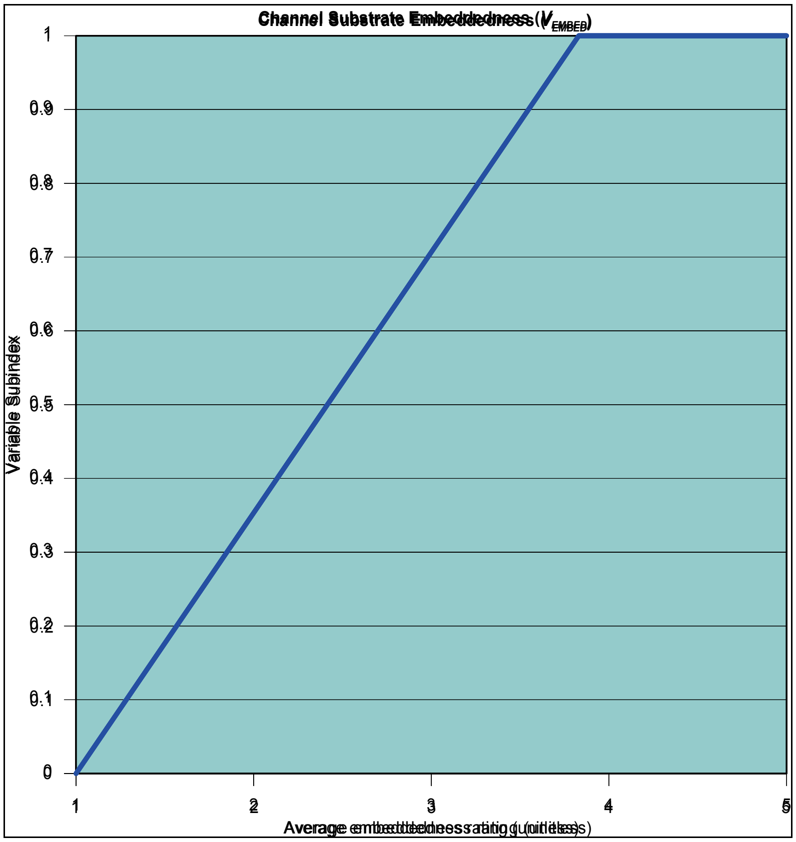
Figure 12. Examples of embeddedness ratings in perennial streams, clockwise from top left: (a) embeddedness rating of 5 (bedrock); (b) embeddedness rating of 4 (5–25 percent of surface covered, surrounded, or buried by fine sediment); (c) embeddedness rating of 3 (26–50 percent of surface covered, surrounded, or buried by fine sediment); (d) embeddedness rating of 1 (>75 percent of surface covered, surrounded, or buried by fine sediment).

Figure 13. Relationship between average embeddedness rating (V_{EMBED}) and functional capacity for headwater streams.



For perennial streams, average Channel Substrate Embeddedness within the reference domain ranged from 1.7 to 4.8. All reference standard reaches had average embeddedness ratings of 3.8 to 4.8. Embeddedness ratings of less than 3.8 are assigned reduced subindex scores (Figure 14). Constructed channels in the perennial subclass tend to contain artificial substrate, which receives a subindex score of one. SARs with average embeddedness ratings of one provide little or no cover for macroinvertebrates and amphibians, and thus are assigned a subindex score of zero.

Figure 14. Relationship between average embeddedness rating of substrate (V_{EMBED}) and functional capacity for perennial streams.



Channel Substrate Size ($V_{SUBSTRATE}$)

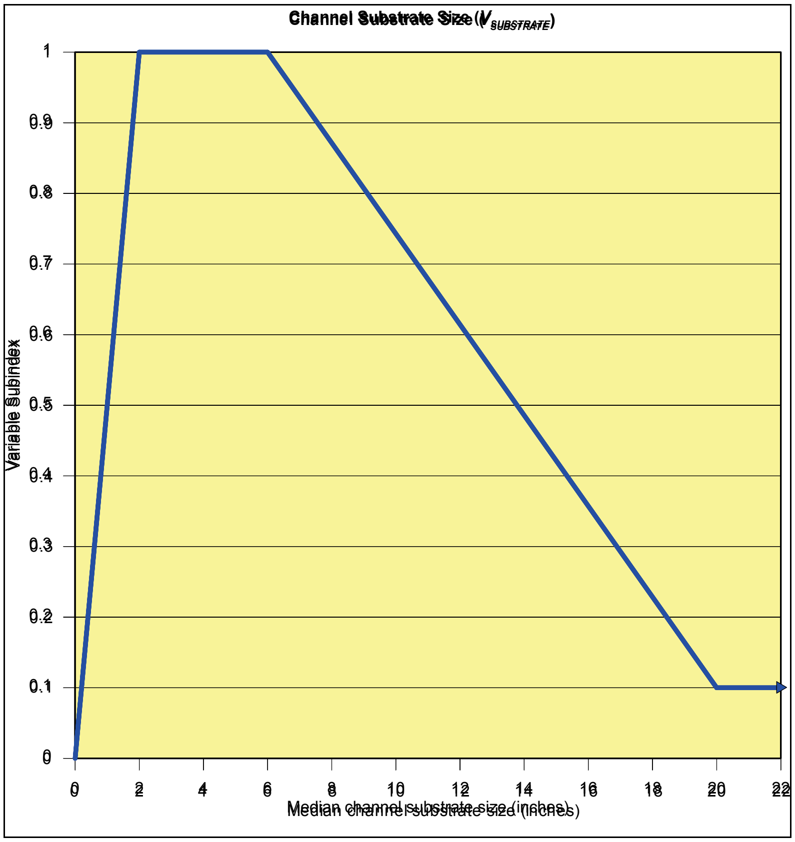
For the purpose of this guidebook, Channel Substrate Size is defined as the median size of the bed material within the stream channel (Figure 15). Substrate size affects the dissipation of stream energy and the availability of habitat for macroinvertebrates, salamanders, and fish (Gordon et al. 2006; Sutherland et al. 2002). An increase in fine particles can reduce the diversity and density of biotic communities (Lenat et al. 1981). Fine silt and sand particles degrade habitat for aquatic species by obstructing respiration and interfering with feeding (Wiederholm 1984). When mean substrate size decreases, cobble/gravel adapted species tend to be replaced by sand/silt adapted species in both fish (Berkman and Rabeni 1987; Sutherland et al. 2002) and macroinvertebrate communities (Lenat et al. 1979). $V_{SUBSTRATE}$ applies to the Hydrology and Habitat functions for both headwater streams and perennial streams, and applies to the Biogeochemistry function for perennial streams.

Figure 15. Substrate in a headwater stream.

For headwater streams, reference standard streams display median substrate sizes ranging from 2 to 6 in. (5 to 15 cm), and receive a variable subindex score of 1.0. Within the reference data set, the median substrate size ranged from 0 to 20 in. (51 cm). SARs with a median substrate size greater than 6 in. (15 cm) are assigned subindex scores that decrease linearly to 0.1 at 20 in. (51 cm) (Figure 16). Variable subindex scores for Channel Substrate Size do not reach zero for large substrate sizes, including bedrock, because large substrate sizes still provide energy dissipation and potential habitat. Substrate composed of concrete or other artificial channel materials are assigned a subindex value of zero. The median substrate size for all reference SARs was 3.5 in. (9 cm). See Chapter 3 and Appendix B for guidance on determining Channel Substrate Size.

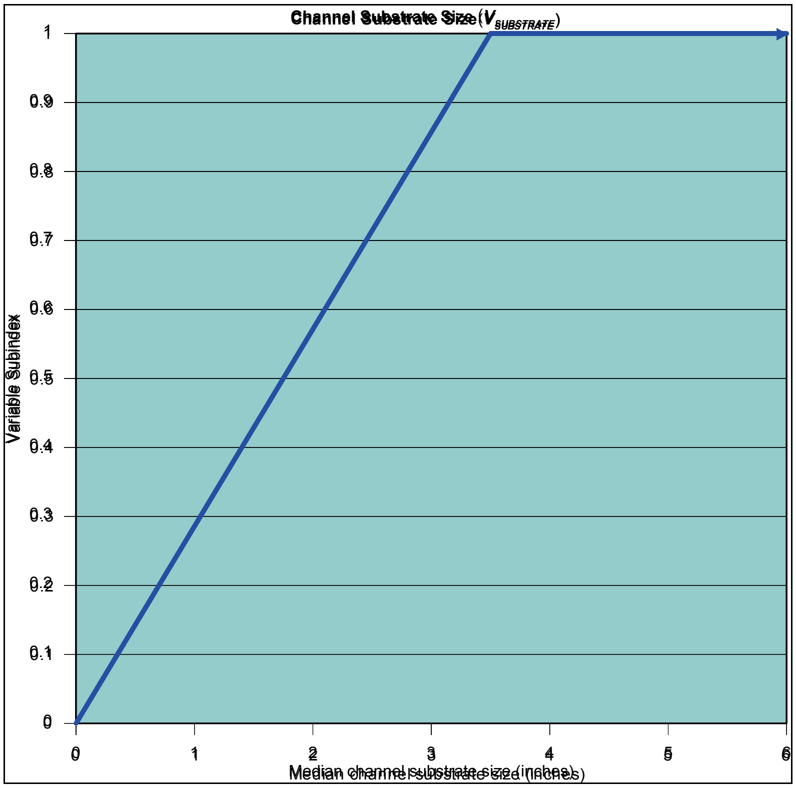
A median substrate size less than 2 in. (5 cm) represents a negative impact to the stream. It reflects an increase in channel sedimentation, due to past or current erosion of the stream bank or surrounding watershed that is not being moved down stream by the current stream energy. Fine sediments fill spaces between coarse particles and reduce habitat for macroinvertebrates, salamanders, and fish. As fine sediments increase, there is a reduction in energy dissipation.

Figure 16. Relationship between median Channel Substrate Size ($V_{SUBSTRATE}$) and functional capacity for headwater streams. Concrete and other artificial materials are assigned a subindex value of zero.



Perennial streams within the reference domain displayed median substrate sizes ranging from 0.1 to 5.7 in (0.2 to 14.2 cm). The median size of substrate in reference standard reaches ranged from 3.5 to 5.6 in. (8.9 to 14.2 cm). Median substrate values above 3.5 in. (8.9 cm) receive a variable subindex score of 1.0. A linear decrease in subindex scores is assigned from 1.0 to 0 as median substrate size declines from reference standard range (Figure 17).

Figure 17. Relationship between median Channel Substrate Size ($V_{SUBSTRATE}$) and functional capacity for perennial streams.



Channel Bank Erosion *(V_{BERO})*

This variable is only used for the headwater stream subclass. Channel Bank Erosion quantifies the proportion of stream channel bank within the SAR displaying signs of erosion or bare stream bank consisting of exposed soil that could contribute fine particles to the stream channel. Channel Bank Erosion is defined as disturbed, scoured sections of the stream channel bank. Eroded banks have exposed soil above or below the waterline that may contribute sediment to the channel and increase substrate embeddedness. The stream channel bank was disturbed by the movement of water, the scraping of debris within the stream channel, or stream bank subsidence (i.e., bank failure) caused by undercutting and other fluvial processes. It is not necessary for the entire height of the stream channel bank to exhibit erosion. Any portion of the bank exhibiting erosion should be included in this measurement. Areas of erosion are recorded for each side of the stream and added together to yield a total length of stream channel bank displaying erosion for the entire SAR (Figure 18). This value is converted to represent the proportion of stream bank displaying erosion (Equation 1). Channel Bank Erosion values range from 0 to 200 percent to account for both stream banks. V_{BERO} applies to the Hydrology function for headwater streams.

Figure 18. Headwater stream channel with short section of eroded bank on the left channel bank and no bank erosion on right channel bank.

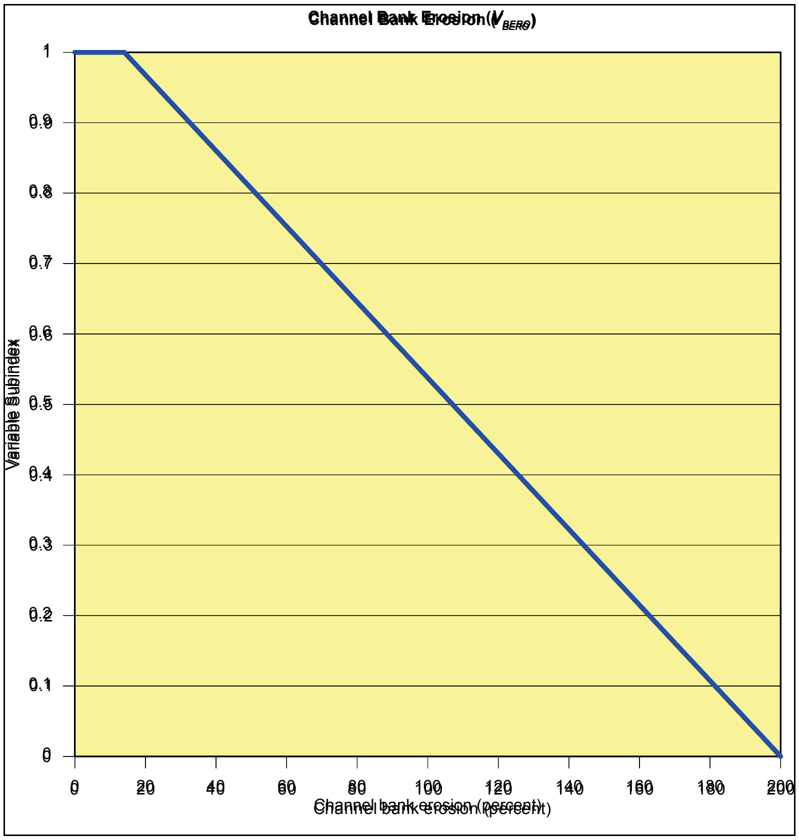
$$\text{Channel Bank Erosion} = \left(\frac{\text{ft. left bank erosion} + \text{ft. right bank erosion}}{\text{SAR length}} \right) \times 100\% \qquad (1)$$

The erosion of the stream channel bank and the subsequent release of sediments change the chemistry, biology, water quality, and physical form of downstream reaches. Channel bank erosion plays an important role in stream channel degradation and contributes to watershed sediment yields (Wynn and Mostaghimi 2006). Channel bank erosion and retreat also impact riparian ecosystems and floodplain residents, and threaten streamside infrastructure (Wynn and Mostaghimi 2006).

Both natural and anthropogenic processes cause Channel bank erosion. Changes in channel form result from frost action, flooding, trampling, agriculture, and other factors (Gordon et al. 2006; Lenat 1984). Channel bank erosion occurs as a result of several interrelated processes. Fluvial processes erode soil particles from the stream channel bank by direct physical action. Subaerial and other climatic processes lead to cracking and weakening of the soil, which increases the efficiency of fluvial erosion. In headwater streams, subaerial processes (e.g., soil desiccation and freeze-thaw cycling) are a major cause of stream bank retreat as soils are broken into small peds and crumbs that can be easily eroded by fluvial action (Wynn and Mostaghimi 2006).

Measurements of stream bank erosion within the reference domain ranged from 0 to 200 percent when banks on both sides of the channel were eroded the entire length of the SAR. Based on data collected at reference standard reaches, stream bank erosion values between 0 and 14 percent are assigned a variable subindex score of 1.0. SARs with greater amounts of stream bank erosion are assigned a lower subindex score. The subindex score decreases linearly beyond the reference standard range as Channel Bank Erosion increases (Figure 19).

Figure 19. Relationship between Channel Bank Erosion (V_{BERO}) and functional capacity for headwater streams.



Streambank Stability ($V_{BANKSTAB}$)

This variable is an index reflecting stream bank integrity in perennial streams. Streambank Stability incorporates three factors: (1) the percentage of streambank length exhibiting erosion observed above bankfull stage, (2) height category of eroded bank (Table 2), and (3) the amount of artificially stabilized stream bank (e.g., concrete, boulders, or riprap) (Equation 2, Table 2, Figure 20). For each section of eroded or stabilized stream bank, the erosion multiplier shown in Table 2 multiplies the length of erosion in feet. The weighted erosion lengths are summed and divided by the length of thalweg in the SAR, then multiplied by 100 (Equation 2). Streambank Stability values range from 0 to 200 to account for both stream banks. Although erosion is a natural process that occurs, to some extent, at all perennial streams, rates of bank collapse exceeding equilibrium are associated with altered hydrology and degradation of channel conditions. Stable undercut banks and erosion below bankfull stage are not included in the measurement of Streambank Stability. While less desirable than natural, uneroded bank conditions, artificially stabilized banks are preferable to large amounts of erosion, and thus are assigned a value equivalent to the lowest erosion multiplier. For perennial streams, Streambank Stability applies to the Hydrology function.

$$\text{Streambank Stability} = 100\left(\frac{\sum_{i=1}^{n}\left(\text{bank length}_i \times \text{erosion multiplier}_i\right)}{\text{SAR length}}\right) \tag{2}$$

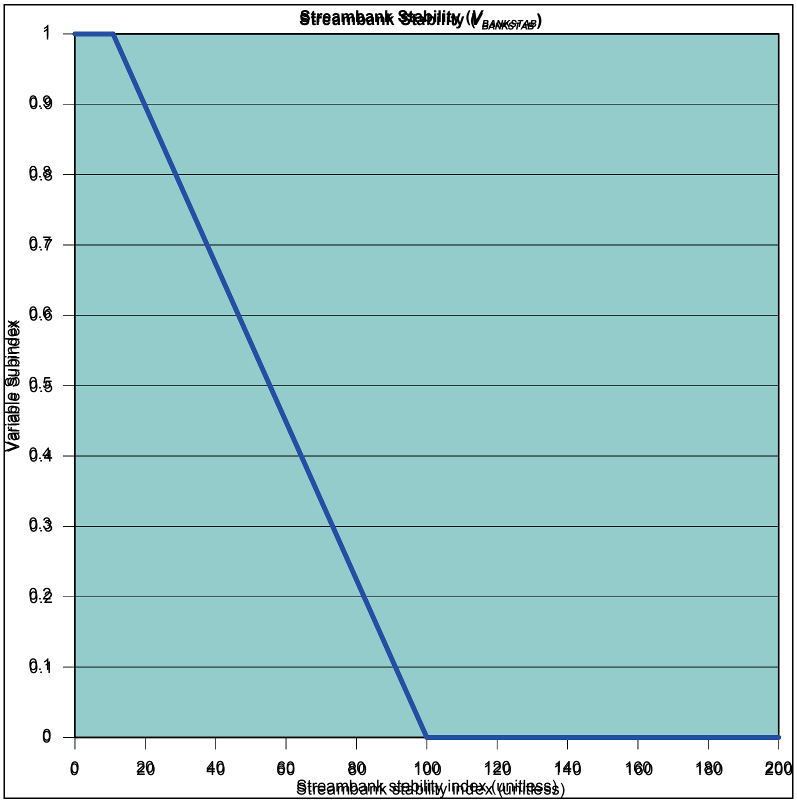
Table 2. Erosion height rating for calculating Streambank Stability in perennial streams.

Height of erosion above bankfull stage (ft)	Height category	Erosion multiplier
0.1–2	1	0.5
2.1–4	2	0.7
>4	3	1
Artificial Bank Stabilization	4	0.5

Figure 20. Examples of erosion height categories (bankfull stage indicated by red lines): (a) erosion 0.1–2 ft above bankfull stage; (b) erosion 2.1–4 ft above bankfull stage; (c) erosion >4 ft above bankfull stage; artificial bank stabilization with (d) boulders, (e) concrete and boulders, and (f) riprap.

Streambank Stability indices within the reference domain ranged from 0 to 113. Based on data collected at reference standard reaches, $V_{BANKSTAB}$ index values between 0 and 10.8 are assigned a variable subindex score of 1.0. SARs with greater amounts of stream bank erosion are assigned a lower subindex score. The subindex score decreases linearly between 10.8 and 100 (Figure 21).

Figure 21. Relationship between Streambank Stability index ($V_{BANKSTAB}$) and functional capacity.



Large Woody Debris (V_{LWD})

Large Woody Debris (LWD) is an indicator of long-term accumulation of organic matter from vegetation within the riparian/buffer zone and upstream locations. LWD within the riparian/buffer zone and channel is a source of food and cover for macroinvertebrates, salamanders, and fish (Johnson et al. 2003; Lewis 1969; Lockaby et al. 2002; Whiles and Grubaugh 1996). LWD influences biogeochemical cycling by providing nutrients and other compounds directly to the stream channel as well as trapping smaller organic matter (Bilby and Likens 1980; Ehrman and Lamberti 1992). LWD in the stream channel dissipates flow energy, increasing bank stability, formation of channel features, and sediment storage (Bilby 1984). For headwater streams, V_{LWD} applies to Hydrology, Biogeochemistry, and Habitat functions. For perennial streams, V_{LWD} applies to the Habitat function.

Figure 22. Headwater stream channel and riparian/buffer zone containing Large Woody Debris (V_{LWD}).

LWD provides an interface between aquatic and terrestrial ecosystems, and the importance of LWD in temperate streams has been well documented (Hilderbrand et al. 1997). LWD affects channel geomorphic processes including the formation of pools and riffles, channel roughness, and channel shifting (Montgomery and Piegay 2003; Scherer 2004). LWD also dissipates the energy of water within the stream channel and decreases the power of tributaries entering the stream from the surrounding watershed. LWD decreases sediment transport power in stream ecosystems (Hedman et al. 1996; Naiman et al. 1989). Within the stream channel, LWD creates habitat for macroinvertebrates and provides cover and camouflage for fish (Angermeier and Karr 1984). Removal of LWD has been shown to result in stream down-cutting and widening, increased transport of bedload materials, and streambank subsidence (Hilderbrand et al. 1997). Amounts of LWD exceeding those found at reference standard stream reaches can result from ice or wind storms, insects, fire, disease, or anthropogenic disturbances, such as poor forest management practices or recent timber harvests.

LWD influences the movement, storage, and addition of organic matter into stream ecosystems (Hilderbrand et al. 1997), and it is a source of particulate organic matter (Fischenich and Morrow 2000). Water currents around LWD create pools that trap and store organic matter (e.g., leaf litter, twigs, etc.) for later release (Scherer 2004). Wood in channel and stream ecosystems provides refuge and overhead cover for a variety of species (Fischenich and Morrow 2000). The presence of LWD provides substrate and promotes invertebrate colonization and establishment (Hilderbrand et al. 1997; Fischenich and Morrow 2000).

V_{LWD} is defined as the number of down woody stems at least 4 in. (10 cm) in diameter and at least 36 in. (91 cm) long per 100 feet (30.5 m) of SAR length. V_{LWD} is measured using a count of LWD and includes materials located within the stream channel and in the riparian/buffer zone (Figure 22).

On headwater reference standard reaches within the reference domain, counts of LWD ranged from 8 to 20 pieces per 100 ft (30.5 m) of SAR. SARs lacking LWD are assigned a subindex score of 0. A linear increase in subindex score occurs as the amount of LWD increases from 0 to 8 pieces per 100 ft of SAR. A linear decrease is applied as the amount of LWD increases above 20 pieces per 100 ft of SAR to a subindex score of 0.5 at 60 pieces of LWD per 100 ft of SAR (Figure 23).

At perennial reference standard reaches within the reference domain, LWD ranged from 14–22 pieces per 100 ft (30.5 m) of SAR length. SARs lacking LWD are assigned a subindex score of 0.0. A linear increase in subindex score is applied for the amount of LWD ranging from 0 to 14. A linear decrease is assigned as the amount of LWD increases above 22 pieces per 100 ft of SAR to a subindex score of 0.5 at 45 pieces of LWD per 100 ft (Figure 24).

Figure 23. Relationship between Large Woody Debris (V_{LWD}) and functional capacity for headwater streams.

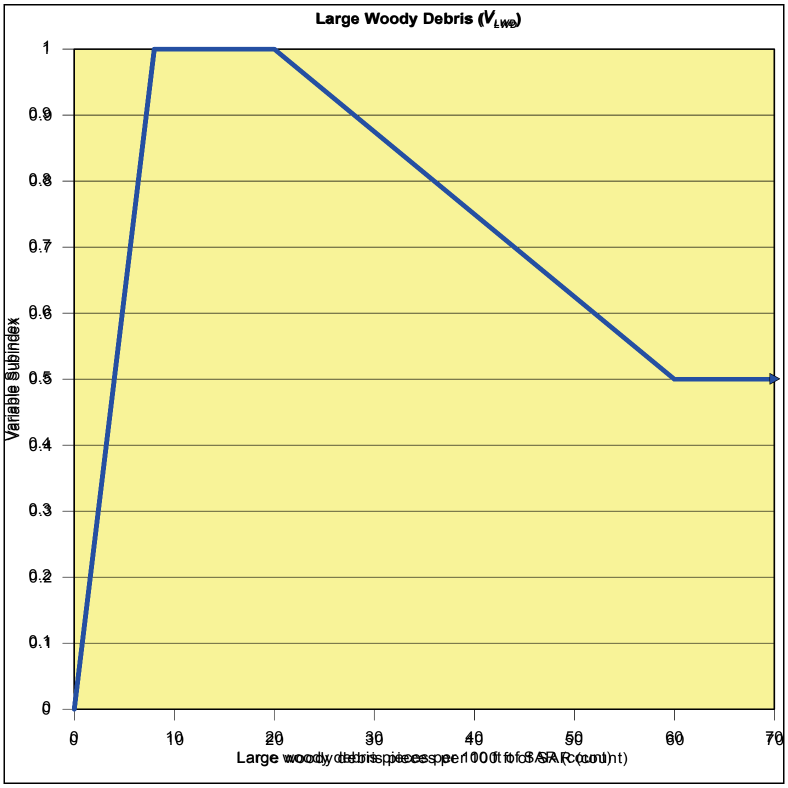
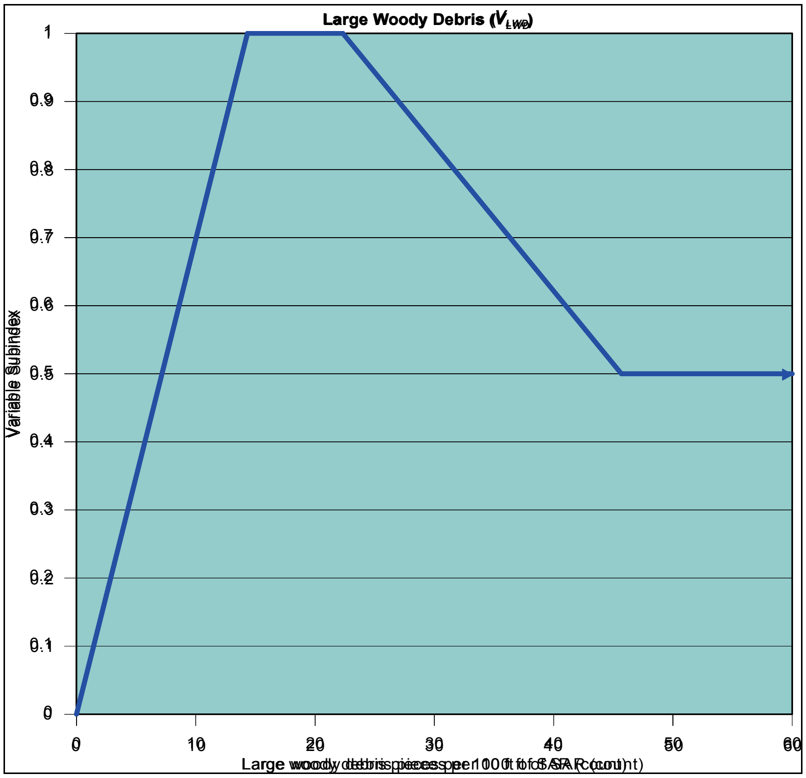


Figure 24. Relationship between the count of Large Woody Debris per 100 ft SAR (V_{LWD}) and functional capacity for perennial streams.



Riparian/Buffer Zone Tree Diameter (V_{TDBH})

This variable is the average diameter of living trees measured at breast height (DBH) within the riparian/buffer zone (Figure 25). Trees are included when the DBH is at least 4 in. (10 cm). For headwater streams, V_{TDBH} applies to the Biogeochemistry and Habitat functions. For perennial streams, V_{TDBH} applies to the Habitat function.

Figure 25. Stream reaches (a) with and (b) without riparian/buffer zone forests.

The riparian/buffer zone forms a region of interaction that connects the stream channel to the surrounding root systems, tree canopy, and landscape. Riparian/buffer zone forests regulate many of the ecological functions of stream ecosystems. Chemical, physical, and biotic integrity improve with forest maturity (Rheinhardt et al. 2007). Mature forests provide structural features lacking in younger forest stands, and *VTDBH* reflects basal area, a surrogate measure of successional status (Rheinhardt et al. 2007). Trees in the riparian/buffer zone affect stream lighting, temperature, nutrient cycling, hydrology, physical structure, habitat, and food sources (Hession et al. 2000). Riparian/buffer zone forests also provide stream bank structure and slow erosion. Leaves and branches from trees in the riparian/buffer zone provide nutrients to aquatic species, and leaf litter provides a major energy base for streams (Benfield et al. 1991). Fallen trees supply the stream channel with LWD (e.g., bole, limb, and root wad); thus providing an important component to the ecology and morphology of headwater streams (Hedman et al. 1996). It has also been shown that forested riparian/buffer zones promote stream stability and water quality more effectively than areas dominated by plants in the lower herbaceous strata (Osborne and Kovacic 1993).

For headwater streams, the mean Riparian/Buffer Zone Tree Diameter within the reference domain ranged from 5 to 18 in. (12.7 to 45.7 cm). Based on data collected at reference standard reaches, average DBH values at least 8.7 in. (22.1 cm) are assigned a variable subindex score of 1.0. A linear decrease in the subindex score from 1.0 to 0.1 is assigned as average DBH declines from reference standard range (Figure 26). If no trees in the riparian/buffer zone reach the minimum DBH of 4 in. (10 cm), the variable scaling shown in Figure 26 would not apply and V_{TDBH} would receive a subindex score of zero.

For perennial streams, the Riparian/Buffer Zone Tree Diameter for all trees at least 4 in. (10 cm) in diameter is used at all SARs, regardless of the amount of canopy cover. Mean tree diameter is measured within at least four 0.032-acre subplots (described in Chapter 3) within the riparian/buffer zone and then averaged across subplots. Mean tree diameter measured in riparian/buffer zone subplots ranged from 0 (no trees) to 16.8 in (0 to 42.7 cm). Based on data collected at reference standard reaches, average DBH values of at least 9.3 in. (23.6 cm) are assigned a subindex score of 1.0. Subindex scores decrease linearly from 1.0 to 0 (Figure 27).

Figure 26. Relationship between Riparian/Buffer Zone Tree Diameter (V_{TDBH}) and functional capacity for headwater streams.

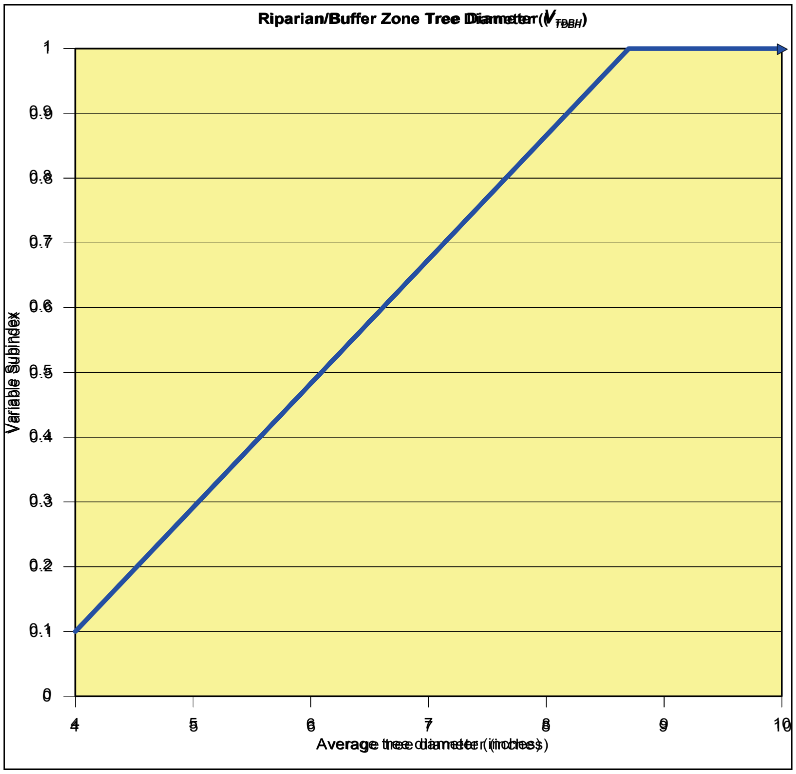
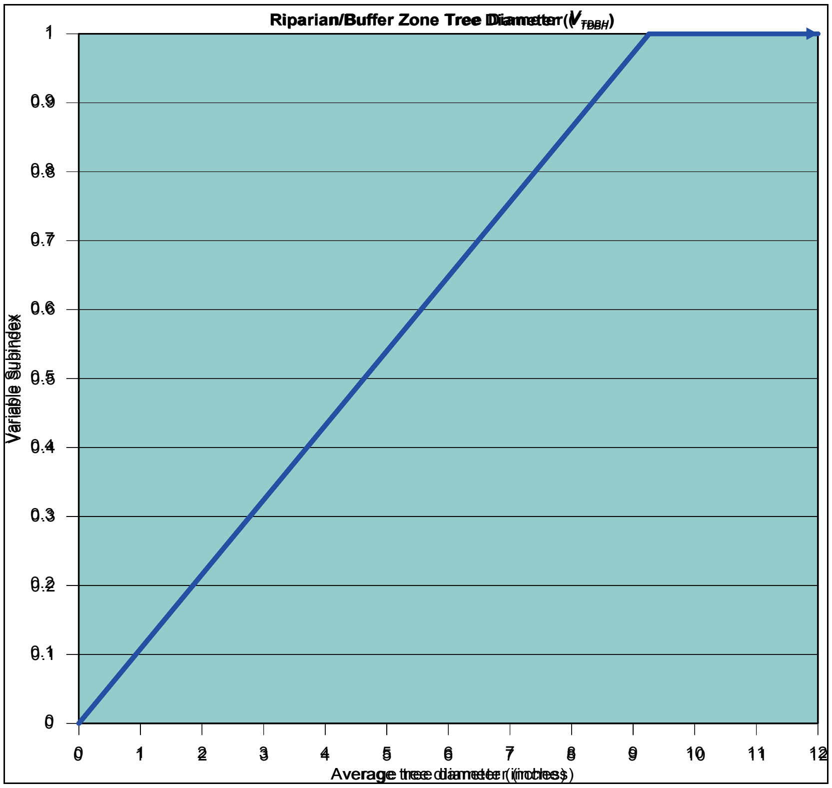


Figure 27. Relationship between Riparian/Buffer Zone Tree Diameter (V_{TDBH}) and functional capacity for perennial streams.



Riparian/Buffer Zone Tree Density (V_{TDEN})

Riparian/Buffer Zone Tree Density is only used for the perennial stream subclass. This variable is defined as the average number of trees ≥ 4 in (10 cm) diameter per acre. Tree density is measured within at least four 0.032-acre subplots within the riparian/buffer zone. V_{TDEN} applies to the Biogeochemistry function for perennial streams.

Tree density relates to successional status within the riparian/buffer zone and provides additional information compared to measuring tree diameter (Roy et al. 2005a). Areas recently subjected to disturbance or forest clearing exhibit low tree density values, whereas early- to mid-successional forests display high tree densities which later decrease as stem exclusion (i.e., natural thinning resulting from competition for light) occurs and forest succession continues (Oliver 1981). Measurements of tree diameter are particularly useful in situations where measuring percent canopy cover is inadequate, such as in artificially thinned parks and residential areas in which percent canopy cover values remain high despite selective tree removal.

Tree density values within the reference domain ranged from 0 to 366 trees per acre. At reference standard reaches, tree density values ranged from 135 to 262 trees per acre. SARs lacking trees (i.e., density equals 0) are assigned a subindex score of 0. A linear increase in subindex score is assigned for tree densities ranging from 0 to 135 (Figure 28). A linear decrease is applied as the number of trees per acre decreases above 262 to a subindex score of 0.5 at 366 trees per acre.

Riparian/Buffer Zone Snag Density (V_{SNAG})

Snags are defined herein as standing dead trees that are at least 4 in. (10 cm) in diameter and at least 36 in. (90 cm) in height (Figure 29). Riparian/Buffer Zone Snag Density is defined as the number of individual snags per 100 ft (30.5 m) of the SAR, including the stream channel and the adjacent riparian/buffer zone extending 25 ft (7.6 m) wide on either side of the channel. V_{SNAG} applies to the Habitat function for headwater streams.

Figure 28. Relationship between density of trees/acre (V_{TDEN}) and functional capacity for perennial streams.

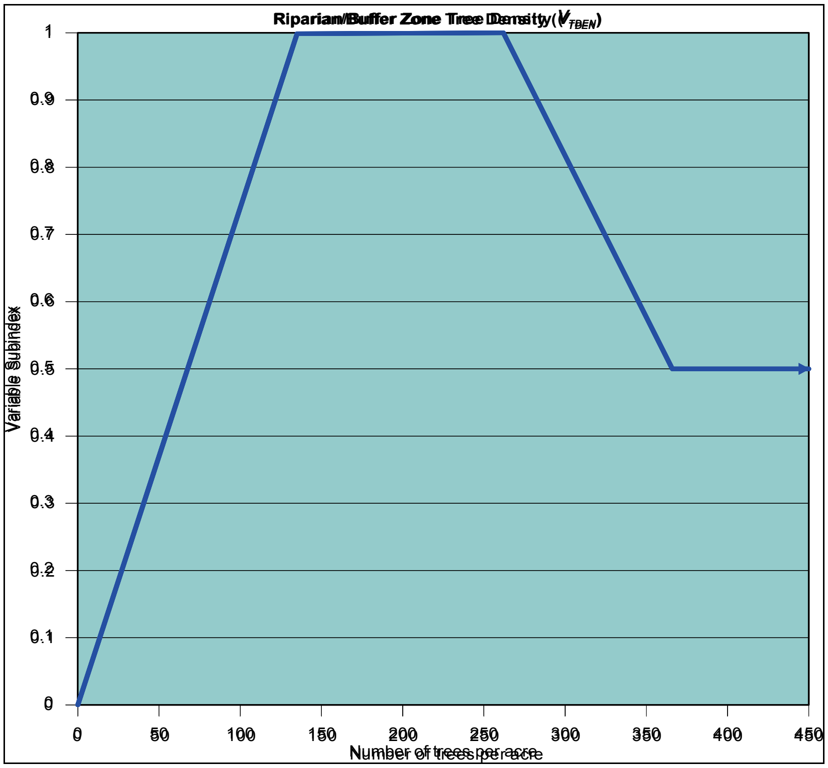
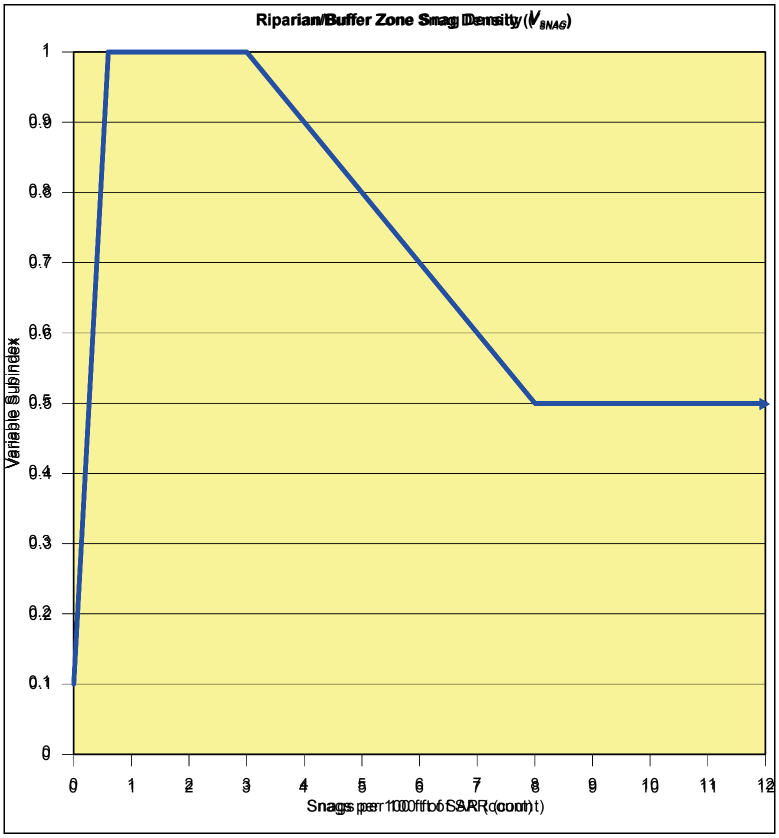


Figure 29. Lone snag within the riparian/buffer zone of a headwater stream.

Snags are found in forests throughout the region and provide important resources to terrestrial and aquatic ecosystems (McComb and Muller 1983; Franklin et al. 1987). Snags provide habitat for many wildlife species (McComb and Muller 1983), and they are an important source of nutrients and potential woody debris in riparian and stream ecosystems (Sharitz et al. 1992; Harmon et al. 1986). Snags influence channel and riparian morphology, surface runoff patterns, and decrease erosion (Franklin et al. 1987).

The number of snags within the reference domain ranged from 0.0 to 8.0 snags per 100 ft (30.5 m) of SAR length in the riparian/buffer zone. In reference standard reaches, the number of snags per 100 ft of SAR ranged between 0.6 and 3.0. SARs lacking snags within the riparian/buffer zone are assigned a subindex of 0.1. A linear increase and decrease in the subindex score is applied as snag count diverges from the reference standard range (Figure 30). Variable subindex scores increase from 0.1 at 0.0 snags per 100 ft of SAR to a subindex of 1.0 at 0.6 snags per 100 ft of SAR, and decrease to a subindex of 0.5, above 8.0 snags per 100 ft of SAR.

Figure 30. Relationship between Riparian/Buffer Zone Snag Density (V_{SNAG}) and functional capacity for headwater streams.



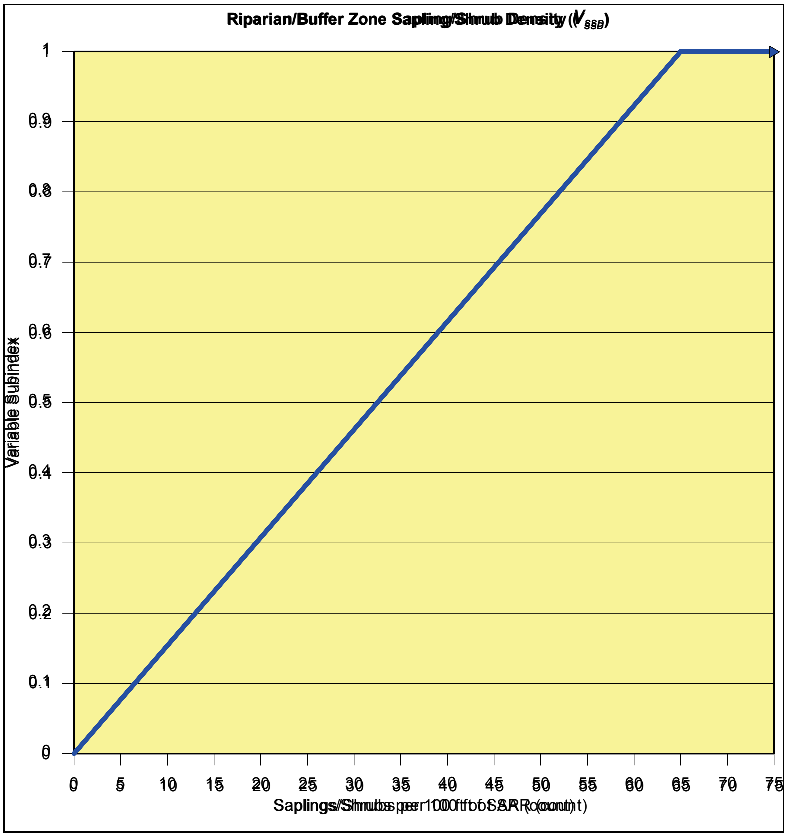
Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})

Riparian/Buffer Zone Sapling/Shrub Density is only used for the headwater stream subclass. This variable is defined as the density of woody stems greater than 36 in. (90 cm) in height and less than 4 in. (10 cm) DBH (e.g., shrubs, saplings, and understory trees). Riparian/Buffer Zone Sapling/Shrub Density is measured per 100 ft (30.5 m) of SAR in the riparian/buffer zone extending 25 ft (7.6 m) wide on either side of the channel. Shrubs contribute to the structure of the plant community, particularly if trees are absent. They take up nutrients, produce biomass, and provide cover and breeding sites for wildlife. Shrubs may dominate the community in headwater stream systems during early to mid-successional stages (Figure 31). V_{SSD} applies to the Biogeochemistry and Habitat functions, and it is only measured if Channel Canopy Cover is less than 20 percent.

Figure 31. Riparian/buffer zone dominated by saplings and shrubs.

Riparian/Buffer Zone Sapling/Shrub Density is not used to evaluate headwater streams that have a well-developed channel canopy. Instead, V_{SSD} is measured only in areas with less than 20 percent Channel Canopy Cover due to recent natural or anthropogenic disturbance. In this context, V_{SSD} reflects the amount of woody regeneration on the site that contributes immediately to carbon cycling, provides habitat for wildlife, and will eventually produce a mature forest canopy. Therefore, higher values of sapling/shrub cover are desirable in areas with poor Channel Canopy Cover as saplings and shrubs become a major component of Biogeochemistry and Habitat functions. Sapling/shrub density along reference standard reaches with less than 20 percent Channel Canopy Cover ranged from 10 to 674 stems per 100 ft. A subindex of 1.0 is assigned when sapling/shrub density is at least 65 stems per 100 ft of SAR (Figure 32).

Figure 32. Relationship between Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD}) and functional capacity for headwater streams.



This approach deviates from reference standard conditions because, as discussed above, reference standard reaches did not include areas with a poorly developed canopy. A cover of sapling and shrubs provides a decreased level of function from a forested community, but provides greater functionality than bare soil. Due to the form of the assessment equations, locations utilizing V_{SSD} in lieu of tree canopy cover cannot receive a functional capacity index of 1.0 (Figure 32).

Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH})

This variable is only used for the headwater stream subclass and is defined as a measure of the native tree species richness per 100 ft of SAR length within the channel and the riparian/buffer zone extending 25 ft (7.6 m) wide on either side of the stream channel. This variable reflects a modified approach based on concepts in Andreas and Lichvar (1995), Smith and Klimas (2002), and Rheinhardt et al. (2007). As Smith and Klimas (2002) recommended, plants occurring in the tallest stratum present were the focal point. In reference standard headwater streams, the tallest stratum is composed of native trees. In headwater stream systems that have undergone recent and severe natural or anthropogenic disturbance, exotic, invasive trees, saplings, and shrubs or herbaceous species may dominate the tallest stratum. The richness of the tallest layer is a good indicator of overall community composition and successional patterns (i.e., appropriate sapling/shrub composition indicates appropriate future canopy composition) (Rheinhardt et al. 2007). Reference standard reaches within the reference domain are relatively diverse with several tree species present. Note that the tree stratum includes all trees at least 4 in. (10 cm) DBH. V_{SRICH} applies only to the Habitat function for headwater streams.

Tree species are classified into two groups (Table 3). Group 1 consists of species that characterize relatively undisturbed headwater streams in the reference domain. Rheinhardt et al. (2007) identified several of the same species as dominant within the Piedmont region of the Ridge and Valley Physiographic Province. Any tree species occurring in more than three reference standard reaches was included in Group 1. Group 2 consists of non-native (exotic) species or native invasive species associated with degraded SARs. The list of exotic species in Group 2 is based on data from USDA (2009) plants database (http://plants.usda.gov/) and the West Virginia Division of Natural Resources (2003) list of invasive species (http://www.wvdnr.gov/wildlife/invasivewv.shtm). Photos of all species in Group 1 and tree species in Group 2 are provided in Appendix C.

Table 3. Species used to calculate V_{SRICH} in the riparian/buffer zone of headwater streams.

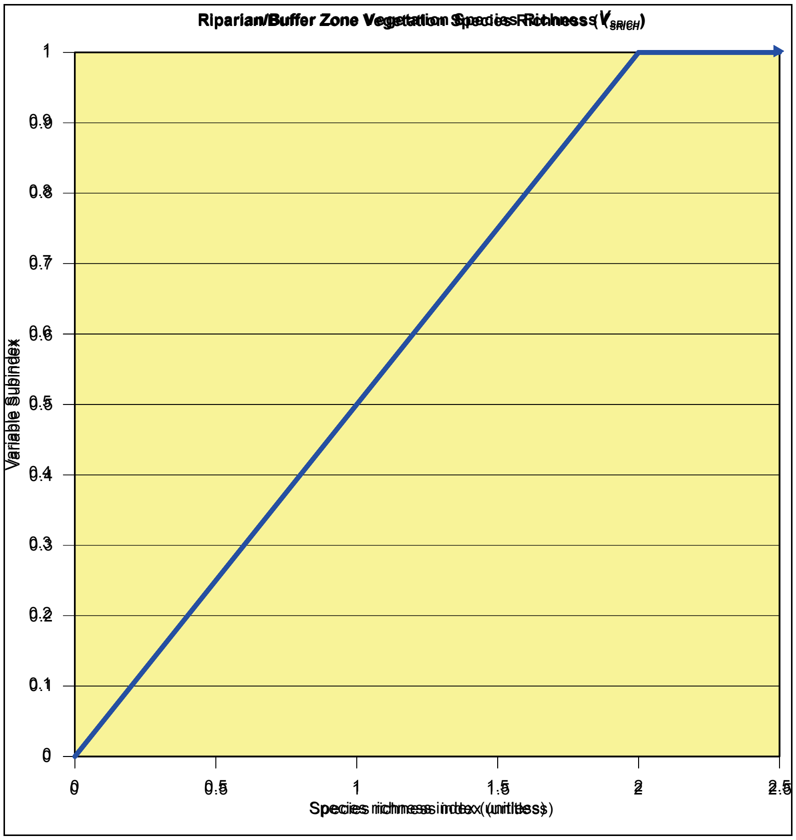
Scientific Name	Common Name	Scientific Name	Common Name
Group 1		Group 2	
Acer pensylvanicum	striped maple	*Ailanthus altissima*	tree of heaven
Acer rubrum	red maple	*Albizia julibrissin*	silktree
Acer saccharum	sugar maple	*Alliaria petiolata*	garlic mustard
Aesculus flava	yellow buckeye	*Alternanthera philoxeroides*	Alligator weed
Asimina triloba	pawpaw	*Aster tataricus*	tatarian aster
Betula alleghaniensis	yellow birch	*Cerastium fontanum*	common mouse-ear
Betula lenta	black birch	*Coronilla varia*	crown vetch
Carya cordiformis	bitternut hickory	*Elaeagnus umbellata*	autumn olive
Carya glabra	pignut hickory	*Lespedeza bicolor*	shrub lespedeza
Carya ovata	shagbark hickory	*Lespedeza cuneata*	sericea lespedeza
Carya tomentosa	mockernut hickory	*Ligustrum obtusifolium*	border privet
Cornus florida	flowering dogwood	*Ligustrum sinense*	Chinese privet
Fagus grandifolia	American beech	*Lonicera japonica*	Japanese honeysuckle
Fraxinus americana	white ash	*Lonicera tatarica*	Tatarian honeysuckle
Liriodendron tulipifera	tuliptree	*Lotus corniculatus*	bird's-foot trefoil
Magnolia acuminata	cucumber-tree	*Lythrum salicaria*	purple loosestrife
Magnolia tripetala	umbrella-tree	*Microstegium vimineum*	Nepalese browntop
Nyssa sylvatica	blackgum	*Paulownia tomentosa*	princesstree
Oxydendrum arboreum	sourwood	*Fallopia japonica*	Japanese knotweed
Pinus strobus	eastern white pine	*Pueraria montana*	kudzu
Prunus serotina	black cherry	*Rosa multiflora*	multiflora rose
Quercus alba	white oak	*Sorghum halepense*	Johnsongrass
Quercus coccinea	scarlet oak	*Verbena brasiliensis*	Brazilian vervain
Quercus imbricaria	shingle oak		
Quercus montana	chestnut oak		
Quercus rubra	northern red oak		
Quercus velutina	black oak		
Sassafras albidum	sassafras		
Tilia americana	American basswood		
Tsuga canadensis	eastern hemlock		
Ulmus americana	American elm		

The following equation is used to determine the value of the Riparian/Buffer Zone Species Richness Variable:

$$\text{Riparian/Buffer Zone Species Richness} = \left[\frac{(\text{Group 1 species} - \text{Group 2 species})}{\text{Total length of SAR (ft)}} \times 100\right] \times \left[1 - \left(\frac{0.1 \times \text{Group 2 species}}{\text{Total length of SAR (ft)}}\right)\right] \tag{3}$$

In reference standard headwater streams within the reference domain, vegetation composition included only species listed in Group 1, and the number of tree species observed was at least 2.1 per 100 ft (30.5 m) of SAR length (Figure 33). As Riparian/Buffer Zone Vegetation Species Richness deviates from reference standard conditions, functional capacity indices decline. The range in the number of species for all reference reaches was 0 to 7.4 per 100 ft.

Figure 33. Relationship between Riparian/Buffer Vegetation Species Richness (V_{SRICH}) and functional capacity for headwater streams.



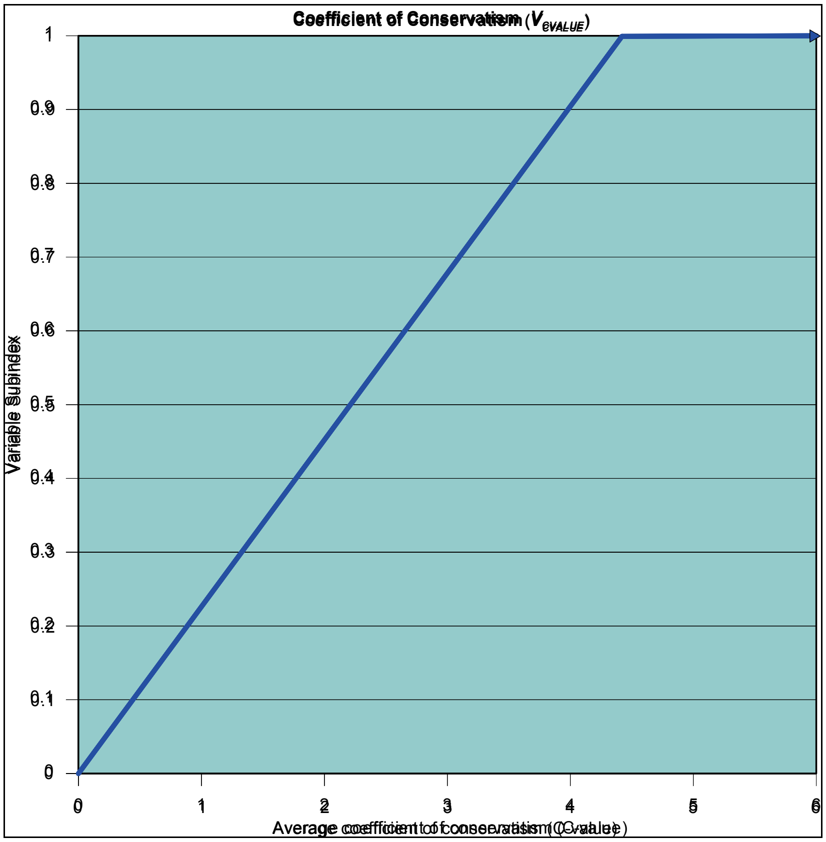
Coefficient of Conservatism (V_{CVALUE})

Coefficient of Conservatism is used for the perennial stream subclass, and it is defined as the average of published Coefficients of Conservatism (C-values) for trees, as well as non-native species of all vegetation strata within the series of 0.032-acre subplots described in Chapter 3. C-values are based on the tolerance to alteration and habitat degradation of each plant taxon, as well as its level of fidelity to a particular habitat type. Based on the West Virginia Natural Heritage Program (2012), C-Values are a ranking of 0 to 10. Species receiving a score of 10 have narrow habitat requirements and/or little tolerance to natural or anthropogenic disturbance. Habitat generalists and disturbance tolerant species are assigned lower scores, and non-native species are assigned scores of 0.0. V_{CVALUE} applies to the Habitat function for perennial streams. C-values for species commonly observed within the reference domain are provided in Table B1. Rentch and Anderson (2006) provide additional information on determining C-values.

Vegetation species composition integrates numerous aspects of ecosystem condition, including past as well as present anthropogenic and natural disturbances, hydrologic regime, patch size, habitat type, and seral stage. C-values have been shown to accurately distinguish between levels of alteration (Lopez and Fennessy 2002), and a negative relationship has been documented between average C-value and intensity of landscape development (Cohen et al. 2004). Vegetation species composition can also reflect biogeochemical processes, and research utilizing C-values has displayed correlations with soil chemistry features such as soil total organic carbon, phosphorus, and calcium (Bourdaghs et al. 2006).

Average C-values at streams within the reference domain ranged from 0 to 5.8. At reference standard sites, C-values ranged from 4.4 to 5.5. SARs with C-values of zero are assigned a subindex score of 0.0. A linear increase in subindex score is applied to C-values ranging from 0 to 4.4 (Figure 34).

Figure 34. Relationship between Coefficient of Conservatism scores (V_{CVALUE}) and functional capacity for perennial streams.



Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)

This variable is only used for the headwater stream subclass and consists of the average percent cover of detrital material on the soil surface within the riparian/buffer zone. Soil detritus is defined as the soil layer dominated by partially decomposed but still recognizable organic material, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground (Figure 35). Detritus includes materials less than 4 in. (10 cm) in diameter, less than 36 in. (90 cm) long, and includes fibric or hemic material (e.g., peat or mucky peat). Detritus is a direct indication of short-term (one or two years) accumulation of organic matter, primarily from vegetation within the riparian/buffer zone, and it is a source of food and cover for macroinvertebrates and salamanders. The presence or absence of detritus in the channel is not considered. $V_{DETRITUS}$ applies to the Biogeochemistry and Habitat functions for headwater streams.

Figure 35. Example of a headwater stream riparian/buffer zone in which estimated detritus cover was 100 percent.

Litter fall (e.g., leaves and twigs) is a primary source for organic materials in headwater streams (Wipfli et al. 2007). Leaf litter from the near-stream riparian/buffer zone has been shown to be the dominant source of streamwater dissolved organic carbon (Dalva and Moore 1991). Generation of dissolved organic carbon from leaf litter is a result of chemical leaching of soluble compounds, dissolved organic carbon released during microbial breakdown of the litter, and carbon released during invertebrate feeding on decaying leaf litter (Meyer and O'Hop 1983). All of these pathways are likely decreased when litter is absent from the stream system (Wallace et al. 1997).

Leaf litter and other organic detritus supply energy subsidies to the aquatic food web (Meyer et al. 1998; Vannote et al. 1980) and cover for macroinvertebrates and salamanders. It has been shown that when less leaf litter is present in the stream system, less dissolved organic carbon is produced from invertebrate feeding due to fewer leaf-shredding invertebrates (Wallace et al. 1997). Terrestrial invertebrates occur along riparian corridors, and they are associated with leaf litter and riparian soils (Allan et al. 2003). Commonly occurring terrestrial invertebrate groups include aphids, leafhoppers, beetles, caterpillars, sawflies, spiders, mites, springtails, small wasps, and flies, and all contribute substantially to the diets of consumers in streams (Hynes 1970; Hunt 1975; Mason and Macdonald 1982; Baxter et al. 2004, 2005).

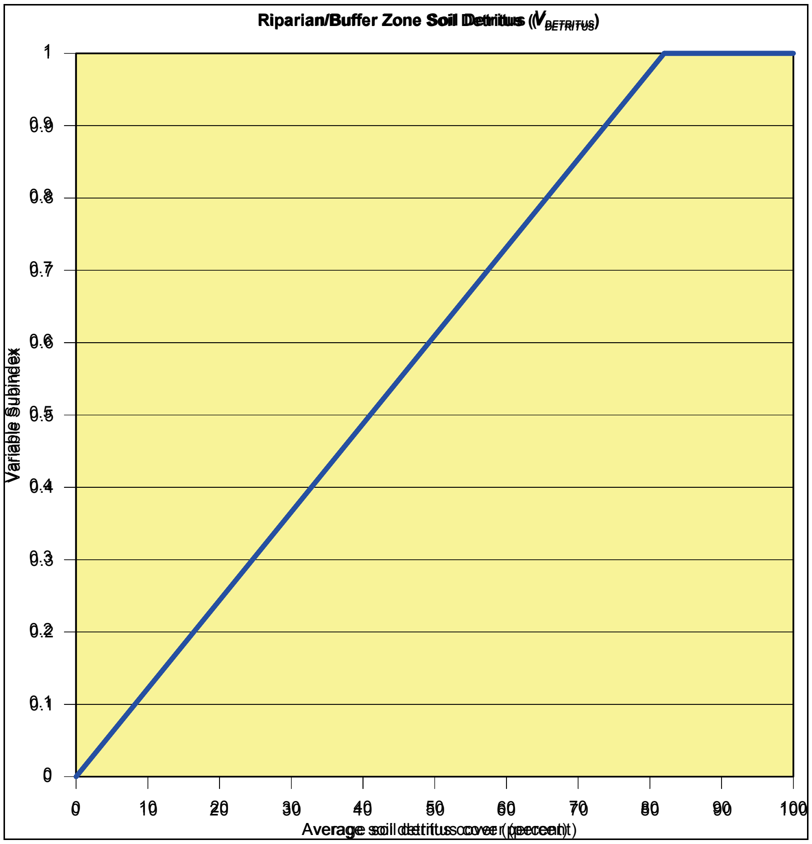
Detritus is important for salamander habitat because many salamanders are most active at night and hide under logs, leaves, bark, and other objects during the day (Jung et al. 2004). A barren stream bank will be devoid of Plethodontid salamanders regardless of other habitat characteristics. Because they are lungless, respiration in Plethodontids is primarily cutaneous, making them particularly prone to desiccation. There is no physiological control over water loss, and because smaller salamanders have more evaporative surface area in relation to body volume, they desiccate faster than larger salamanders (Spotila 1972). These salamanders are primarily limited to foraging when conditions are cool and wet, and at other times they seek refuge under objects such as leaves, bark, or woody debris (Knapp et al. 2003). With a decrease in leaf litter production and moisture and an increase in temperatures, soil invertebrate prey is reduced, and the biomass of salamanders decreases (Burke and Nol 1998).

The cover of Riparian/Buffer Zone Soil Detritus in headwater streams ranged from 0 to 100 percent. Based on data from reference standard reaches, a variable subindex of 1.0 is assigned when detrital cover is between 82 and 100 percent. SARs lacking detrital cover are assigned a subindex of 0.0. A linear increase in the subindex score assigned as detrital cover increases from 0 to 82 percent (Figure 36).

Riparian/Buffer Zone Herbaceous Cover (V_{HERB})

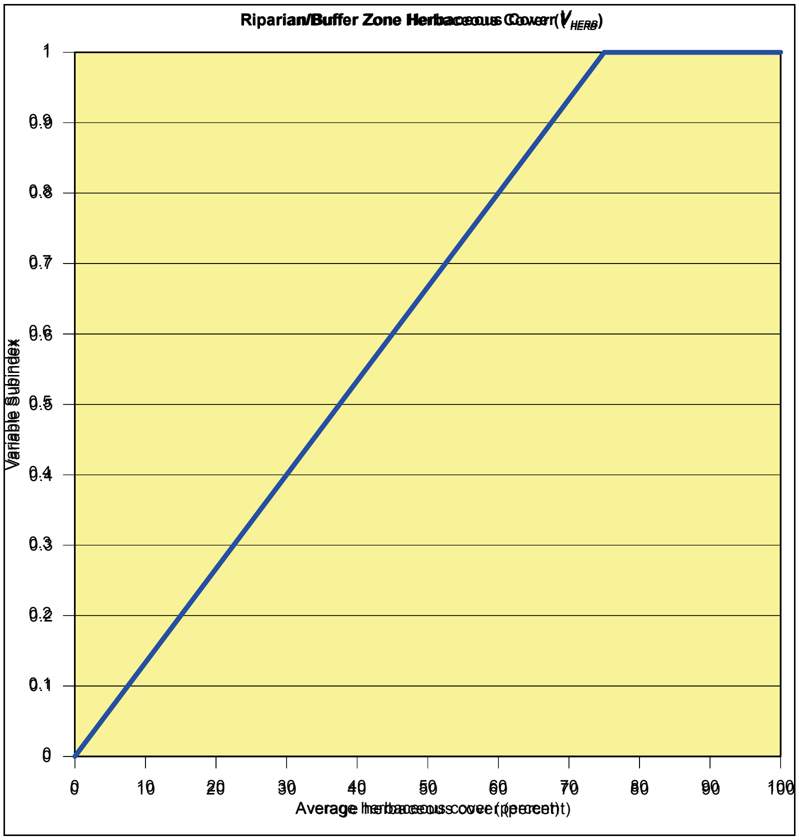
This variable is only used for the headwater stream subclass is defined as the average percent cover of herbaceous vegetation within the riparian/buffer zone. Herbaceous cover is defined as all herbaceous vegetation, regardless of height. Herbaceous cover does not include woody species defined as sapling/shrub. V_{HERB} applies to the Biogeochemistry and Habitat functions for headwater streams.

Figure 36. Relationship between Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$) and functional capacity for headwater streams.



V_{HERB} is not used to evaluate headwater stream systems that have a well-developed tree canopy. Instead, *V_{HERB}* is measured only in areas where Channel Canopy Cover is less than 20 percent. Even under these conditions, ground-layer vegetation contributes organic material to the carbon cycle, provides some cover for wildlife, reduces sediment to the stream channel, and helps produce conditions favorable to the regeneration of a woody midstory and canopy. Herbaceous vegetation cover on reference SARs with less than 20 percent Channel Canopy Cover ranged from 75 to 100 percent. A subindex of 1.0 is assigned when herbaceous cover is at least 75 percent. A linear decrease in subindex score is applied for less than 75 percent herbaceous cover to a subindex score of zero if no herbaceous cover is present (Figure 37). Assessment equations using *V_{HERB}* in lieu of tree canopy cover cannot result in a functional capacity index of 1.0.

Figure 37. Relationship between Riparian/Buffer Zone Herbaceous Cover (V_{HERB}) and functional capacity for headwater streams.



Watershed Land-use (V_{WLUSE})

This variable is only used for the headwater stream subclass and is defined as the surface runoff potential from the watershed outside the riparian/buffer zone into headwater streams. Variable scores are a weighted average of land use indices for land-use types based on percent land cover (Table 4). To calculate this variable subindex score, the percentage of the watershed in each of the land-use categories (i.e., forested, residential, industrial, etc.) must be calculated or estimated. This requires the use of internet resources, landscape images, and/or GIS, along with field reconnaissance and verification. V_{WLUSE} applies to the Hydrology, Biogeochemistry, and Habitat functions for headwater streams.

Table 4. Watershed Land-use.

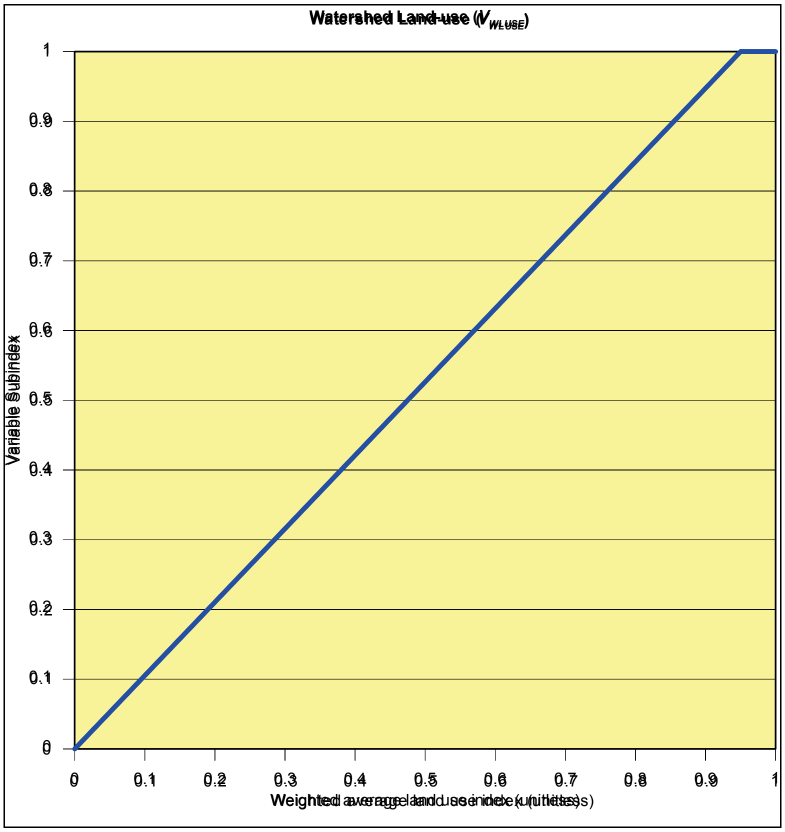
Land-use type	Land-use index
Forest and native range	1.0
Low density residential (≥1 acre lots)	0.3
Open space (pasture, lawns, parks, golf courses, cemeteries):	0.2
High density residential (<1 acre lots)	0.1
Impervious areas (parking lots, roofs, driveways, etc)	0
Gravel	0
Industrial, commercial and business	0
Newly graded areas (bare soil, no vegetation or pavement)	0

Landscape-based metrics of land-use and land cover affect runoff quantity and water quality within watersheds (Jones et al. 2001; Rheinhardt et al. 2009). Upland land-use conditions determine the structure and function of downstream environments (Bolstad et al. 2003). With increased disturbance and decreased infiltration capacity in the surrounding watershed, more surface water enters downstream waters than under reference conditions (Simmons et al. 2008; Townsend et al. 2009; DeFries and Eshleman 2004). Increased runoff promotes sediment and nutrient loading, and impacts water quality during base and peak flow events (Poor and McDonnell 2007; Herlihy et al. 1998; Bolstad and Swank 1997).

Reference standard watersheds had high percentages of land with forest and native range coverage. Reference standard reaches contained a maximum of six percent impervious surfaces as roads and gravel areas, and no industrial, agricultural, or residential areas. Although land clearing for agricultural, pastureland, limited road building, and forestry activities affected some reference standard reaches, soil conditions remained stable and displayed limited erosion.

Other sites within the reference domain contained additional land-uses, including large areas of grass cover, industrial coverage, agricultural land-uses, roads and gravel pads, and residential coverage, resulting in decreased subindex scores. Weighted average Watershed Land-use indices between 0.95 and 1.0 receive a subindex score of 1.0, and subindex scores decline linearly to zero as the weighted average Watershed Land-use index drops from 0.95 to 0.0 (Figure 38).

Figure 38. Relationship between Watershed Land-use (V_{WLUSE}) and functional capacity for headwater streams.



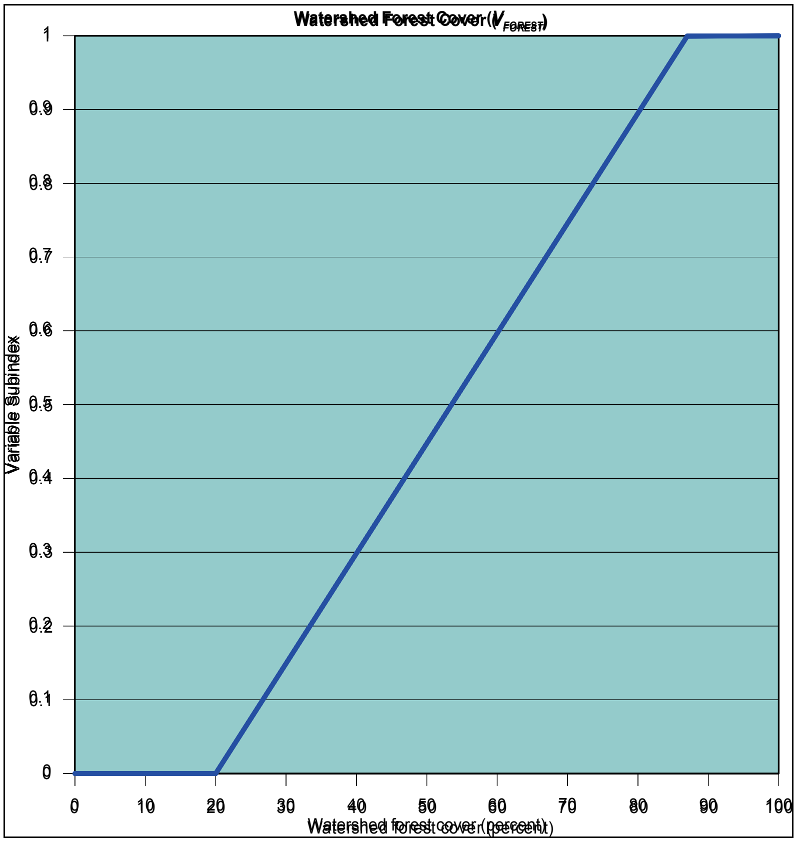
Watershed Forest Cover (V_{FOREST})

This variable is only used for the perennial stream subclass and is defined as the percentage of forested land cover in the entire stream watershed outside of the riparian buffer zone. Calculation of Watershed Forest Cover requires the use of internet resources, landscape images, and/or GIS, along with field reconnaissance and verification. V_{FOREST} applies to the Hydrology, Biogeochemistry, and Habitat functions for perennial streams.

The amount of forested habitat available at a watershed level influences biotic stream communities by affecting in-stream conditions as well as habitat availability for dispersal. Mountaintop mining, currently the most common reason for conversion from forested watersheds to other land uses in Appalachia (Bernhardt and Palmer 2011), has been linked to shifts in fish species composition as well as decreases in fish species richness, abundance, and biomass (Stauffer and Ferreri 2002, Hitt and Chambers 2014). Removal of forest cover increases sedimentation in stream channels, and the relative abundance of fish which spawn in gravel and crevices has been shown to decrease as non-forested land cover increases (Sutherland et al. 2002). The relative abundance of stream salamanders has shown an inverse relationship with the percentage of disturbed habitat within stream watersheds (Willson and Dorcas 2003). Decreased forest coverage in watersheds relates to stream characteristics including substrate type and algal abundance, which are habitat features that influence benthic macroinvertebrate community composition (Richards and Host 1994).

Watershed Forest Cover of stream watersheds within the reference domain ranged from 53 to 100 percent. All reference standard reaches were located in watersheds composed of 87 to 99 percent forest cover and receive a subindex score of 1.0. Streams within watersheds containing no greater than 20 percent forest cover are assigned a subindex of zero. A linear increase in subindex is applied for Watershed Forest Cover values ranging from 20 to 87 percent (Figure 39).

Figure 39. Relationship between Watershed Forest Cover within the watershed (*V_{FOREST}*) and functional capacity for perennial streams.



Functions

This guidebook addresses three functions: (1) Hydrology, (2) Biogeochemistry, and (3) Habitat. For each function, the assessment equation is presented for headwater streams, followed by the assessment equation for perennial streams.

The following sequence is used to present and discuss each function:

- *Definition:* Defines the function.
- *Rationale for selecting the function*: Provides valid reasoning for the selection of a function and discusses onsite and offsite effects that may occur as a result of lost functional capacity.
- *Characteristics and processes that influence the function*: Describes the characteristics and processes of the stream and the surrounding landscape that influence the function and lay the groundwork for the description of assessment variables.
- *Functional capacity index*: Describes the assessment equation from which the functional capacity index is derived and discusses how assessment variables interact to influence functional capacity.

Hydrology

Definition

The Hydrology function comprises a suite of hydrologic functions, including the ability of a stream to dissipate energy associated with flow velocity and to transport water downstream and maintenance of a characteristic hydrograph. Potential independent, quantitative measures that may be used in validating the functional index include direct measures of water flow in the channel over time (ft/sec), measurements of stream channel roughness, and studies examining flow dynamics, connectivity, and retention times.

Rationale for selecting the function

Water transport and energy dissipation are fundamental physical functions performed by all stream systems. The energy produced by flowing water of streams affects the amount of sediment, organic matter, and nutrients that are transported downstream (Chang 2006; Gordon et al. 2006; Leopold et al. 1992; Leopold 1994). Hydrologic alterations often increase runoff and bank erosion, resulting in more fine sediment entering the stream channel

(Allan et al. 1997; Paul and Meyer 2001). Excess sediment can reduce habitat for macroinvertebrates, amphibians, and fish if stream energy is insufficient to remove it from the stream (Allan 2004; Burkhead and Jelks 2001; Henley et al. 2000; Merritt et al. 2008; Sutherland et al. 2002; Wood and Armitage 1997). Organic matter and nutrients traveling from upstream are a source of food for macroinvertebrates and vertebrates that live in downstream reaches (Jung et al. 2004).

Characteristics and processes that influence the function

The characteristics and processes that influence the capacity of a stream to dissipate energy and convey water have both natural and anthropogenic origins. Climate, landscape-scale geomorphic characteristics, and characteristics of the soil within the watershed are factors largely established by natural processes. However, even landscape-scale geomorphic characteristics and soils can be altered by anthropogenic alterations.

Human activities may have a profound effect on the amount of water entering the stream and the dissipation of stream energy. Modifications to the watershed surrounding the channel may alter the amount and timing of water and sediment delivery to the channel through overland flow. Land-use changes such as logging, urban development, agriculture, grazing, or filling are modifications that directly affect this function (Allan et al. 1997; Allan 2004; Gordon et al. 2006; Leopold and O'Brien 1968; Paul and Meyer 2001).

Removing LWD, reducing the median size of the channel substrate, or increasing the degree of embeddedness through increased sediment deposition in the channel, result in a reduction of energy dissipation in the channel. Conversely, if the amount of water to the channel is increased, then LWD and fine particles from the channel can be flushed from the channel. Unaltered stream flow velocities recruit LWD into the ecosystem, flush excess fine particles downstream, and sustain low levels of embeddedness, thereby, maintaining energy dissipation at a level consistent with reference standard conditions.

Functional capacity index – headwater streams

The following variables are used in the assessment equation for the Hydrology function for the headwater stream subclass:

- Channel Substrate Embeddedness (V_{EMBED})

- Channel Substrate Size ($V_{SUBSTRATE}$)
- Channel Bank Erosion (V_{BERO})
- Large Woody Debris (V_{LWD})
- Watershed Land-use (V_{WLUSE})

The assessment equation for calculating the FCI for the Hydrology function in headwater streams is given below (Equation 4). This equation is only appropriate for headwater streams and should not be applied to channels with less than four percent slope.

$$FCI = \left\{ \frac{V_{WLUSE} + \left[\frac{V_{LWD} + \min\left(V_{SUBSTRATE}, V_{EMBED}, V_{BERO}\right)}{2} \right]}{2} \right\} \tag{4}$$

In this equation, changes in hydrology, including water flow and dissipation of stream energy in headwater streams relative to reference standard conditions, depend on the roughness of the channel, materials in the channel and riparian/buffer zone that will slow the flow of water, and the amount of water that is delivered to the channel through overland flow. The assessment equation indicates that if LWD and the appropriate channel substrate are in place, the channel does not have an excessive amount of sediment, the channel banks are not excessively eroded, and the surrounding watershed has not been excessively altered by anthropogenic disturbances, then channel flow, sediment transport, and stream energy are appropriate for the channel. In the first part of the equation, V_{WLUSE} represents water inputs from the surrounding watershed. If the amount of forest cover in the watershed decreases, then the amount of water and timing of water delivery through overland flow to the stream channel will increase in relation to reference standard conditions. In the second part of the equation, the lowest value from $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO} is used to represent the effects of channel degradation from reference standard conditions. The lowest score from $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO} is averaged with V_{LWD} reflecting that LWD is independent, but equally important in its effect on hydrologic flow and dissipation of stream energy. V_{WLUSE} is combined with the result of the second part of the equation using an arithmetic mean. As a result, input from the surrounding watershed is of equal importance in the function of channel hydrology and the dissipation of stream energy as the average of V_{LWD} and the minimum score of $V_{SUBSTRATE}$, V_{EMBED}, or V_{BERO}.

Functional capacity index – perennial streams

The following variables are used in the Hydrology functional assessment equation for the perennial stream subclass:

- Streambank Stability ($V_{BANKSTAB}$)
- Channel Substrate Size ($V_{SUBSTRATE}$)
- Channel Substrate Embeddedness (V_{EMBED})

The assessment equation for calculating the FCI for the Hydrology function in perennial streams is given below.

$$FCI = \left\{ \frac{V_{BANKSTAB} + \min \left(V_{EMBED}, V_{SUBSTRATE}\right)}{2} \right\} \tag{5}$$

In this equation, the condition of the stream channel and the roughness of the channel substrate represent changes in hydrology, including water flow and dissipation of stream energy in perennial streams relative to reference standard conditions. If appropriate channel substrate is in place, then the channel does not have an excessive amount of sediment. Also, if the channel banks are not excessively eroded, then channel flow, sediment transport, and stream energy are likely appropriate for the channel. The lowest value of either $V_{SUBSTRATE}$ or V_{EMBED} represents hydrologic impacts to the channel substrate. $V_{BANKSTAB}$ is given equal weighting to the channel substrate variables, $V_{SUBSTRATE}$ or V_{EMBED}, since the amount of stream bank degradation and channel substrate quality are equally important indicators of hydrologic conditions.

Biogeochemistry

Definition

The Biogeochemistry function comprises a suite of biogeochemical processes including the ability of the stream ecosystem to retain and transform inorganic materials needed for biological processes into organic forms and to oxidize those organic molecules back into elemental forms through respiration and decomposition. Thus, biogeochemical cycling includes the activities of producers, consumers, and decomposers. Potential independent, quantitative measures that may be used in validating the functional index include direct measurements of net annual productivity (g/m^2), annual accumulation of organic matter (g/m^2), and nutrient transport to downstream environments.

Rationale for selecting the function

Biogeochemical cycling is a fundamental function performed by all ecosystems (Mitsch and Gosselink 2000). A sustained supply of organic carbon provides for maintenance of the characteristic plant community including riparian primary productivity, composition, and diversity (Bormann and Likens 1970; Whittaker 1975; Perry 1994). The riparian plant community (producers) provides the food and habitat structure (energy and materials) needed to maintain the characteristic animal community (consumers) (Fredrickson 1978). In time, the plant and animal communities serve as a source of detritus, providing energy and materials to maintain the characteristic community of decomposers. The decomposers break down organic materials into simpler elements and compounds that can reenter the nutrient cycle (Reiners 1972; Dickinson and Pugh 1974; Pugh and Dickinson 1974; Schlesinger 1977; Singh and Gupta 1977; Hayes 1979; Harmon et al. 1986; Vogt et al. 1986). Watershed and stream alterations that lead to an increase in nutrient inputs to stream channels beyond the ability of stream organisms to process can result in ecological consequences downstream (Covich et al. 1999; Newbold et al. 2011; Peterson et al. 2001).

Characteristics and processes that influence the function

Biogeochemical cycling is a function of biotic and abiotic processes that result from conditions within and around the stream. In stream ecosystems, nutrients and other compounds are stored within, and cycled among, four major compartments: (a) soils and sediments, (b) primary producers such as vascular and nonvascular plants, (c) consumers such as animals, fungi, and bacteria, and (d) dead organic matter, such as leaf litter and woody debris, collectively referred to as detritus. Maintenance of characteristic primary productivity of the plant community sets the stage for all subsequent transformations of energy and materials at each trophic level within the ecosystem. Alterations to hydrologic inputs, outputs, or storage and/or changes to the characteristic plant community will directly affect the way in which the ecosystem can perform this function.

The ability of a stream ecosystem to perform this function depends upon the transfer of nutrients and other compounds between trophic levels, the rate of decomposition, and the flux of materials in and out of the ecosystem. A change in the ability of one trophic level to process carbon will result in changes in the processing of nutrients and other compounds in other trophic levels (Carpenter 1988).

The ideal approach for assessing biogeochemical cycling would be to measure the rate at which nutrients and other compounds are transferred and transformed between and within trophic levels over several years. However, the time and effort required to make these measurements are well beyond a rapid assessment procedure, so stream characteristics, plant community structure, and other factors are used as functional indicators. Changes in vegetative cover directly affect the amount of nutrients and other compounds present in the stream channel (Gregory et al. 1991, Osborne and Kovacic 1993). Canopy removal directly affects the amount and type of detritus present in the stream system and increases primary production within the stream by allowing more solar radiation to reach the stream channel (Minshall 1978, Osborne and Kovacic 1993). Changes in hydrology or vegetation, deposition of fill material, excavation, or recent fire can alter the amount of nutrients and other compounds in the soil. Changes to the hydrology of stream ecosystems, primarily through increased surface water flow or ponding, affects biogeochemical cycling (Allan et al. 1997, Paul and Meyer 2001). Increased surface water flow can sweep nutrients and other compounds from the stream channel and disrupt the biogeochemical cycle. Ponding reduces the rate of decomposition, increases the accumulation of nutrients and other compounds, and changes the vegetative community. Measurements of these watershed, stream, and vegetative characteristics reflect the level of biogeochemical cycling taking place within an ecosystem.

Functional capacity index – headwater streams

The following variables are used in the assessment equation for the Biogeochemistry function for the headwater stream subclass:

- Channel Substrate Embeddedness (V_{EMBED})
- Large Woody Debris (V_{LWD})
- Riparian/Buffer Zone Tree Diameter (V_{TDBH})
- Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})
- Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)

- Riparian/Buffer Zone Herbaceous Cover (V_{HERB})
- Watershed Land-use (V_{WLUSE})

Assessment equations for calculating the FCI of the Biogeochemistry function in headwater streams are given below. The equations depend, in part, on the vegetative cover over the stream channel. If the stream channel contains an average Channel Canopy Cover of at least 20 percent, then Equation 6 is used. If the stream channel's average Channel Canopy Cover is less than 20 percent, then Equation 7 is used.

$$FCI = \left\{ V_{EMBED} \times \left[\frac{\left(\frac{V_{LWD} + V_{DETRITUS} + V_{TDBH}}{3} \right) + V_{WLUSE}}{2} \right] \right\}^{1/2} \qquad (6)$$

$$FCI = \left\{ V_{EMBED} \times \left[\frac{\left(\frac{V_{LWD} + V_{DETRITUS} + V_{SSD} + V_{HERB}}{4} \right) + V_{WLUSE}}{4} \right] \right\}^{1/2} \qquad (7)$$

In these equations, changes in the biogeochemical cycling capacity of headwater stream ecosystems relative to reference standard conditions depend on the relative roughness of the channel and the potential to supply, sequester, and transform nutrients and other compounds. The equations reflect the concept that if nutrients and other compounds and vegetation are in place and anthropogenic hydrologic disturbance is not present in the stream channel or the surrounding watershed, then biogeochemical cycling will occur at an appropriate rate. In the first part of each equation, V_{EMBED} represents the retention of nutrients and other compounds in the channel. In the second part, V_{LWD} is used as an indicator of long-term accumulation of nutrients and other compounds within the channel and immediately adjacent to the channel, while $V_{DETRITUS}$ is used as an indicator of recent input and accumulation of nutrients and other compounds. For example, if vegetation has been removed from the riparian/buffer zone during the previous year or two, then the amount of detritus will likely be reduced or absent. Also, if the hydrology of the surrounding watershed has been altered to the point that detritus is being flushed from the headwater ecosystem, then this alteration should be reflected in the amount of detrital cover and LWD in the stream system.

The variables V_{LWD}, $V_{DETRITUS}$, and V_{TDBH}, or V_{SSD} and V_{HERB} are combined using an arithmetic mean based on the presence or absence of adequate canopy cover. LWD, detritus, and vegetation are considered to be of equal importance in biogeochemical cycling. If the amount of vegetation, represented by percent cover, is reduced, then biogeochemical cycling will be reduced. In Equation 7, the two parts are divided by a factor of four to reflect the concept that SARs dominated by saplings/shrubs or herbaceous vegetation do not exhibit biogeochemical cycles at the same rate as a mature forest. For sapling/shrub-dominated areas, the maximum FCI is 0.7, however assessment variables are unlikely to exhibit the high subindex values necessary to achieve the maximum score in SARs with deforested riparian/buffer zones.

Functional capacity index – perennial streams

The following variables are used in the assessment equation for the Biogeochemistry function for the perennial stream subclass:

- Channel Substrate Embeddedness (V_{EMBED})
- Channel Substrate Size ($V_{SUBSTRATE}$)
- Channel Canopy Cover ($V_{CCANOPY}$)
- Riparian/Buffer Zone Tree Density (V_{TDEN})

The assessment equation for calculating the FCI for the Biogeochemistry function in perennial streams is given below. This equation is only appropriate for perennial streams and should not be applied to channels with greater than four percent slope.

$$FCI = \left\{ \frac{\min\left(V_{EMBED}, V_{SUBSTRATE}\right) + \min\left(V_{CCANOPY}, V_{TDEN}\right)}{2} \right\} \qquad (8)$$

In this equation, changes in the biogeochemical cycling capacity of perennial stream ecosystems relative to reference standard conditions depend on the relative roughness of the channel and the potential to supply, sequester, and transform nutrients and other compounds. The equation reflects the concept that if the stream channel and riparian areas remain intact, biogeochemical cycling will occur at a rate characteristic of reference standard conditions. In the first part of each equation, the lowest value of either V_{EMBED} or $V_{SUBSTRATE}$ represents the retention of nutrients and other compounds in the channel. If substrate size and embeddedness is at reference standard condition, then organic matter will be trapped in the stream channel where it can be broken down by benthic organisms. The second part of the equation uses the lowest score for $V_{CCANOPY}$ and V_{TDEN} to represent vegetation contributions to biogeochemical cycling. Compared to reference standard reaches, streams with either reduced canopy cover over the stream or lower tree density in the riparian/buffer zone contribute fewer nutrients and other compounds to the stream channel (Noble et al. 2014).

Habitat

Definition

The Habitat function reflects the capacity of a stream ecosystem to provide critical life requisites for selected components of the vertebrate and invertebrate wildlife communities. Stream ecosystems provide habitat for numerous species of macroinvertebrates, amphibians, fish, reptiles, birds, and mammals. Amphibians, macroinvertebrates, and in the case of perennial streams, fish, were selected as the focus of this function. Amphibians were chosen because of the importance of streams as breeding habitat. Various species of salamanders and frogs breed in shallow streams, temporary ponds, and moist leaf litter within riparian/buffer zones. In the adult stages, they often disperse into suitable habitat in the adjacent landscape.

A potential independent, quantitative measure of this function, which could be used to validate the assessment equation (Wakeley and Smith 2001), is the combined species richness of macroinvertebrates and amphibians that use stream ecosystems in the reference domain. Data requirements for assessment validation include direct monitoring of animal communities using appropriate techniques for each taxon. Gibbons and Semlitsch (1981) described procedures for sampling small-animal populations, including reptiles and amphibians. Heyer et al. (1994) and Dodd (2003) described monitoring procedures for amphibians.

Rationale for selecting the function

Streams and their surrounding landscapes are recognized as valuable habitats for a diversity of animal species including both vertebrates and invertebrates. Many animal species associated with streams have experienced serious population declines, particularly amphibians, macroinvertebrates, and fish (Stuart et al. 2004; Warren et al. 1997). Burton and Likens (1975) reported that amphibians constitute the single largest source of vertebrate biomass in some ecosystems. Because many amphibians require both aquatic and adjacent terrestrial habitats, they serve as a conduit for energy exchange between the two systems (Mitchell et al. 2004). Fish replace amphibians as the dominant predators in perennial streams. Some fish species are sensitive to changes in channel morphology and water quality, causing fish species composition to change as a result of stream alterations (Karr 1981). Similarly, macroinvertebrate community assemblages exhibit a shift towards dominance by disturbance-tolerant taxa when stream alterations occur (Hodkinson and Jackson 2005; Pond et al. 2014). Bailey et al. (2006), Carlander (1997), Etnier and Starnes (1993), Petranka (2010), and Merritt et al. (2008) provide additional information regarding characteristic habitat assemblages in perennial and headwater stream communities.

Characteristics and processes that influence the function

For the purpose of this guidebook, assessments focus on impacts to invertebrates, fish, and amphibians. Balanced in-stream communities, characteristic of unaltered streams are associated with physical characteristics such as low embeddedness (Lenat et al. 1981), varying substrate sizes (Sutherland et al. 2002), availability of woody debris (Angermeier and Karr 1984), and the absence of temperature extremes (Lessard and Hayes 2003). The presence of diverse substrate is particularly important for fish, which can be divided into "spawning guilds" depending on reproductive strategy (Sutherland et al. 2002). For example, benthic nest-builders use gravel to build nesting mounds, benthic crevice spawners use existing crevices among gravel and cobble in riffles, and gravel spawners spawn directly in gravel substrata. Benthic macroinvertebrates use interstitial spaces between bed particles for cover and tend to be found most densely in riffle habitats (Brown and Brussock 1991). The availability of pools is important for fish, which have shown a positive relationship between pool depth and survival (Harvey and Stuart 1991).

Many of the habitat requirements for stream biota are impacted by hydrology. Hydrologic changes associated with watershed alterations change flow conditions, which can impact fish by washing away eggs, larvae, and juveniles (Power et al. 1996; Freeman et al. 2001). Hydrologic alterations often increase erosion and fine sediment loading, processes associated with simplification of community structure in fish and macroinvertebrates (Berkman and Rabeni 1997; Roy et al 2005b; Wood and Armitage 1997). Fine sediment coats fish and macroinvertebrate gills, inhibiting respiration and causing physiological stress (Sutherland et al. 2002; Wood and Armitage 1997). Sedimentation increases turbidity and slows primary production, which can have cascading effects through the aquatic food web (Henley et al. 2000). Scouring and sedimentation also decrease channel structural variability and eliminate important bedform features used by macroinvertebrate and fish for breeding, foraging, and refuge (Beschta and Platts 1986; Frissell et al. 1986). Salamanders that use streams for reproduction are also vulnerable to hydrologic alteration, which can impact breeding activity because of the length of time needed for egg development and maturation of young. In headwater streams, artificially increasing the amount of time that surface water is present in the ecosystem, by altering channel runoff, can potentially reduce the suitability for amphibians by allowing predatory fish populations to become established (Bailey et al. 2006).

Besides the effects of hydrologic alterations on animals, indirect effects can occur through changes in the riparian plant community. It is assumed that forested streams with unaltered hydrology that have not been subjected to significant disturbances for long periods support a characteristic, riparian vegetation composition and structure (e.g., tree size, density, stratification, etc.). Animal species have evolved with and adapted to these conditions. Thus, alterations to land use or hydrology have the potential to change the composition and structure of the animal community. Other factors can also affect plant and animal communities, including droughts and catastrophic storms, competition, disease, browsing pressure, shade tolerance, community succession, and natural and anthropogenic disturbances. Below is an overview of the relationships between specific characteristics of the plant community and animal utilization of forested ecosystems, including streams. Hunter (1990) and Morrison et al. (1992) provide additional information on this subject.

Riparian habitat structure is an important determinant of wildlife species composition and diversity (Meyer et al. 2007). Undisturbed riparian stream ecosystems within the reference domain support multiple vegetative strata. This structural complexity provides a myriad of habitat conditions for animals and allows numerous species to coexist in the same area (Schoener 1986).

Terrestrial areas immediately adjacent to streams are also important to the integrity of the stream ecosystem itself. Such areas reduce the amounts of silt, contaminants, nutrients, and pathogens that enter the stream, and moderate physical parameters of the stream such as temperature (Rohde et al. 1980; Young et al. 1980; Hupp et al. 1993; Snyder et al. 1995; Daniels and Gilliam 1996; Semlitsch and Jensen 2001; Semlitsch and Bodie 2003). The buffering capability of the riparian/buffer zone improves water quality for fish, macroinvertebrates, and amphibians and provides benefits to the entire wildlife community.

While the structure of the riparian forest in the immediate vicinity of a stream is an important determinant of the availability and quality of the aquatic habitat, the characteristics of adjacent terrestrial habitat within the watershed of a stream are equally critical to many species. Semlitsch and Jensen (2001) suggested that terrestrial habitat be referred to as part of the "core habitat" used by amphibians, because it is as essential as the breeding site itself. This is different from the traditional concept of the "buffer zone" commonly recommended to protect various functions (Boyd 2001). In their review of the literature on amphibian terrestrial habitats, Semlitsch and Bodie (2003) found that habitat features such as leaf litter, coarse woody debris (i.e., logs), boulders, small mammal burrows, cracks in rocks, spring seeps, and rocky pools were important for foraging, refuge, or over-wintering. A well-developed canopy (for shade), coarse woody debris, and litter (for refuge and food) were considered essential habitat features. The abundance of litter is related to the age of forest stands. The litter layer in an older forest usually remains thicker than in a younger forest due to the differential amount of foliage produced. Young stands do not begin to contain significant amounts of litter and coarse woody debris until natural thinning begins. Shade, which is critical to some amphibian species in slowing or preventing dehydration (Spight 1968; Rothermel and Semlitsch 2002), is provided to some extent in all forest stands. However, shade is not likely to be effective until tree canopies begin to close (Rothermel and Semlitsch 2002). Thus total canopy cover is an important consideration in evaluating amphibian habitat in forest ecosystems.

Functional capacity index – headwater streams

The following variables are used in the assessment equation for the Habitat function for the headwater stream subclass:

- Channel Canopy Cover ($V_{CCANOPY}$)
- Channel Substrate Embeddedness (V_{EMBED})
- Channel Substrate Size ($V_{SUBSTRATE}$)

- Channel Bank Erosion (V_{BERO})
- Large Woody Debris (V_{LWD})
- Riparian/Buffer Zone Tree Diameter (V_{TDBH})
- Riparian/Buffer Zone Snag Density (V_{SNAG})
- Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})
- Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH})
- Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)
- Riparian/Buffer Zone Herbaceous Cover (V_{HERB})
- Watershed Land-use (V_{WLUSE})

The equation used for deriving the functional capacity index for the Habitat function in headwater stream ecosystems depends, in part, on the canopy cover over the stream channel. If the SAR supports an average Channel Canopy Cover of at least 20 percent, then Equation 9 is used. If the SAR average Channel Canopy Cover is less than 20 percent, then Equation 10 is used.

$$FCI = \left\langle \left[\frac{V_{CCANOPY} + \min\left(V_{EMBED}, V_{SUBSTRATE}\right)}{2}\right] \times \left\{ \frac{\left(\frac{V_{LWD} + V_{DETRITUS}}{2}\right) + \left[\frac{\left(\frac{V_{SNAG} + V_{TDBH} + V_{SRICH}}{3}\right) + V_{WLUSE}}{2}\right]}{2} \right\} \right\rangle^{1/2} \tag{9}$$

$$FCI = \left\langle \min\left(V_{EMBED}, V_{SUBSTRATE}\right) \times \left\{ \frac{\left(\frac{V_{LWD} + V_{DETRITUS}}{2}\right) + \left[\frac{\left(\frac{V_{SNAG} + V_{SSD} + V_{HERB} + V_{SRICH}}{6}\right) + V_{WLUSE}}{4}\right]}{2} \right\} \right\rangle^{1/2} \tag{10}$$

This equation reflects the ability of headwater stream ecosystems to provide critical life requisites for wildlife, with an emphasis on macroinvertebrates and amphibians. If the components of this equation are similar to those found under reference standard conditions, then it is likely that the entire complement of amphibians and macroinvertebrates characteristic of headwater stream ecosystems within the reference domain will be present.

The first part of each equation is an expression of the structural components in the stream channel that directly relate to macroinvertebrate and amphibian habitat. The second part of each equation contains variables that reflect seral stage, food production potential, availability of dispersal habitat, and other factors that depend on stand structure, maturity, and connectivity. Riparian/Buffer Zone Tree Diameter (V_{TDBH}) is used when trees dominate the ecosystem (Channel Canopy Cover is at least 20 percent). Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD}) and Riparian/Buffer Zone Herbaceous Vegetation (V_{HERB}) are both used when Channel Canopy Cover is less than 20 percent. Other features of forested headwater stream ecosystems, such as snags, are also important habitat for many species. Channel integrity is critical to the maintenance of wildlife habitat; therefore, the channel components are used as a multiplier in each equation. Watershed Land-use (V_{WLUSE}) influences the hydrologic regime, an essential habitat component, as a source of water for breeding amphibians and macroinvertebrates. Watershed Land-use (V_{WLUSE}) and Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH}) capture plant community and offsite conditions on which the animal community depends. The variables in the second part of Equations 9 and 10 are compensatory (i.e., a low value for one term will be offset by a high value for the other(s)). In a headwater stream ecosystem where Channel Canopy Cover is at least 20 percent, the maximum possible FCI is 1.0. In headwater streams where Channel Canopy Cover is less than 20 percent, the maximum FCI is 0.8; however, assessment variables are unlikely to exhibit the high subindex values necessary to achieve the maximum score in SARs with deforested riparian/buffer zones.

Functional capacity index – perennial streams

The following variables are used in the assessment equation for the Habitat function for the perennial stream subclass:

- Channel Canopy Cover ($V_{CCANOPY}$)
- Channel Substrate Embeddedness (V_{EMBED})
- Channel Substrate Size ($V_{SUBSTRATE}$)
- Large Woody Debris (V_{LWD})
- Percent Forest (V_{FOREST})
- Riparian/Buffer Zone Tree Diameter (V_{TDBH})
- Coefficient of Conservatism (V_{CVALUE})

The assessment equation for calculating the FCI for the Habitat function in perennial streams is given below. This equation is only appropriate for perennial streams and should not be applied to channels with greater than four percent slope.

$$FCI = \left\{ \frac{V_{CANOPY} + \min\left(V_{EMBED}, V_{SUBSTRATE}\right)}{2} \right\} \times \left\{ \frac{V_{LWD} + V_{FOREST} + \left(\frac{V_{DBH} + V_{CVALUE}}{2} \right)}{3} \right\}^{1/2} \qquad (11)$$

Equation 11 reflects the ability of perennial stream ecosystems to provide critical life requisites for wildlife, with an emphasis on macroinvertebrates, amphibians, and fish. If the subindex scores for the variables found in this equation are similar to those found under reference standard conditions, then it is likely that a balanced community of amphibians, macroinvertebrates, and fish characteristic of perennial stream ecosystems within the reference domain will be present. The first part of the equation represents stream channel components, which influence conditions for stream organisms, including amphibians, macroinvertebrates, and fish. $V_{CCANOPY}$ is an important variable in the equation, because canopy cover over the channel is critical for mitigating temperature extremes. V_{EMBED} and $V_{SUBSTRATE}$ reflect the quality of benthic habitat for stream organisms. The second part of the equation represents riparian/buffer zone and watershed characteristics. The variable V_{LWD} represents the availability of cover for organisms in the riparian/buffer zone and within the channel. V_{FOREST} reflects the availability of forested habitat within the watershed, a critical component for amphibians and other wildlife. V_{TDBH} and V_{CVALUE} are measures of forest seral stage and species composition in the riparian/buffer zone, and both are weighted equally in the equation.

3 Assessment Protocol

This chapter outlines a protocol for collecting and analyzing the data necessary to assess the functional capacity of a stream in the context of a Section 404 permit review or similar assessment scenario. In practical terms, this translates into an assessment of the functional capacity of the stream reach under both pre-project and post-project conditions, and the subsequent determination of how FCIs have changed or are expected to change as a result of the project. Data for the pre-project assessment are collected under existing conditions at the project stream reach, while data for the post-project assessment are normally based on the conditions expected to exist following proposed project impacts. A skeptical, conservative, and well-documented approach is required in defining post-project conditions. This recommendation is based on the often-observed lack of similarity between predicted or engineered post-project conditions and actual post-project conditions. This chapter discusses each of the following tasks required to complete an assessment of headwater streams or perennial streams:

1. Define Assessment Objectives
2. Characterize the Project Area
3. Screen for Red Flags
4. Define the Stream Assessment Reach
5. Determine the Stream Subclass
6. Collect the Data
7. Analyze the Data
8. Apply Assessment Results

Define Assessment Objectives

Begin the assessment process by unambiguously identifying the purpose of the assessment. Identifying the purpose can be as simple as stating, “The purpose of this assessment is to determine how the proposed project will impact stream functions.” Other potential objectives could be as follows:

1. Compare several streams as part of an alternatives analysis.
2. Identify specific actions that can be taken to minimize project impacts.
3. Document baseline conditions at a stream reach.
4. Determine mitigation requirements.
5. Determine mitigation success.

6. Determine the effects of a stream management technique.

Frequently, multiple reasons are identified for conducting an assessment. Carefully defining the purpose(s) facilitates communication and understanding among the people involved in the assessment and makes the goals of the assessment clear to interested parties. In addition, defining the purpose helps to clarify the approach that should be taken. The specific approach will vary, to some degree, depending upon whether the project is a Section 404 permit review, or a component of an Advanced Identification (ADID), Special Area Management Plan (SAMP), or some other scenario.

Characterize the Project Area

Characterizing the project area involves describing the area in terms of climate, surficial geology, geomorphic setting, surface and groundwater hydrology, vegetation, soils, land-use, proposed impacts, and any other characteristics and processes that have the potential to influence how streams in the project area perform functions. The characterization should be written and accompanied by maps and figures, including photographs, that show project area boundaries, jurisdictional boundaries, the boundaries of the Stream Assessment Reach (discussed later in this chapter), proposed impacts, roads, mining, buildings, soil types, plant communities, threatened or endangered species habitat, and other important features. Aerial photographs, topographic and National Wetland Inventory (NWI) maps, and soil surveys are sources of information useful in characterizing a project area.

Screen for Red Flags

Red flags are features within or near the project area that merit special recognition or protection based on objective criteria (Table 5). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the stream or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of stream functions. An assessment of stream functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of stream functions may be unnecessary because the project may be denied or modified strictly based on the potential impacts to threatened or endangered species or habitat.

Table 5. Red Flag Features and Respective Program/Agency Authority.

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing Critical Habitat for Species of Special Concern	B, C, F
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or flood-prone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, F
Areas identified as significant under the RAMSAR Treaty	H
Areas supporting rare or unique plant communities	C, H
Areas designated as Sole Source Groundwater Aquifers	I, L
Areas protected by the Safe Drinking Water Act	I, L
City, County, State, and National Parks	D, F, H, L
Areas supporting threatened or endangered species	B, C, F, H, I
Areas with unique geological features	H
Areas protected by the Wild and Scenic Rivers Act	D
Areas protected by the Wilderness Act	D
State listed special use waters (High Quality Waters or Trout Waters)	F, I

[1] Program Authority / Agency

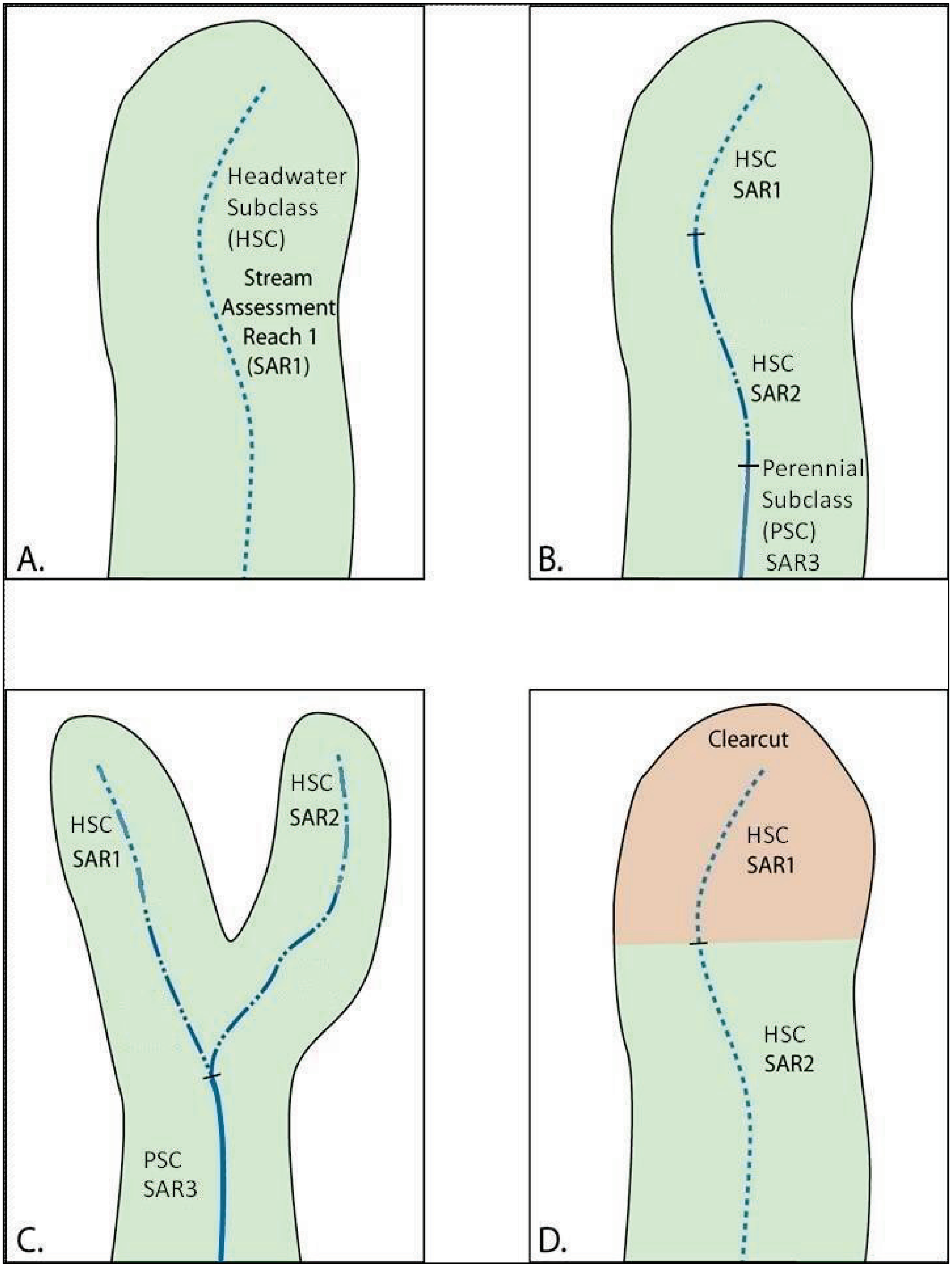
A = Bureau of Indian Affairs
B = National Marine Fisheries Service
C = U.S. Fish and Wildlife Service
D = National Park Service
E = State Coastal Zone Office
F = State Departments of Natural Resources, Fish and Game, etc.
G = State Historic Preservation Office
H = State Natural Heritage Offices
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Agency
K = Natural Resources Conservation Service
L = Local Government Agencies

Define the Stream Assessment Reach

The Stream Assessment Reach (SAR) is an area of the stream within a project area that belongs to a single regional stream subclass and is relatively homogeneous with respect to the site-specific criteria used to assess stream functions (i.e., Hydrology, Biogeochemical Cycling, and Habitat). For SARs in the headwater subclass, a minimum thalweg length of 100 ft is suggested, and a minimum thalweg length of 300 ft is suggested for perennial stream SARs. In many project areas, there will be just one SAR representing a single stream subclass, as illustrated in Figure 40A. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple SARs within the project area.

Various other situations may necessitate defining and assessing multiple SARs within a project area. For example, the first situation exists when more than one regional stream subclass occurs within a project area. This would include project areas containing headwater and perennial SARs (Figure 40B). In this example, the headwater portion of the stream is divided into two reaches because of spatial heterogeneity (e.g., differences in flow permanence or canopy cover characteristics between the two headwater reaches). Another situation exists when separated stream reaches of the same regional subclass occur in the project area (Figure 40C). This occurs when the project area contains several stream reaches or lobes. These lobes may be headwater or perennial and should be assessed separately. The situation may exist when a physically contiguous stream reach of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures (Figure 40D). These differences may be a result of natural disturbances (e.g., wind throw, insect activity, and ice storms) or anthropogenic alteration (e.g., logging, surface mining, and hydrologic alterations). For example, Figure 40D depicts a headwater stream reach in which the upper portion of the reach has been clear-cut. The disturbed and undisturbed sections of stream should be assessed separately as independent SARs.

Figure 40. Examples of possible SARs for stream assessments.



There are elements of subjectivity and practicality in determining what constitutes a significant difference in portions of the SAR. Field experience, with the regional subclass under consideration, provides a sense of the range of variability that typically occurs and the understanding necessary to make reasonable decisions about defining multiple SARs. For example, recent logging in a portion of a watershed may be a criterion for designating two SARs (Figure 40D). The presence of relatively minor differences resulting from natural variability (e.g., average tree diameter, percent cover of detritus, or percent bank erosion) should not be used as a basis for dividing a contiguous stream reach into multiple SARs. However, disturbances caused by rare and destructive natural events (e.g., flooding, ice storms, etc.) should be used as a basis for defining SARs. A sketch and recent aerial photograph of the proposed project area can be helpful in determining the extent of SARs.

Determine the Subclass

This guidebook describes headwater and perennial streams across the Appalachian Region. Determining the correct subclass is essential to completing a meaningful assessment. Subclasses are based on hydrogeomorphic characteristics. As previously noted, assessments are not designed for use on SARs with substrate made up of greater than 50 percent bedrock. Headwater streams in the reference domain were defined previously as first- and second-order headwater streams with an average slope greater than four percent, that are supported by precipitation and groundwater inputs from the surrounding landscape, and are not dominated by riverine processes. The headwater subclass includes both ephemeral and intermittent stream reaches. Perennial streams were defined previously as third-order streams and above, which (1) have an average slope less than four percent, (2) receive year-round flow, (3) remain shallow enough that a person can safely wade across during normal flow conditions, and (4) are narrow enough that the potential exists for full tree canopy closure over the channel (see Chapter 1). Slope can be measured using a laser clinometer or hand-held clinometer. Current aerial photographs, topographic maps, soils maps, NWI maps, local knowledge, sketches, or other available information can be used to help distinguish headwater streams from perennial streams. In some cases where it is impossible to determine the stream subclass from remotely sensed data or maps, an on-site investigation would be necessary. Some extremely disturbed streams are difficult or impossible to evaluate, even during an on-site examination. In these cases, historical aerial photographs or knowledge of local experts may be helpful in determining the stream subclass.

Collect the Data

The first step in data collection is to identify and delineate the project area and SAR on aerial photographs and topographic maps using the most recent and highest quality images and maps available. It is usually necessary to verify decisions made from photo interpretation in the field during project area reconnaissance.

Variables used in the assessment of stream functions were defined and discussed in Chapter 2. Information needed to determine the variable subindex score is collected at various spatial scales. For headwater streams, $V_{CCANOPY}$, V_{EMBED}, $V_{SUBSTRATE}$, and V_{BERO} are four variables that describe stream channel conditions (Figure 41). The next five variables, V_{LWD}, V_{SNAG}, V_{TDBH}, V_{SSD}, and V_{SRICH}, are collected in the riparian/buffer zone, and the adjacent channel. $V_{DETRITUS}$ and V_{HERB} are collected in subplots within the riparian/buffer zone, excluding the channel. The remaining variable, V_{WLUSE}, is evaluated through aerial photo interpretation of the upland watershed outside the riparian/buffer zone and verified in the field during field reconnaissance (Figure 41). The data sheet shown in Figure 43 is organized to facilitate data collection at each spatial scale.

For perennial streams, four variables, $V_{CCANOPY}$, V_{EMBED}, $V_{SUBSTRATE}$, and $V_{BANKSTAB}$, describe conditions in the stream channel (Figure 42). The next four variables, V_{LWD}, V_{TDBH}, V_{TDEN}, and V_{CVALUE}, are collected in the riparian/buffer zone. The riparian/buffer zone and the adjacent channel are both evaluated for VLWD (Figure 42). The remaining variable, V_{FOREST}, is evaluated through aerial photo interpretation of the upland watershed outside the riparian/buffer zone and verified in the field during field reconnaissance. The data sheet (Figure 44) is organized to facilitate data collection at each spatial scale. Instructions for measuring each variable are given below.

Figure 41. Example of a typical sample layout for a headwater stream.

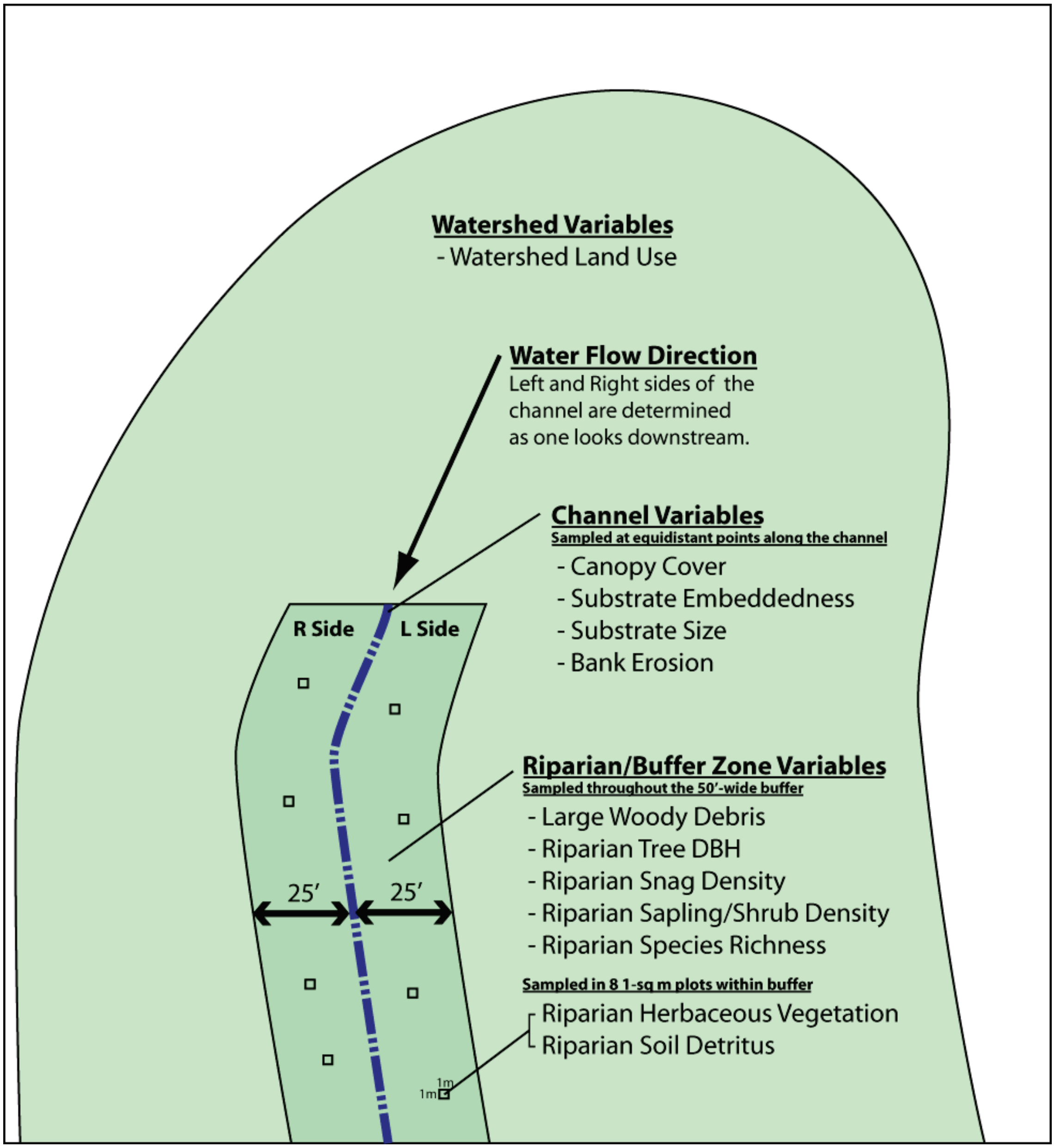


Figure 42. Example of a typical sample layout for a perennial stream.

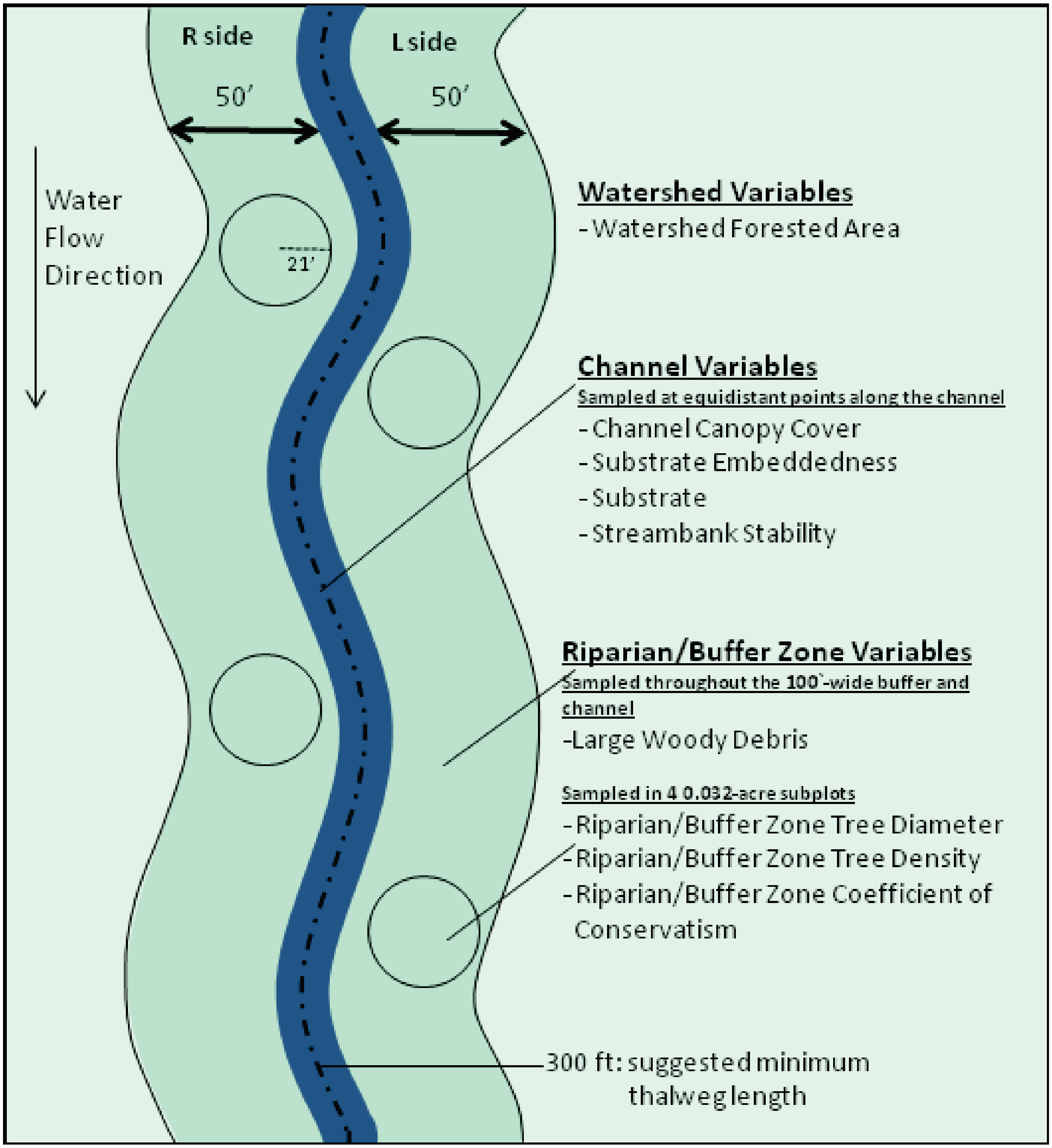
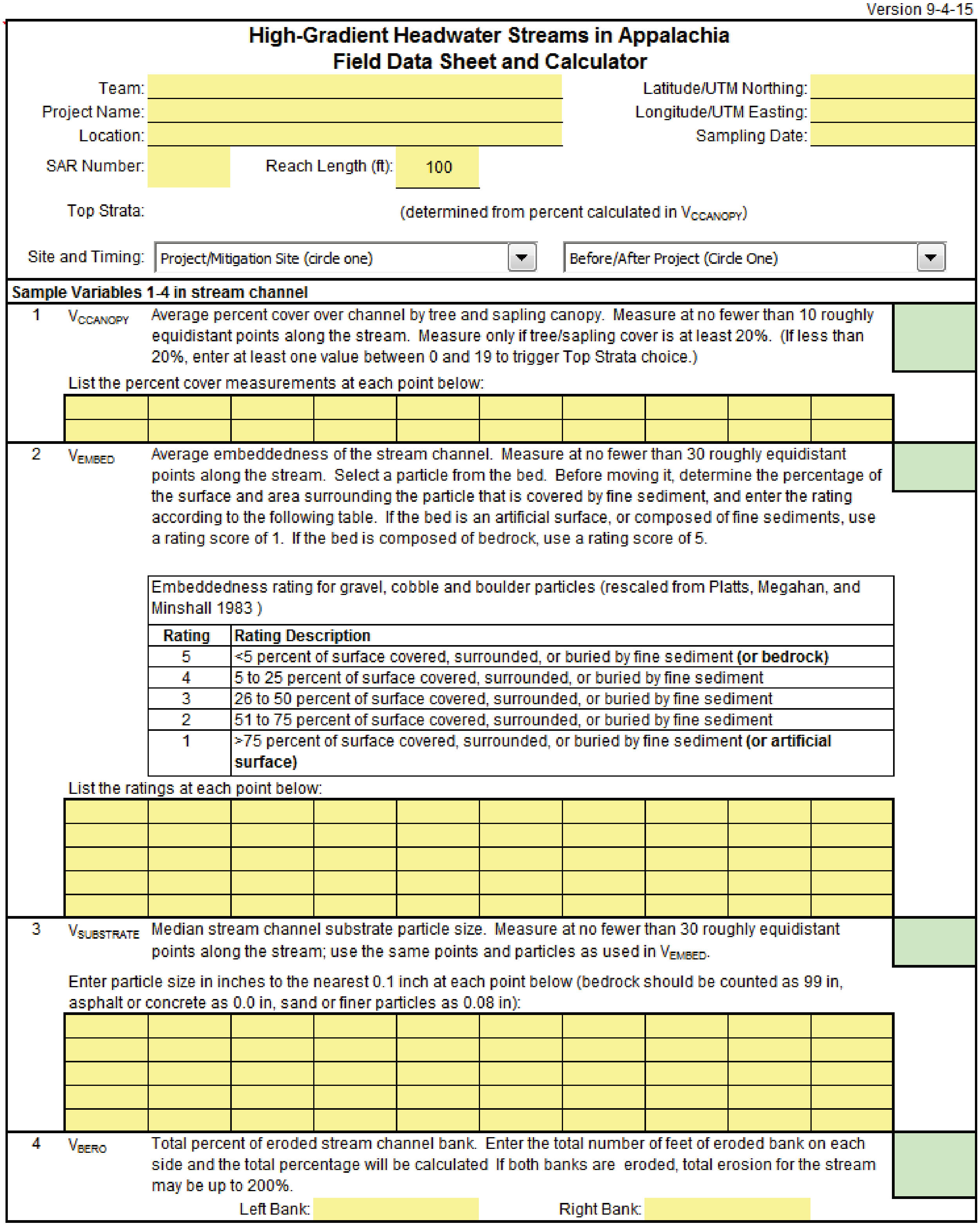


Figure 43. Data entry form for headwater stream assessments. (continued)



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High-Gradient Headwater Streams in Appalachia
Field Data Sheet and Calculator

Team:

Project Name:

Location:

Latitude/UTM Northing:

Longitude/UTM Easting:

Sampling Date:

SAR Number:

Reach Length (ft): 100

Top Strata: (determined from percent calculated in $V_{CCANOPY}$)

Site and Timing: Project/Mitigation Site (circle one) ▼ Before/After Project (Circle One) ▼

Sample Variables 1-4 in stream channel

1 $V_{CCANOPY}$ Average percent cover over channel by tree and sapling canopy. Measure at no fewer than 10 roughly equidistant points along the stream. Measure only if tree/sapling cover is at least 20%. (If less than 20%, enter at least one value between 0 and 19 to trigger Top Strata choice.)

List the percent cover measurements at each point below:

2 V_{EMBED} Average embeddedness of the stream channel. Measure at no fewer than 30 roughly equidistant points along the stream. Select a particle from the bed. Before moving it, determine the percentage of the surface and area surrounding the particle that is covered by fine sediment, and enter the rating according to the following table. If the bed is an artificial surface, or composed of fine sediments, use a rating score of 1. If the bed is composed of bedrock, use a rating score of 5.

Embeddedness rating for gravel, cobble and boulder particles (rescaled from Platts, Megahan, and Minshall 1983)

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment **(or bedrock)**
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment **(or artificial surface)**

List the ratings at each point below:

3 $V_{SUBSTRATE}$ Median stream channel substrate particle size. Measure at no fewer than 30 roughly equidistant points along the stream; use the same points and particles as used in V_{EMBED}.

Enter particle size in inches to the nearest 0.1 inch at each point below (bedrock should be counted as 99 in, asphalt or concrete as 0.0 in, sand or finer particles as 0.08 in):

4 V_{BERO} Total percent of eroded stream channel bank. Enter the total number of feet of eroded bank on each side and the total percentage will be calculated If both banks are eroded, total erosion for the stream may be up to 200%.

Left Bank:

Right Bank:

Figure 43. (continued)

Sample Variables 5-9 within the entire riparian/buffer zone adjacent to the stream channel (25 feet from each bank).

5 V_{LWD} Number of down woody stems (at least 4 inches in diameter and 36 inches in length) per 100 feet of stream reach. Enter the number from the entire 50'-wide buffer and within the channel, and the amount per 100 feet of stream will be calculated.

Number of downed woody stems:

6 V_{TDBH} Average dbh of trees (measure only if $V_{CCANOPY}$ tree/sapling cover is at least 20%). Trees are at least 4 inches (10 cm) in diameter. Enter tree DBHs in inches.

List the dbh measurements of individual trees (at least 4 in) within the buffer on each side of the stream below:

Left Side					Right Side				

7 V_{SNAG} Number of snags (at least 4" dbh and 36" tall) per 100 feet of stream. Enter number of snags on each side of the stream, and the amount per 100 feet will be calculated.

Left Side: Right Side:

8 V_{SSD} Number of saplings and shrubs (woody stems up to 4 inches dbh) per 100 feet of stream (measure only if tree cover is <20%). Enter number of saplings and shrubs on each side of the stream, and the amount per 100 ft of stream will be calculated.

Left Side: Right Side:

9 V_{SRICH} Riparian vegetation species richness per 100 feet of stream reach. Check all species present from Group 1 in the tallest stratum. Check all exotic and invasive species present in all strata. Species richness per 100 feet and the subindex will be calculated from these data.

Group 1 = 1.0

- ☐ *Acer pensylvanicum*
- ☐ *Acer rubrum*
- ☐ *Acer saccharum*
- ☐ *Aesculus flava*
- ☐ *Asimina triloba*
- ☐ *Betula alleghaniensis*
- ☐ *Betula lenta*
- ☐ *Carya cordiformis*
- ☐ *Carya glabra*
- ☐ *Carya ovata*
- ☐ *Carya tomentosa*
- ☐ *Cornus florida*
- ☐ *Fagus grandifolia*
- ☐ *Fraxinus americana*
- ☐ *Liriodendron tulipifera*
- ☐ *Magnolia acuminata*
- ☐ *Magnolia tripetala*
- ☐ *Nyssa sylvatica*
- ☐ *Oxydendrum arboreu*
- ☐ *Pinus strobus*
- ☐ *Prunus serotina*
- ☐ *Quercus alba*
- ☐ *Quercus coccinea*
- ☐ *Quercus imbricaria*
- ☐ *Quercus montana*
- ☐ *Quercus rubra*
- ☐ *Quercus velutina*
- ☐ *Sassafras albidum*
- ☐ *Tilia americana*
- ☐ *Tsuga canadensis*
- ☐ *Ulmus americana*

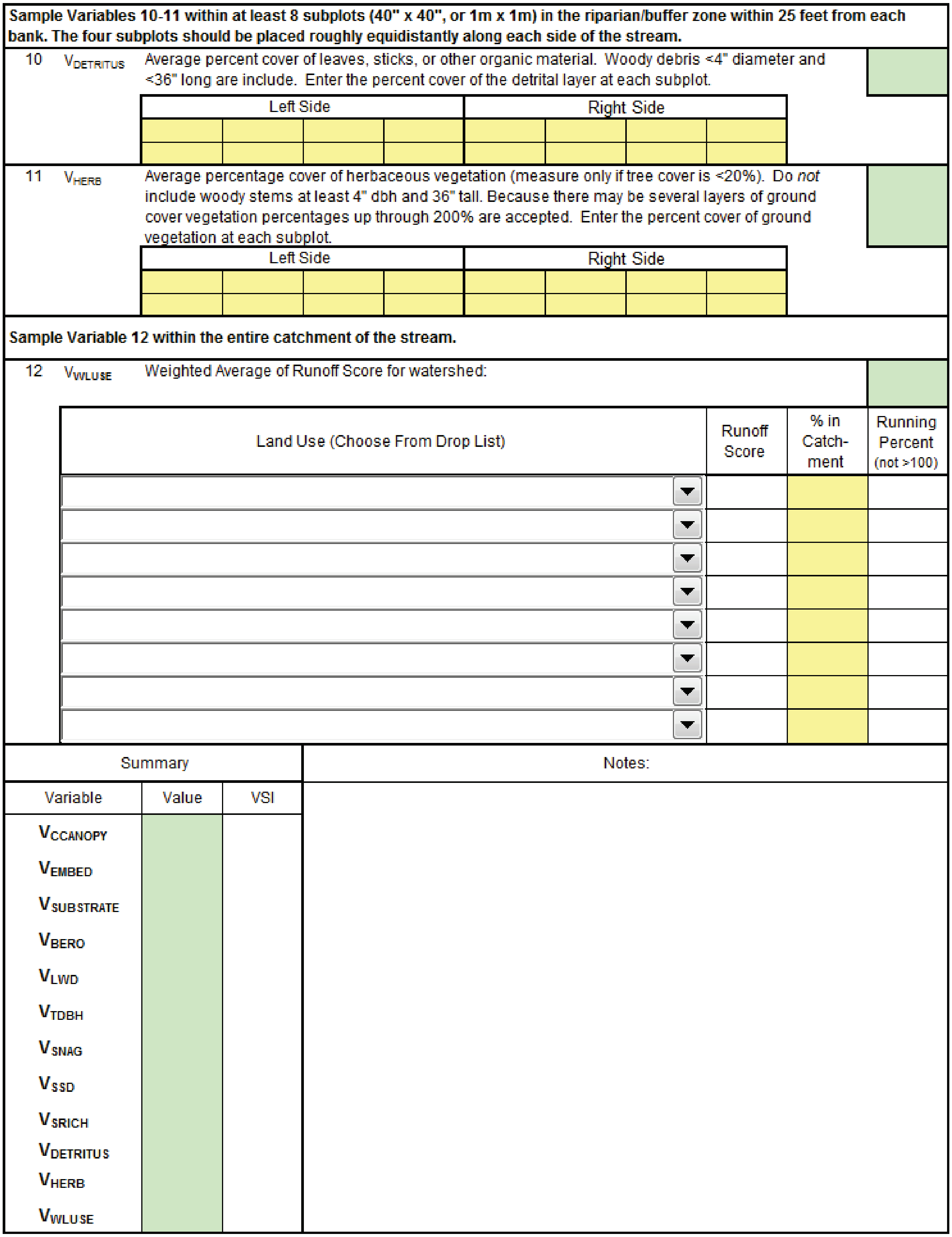
Group 2 (-1.0)

- ☐ *Ailanthus altissima*
- ☐ *Albizia julibrissin*
- ☐ *Alliaria petiolata*
- ☐ *Alternanthera philoxeroides*
- ☐ *Aster tataricus*
- ☐ *Cerastium fontanum*
- ☐ *Coronilla varia*
- ☐ *Elaeagnus umbellata*
- ☐ *Fallopia japonica*
- ☐ *Lespedeza bicolor*
- ☐ *Lespedeza cuneata*
- ☐ *Ligustrum obtusifolium*
- ☐ *Ligustrum sinense*
- ☐ *Lonicera japonica*
- ☐ *Lonicera tatarica*
- ☐ *Lotus corniculatus*
- ☐ *Lythrum salicaria*
- ☐ *Microstegium vimineum*
- ☐ *Paulownia tomentosa*
- ☐ *Pueraria montana*
- ☐ *Rosa multiflora*
- ☐ *Sorghum halepense*
- ☐ *Verbena brasiliensis*

0 Species in Group 1

0 Species in Group 2

Figure 43. (concluded).



Sample Variables 10-11 within at least 8 subplots (40" x 40", or 1m x 1m) in the riparian/buffer zone within 25 feet from each bank. The four subplots should be placed roughly equidistantly along each side of the stream.

10 $V_{DETRITUS}$ Average percent cover of leaves, sticks, or other organic material. Woody debris <4" diameter and <36" long are include. Enter the percent cover of the detrital layer at each subplot.

Left Side				Right Side			

11 V_{HERB} Average percentage cover of herbaceous vegetation (measure only if tree cover is <20%). Do *not* include woody stems at least 4" dbh and 36" tall. Because there may be several layers of ground cover vegetation percentages up through 200% are accepted. Enter the percent cover of ground vegetation at each subplot.

Left Side				Right Side			

Sample Variable 12 within the entire catchment of the stream.

12 V_{WLUSE} Weighted Average of Runoff Score for watershed:

Land Use (Choose From Drop List)	Runoff Score	% in Catchment	Running Percent (not >100)
▼			
▼			
▼			
▼			
▼			
▼			
▼			
▼			

Summary

Variable	Value	VSI
$V_{CCANOPY}$		
V_{EMBED}		
$V_{SUBSTRATE}$		
V_{BERO}		
V_{LWD}		
V_{TDBH}		
V_{SNAG}		
V_{SSD}		
V_{SRICH}		
$V_{DETRITUS}$		
V_{HERB}		
V_{WLUSE}		

Notes:

Figure 44. Data entry form for perennial stream assessments. (continued)

Version 5-29-15

Low-Gradient Perennial Streams in Appalachia
Field Data Sheet and Calculator

Assessment Team:
Project Name:
Location:
Latitude/UTM Northing:
Longitude/UTM Easting:
Sampling Date:

SAR Number: Thalweg Length (ft): (300 ft suggested minimum)

Site and Timing: Project/Mitigation Site (circle one) ▼ Before/After Project (Circle One) ▼

Sample Variables 1-4 in stream channel

1 $V_{CCANOPY}$ Average percent cover over channel by tree and sapling canopy. Measure at no fewer than 10 roughly equidistant points along the stream. Measure for all streams, even if cover is less than 20%.

List the percent cover measurements at each point below (between 0 and 100):

2 V_{EMBED} Average embeddedness of the stream channel. Measure at no fewer than 60 roughly equidistant points along the stream. Select a particle from the bed. Before moving it, determine the percentage of the surface and area surrounding the particle that is covered by fine sediment, and enter the rating according to the following table. If the bed is an artificial surface, or composed of fine sediments, use a rating score of 1. If the bed is composed of bedrock, use a rating score of 5.

Embeddedness rating for gravel, cobble and boulder particles (rescaled from Platts, Megahan, and Minshall 1983)

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment **(or bedrock)**
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment **(or artificial surface)**

List the ratings at each point below:

3 $V_{SUBSTRATE}$ Median stream channel substrate particle size. Measure at no fewer than 60 roughly equidistant points along the stream; use the same points and particles as used in V_{EMBED}.

Enter particle size in inches to the nearest 0.1 inch at each point below (bedrock should be counted as 99 in, asphalt or concrete as 0.0 in, sand or finer particles as 0.08 in):

Figure 44. (continued).

4 $V_{BANKSTAB}$ This variable is an index incorporating three elements of bank stability: 1) bank erosion length, 2) height category of eroded bank, and 3) length of artificial stream bank stabilization. Measure the length of the SAR along the thalweg, and enter at the top of the page. Record the length of each eroded area, using the drop down menus to select erosion class. Measure erosion on both sides of the stream. Index ranges from 0 to 200.

☐ Check here if there is no erosion on either bank.

Length of SAR at thalweg (ft):

Total Weighted Erosion length (ft):

Left Stream Bank				**Right Stream Bank**			
Height of Erosion Category	Height Index	Length	Contri-bution	Height of Erosion Category	Height Index	Length	Contri-bution
Left Bank Erosion length:		0 ft		Right Bank Erosion length:		0 ft	

Sample Variable 5 within the entire riparian/buffer zone adjacent to the stream channel (50 feet from each bank).

5 V_{LWD} Number of down woody stems (at least 4 inches in diameter and 36 inches in length) per 100 feet of stream reach. Enter the number from the entire buffer: 50' from each bank and within the channel. The amount per 100 feet of stream will be calculated.

Number of downed woody stems:

Sample Variable 6-9 within at least four 0.032-acre (21' radius) plots within the riparian/buffer zone adjacent to the stream channel (50 feet from each bank).

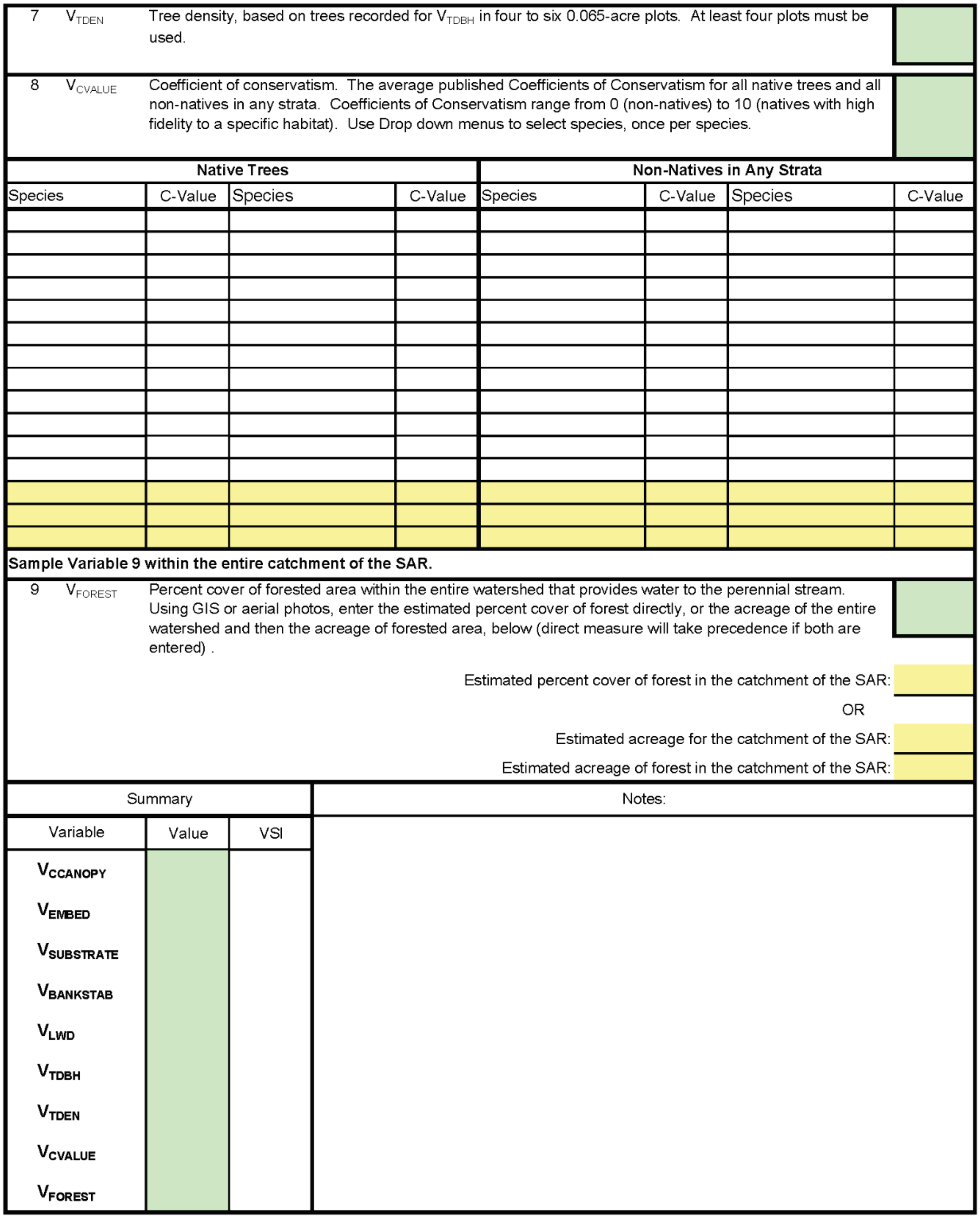
6 V_{TDBH} Average dbh of trees. Trees are at least 4 inches (10 cm) in diameter. Enter tree DBHs in inches.

Use at least 4 plots.

List the dbh measurements of individual trees (at least 4 in) within 4-6 plots placed in the buffer on each side of the stream:

Plot 1		**Plot 2**		**Plot 3**		**Plot 4**		**Plot 5**		**Plot 6**	
☐ Plot Used ☐ No Trees		☐ Plot Used ☐ No Trees		☐ Plot Used ☐ No Trees		☐ Plot Used ☐ No Trees		☐ Plot Used ☐ No Trees		☐ Plot Used ☐ No Trees	
Plot Average		Plot Average		Plot Average		Plot Average		Plot Average		Plot Average	

Figure 44. (concluded).



7	V_{TDEN}	Tree density, based on trees recorded for V_{TDBH} in four to six 0.065-acre plots. At least four plots must be used.	
8	V_{CVALUE}	Coefficient of conservatism. The average published Coefficients of Conservatism for all native trees and all non-natives in any strata. Coefficients of Conservatism range from 0 (non-natives) to 10 (natives with high fidelity to a specific habitat). Use Drop down menus to select species, once per species.	

Native Trees				Non-Natives in Any Strata			
Species	C-Value	Species	C-Value	Species	C-Value	Species	C-Value

Sample Variable 9 within the entire catchment of the SAR.

9	V_{FOREST}	Percent cover of forested area within the entire watershed that provides water to the perennial stream. Using GIS or aerial photos, enter the estimated percent cover of forest directly, or the acreage of the entire watershed and then the acreage of forested area, below (direct measure will take precedence if both are entered) .	

Estimated percent cover of forest in the catchment of the SAR:

OR

Estimated acreage for the catchment of the SAR:

Estimated acreage of forest in the catchment of the SAR:

Summary			Notes:
Variable	Value	VSI	
$V_{CCANOPY}$			
V_{EMBED}			
$V_{SUBSTRATE}$			
$V_{BANKSTAB}$			
V_{LWD}			
V_{TDBH}			
V_{TDEN}			
V_{CVALUE}			
V_{FOREST}			

4 Headwater Stream Variable Protocols

Channel Variables for Headwater Streams

Data on vegetation and structure are collected within the headwater stream channel (Figure 41). Measurements of SAR length are required to determine a number of assessment variables. SAR length can be determined using a measuring tape, which will assist in determining spacing for the measurement of several variables. When possible, a minimum 100 ft of thalweg length should be used, and a longer stream reach may be selected if necessary to capture reach conditions. Several assessment variables require the repeated measurement of a single parameter at approximately equally spaced, representative points along the stream channel (e.g., $V_{CCANOPY}$, V_{EMBED}, and $V_{SUBSTRATE}$). V_{BERO} requires the measurement of the number of feet of bare or scoured channel bank that could provide fine sediment to the stream channel. All variables should be recorded in English units on the data form. During periods of leaf fall or snow, leaf or snow removal may be required to examine the stream channel and adjacent areas below these materials to accurately measure assessment variables.

The data sheets are available as Excel spreadsheets, which can be printed and taken into the field. They are also calculators, and entering the data into them will automatically calculate averages, variable subindex scores, and functional capacity indices. The directions below also allow for the manual calculation of all parameters.

Channel Canopy Cover ($V_{CCANOPY}$)

$V_{CCANOPY}$ is the average percent cover of the canopy over the stream channel. Channel Canopy Cover should reflect all canopy (measured as described) regardless of the source (e.g., tree, sapling, shrub, or vines). Use the following procedure to measure $V_{CCANOPY}$:

1. If no trees, saplings, or shrubs are present within the riparian/buffer zone or stream channel, then the variable would not be used, and the following steps can be skipped.
2. Using a densitometer, spherical crown densiometer, or equivalent device designed for estimating percent canopy cover, estimate the amount of light obscured by vegetation cover while standing in the stream channel within the SAR. Follow all manufacturers' instructions. Only the contribution from

leaves, branches, and other vegetation constituents should be included in the measurement. Do not include shadows from surrounding hills or manmade structures when estimating percent canopy cover. Measurements should reflect all canopy cover regardless of the source (e.g., trees, saplings, or shrubs).

3. Examine the sky directly above.
4. Estimate the percentage of the canopy above that is obscured by tree branches and leaves. Estimating percent canopy cover can be difficult in winter when there are no leaves on the trees. However, with practice a reasonable estimate can be made by visualizing the trees with leaves. If necessary, revisit the site when the trees have leaves.
5. Record the percent canopy cover estimate on the data sheet.
6. Repeat the process a minimum of nine times at approximately evenly spaced locations along the SAR. This will result in a minimum of ten measurements. Longer SARs or those with a diverse canopy may require additional data points.
7. Average all of the estimates of percent canopy cover.
8. Using Figure 9, determine the subindex score for $V_{CCANOPY}$.

Substrate Embeddedness (V_{EMBED})

V_{EMBED} is the average embeddedness value of the stream substrate. Embeddedness is a measure of the degree to which coarse substrates (e.g., gravel, cobble, and boulders) are covered, surrounded, or buried by fine sediments. Fine sediments include sand, silt, and clay sized (≤0.08 in. (0.2 cm)) particles. The purpose of V_{EMBED} and $V_{SUBSTRATE}$ is to characterize the substrate of the channel. Use the following procedure to measure V_{EMBED}:

1. Embeddedness is measured concurrently with $V_{SUBSTRATE}$ using the same substrate particle.
2. At 30 or more evenly spaced points along the length of the SAR, select at random (i.e., blind) a substrate particle. For example, with eyes closed, reach into the stream and evaluate the first particle (e.g., sand, silt, clay, gravel, cobble, or boulder) that is touched. It is important not to intentionally select substrate particles only from the center of the channel, pools, runs, or other channel features. Before each particle is removed and measured for size, visually estimate the percentage of the particle that is covered, surrounded, or buried with fine materials, and assign the appropriate rating using Table 6.
3. Substrate particles consisting of sand, silt, and clay receive an embeddedness score of one. Concrete or other artificial substrate would

also receive an embeddedness score of one. Areas of bedrock receive an embeddedness score of five.

4. Record the embeddedness rating based on Table 6 on the datasheet. Do not record the percent embeddedness.
5. Average the embeddedness rating score for all substrate particles measured.
6. Using Figure 13, determine the subindex score for V_{EMBED}.

Table 6. Embeddedness rating for gravel, cobble, and boulder sized particles (rescaled from Platts et al. 1983).

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment (or bedrock)
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment (or artificial substrate)

Channel Substrate Size ($V_{SUBSTRATE}$)

$V_{SUBSTRATE}$ is the median size of the stream substrate. Use the following procedure to measure $V_{SUBSTRATE}$:

1. Using the same particles selected for V_{EMBED}, measure the size of the particle to the nearest 0.1 in. (3 mm) along the longitudinal (intermediate) axis (See Appendix B).
2. Bedrock should be counted as 99 in. (251 cm).
3. Concrete or asphalt should be counted as zero.
4. Sand or finer sized particles can be recorded as 0.08 in. (0.2 cm).
5. Calculate the median value for all particles measured.
6. Using Figure 16, determine the subindex score for $V_{SUBSTRATE}$.

Channel Bank Erosion (V_{BERO})

V_{BERO} is the percentage of the total length of stream bank that shows signs of erosion along the SAR. Channel Bank Erosion is defined as disturbed, scoured sections of stream bank that have exposed soil above or below the waterline. These areas are often vertical, can range from a few inches to several feet high, and have little or no vegetative or detrital cover. Exposed roots along the stream bank can help identify eroded areas. Do not include undercut banks that have a stable overhang of roots and soil, and no evidence of active collapse. V_{BERO} is standardized to a percent. The percent could potentially reach 200 if both the left and right channel banks were eroded along the entire length of the SAR. Use the following procedure to measure V_{BERO}:

1. While standing in the channel of the SAR, measure the length of both the left and right stream banks that display signs of erosion. Note that the entire height of the channel bank is not required to exhibit erosion. Any portion of the bank exhibiting erosion should be included in this measurement.
2. Record the number of feet of left Channel Bank Erosion and right Channel Bank Erosion separately on the data sheet.
3. Total the number of feet of left and right Channel Bank Erosion and divide by the length of the stream channel; then multiply by 100 (Equation 12).

$$\text{Channel Bank Erosion} = \left(\frac{\text{ft. left bank erosion} + \text{ft. right bank erosion}}{\text{SAR length}}\right) \times 100\% \tag{12}$$

4. Use Figure 19 to determine the subindex score for V_{BERO}.

Riparian / Buffer Zone Variables for Headwater Streams

Data for some variables within the riparian/buffer zone (i.e., V_{LWD}, V_{SNAGS}, V_{TDBH}, and V_{SSD}) of headwater streams are collected within the entire riparian/buffer zone extending 25 ft (7.6 m) from each bank of the stream as well as the channel (Figure 41). Other variables are collected in 40 in. x 40 in. (1 m x 1 m) subplots within the riparian/buffer zone (i.e., $V_{DETRITUS}$ and V_{HERB}), which do not include the stream channel. Data collected within the riparian/buffer zone can be subdivided into left and right sections for the convenience of data collection (Figure 41). The right and left portions of the sample area are always determined while facing downstream (Figure 41). The data from all subplots are combined to determine the subindex score for each variable.

Large Woody Debris (V_{LWD})

V_{LWD} consists of the number of individual pieces of down woody stems per 100 feet (30.5 m) of SAR within the channel and riparian/buffer zone. Large Woody Debris (LWD) is defined as down woody stems ≥4 in. (10 cm) in diameter and ≥36 in. (91.4 cm) long. Use the following procedure to measure V_{LWD}:

1. Count each individual piece of LWD along the entire SAR. This includes all LWD located in the riparian/buffer zone and within the stream channel. In some cases, pieces of LWD will extend outside the riparian/buffer zone. Pieces extending outside the riparian/buffer zone should be counted if a section at least 36 in. (91.4 cm) long and 4 in. (10 cm) in diameter extends into the riparian/buffer zone or the stream channel. Distinct pieces of LWD located within log jams or piles should be counted individually. Sections of downed wood or logs that are broken, but are obviously sections of the same tree, should be counted as one piece.
2. Record the total number of LWD on the data sheet.
3. Divide the total number of LWD by the length of the SAR, and then multiply by 100 to determine the number of Large Woody Debris per 100 feet of SAR.
4. Use Figure 23 to determine the subindex score for V_{LWD}.

Riparian/Buffer Zone Tree Diameter (V_{TDBH})

V_{TDBH} is the average diameter at breast height (DBH) for all trees within the riparian/buffer zone. DBH is measured at 55 in. (1.4 m) above the ground. For the purpose of this guidebook, a tree is defined as a living, woody plant with DBH ≥4 in. (10 cm). For headwater streams, if Channel Canopy Cover is <20 percent, the tree stratum is ignored, the following steps related to V_{TDBH} can be skipped, and data for V_{SSD} and V_{HERB} must be collected. Use the following procedure to measure V_{TDBH}:

1. Measure the DBH of all trees within the entire riparian/buffer zone, including any trees that occur in the stream channel of the SAR. Measurements should be made using tree calipers, DBH tape, or an equivalent device. The National Forestry Handbook (NRCS 2004) is a good source of information regarding tools and methods for measuring tree diameter. All manufacturers' instructions should be followed. The tree should be measured if any part of the stem is within the sample area.
2. Calculate the average tree diameter by summing DBH measurements and dividing by the total number of trees measured.
3. Use Figure 26 to determine the subindex score for V_{TDBH}.

Riparian/Buffer Zone Snag Density (V_{SNAG})

V_{SNAG} is the total number of snags per 100 ft of SAR. Snags are defined as standing dead trees. In order to be considered, snags must be woody species ≥4 in. (10 cm) in diameter and ≥36 in. (91.4 cm) in height. If the snag is not standing at the time of site evaluation, it is not measured. Instead, it should be included in the measure of V_{LWD}. Use the following procedure to measure V_{SNAG}:

1. Count all snags within the entire riparian/buffer zone, including any snags that occur in the stream channel of the SAR. Snags should be counted if any part of the stem is within the sample area. It is not necessary to continue counting beyond eight snags.
2. Divide the total number of snags by the length of the SAR; then multiply by 100 to determine the number of snags per 100 feet of SAR.
3. Use Figure 30 to determine the subindex score for V_{SNAG}.

Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})

V_{SSD} is the number of shrubs and saplings per 100 feet of SAR within the riparian/buffer zone including the channel. Saplings and shrubs are defined as all woody species <4 in. (10 cm) in DBH and >36 in. (90 cm) in height. They do not include soft-tissued, herbaceous plants or woody vines. Measure this variable only when Channel Canopy Cover is <20 percent. If the Channel Canopy Cover is ≥20 percent, calculation of V_{SSD} can be skipped. Use the following procedure to measure V_{SSD}:

1. Count each woody stem within the entire riparian/buffer zone and the stream channel. In cases where multiple stems arise from the same plant, count all stems above a height of 6 in. (15 cm) from the ground surface. Stems that originate outside of the riparian/buffer zone are not counted. Record the total number of stems for the left side and right side of the SAR on the datasheet. It is not necessary to continue counting stems once the sapling/shrub count reaches 65 stems for every 100 feet of SAR.
2. Total the number of stems within the riparian/buffer zone.
3. Divide the total number of stems by the length of the SAR; then multiply by 100 to determine the number of sapling/shrub stems per 100 feet of SAR.
4. Use Figure 32 to determine the variable subindex for V_{SSD}.

Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH})

V_{SRICH} is a modified measure of species richness. The number of desirable, native species listed in Group 1 is determined, then adjusted based on the number of invasive or non-native species listed in Group 2 (Table 3). Photographs of all Group 1 species and all tree species from Group 2 are provided in Appendix C. For Group 1 species, the tree stratum is used if

Channel Canopy Cover ($V_{CCANOPY}$) is ≥20 percent. If Channel Canopy Cover ($V_{CCANOPY}$) is <20 percent, then the sapling/shrub stratum is used. If both tree and sapling/shrub strata are absent, then the variable subindex score equals zero and calculation of V_{SRICH} can be skipped. Species from Group 2 should be recorded regardless of the strata in which they occur. Use the following procedure to measure V_{SRICH}:

1. On the data form (Figure 43), place a check mark beside each species in Group 1 (in the stratum being measured) or Group 2 (in any vegetation stratum) that is observed in the riparian/buffer zone, including the channel (Table 3). Species not listed under Group 1 or Group 2 should be disregarded.
2. If the number from Group 2 is larger than the number from Group 1, then the subindex score equals zero for V_{SRICH} and calculation of Riparian/Buffer Zone Species Richness can be skipped.
3. Calculate Riparian/Buffer Zone Species Richness using Equation 13. In the first portion of the equation, the difference between the number of species of Group 1 and Group 2 is standardized based on the length of stream examined. The second portion of the equation further decreases the species richness variable score based on the number of invasive or non-native species.

$$\begin{aligned}\text{Riparian/Buffer Zone Species Richness} &= \left[\frac{(\text{Group 1 species} - \text{Group 2 species})}{\text{Total length of SAR (ft)}} \times 100\right] \\ &\times \left[1 - \left(\frac{0.1 \times \text{Group 2 species}}{\text{Total length of SAR (ft)}}\right)\right]\end{aligned} \tag{13}$$

4. Use Figure 33 to determine the subindex score for V_{SRICH}.

Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)

$V_{DETRITUS}$ is the average percent cover of detrital material on the soil surface within the riparian/buffer zone. Soil detritus is defined as the soil layer dominated by partially decomposed, but still recognizable organic materials, such as leaves, sticks, needles, flowers, fruits, insect frass, dead moss, or detached lichens on the surface of the ground. Detrital materials do *not* include living, vegetative ground cover. Detrital materials include woody debris that have diameters <4 in. (10 cm) and are <36 in. (91.4 cm) long. Detrital material includes soil material that would classify as fibric or hemic material (e.g., peat or mucky peat). Percent detrital cover is determined using a visual estimate. Use the following procedure to measure $V_{DETRITUS}$:

1. Visually estimate the percent cover of leaves, sticks, or other organic material (Appendix B, Figure B1, and B2) within eight or more 40 in. x 40 in. (1 m x 1 m) plots in representative locations of the riparian/buffer zone (four plots on each side of the channel; Figure 41).
2. Average the percent cover estimates of all plots.
3. Use Figure 36 to determine the subindex score for $V_{DETRITUS}$.

Riparian/Buffer Zone Herbaceous Cover (V_{HERB})

V_{HERB} is the average percent cover of living herbaceous plant material. Herbaceous plants are the lowest strata on a site and do *not* include woody species ≤4 in. (10 cm) in DBH and >36 in. (90 cm) in height. Measure this variable only when the Channel Canopy Cover is <20 percent. Use the following procedure to measure V_{HERB}; however, if the Channel Canopy Cover ($V_{CCANOPY}$) is ≥20 percent, then the following steps can be skipped:

1. Using the same eight or more representative 40 in. x 40 in. (1 m x 1 m) plots used to estimate $V_{DETRITUS}$, visually estimate the percent absolute cover of herbaceous plant material (Appendix B, Figures B1 and B2).
2. Average the percent herbaceous cover estimates of all plots.
3. Use Figure 37 to determine the subindex score for V_{HERB}.

Watershed Land-use (V_{WLUSE})

Data gathered within watersheds of headwater streams is interpreted from aerial photos or publicly available GIS data and verified during field reconnaissance of the area above the riparian/buffer zone and within the watershed of the headwater stream.

V_{WLUSE} *is the* weighted average land-use index for the watershed that provides water to the headwater stream. If the watershed has a closed forest canopy (i.e., 100 percent cover), then the variable subindex score equals 1.0, and the following steps can be skipped. Use the following procedure to measure V_{WLUSE}; however, if the watershed has a closed forest canopy (i.e., 100 percent cover), then the variable subindex score equals 1.0, and the following steps can be skipped:

1. Use topographic maps, GIS data, or other sources to delineate the watershed above the lowest point of the SAR. Do not include areas from which water is being diverted away from the SAR; include any adjacent watershed area from which water is being imported into the watershed.
2. Use GIS techniques or aerial photographs along with field reconnaissance to determine the percentage of each land-use type (Table 7) in the watershed.
3. Determine a weighted average (by area) of land-use indices for the watershed. An example can be found in Appendix B.
4. Use Figure 38 to determine the subindex score for V_{WLUSE}.

Table 7. Watershed Land-use.

Land-use type	Land-use index
Forest and native range	1.0
Low density residential ($\geq$1 acre lots)	0.3
Open space (pasture, lawns, parks, golf courses, cemeteries):	0.2
High density residential (<1 acre lots)	0.1
Impervious areas (parking lots, roofs, driveways, etc)	0
Gravel	0
Industrial, commercial, and business	0
Newly graded areas (bare soil, no vegetation or pavement)	0

5 Perennial Stream Variable Protocols

Channel Variables for Perennial Streams

Data on Channel Canopy Cover, Substrate Embeddedness, Substrate, and Streambank Stability are collected from within the stream channel (Figure 42). Measurements of SAR length are required to determine a number of assessment variables. SAR length can be determined using a measuring tape stretched along the stream thalweg (i.e., the deepest part of the stream channel), which will assist in determining spacing for the measurement of several variables. When possible, a minimum 300 ft of thalweg length should be used, and a longer stream reach may be selected if necessary to capture reach conditions. Several assessment variables require the repeated measurement of a single parameter at approximately equally spaced, representative points along the stream channel (e.g., $V_{CCANOPY}$, V_{EMBED}, $V_{SUBSTRATE}$). $V_{BANKSTAB}$ requires the measurement of the number of feet of eroded channel bank that potentially contribute fine sediment to the stream channel. All variables should be recorded in English units on the data form. During periods of leaf fall or snow, brushing leaves and snow out of the way to accurately measure assessment variables may be required to examine the stream channel and adjacent areas below these materials.

The data sheets are available as Excel spreadsheets, which can be printed and taken into the field. They are also calculators, and entering the data into them will automatically calculate averages, variable subindex scores, and functional capacity indices. The directions below also allow for the manual calculation of all parameters.

Channel Canopy Cover ($V_{CCANOPY}$)

$V_{CCANOPY}$ is the average percent cover of the canopy over the stream channel. Channel Canopy Cover measurements are collected in the same way as for headwater streams. Use the following procedure to measure $V_{CCANOPY}$:

1. Using a densitometer, spherical crown densiometer, or equivalent device designed for estimating percent canopy cover, estimate the amount of sky obscured by vegetation cover while standing in the stream channel within the SAR. Follow all manufacturers' instructions. Only the contribution from leaves, branches, and other vegetation constituents should be included in

the measurement. Do not include shadows from surrounding hills or manmade structures when estimating percent canopy cover. Measurements should reflect all canopy cover regardless of source (e.g., trees, saplings, shrubs).

2. Examine the sky directly above.
3. Estimate the percentage of the canopy above that is obscured by tree branches and leaves. Estimating percent canopy cover can be difficult in winter when there are no leaves on the trees. However, with practice a reasonable estimate can be made by visualizing the trees with leaves. If necessary, revisit the site when the trees have leaves.
4. Record percent Channel Canopy Cover on the data sheet.
5. Measure canopy cover a minimum of ten times at locations approximately evenly spaced along the SAR. Longer SARs or those with a diverse canopy may require additional data points.
6. Average all of the estimates of percent canopy cover.
7. Using Figure 10, determine the subindex score for $V_{CCANOPY}$.

Substrate Embeddedness (V_{EMBED})

V_{EMBED} is the average embeddedness value of the stream substrate. Embeddedness is a measure of the degree to which coarse substrates (e.g., gravel, cobble, and boulders) are covered, surrounded, or buried by fine sediments. Fine sediments include sand, silt, and clay sized (≤0.08 in. (0.2 cm)) particles. The purpose of V_{EMBED} and $V_{SUBSTRATE}$ are to characterize the substrate of the channel. Use the following procedure to measure V_{EMBED}:

1. Embeddedness is measured concurrently with $V_{SUBSTRATE}$ using the same substrate particle.
2. At 60 or more evenly spaced points along the length of the SAR, randomly select (i.e., blind) a substrate particle. For example, with eyes closed, reach into the stream and evaluate the first particle (e.g., sand, silt, clay, gravel, cobble, or boulder) that is touched. It is important not to intentionally select substrate particles only from pools, runs, center of the channel, or other channel feature. Before each particle is removed and measured for size, visually estimate the percentage of the particle that is covered, surrounded, or buried with fine materials, and assign the appropriate rating using Table 8.

Table 8. Embeddedness rating for gravel, cobble, and boulder sized particles (rescaled from Platts et al. 1983).

Rating	Rating Description
5	<5 percent of surface covered, surrounded, or buried by fine sediment (or bedrock)
4	5 to 25 percent of surface covered, surrounded, or buried by fine sediment
3	26 to 50 percent of surface covered, surrounded, or buried by fine sediment
2	51 to 75 percent of surface covered, surrounded, or buried by fine sediment
1	>75 percent of surface covered, surrounded, or buried by fine sediment (or artificial substrate)

3. Substrate particles consisting of sand, silt, and clay receive an embeddedness score of one. Concrete or other artificial substrate would also receive an embeddedness score of one. Areas of bedrock receive an embeddedness score of five.
4. Using Table 6, record the embeddedness rating on the datasheet. Do not record the percent embeddedness.
5. Average the embeddedness rating score for all substrate particles measured.
6. Using Figure 14, determine the subindex score for V_{EMBED}.

Channel Substrate Size($V_{SUBSTRATE}$)

$V_{SUBSTRATE}$ is the median size of the stream substrate. Use the following procedure to measure $V_{SUBSTRATE}$:

1. Using the same particles selected for V_{EMBED}, measure to the nearest 0.1 in. (3 mm) the size of the particle along the longitudinal (intermediate) axis (See Appendix B).
2. Bedrock should be counted as 99 in. (251 cm).
3. Concrete or asphalt should be counted as zero.
4. Sand or finer sized particles can be recorded as 0.08 in. (0.2 cm).
5. Calculate the median value for all particles measured.
6. Using Figure 17, determine the subindex score for $V_{SUBSTRATE}$:

Streambank Stability ($V_{BANKSTAB}$)

$V_{BANKSTAB}$ incorporates three elements of bank stability measurements, including (1) bank erosion length, (2) height category of eroded bank (Table 9), and (3) length of artificial stream bank stabilization. Eroded stream banks are often vertical, ranging from a few inches to several feet high, and have little or no vegetative or detrital cover. Exposed roots along the stream bank can help identify eroded areas. Do not include erosion below bankfull stage (Appendix B), or undercut banks that have a stable overhang of roots and soil and no evidence of active collapse. Use the following procedure to measure $V_{BANKSTAB}$:

1. While standing in the channel of the SAR, identify bankfull stage for each side of the stream (Figure 45, Appendix B).
2. Lay a measuring tape along the stream thalweg (i.e., deepest part of the stream channel) for the entire length of the stream assessment reach.
3. Identify each portion of stream bank that displays erosion above bankfull stage, or is artificially stabilized with riprap, gabions, wood, or other structures.
4. For each section of eroded bank identified, place the bottom of a ruler at bankfull stage and measure the height of erosion (ft) from bankfull stage up (Figure 45). Use the measurement to assign the section of stream bank to one of the categories shown in Table 9. If multiple erosion height categories are observed, measure these areas as separate sections of stream bank. Artificial bank stabilization is assigned a separate category, and it is not necessary to measure height of bank stabilization.
5. Using the measuring tape in the stream thalweg, measure the length of erosion or bank stabilization for each eroded or stabilized section of stream bank along with height category (Figure 45). Separately record the number of feet of left channel bank erosion or stabilization and right channel bank erosion or stabilization on the data sheet.
6. For each section of eroded or stabilized stream bank, multiply the length of erosion in feet by the erosion multiplier shown in Table 9.
7. Sum the weighted erosion lengths, and divide by the length of the stream channel; then multiply by 100 (Equation 14).
8. Use Figure 21 to determine the subindex score for $V_{BANKSTAB}$.

Table 9. Erosion height rating for calculating Streambank Stability in perennial streams.

Height of erosion above bankfull stage (ft)	Height category	Erosion multiplier
0.1–2	1	0.5
2.1–4	2	0.7
>4	3	1
Artificial Bank Stabilization	4	0.5

$$\text{Streambank Stability} = 100\left(\frac{\sum_{i=1}^{n}\left(\text{bank length}_i \times \text{erosion multiplier}_i\right)}{\text{SAR length}}\right) \tag{14}$$

Figure 45. Examples of $V_{BANKSTAB}$ measurements, clockwise from top left: (a) laying measuring tape along stream thalweg in preparation for measuring erosion length; (b) measurement of eroded bank length; (c) determination of erosion height above bankfull stage: horizontal line indicates bankfull stage, vertical arrow indicates height of erosion above bankfull stage; (d) measurement of erosion height above bankfull stage: horizontal line indicates bankfull stage.

Riparian / Buffer Zone Variables for Perennial Streams

Data for V_{LWD} is collected within the entire riparian/buffer zone of perennial streams, extending 50 ft from each bank of the stream, as well as within the stream channel (Figure 42). Data for vegetation variables (V_{TDBH}, V_{TDEN}, and V_{CVALUE}) are collected within at least four 21-ft-radius (0.032-acre) subplots within the riparian/buffer zone. Subplots that are representative of current conditions within the riparian/buffer zone should be selected. For example, a site with a road within 50 ft of the stream channel may have one or more subplots that partially or fully encompass the road. Ideally two subplots should be placed on either side of the stream, but if one side of the stream is inaccessible (e.g., extremely steep terrain), it may be necessary to place all four subplots on one side of the stream. The data from all subplots are combined to determine the subindex score for each variable.

Large Woody Debris (V_{LWD})

V_{LWD} is the number of individual pieces of down woody stems per 100 feet of SAR within the channel and riparian/buffer zone. Large Woody Debris is defined as down woody stems ≥4 in. (10 cm) in diameter and ≥36 in. (91.4 cm) long. Use the following procedure to measure V_{LWD}:

1. Count each individual piece of Large Woody Debris along the entire SAR. This includes all Large Woody Debris located in the riparian/buffer zone extending 50 ft from each stream bank and within the stream channel. In some cases, pieces of Large Woody Debris will extend outside the riparian/buffer zone. Pieces extending outside the riparian/buffer zone should be counted if a section at least 36 in. (91.4 cm) long and 4 in. (10 cm) in diameter extends into the riparian/buffer zone. Distinct pieces of Large Woody Debris located within logjams or piles should be counted individually. Sections of downed wood or logs that are broken, but are obviously sections of the same tree, should be counted as one piece.
2. Record the total number of Large Woody Debris on the data sheet.
3. Divide the total number of Large Woody Debris by the length of the SAR, and then multiply by 100 to determine the number of Large Woody Debris per 100 feet of SAR.
4. Use Figure 24 to determine the subindex score for V_{LWD}.

Riparian/Buffer Zone Tree Diameter (V_{TDBH})

V_{TDBH} is the average diameter at breast height (DBH) per plot for trees within at least four 21-ft-radius, 0.032-acre subplots in the riparian/buffer zone. DBH is measured at 55 in. (1.4 m) above the ground. For the purpose of this guidebook, a tree is defined as a living, woody plant with DBH ≥4 in. (10 cm). Use the following procedure to measure V_{TDBH}:

1. Select four 21-ft-radius, 0.032-acre subplots within 50 ft of the channel edge for sampling.
2. Measure the DBH of all trees within each subplot, including any trees that occur in the stream channel of the SAR. Measurements should be made using tree calipers, DBH tape, or equivalent device. The National Forestry Handbook (NRCS 2004) provides information regarding tools and

methods for measuring tree diameter. All manufacturers' instructions should be followed. The tree should be measured if any part of the stem is within the sample area.

3. Calculate the average tree diameter in each plot by summing DBH measurements and dividing by the total number of trees measured. Sum the DBH plot averages, and divide by four to determine average DBH for the stream reach.
4. Use Figure 27 to determine the subindex score for V_{TDBH}.

Riparian/Buffer Zone Tree Density (V_{TDEN})

V_{TDEN} is the average density (trees/acre) of trees in the riparian/buffer zone. Trees are defined as living, woody plants with DBH ≥4 in. (10 cm). This variable is collected during measurement of Riparian/Buffer Zone Tree Diameter (V_{TDBH}). Use the following procedure to measure V_{TDEN}:

1. Sum the total number of trees measured across all four 21-ft radius subplots during Tree Diameter measurements.
2. Divide the total number of trees by 0.13 acres to determine the number of trees per acre.
3. Use Figure 28 to determine the subindex score for V_{TDEN}.

Riparian/Buffer Zone Coefficient of Conservatism (V_{CVALUE})

V_{CVALUE} is the average of published Coefficients of Conservatism (C-values) for all trees ≥4 in. DBH within the 0.032-acre sampling subplots described above (West Virginia Natural Heritage Program 2012). A C-value of 0.0 is assigned to any non-native species occurring in any strata (i.e., herbaceous, shrub, sapling, tree, and vine). Use the following procedure to measure V_{CVALUE}:

1. Within the 0.032-acre subplots described above, list each species encountered for trees ≥4 in. DBH. List each species only once. Also, list any non-native species in the entire riparian buffer zone regardless of stratum.
2. Use Tables B4 and B5 to determine the C-value for each species listed, or select each species in the dropdown menu on the data form.
3. C-values for any additional tree species not found on Table B1 may be found in Rentch and Anderson (2006); if the species is not found in Table B1 or in available literature, it should not be assigned a C-value. Any non-native species not found on Table B2, including agricultural cultivars, should be assigned a C-value of 0.0.

4. Calculate the average C-value across all subplots. The number of trees of each species present does not affect average C-value.
5. Use Figure 34 to determine the subindex score for V_{CVALUE}.

Watershed Variable for Perennial Streams

Data gathered within watersheds of perennial streams is interpreted from aerial photos or GIS data, and verified during field reconnaissance of the area surrounding the riparian/buffer zone and within the watershed of the perennial stream.

Watershed Forested Area (V_{FOREST})

V_{FOREST} is the percent cover of forested area within the watershed above the lowest point of the SAR that provides water to the perennial stream. Use the following procedure to measure V_{FOREST}:

1. Use topographic maps, GIS data, or other sources to delineate the watershed above the lowest point of the SAR (Appendix B, Figure B5). Do not include areas from which water is being diverted away from the SAR. Include any adjacent watershed areas from which water is being imported into the watershed.
2. Use GIS techniques or aerial photographs along with field reconnaissance to determine the percentage of forest cover in the watershed.
3. Use Figure 39 to determine the subindex score for V_{FOREST}.

Analyze the Data

Analyzing field data can be done manually or automatically using a spreadsheet. The first step in analyzing the field data is to transform the field measure of each assessment variable into a variable subindex on a scale of 0 to 1.0 using the graphs and tables in Chapter 2. The second step is to insert the variable subindices into the equations for each assessment function, and calculate the Hydrology, Biogeochemistry, and Habitat FCIs. Finally, multiply the FCI for each function by the total length of the SAR to calculate the number of Functional Capacity Units (FCUs) for each function (Smith et al. 1995).

Apply Assessment Results

Once the assessment and analysis phases are complete, the results can be used to compare the level(s) of function in the same SAR at different points in time or in different SARs at the same point in time. The information can be used to address the specific objectives identified at the beginning of the assessment, such as (a) determining project impacts, (b) comparing project alternatives, (c) determining mitigation requirements, and (d) evaluating mitigation success.

To evaluate project-related impacts, at least two assessments will generally be needed. The first assesses the number of FCUs provided by the stream reach in its pre-project condition. The second assesses the number of FCUs provided by the stream reach in a post-project state, based on proposed project plans and the associated changes to each of the variables. The difference between pre-project and post-project conditions, expressed in numbers of FCUs, represents the potential loss or gain of ecological function due to the project. Similarly, in a mitigation scenario, the difference between the current condition and future condition of a stream, with mitigation actions implemented and successfully completed, represents the potential gain in functional capacity as a result of restoration activities. However, since the mitigation project is unlikely to become fully functional immediately upon completion, a time lag must be incorporated in the analysis to account for the time necessary for the mitigation site to achieve full functional development.

For more information on the calculation of FCUs and their use in project assessments, see Smith et al. (1995 and 2013). Spreadsheets that can be used to help evaluate project impacts and estimate mitigation requirements are available on the web at http://el.erdc.usace.army.mil/wetlands/datanal.html. Frank Hanrahan developed the spreadsheets based on concepts presented by the U.S. Fish and Wildlife Service (1980) and King and Adler (1992). Examples of mitigation and the development of functional recovery trajectories for wetland restoration can be found in Klimas (2006).

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Appendix A: Glossary

Assessment equation: A model that defines the relationship between ecosystem and landscape scale variables and functional capacity of an ecosystem. The model is developed and calibrated using reference sites from a reference domain.

Assessment objective: The reason an assessment of ecological function is conducted. Assessment objectives normally fall into one of three categories: documenting existing conditions, comparing different sites at the same point in time (e.g., alternatives analysis), and comparing the same site at different points in time (e.g., impacts analysis or mitigation success).

Bankfull stage: The level of flow that fills the channel to the top of its banks, at the point where water begins to overflow onto the floodplain (Rosgen 1996).

Bedrock: Underlying geology of the stream channel. Many headwater streams are formed on bedrock channels where stream flow is confined to rock outcrops (Gordon et al. 2006).

Buffer zone: See riparian/buffer zone.

Diameter at breast height (DBH): Tree diameter measured at 4.5 ft (1.4 m) above the ground.

Direct measure: A quantitative measure of an assessment variable.

Embeddedness: An index used to measure the degree to which coarse substrates (e.g., boulders, large cobbles) are surrounded or buried by finer sediments (Gordon et al. 2006).

Ephemeral stream: A stream, or any portion thereof, that has flowing water only during, and for a short duration after, precipitation events in a typical year. Ephemeral stream beds are located above the water table year-round. Groundwater is not a source of water for the stream. Runoff from rainfall is the primary source of water for streamflow (Federal Register 2007). Ephemeral streams typically have flowing water for a few hours to a few days after a storm event and have no discernible floodplain. Ephemeral streams are typically first-order streams and are located near the upper edge of the headwater reach (Gordon et al. 2006).

Exotics: See Invasive species.

Floodplain: A relatively flat valley floor formed by the repeated influence of floods and overbank flow. Headwater streams display little or no floodplain topography (Gordon et al. 2006).

Functional assessment: The process by which the capacity of an ecosystem to perform a function is measured. This approach measures capacity using an assessment equation to determine a functional capacity index.

Functional capacity: The rate or magnitude at which an ecosystem performs a function. Functional capacity is dictated by characteristics of the ecosystem and the surrounding landscape, and interaction between the two.

Functional capacity index (FCI): An index of the capacity of an ecosystem to perform a function relative to other ecosystems in a regional subclass. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates the ecosystem is performing a function at the highest sustainable functional capacity, the level equivalent to an ecosystem under reference standard conditions in a reference domain. An index of 0.0 indicates the system does not perform the function at a measurable level and will not recover the capacity to perform the function through natural processes.

Functional capacity units (FCUs): Measure of functional capacity incorporating length of the assessment reach (FCU = FCI x length of assessment reach).

Headwater stream: The most upstream reach of a watershed or the section of stream channel furthest from the stream mouth. The headwaters are located near the upper edge of the watershed boundary, occupy V-shaped valleys, and encompass ephemeral and intermittent stream sections (Gordon et al. 2006).

Herbaceous layer: The lowest level of vegetative strata on a site made up of non-woody plant species (i.e., herbs). Herbaceous plants are defined as all plant materials on the ground layer ≤ 3 in. DBH and ≤ 36 in. tall. Herbaceous species do not include woody species ≤ 3 in. DBH and greater than 36 in. tall.

High-gradient stream: Streams with channel slopes greater than four percent slope. Typically, small first- and second-order systems located in the headwater regions of a watershed.

Indicator: Observable characteristics that correspond to identifiable variable conditions in a stream or the surrounding landscape.

Intermittent stream: A stream that has flowing water during certain times of the year when groundwater provides water for stream flow. During dry periods, intermittent streams may not have flowing water. Runoff from rainfall is a supplemental source of water for stream flow. These systems are typically located in the headwater region and flow only when they receive water from springs or surface water runoff. These streams are typically first- or second-order, and they are located below ephemeral stream segments near the upper edge of the watershed boundary (Gordon et al. 2006).

Invasive species: Generally, exotic species without natural controls that out-compete native species.

Mitigation: Restoration or creation of a stream reach to replace functional capacity that is lost as a result of project impacts.

Variable: A characteristic of the ecosystem or surrounding landscape that influences the capacity of an ecosystem to perform a function.

Organic matter: Plant and animal residue in the soil in various stages of decomposition.

Organic soil material: Soil material that is saturated with water for long periods or artificially drained and, excluding live roots, has an organic carbon content of 18 percent or more with 60 percent or more clay, or 12 percent or more organic carbon with zero percent clay. Soils with an intermediate amount of clay have an intermediate amount of organic carbon. If the soil is never saturated for more than a few days, it contains 20 percent or more organic carbon.

Perennial stream: A stream that has flowing water year-round during a typical year. Perennial streams are characteristically third-order or higher systems (Gordon et al. 2006).

Pool: A segment of a stream reach where water depths are greater than in the surrounding area, and streamflow velocity is reduced.

Project alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required, and other ways.

Project area: The area that encompasses all activities related to an ongoing or proposed project.

Red flag features: Features of a stream or surrounding landscape to which special recognition or protection is assigned based on objective criteria. The recognition or protection may occur at a federal, state, regional, or local level, and may be official or unofficial.

Reference domain: All streams within a defined geographic area that belong to a single regional subclass.

Reference standards: Conditions exhibited by a group of reference streams that correspond to the highest level of functioning (i.e., highest sustainable capacity) across the suite of functions of the regional subclass. By definition, the highest levels of functioning are assigned an index of 1.0.

Reference streams: Streams that encompass the variability of a regional subclass in a reference domain. Reference streams are used to establish the range of conditions for construction, calibration of functional indices, and reference standards.

Region: A geographic area that is relatively homogeneous with respect to large-scale factors such as climate and geology that may influence how streams function.

Riffle: A shallow stretch of stream where small rippled waves are formed above the stream channel substrate.

Riparian/buffer zone: A terrestrial area directly adjacent to the stream.

Runoff: Water flowing on the surface either by overland sheet flow or by channel flow in rills, gullies, streams, or rivers.

Sapling/shrub cover: A measurement of the abundance of sapling/shrubs. Sapling/shrub cover is a count of saplings or shrubs measured from ground level.

Sapling/shrub layer: For the purpose of this guidebook, the vegetation layer consisting of self-supporting woody plants greater than 39 in. (1 m) in height but less than 4 in. (10 cm) in diameter at breast height.

Soil surface: The soil surface is the top of the mineral soil; or, for soils with an O horizon, the soil surface is the top of the part of the O horizon that is at least slightly decomposed. Fresh leaf or needle fall that has not undergone observable decomposition is excluded from soil and may be described separately (Carlisle 2000).

Stratum/Strata: See vegetative stratum.

Stream assessment reach (SAR): A section of the stream within a project area that belongs to a single regional stream subclass, and is relatively homogeneous with respect to the site-specific criteria (e.g., hydrologic regime, vegetation structure, topography, soils, and successional stage) used to assess stream functions. For the purpose of this guidebook, SAR length is synonymous with thalweg length.

Stream bank erosion: Changes in the channel resulting in the removal of streambank/streambed materials due to frost action, flooding, trampling, vegetation removal, bulldozing, or other factors (Gordon et al. 2006). Erosion includes disturbed, scoured sections of stream bank that have exposed soil above or below the waterline.

Stream channel: The natural bed and banks formed by fluvial processes of accumulating/degrading mineral and organic materials. The natural depression that conveys water within defined banks.

Stream function: The normal activities or actions that occur in streams ecosystems, or simply, the things that streams do. Stream functions result directly from the characteristics of a stream ecosystem and the surrounding landscape and their interactions.

Stream order: Provides a means of ranking relative sizes of streams and drainage areas. First-order streams are small and normally dry, while larger, second-order streams are formed by the junction of two first-order streams; third-order streams are formed by the junction of two second-order streams (Gordon et al. 2006).

Stream reach: Representative homogenous units within a stream segment. A stream reach may encompass the entire length of an ephemeral stream, or may represent a subsection of the stream. Stream reaches are often comprised of riffles and pools, and are used to partition the stream into homogenous sections based on topography, geology, slope, streamflow, and biological characteristics (Gordon et al. 2006).

Subindex graphs: A graphical representation of parameter quality based on data collected within the reference domain. Subindex values can range from 0.0 to 1.0.

Substrate: The particles of organic and inorganic material located on the streambed (Gordon et al. 2006).

Thalweg: The line of lowest elevation within the stream channel.

Variable: An attribute or characteristic of an ecosystem or the surrounding landscape that influences the capacity of the ecosystem to perform a function.

Variable condition: The condition of a variable as determined through quantitative or qualitative measure.

Variable subindex: A measure of how an assessment variable in an ecosystem compares to the reference standards of a regional subclass in a reference domain.

Watershed: The geographic area above a specific point on a stream where surface water would flow or run off into the stream.

Appendix B: Supplementary Materials

This appendix contains additional guidance on measuring variables. It is designed to provide tools and direction to aid in collection of variables. The following pages contain:

1. Assessment variables and applicable ecological functions for headwater and perennial stream assessments (Table B1) – page 137
2. Comparison Charts for Visual Estimates of Channel Canopy Cover, Soil Detritus, and Herbaceous Cover - pages 138-139
3. Substrate Embeddedness – page 139
4. Substrate Size – page 140
5. Coefficients of Conservatism for Common Trees– pages 141-142
6. List of Common Invasive Species – pages 142-143
7. Watershed Land-use measurements – page 144
8. Definition and Identification of bankfull stage – page 146

Table B1. Assessment variables and applicable ecological functions for headwater and perennial stream assessments.

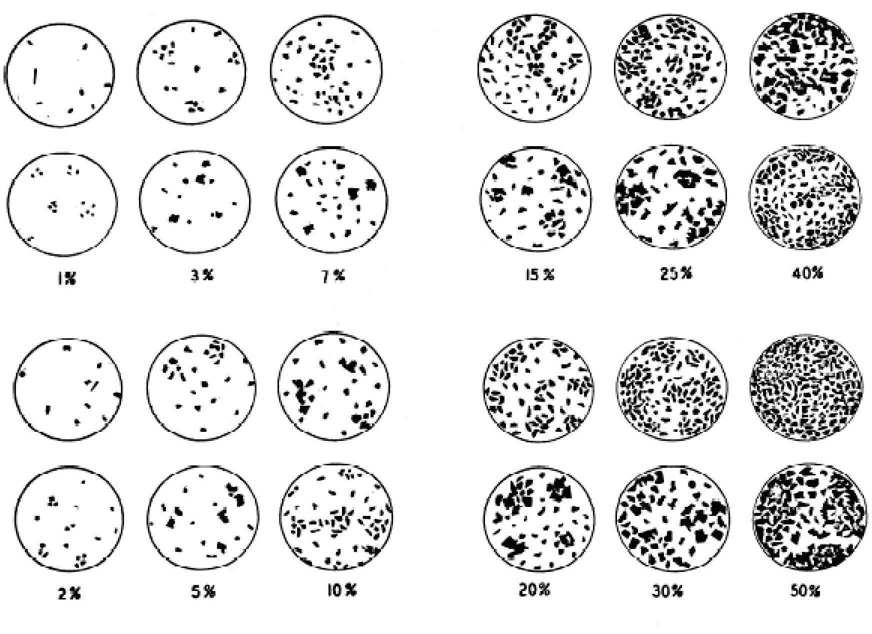
Variable	Headwater Stream Functions	Perennial Stream Functions
Channel Canopy Cover ($V_{CCANOPY}$)	Habitat	Biogeochemistry Habitat
Channel Substrate Embeddedness (V_{EMBED})	Hydrology Biogeochemistry Habitat	Hydrology Biogeochemistry Habitat
Channel Substrate Size ($V_{SUBSTRATE}$)	Hydrology Habitat	Hydrology Habitat Biogeochemistry
Channel Bank Erosion ($V_{EROSION}$)	Hydrology	not used
Streambank Stability ($V_{BANKSTAB}$)	not used	Hydrology
Large Woody Debris (V_{LWD})	Hydrology Biogeochemistry Habitat	Habitat
Riparian/Buffer Zone Tree Diameter (V_{TDBH})	Biogeochemistry Habitat	Habitat
Riparian/Buffer Zone Tree Density (V_{TDEN})	not used	Biogeochemistry
Riparian/Buffer Zone Snag Density (V_{SNAG})	Habitat	not used
Riparian/Buffer Zone Sapling/Shrub Density (V_{SSD})	Biogeochemistry Habitat	not used
Riparian/Buffer Zone Vegetation Species Richness (V_{SRICH})	Habitat	not used
Coefficient of Conservatism (V_{CVALUE})	not used	Habitat
Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$)	Biogeochemistry Habitat	not used
Riparian/Buffer Zone Herbaceous Cover (V_{HERB})	Biogeochemistry Habitat	not used
Watershed Land-use (V_{WLUSE})	Hydrology Biogeochemistry Habitat	not used
Watershed Forest Cover (V_{FOREST})	not used	Hydrology Biogeochemistry Habitat

Visual estimation of cover

The following charts and diagrams contain guidance on estimating percent cover values. The following tools can be used to aid in the estimation of Channel Canopy Cover ($V_{CCANOPY}$), Riparian/Buffer Zone Herbaceous Cover (V_{HERB}), Riparian/Buffer Zone Soil Detritus ($V_{DETRITUS}$), Watershed Land-Use (V_{WLUSE}), and Watershed Forest Cover (V_{FOREST}). The estimation of cover can be difficult and requires practice to achieve repeatable results. The tools provided below can be used to improve accuracy and repeatability.

Figure B1. Comparison charts for estimation of foliage cover for use in measuring $V_{CCANOPY}$ and V_{HERB}.

Comparison Charts for Visual Estimation of Foliage Cover[1]



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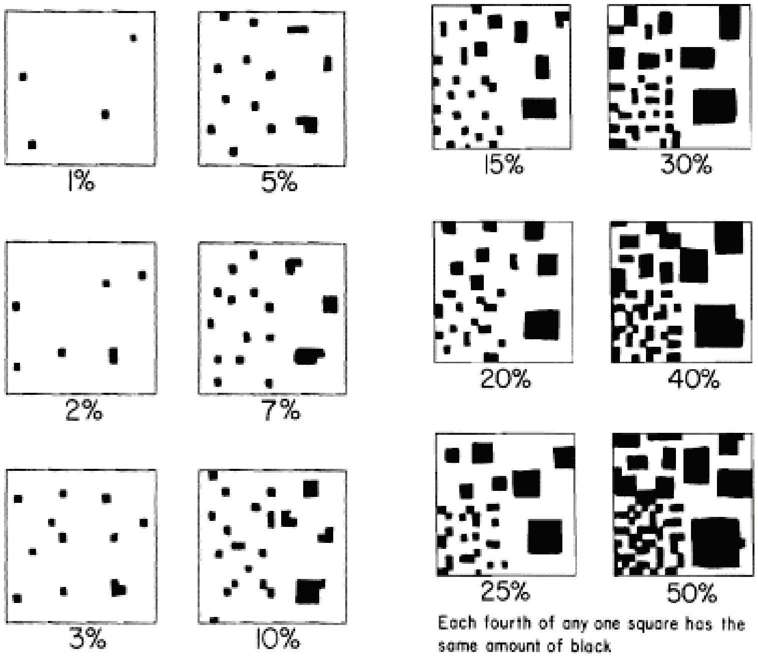
[1] Developed by Richard D. Terry and George V. Chilingar. Published by the Society of Economic Paleontologists in its *Journal of Sedimentary Petrology* 25(3): 229-234, September 1955.

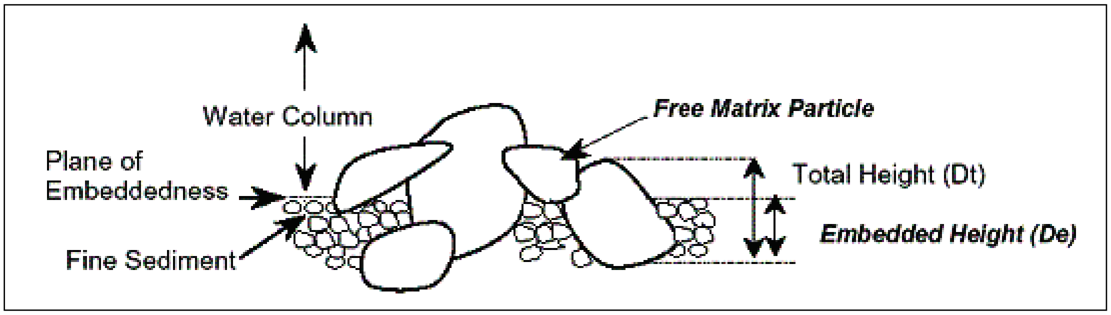
Figure B2. Visual estimates of cover (from Gretag/Macbeth 2000).



Measuring substrate embeddedness

Embededdness can be defined as the degree that larger particles (e.g., boulders, cobble, gravel) are surrounded or covered by fine sediment, or “the amount of fine sediment that is deposited in the interstices between larger stream substrate particles. Embeddedness values are estimated as a percent and recorded on a scale based on the work of Platts et al. (1983). For additional guidance on measuring embeddedness, see "Techniques for measuring substrate embeddedness" Sylte and Fischenich (2002), (http://www.wes.army.mil/el/emrrp).

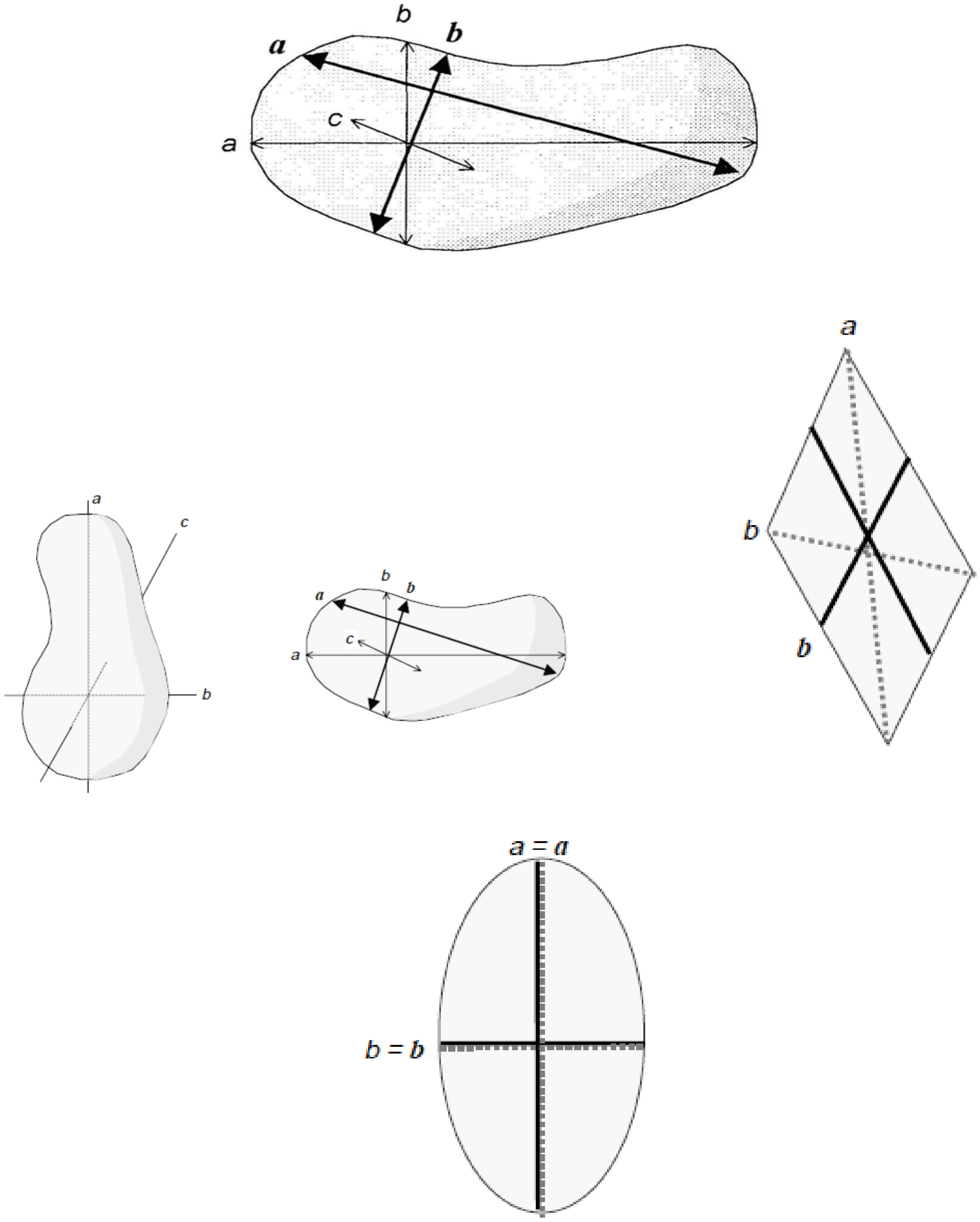
Figure B3. Schematic representation of embeddedness.



Measuring substrate size

Stream particle size (substrate size) is measured according to the procedures outlined in Chapter 3. The axis of measurement is displayed in the following figures. In all cases, the substrate should be measured along the median axis. This axis is represented by axis-b in the following illustrations.

Figure B4. Diagrams of the b-axis measurement of a given stream substrate particle for use in the Wolman Pebble Count method (Bunte and Abt 2001).



Vegetation C-values and Non-native species

Table B2 provides C-values ranging from 0-10 for common tree species found within the reference domain, along with C-values for use in the variable V_{CVALUE}. C-values for additional species can be found in Rentch and Anderson (2006). Table B3 provides a list of common non-native plant species within the reference domain. All non-native species receive a C-value of zero.

Table B2. Coefficients of Conservatism for common tree species.

Common Name	Scientific Name	C-value
boxelder maple	*Acer negundo*	2
black maple	*Acer nigrum*	7
red maple	*Acer rubrum*	3
sugar maple	*Acer saccharum*	6
yellow buckeye	*Aesculus flava*	7
common serviceberry	*Amelanchier arborea*	6
pawpaw	*Asimina triloba*	5
yellow birch	*Betula alleghaniensis*	7
sweet birch	*Betula lenta*	5
river birch	*Betula nigra*	5
American hornbeam	*Carpinus caroliniana*	5
mockernut hickory	*Carya alba*	6
bitternut hickory	*Carya cordiformis*	5
pignut hickory	*Carya glabra*	6
shagbark hickory	*Carya ovata*	6
eastern redbud	*Cercis canadensis*	5
flowering dogwood	*Cornus florida*	5
American Beech	*Fagus grandifolia*	6
white ash	*Fraxinus americana*	5
butternut	*Juglans cinerea*	7
black walnut	*Juglans nigra*	5
sweetgum	*Liquidambar styraciflua*	5
yellow poplar	*Liriodendron tulipifera*	5
cucumbertree	*Magnolia acuminata*	8
Frasier magnolia	*Magnolia frasieri*	9
bigleaf magnolia	*Magnolia macrophylla*	8
umbrella magnolia	*Magnolia tripetala*	7

Common Name	Scientific Name	C-value
red mulberry	*Morus rubra*	6
blackgum	*Nyssa sylvatica*	6
eastern hophornbeam	*Ostrya virginiana*	7
sourwood	*Oxydendrum arboreum*	5
red spruce	*Picea rubens*	8
eastern white pine	*Pinus strobus*	6
American sycamore	*Platanus occidentalis*	5
black cherry	*Prunus serotina*	3
white oak	*Quercus alba*	5
scarlet oak	*Quercus coccinea*	6
pin oak	*Quercus palustris*	5
northern red oak	*Quercus rubra*	6
black oak	*Quercus velutina*	6
black locust	*Robinia pseudoacacia*	2
black willow	*Salix nigra*	2
American basswood	*Tilia americana*	7
eastern hemlock	*Tsuga canadensis*	8
American elm	*Ulmus americana*	5
slippery elm	*Ulmus rubra*	4

Table B3. List of common invasive species

Common Name	Scientific Name	C-value
tree of heaven	*Ailanthus altissima*	0
silktree/mimosa	*Albizia julibrissin*	0
garlic mustard	*Alliaria petiolata*	0
porcelain berry	*Ampelopsis gladulosa var brevipedunculata*	0
coralberry	*Ardisia crenata*	0
common wormwood	*Artemisia vulgaris*	0
Japanese barberry	*Berberis thunbergii*	0
butterfly bush	*Buddleja davidii*	0
northern catalpa	*Catalpa speciosa*	0
Oriental bittersweet	*Celastrus orbiculatus*	0
crown vetch	*Coronilla varia*	0
wild carrot	*Daucus carota*	0
chinese yam	*Dioscorea opposita*	0
autumn olive	*Elaeagnus umbellata*	0

Common Name	Scientific Name	C-value
winged euonymus	*Euonymus alatus*	0
creeping Eunonymus	*Euonymus fortunei*	0
Japanese knotweed	*Fallopia japonica*	0
tall fescue	*Festuca arundinacea*	0
ground ivy	*Glechoma hederacea*	0
daylilly	*Hemerocallis sp*	0
rose of Sharon	*Hibiscus syriacus*	0
St. John's wort	*Hypericum perforatum*	0
shrub lespedeza	*Lespedeza bicolor*	0
sericea lespedeza	*Lespedeza cuneata*	0
border privet	*Ligustrum obtusifolium*	0
Japanese honeysuckle	*Lonicera japonica*	0
honeysuckle bush	*Lonicera maackii*	0
Morrow honeysuckle	*Lonicera morrowii*	0
golden creeping jenny	*Lysimachia nummularia*	0
Nepalese browntop	*Microstegium vimineum*	0
Chinese silvergrass	*Miscanthus sinensis*	0
panicum grass	*Panicum sp.*	0
dallisgrass	*Paspalum dilatatum*	0
princesstree	*Paulownia tomentosa*	0
beefsteak plant	*Perilla frutescens*	0
mahaleb cherry	*Prunus mahaleb*	0
kudzu	*Pueraria montana*	0
multiflora rose	*Rosa multiflora*	0
wineberry	*Rubus phoenicolasius*	0
white willow	*Salix alba*	0
Johnsongrass	*Sorghum halepense*	0
coltsfoot	*Tussilago farfara*	0
moth mullein	*Verbascum blattaria*	0
common mullein	*Verbascum thapsus*	0
periwinkle	*Vinca minor*	0

Watershed Land-use (V_{WLUSE}) and Percent Forest (V_{FOREST})

The following examples show how to estimate the weighted average land-use index for V_{WLUSE} and the percent cover of forest for V_{FOREST}.

For the variable V_{WLUSE} in headwater streams, identify the different land-use types within the watershed of the SAR using recent aerial photography. Estimate the percentage of the watershed in each land-use type (Figure B5),and verify during onsite reconnaissance. Use the spreadsheet provided (example given below) to calculate the functional index score for V_{WLUSE}.

Figure B5. Aerial photograph illustrating the cover types found within a headwater stream watershed, used for calculation of the variable V_{WLUSE}.

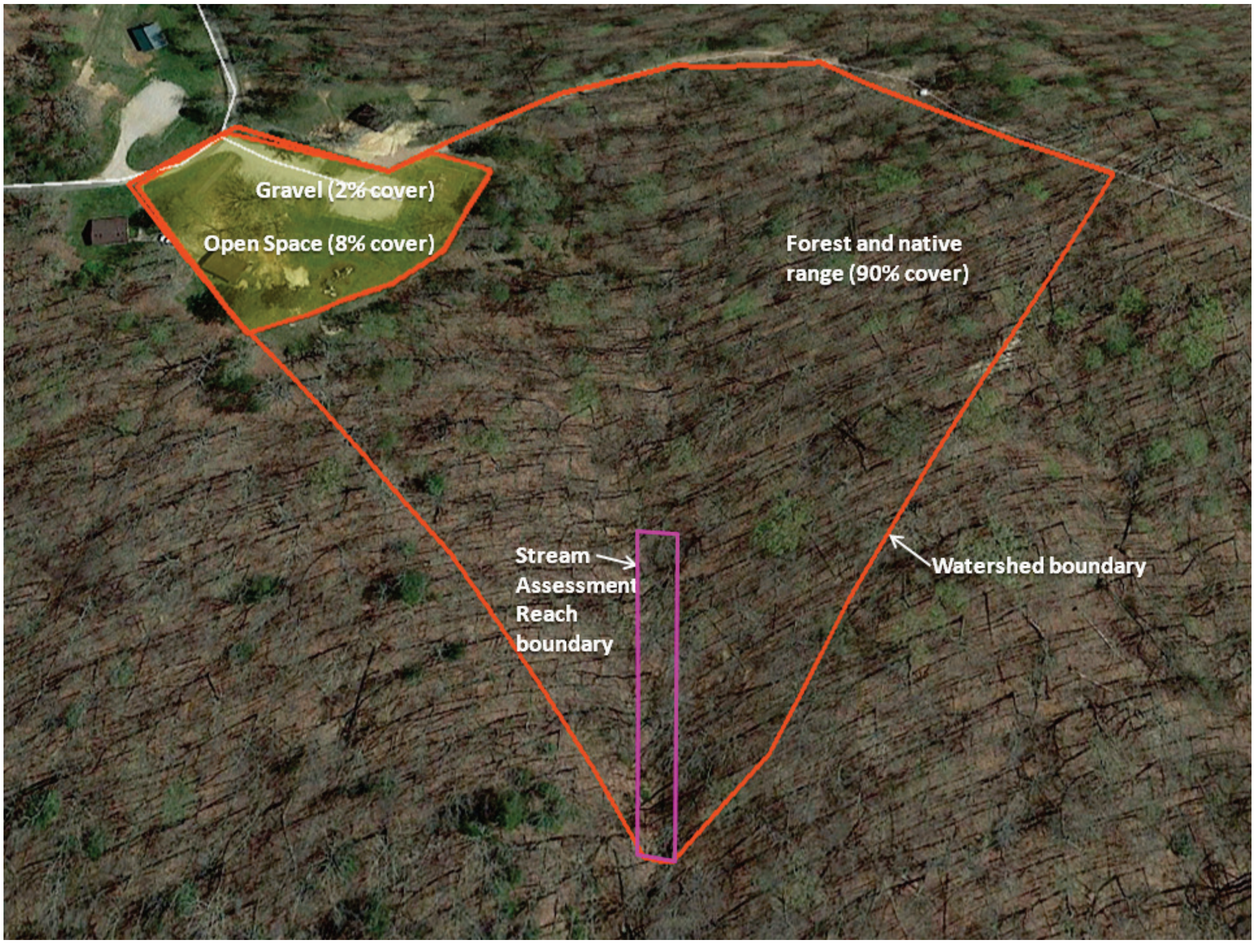
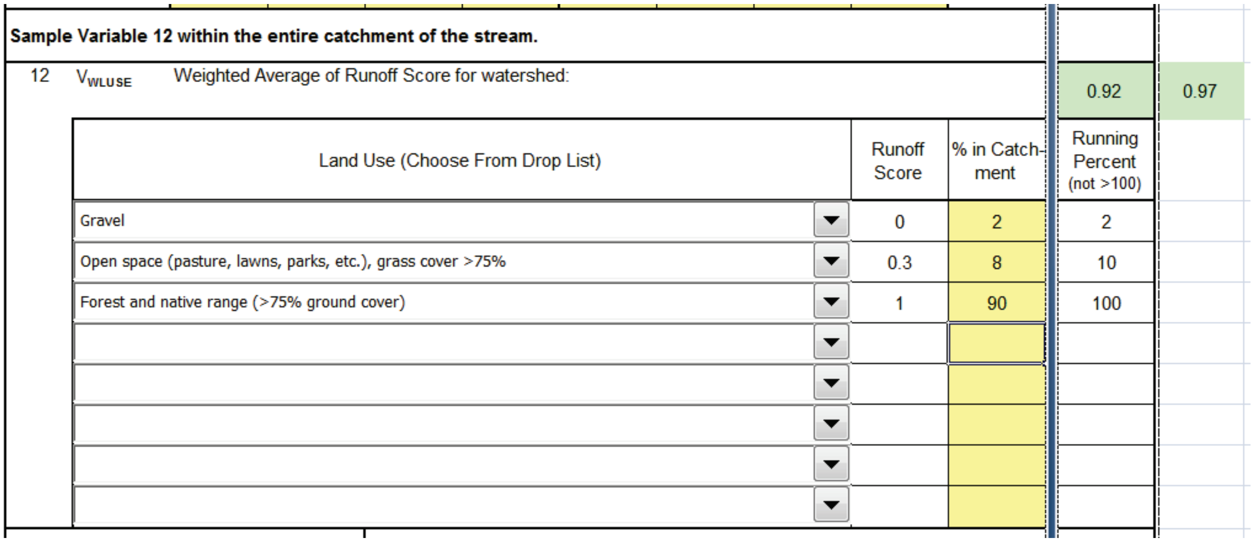


Figure B6. Excel calculator for entering percent cover of each land use type within a headwater watershed when calculating the variable *V_{WLUSE}*



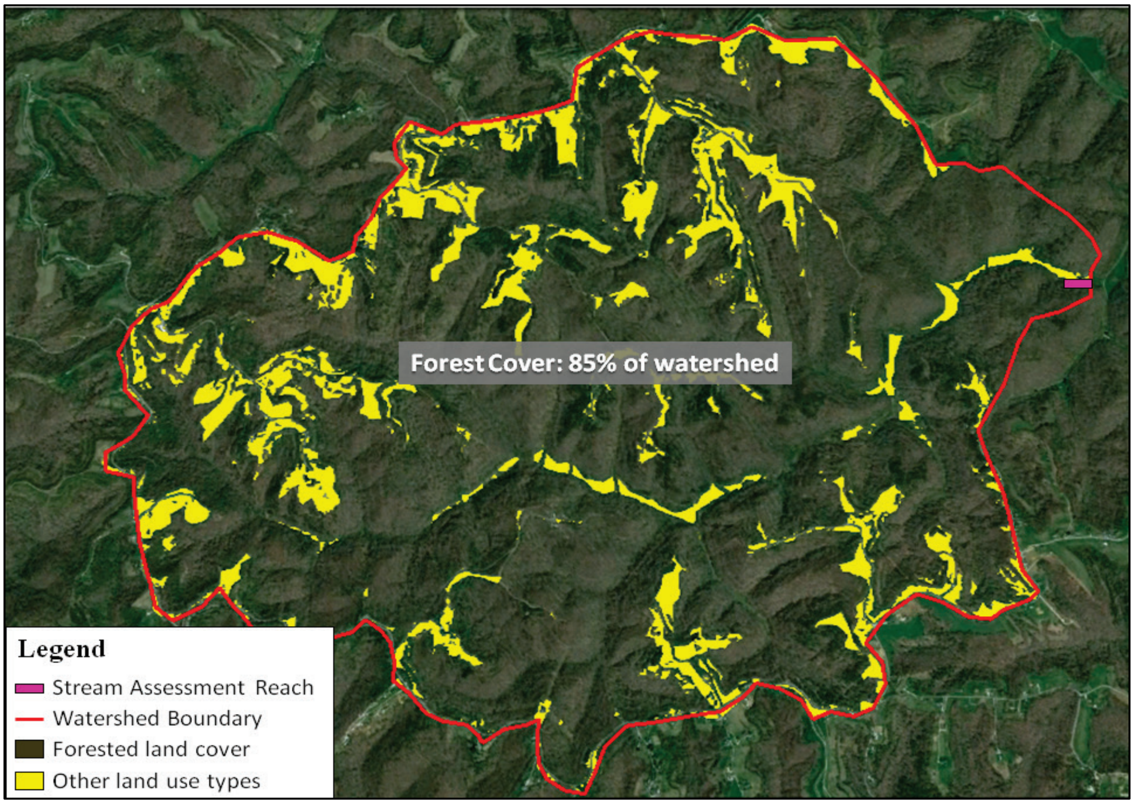
Sample Variable 12 within the entire catchment of the stream.

12 V_{WLUSE} Weighted Average of Runoff Score for watershed: 0.92 0.97

Land Use (Choose From Drop List)	Runoff Score	% in Catchment	Running Percent (not >100)
Gravel	0	2	2
Open space (pasture, lawns, parks, etc.), grass cover >75%	0.3	8	10
Forest and native range (>75% ground cover)	1	90	100

For the variable *V_{FOREST}* in perennial streams, visually identify the percent cover of forest within the watershed of the SAR using recent aerial photography (Figure B7), or use an existing land cover data set. Verify percent cover during onsite reconnaissance.

Figure B7. Aerial photograph illustrating calculation of percent forest cover for the variable *V_{FOREST}* in a perennial stream watershed.



Definition and Identification of Bankfull Stage

The following procedure is used to identify bankfull stage in perennial streams. Accurate determination of the bankfull channel edge is important for measuring erosion height above bankfull stage when recording the variable $V_{BANKSTAB}$ in perennial stream assessments.

Bankfull stage is defined as the level of flow that fills a stream channel to the top of its banks, at the point where water begins to overflow onto the floodplain (Rosgen 1996). When hydrology is relatively stable, stream systems tend to develop equilibrium between flow and channel size, such that the channel contains the stream flow under most flow conditions. In most unaltered streams, flow exceeds bankfull stage and overflows onto the floodplain on an average of every 1–2 years, and average stream discharge fills only about 1/3 of the channel (Leopold et al. 1964).

Multiple field indicators should be used to identify bankfull stage whenever possible. Harrelson et al. (1994) and Rosgen (1996) provide resources for information regarding indicators of bankfull stage. The following procedure, along with the following potential field indicators, can be used to aid in identifying bankfull stage in perennial streams (Figure B8):

1. For streams with well-developed floodplains, bankfull stage is identified as the elevation of the lowest part of the floodplain.
2. When depositional features such as point bars exist, the elevation at the top of the highest point bars will be the same as the elevation at bankfull stage (Figure B8(a)).
3. A break in the slope of banks can often be observed at bankfull stage (Figure B8(b), B8(c), B8(d)).
4. Particle size often changes at bankfull stage, with coarser particles within the channel and finer particles deposited above bankfull stage during flood events (Figure B8(b), B8(c), B8(d), B8(e)).
5. Small benches may be evident at bankfull stage as a result of inundation.
6. A line of riparian vegetation or lichens may be evident at bankfull stage. It is useful to be aware of recent flood or drought history, because riparian vegetation (e.g., grasses) may begin to colonize the stream channel during drought. For this reason, perennial and woody vegetation are more reliable indicators of bankfull stage.
7. Rock staining may occur within the active channel and end at bankfull stage.

8. Roots and root hairs may be exposed within the active channel. These should not be confused with exposed roots resulting from erosion above bankfull stage.
9. In some cases it may be easier to identify bankfull stage on one side of the channel than the other, and the elevation of bankfull stage can be identified on one side and extrapolated to the other side of the stream using a level line or laser level (Figure B8(f)). A common example within the reference domain is a well-developed floodplain on one side of the stream with a steep valley wall on the opposite side (Figure B8(a)).

Figure B8. Examples of bankfull stage, clockwise from top left (red lines indicate bankfull stage in each photo): (a) highest point of depositional features is the same elevation as bankfull stage, which corresponds with the top of a small bench on the right side of the stream and the edge of riparian vegetation; (b) bankfull stage indicators are a break in the slope of the bank, the edge of the riparian vegetation line, and a change in particle size; (c) a stream which is deeply entrenched and likely cut off from the floodplain; bankfull stage indicators are a break in slope and a change in particle size; (d) a stream with high erosion above bankfull stage; bankfull stage indicators are a break in slope, a change in particle size, and the edge of herbaceous vegetation; (e) bankfull stage indicators are the top of a point bar on the right side of the stream and a change in particle size (this photo was taken during a dry period; note that herbaceous vegetation has become established within the active channel);(f) a stream with high-wall erosion on one side of the channel; the elevation at the top of the point bar on the left side of the channel can be used to identify bankfull stage on the right side.

Appendix C: Headwater Tree Species

This appendix provides photos of all tree species used to calculate the variable V_{SRICH} (Table 3) in the riparian/buffer zone of headwater streams, and common tree species used to calculate VCVALUE for perennial streams. Species are alphabetically listed. Photos are provided courtesy of the University of Tennessee Herbarium (2015) unless otherwise noted.

For further information on tree identification, a large number of field guides and other resources exist, including Nelson et al. (2014), Petrides (1998), Sibley (2009), and Williams (2007).

Figure C1. Yellow buckeye (*Aesculus flava*): (a) leaf;(b) and (c) fruit; (d) leaf bud.

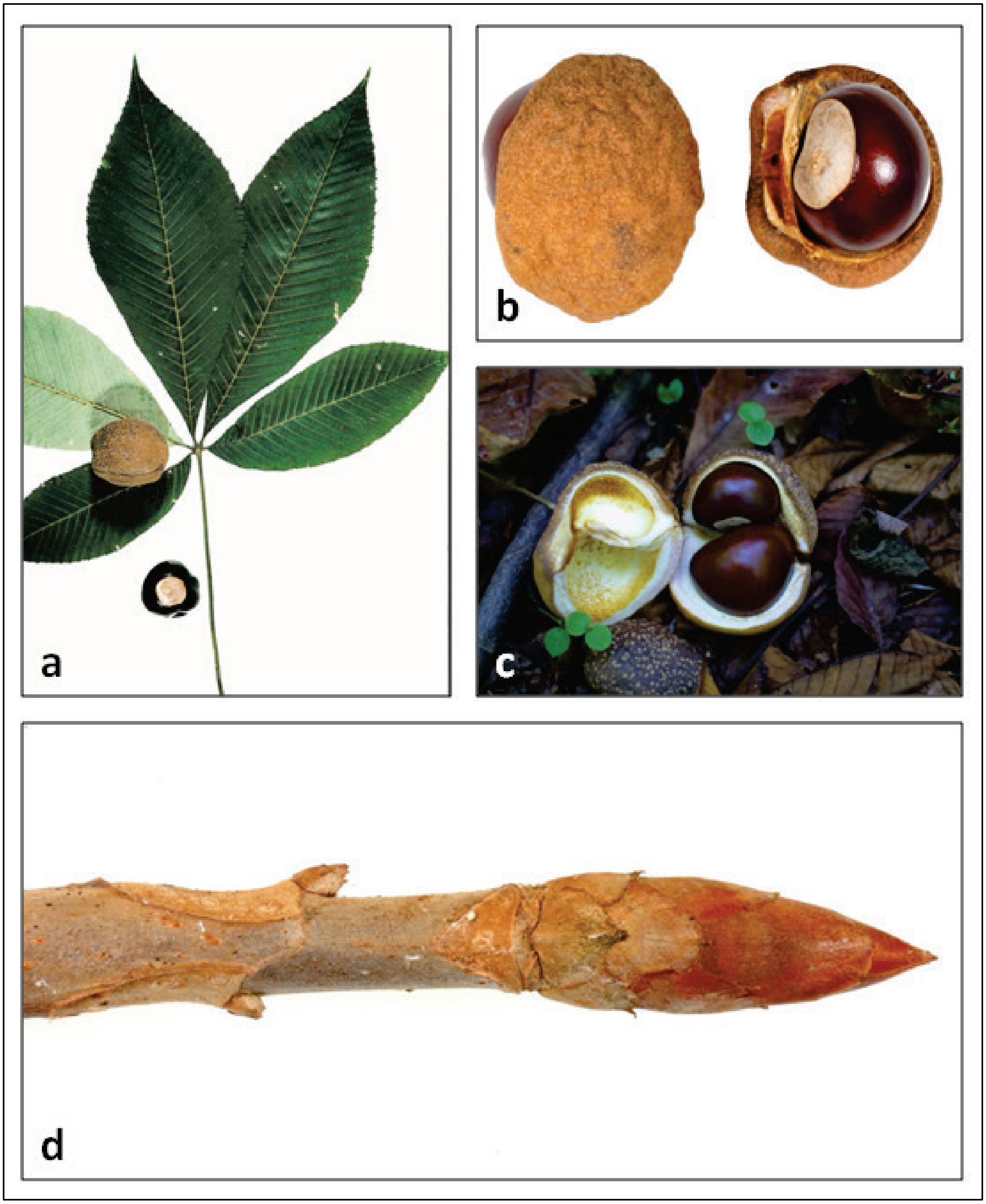


Figure C2. Striped maple (*Acer pensylvanicum*): (a) leaves; (b) bark pattern; (c) flower; (d) leaf buds.

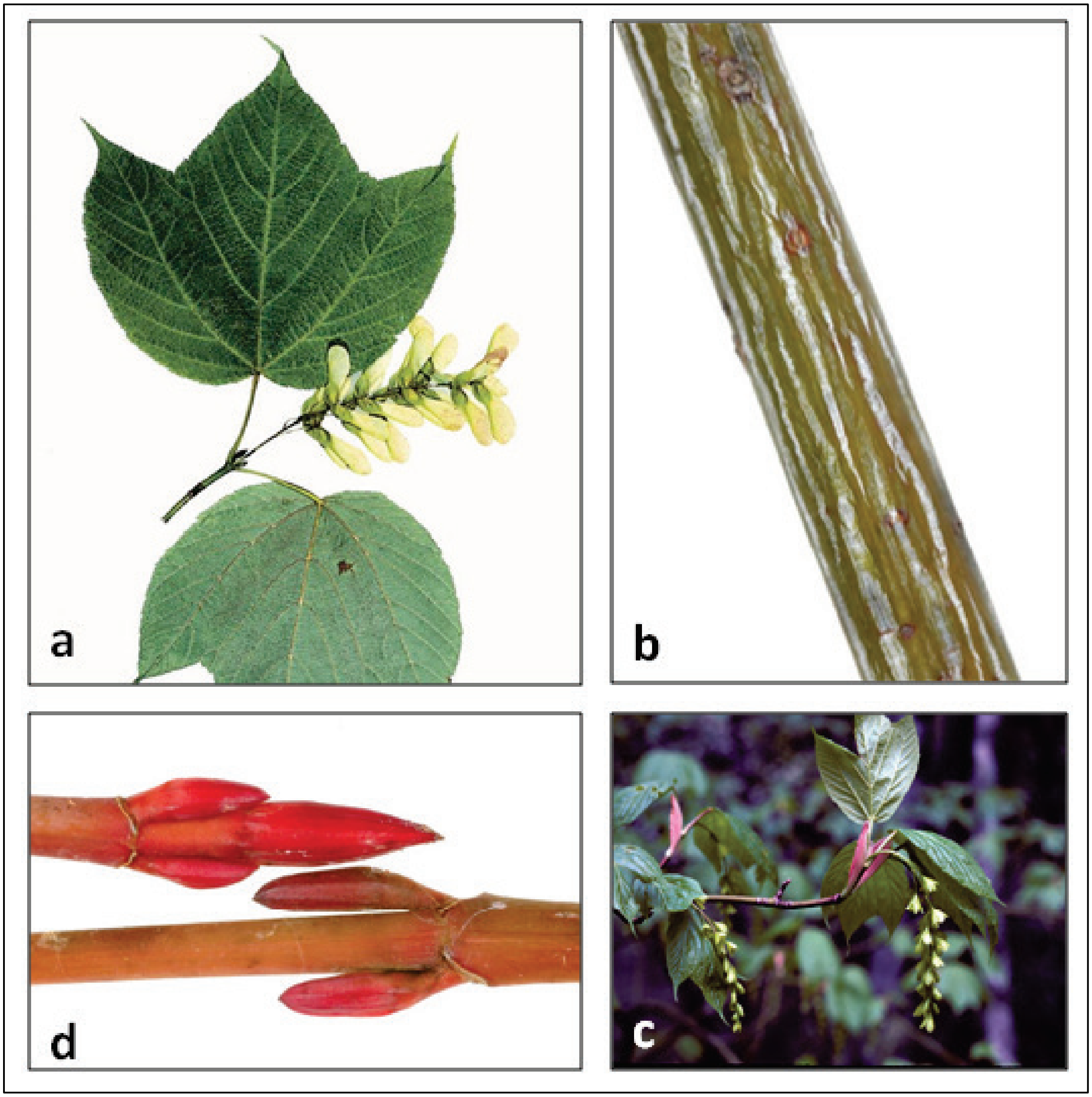


Figure C3. Red maple (*Acer rubrum*): (a) leaves displaying red petioles;(b) twig displaying opposite leaf buds at nodes; (c) flower; (d) fruit; (e) leaf bud.

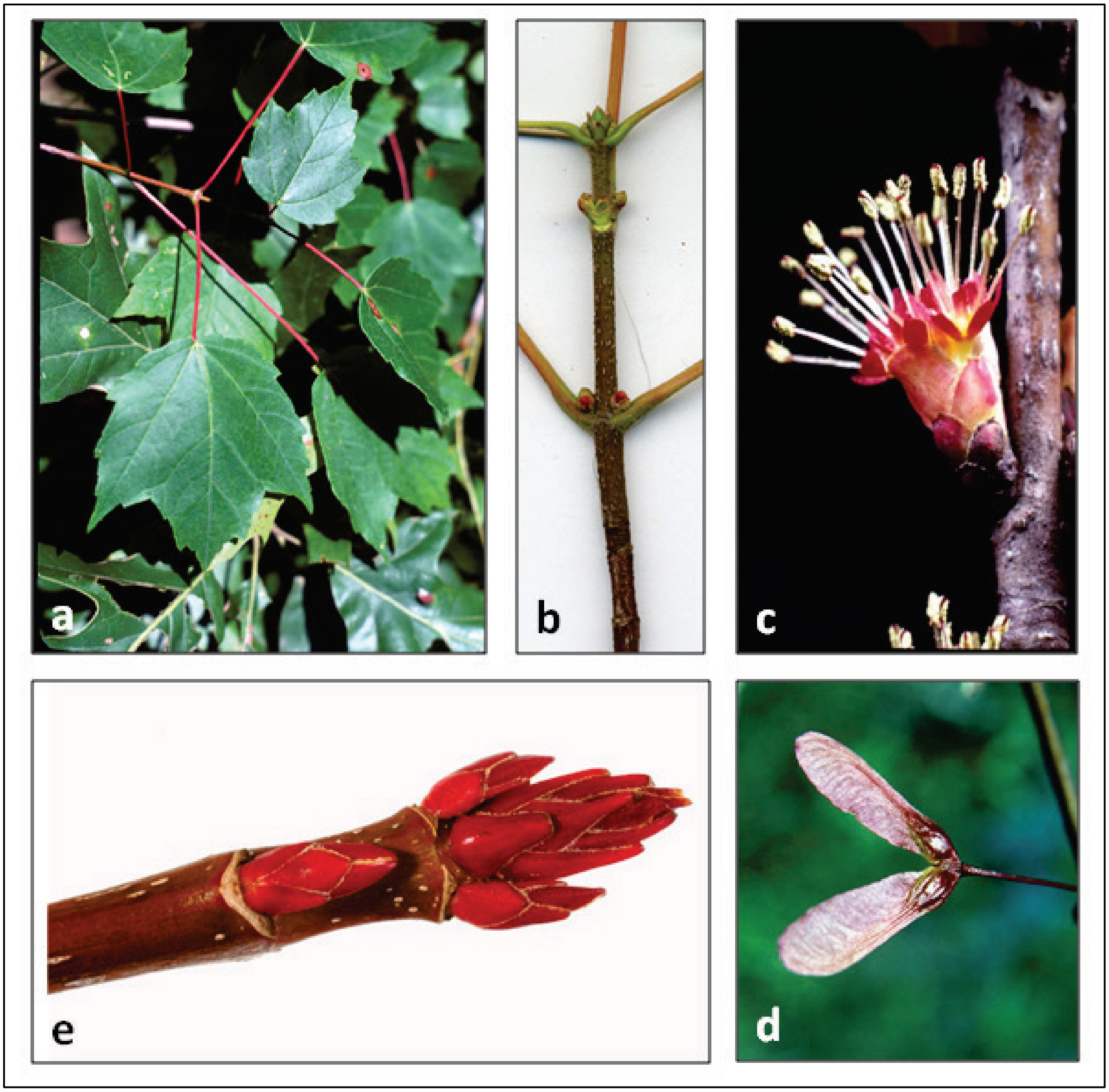


Figure C4. Sugar maple (*Acer saccharum*): (a) leaves; (b) twig displaying opposite leaf buds; (c) fruiting body.

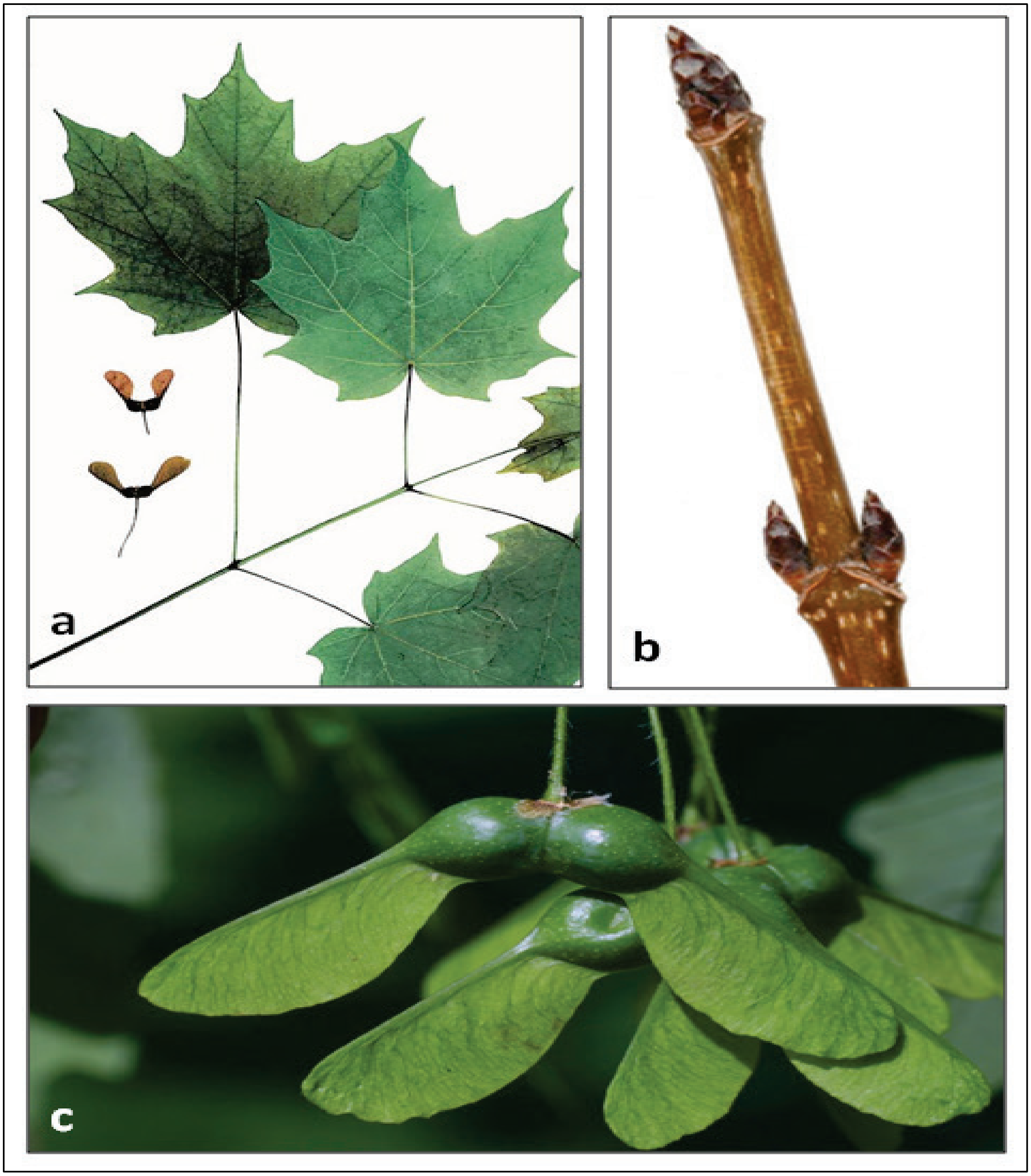


Figure C5. Tree of heaven (*Ailanthus altissima*): (a) and (b) leaf; (c) fruiting body; (d) twig displaying leaflet arrangement.

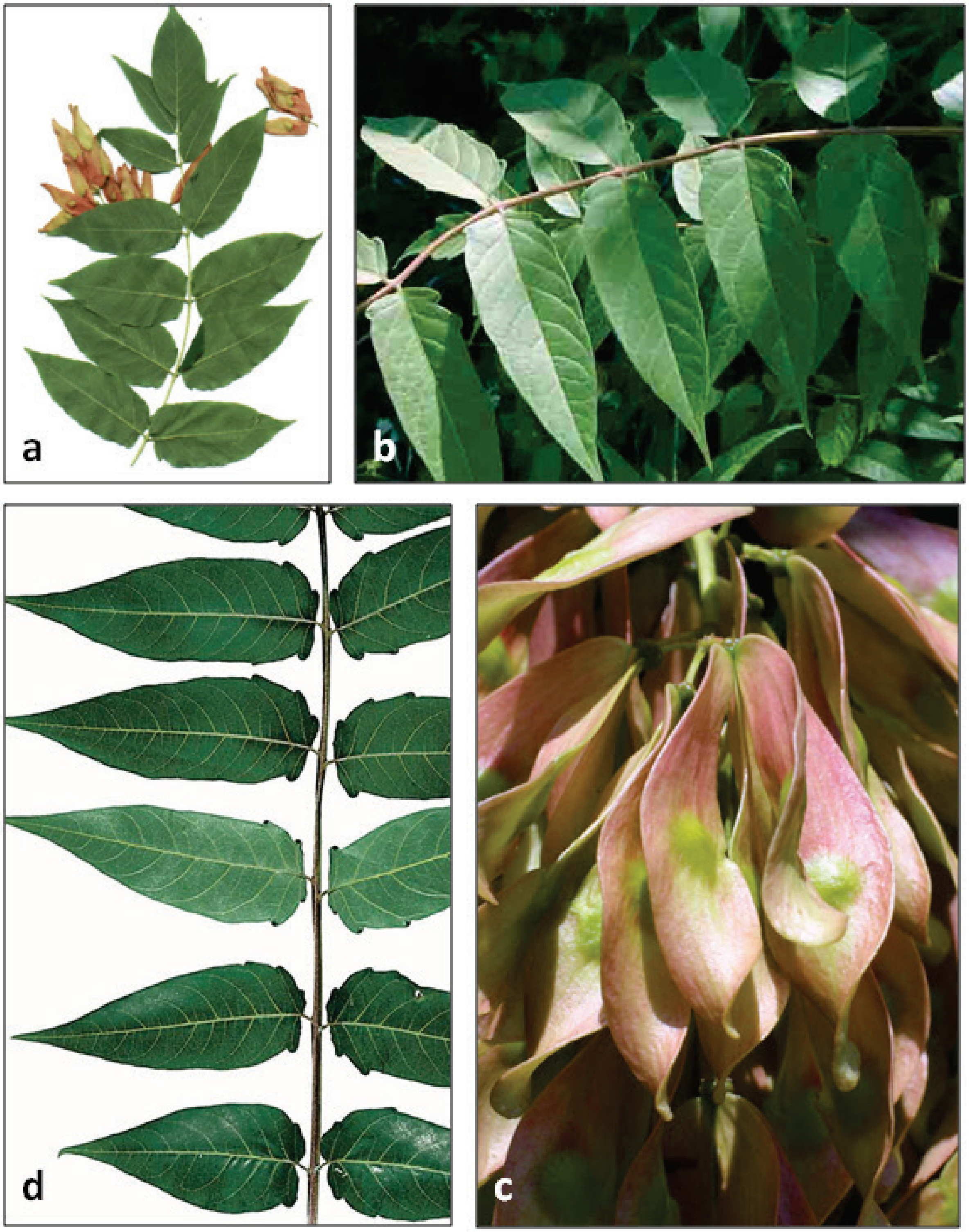


Figure C6. Silktree (*Albizia julibrissin*): (a) leaf displaying alternate, bipinnate leaflets; (b) fruiting body; (c) flower; (d) tree.

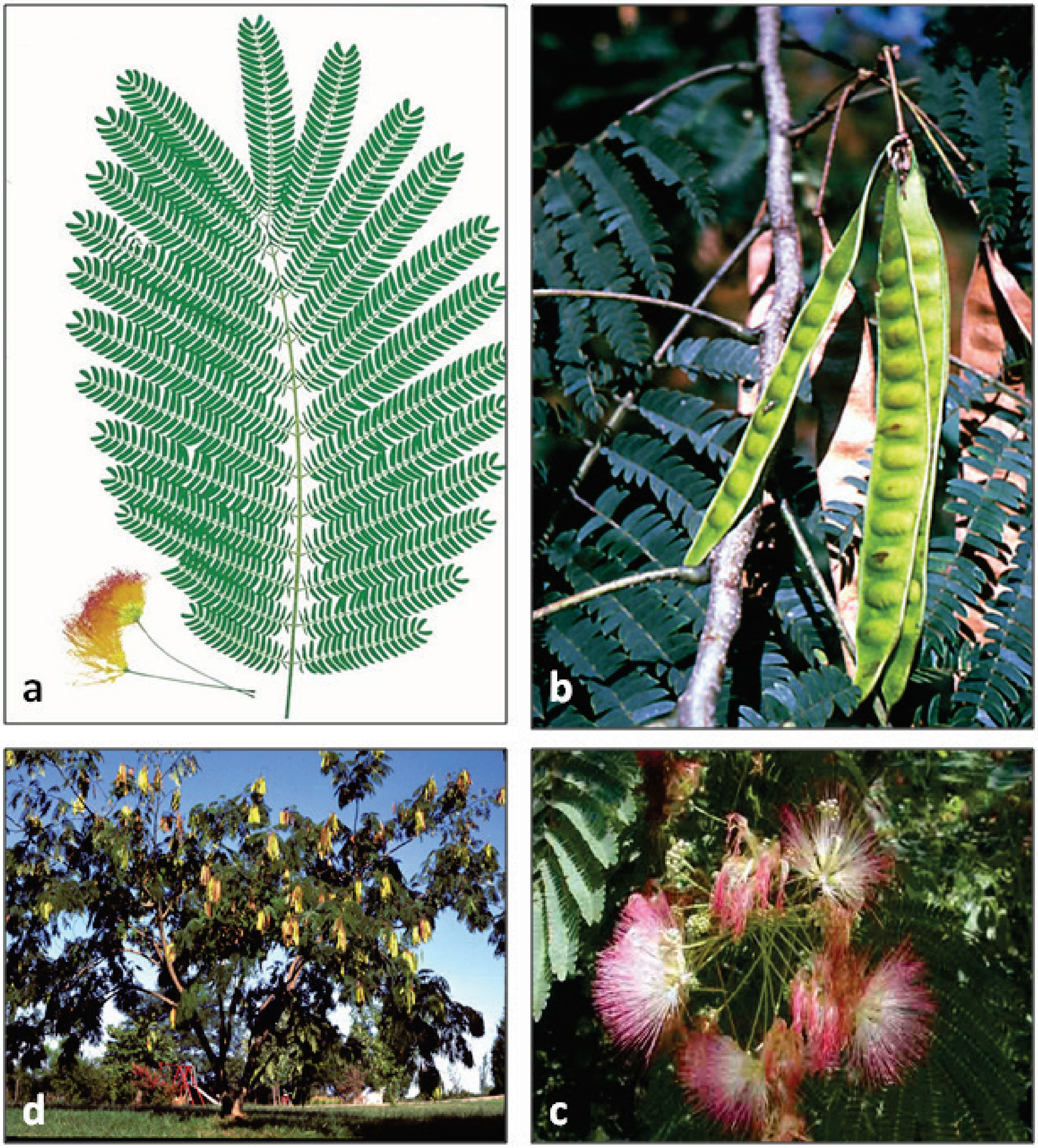


Figure C7. Pawpaw (*Asimina triloba*): (a) leaf and fruit; (b) leaf; (c) fruiting body; (d) flower.

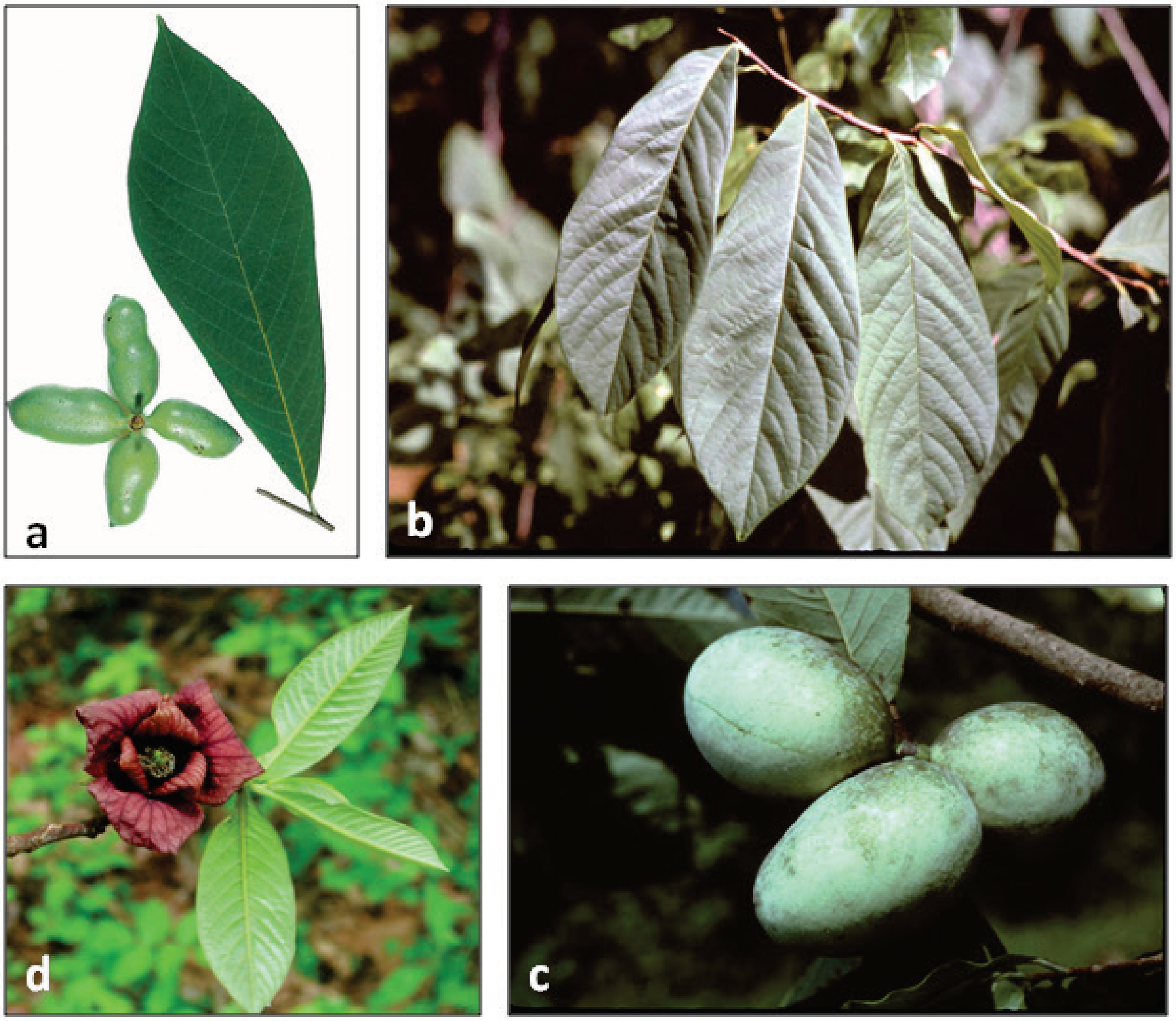


Figure C8. Yellow birch (*Betula alleghaniensis*): (a) leaves; (b) bark displaying typical peeling; (c) leaf bud; (d) female catkin.

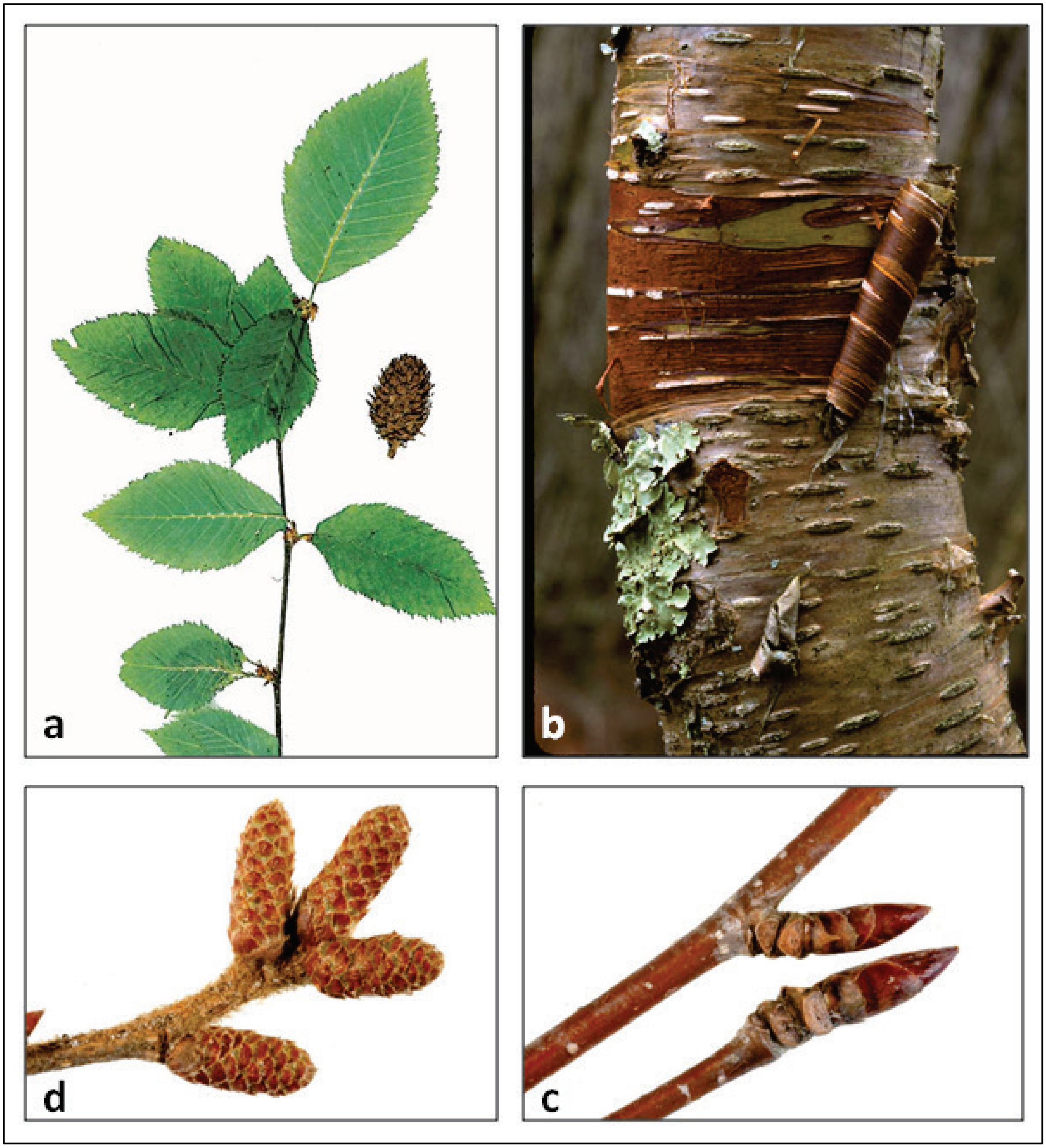


Figure C9. Black birch (*Betula lenta*): (a) leaves; (b) and (c) twig displaying leaf buds; (d) immature female catkin; (e) leaf bud and catkin scales.

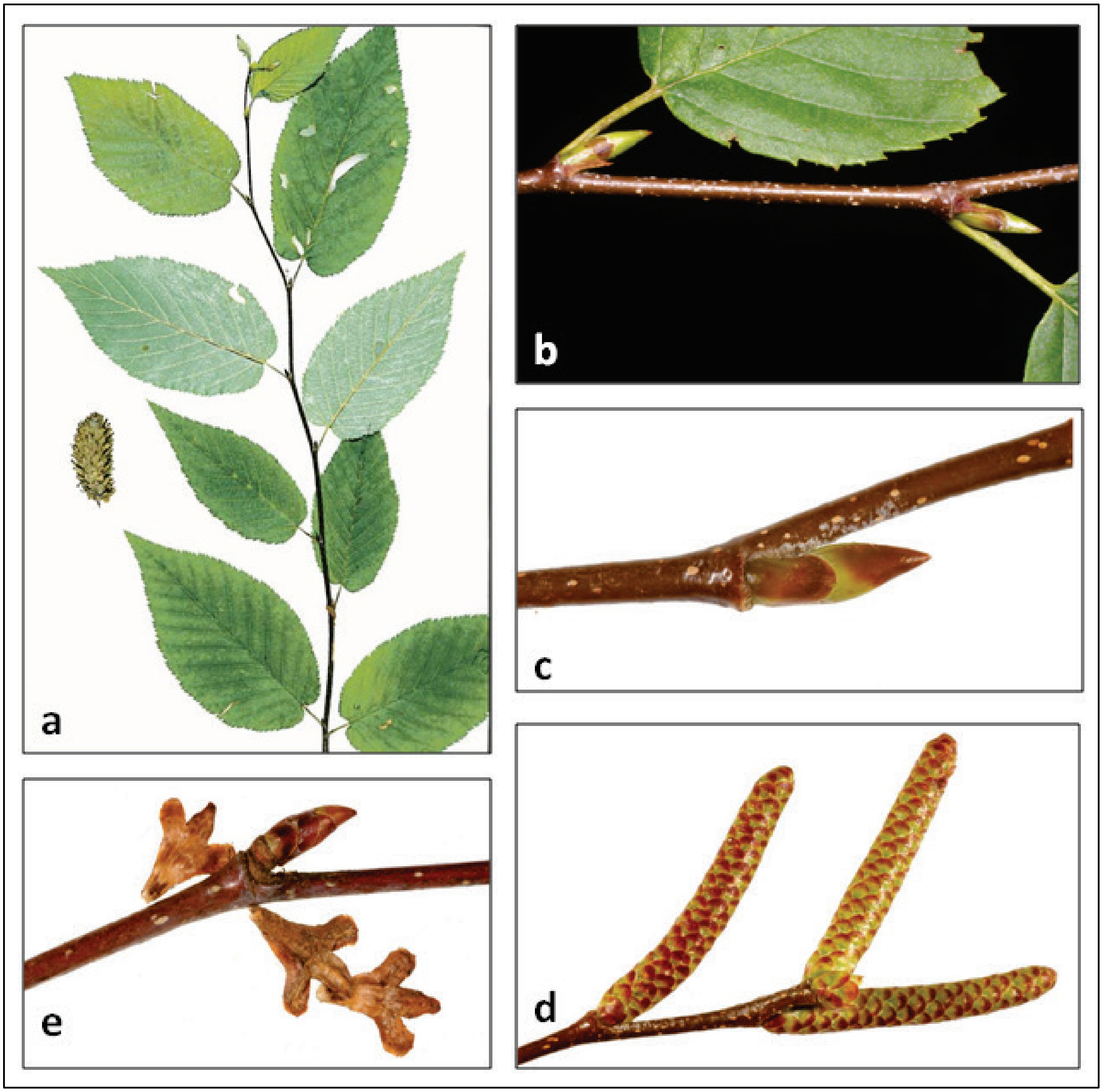


Figure C10. Bitternut hickory (*Carya cordiformis*): (a) leaf; (b) twig displaying leaf scar and buds; (c) fruit.

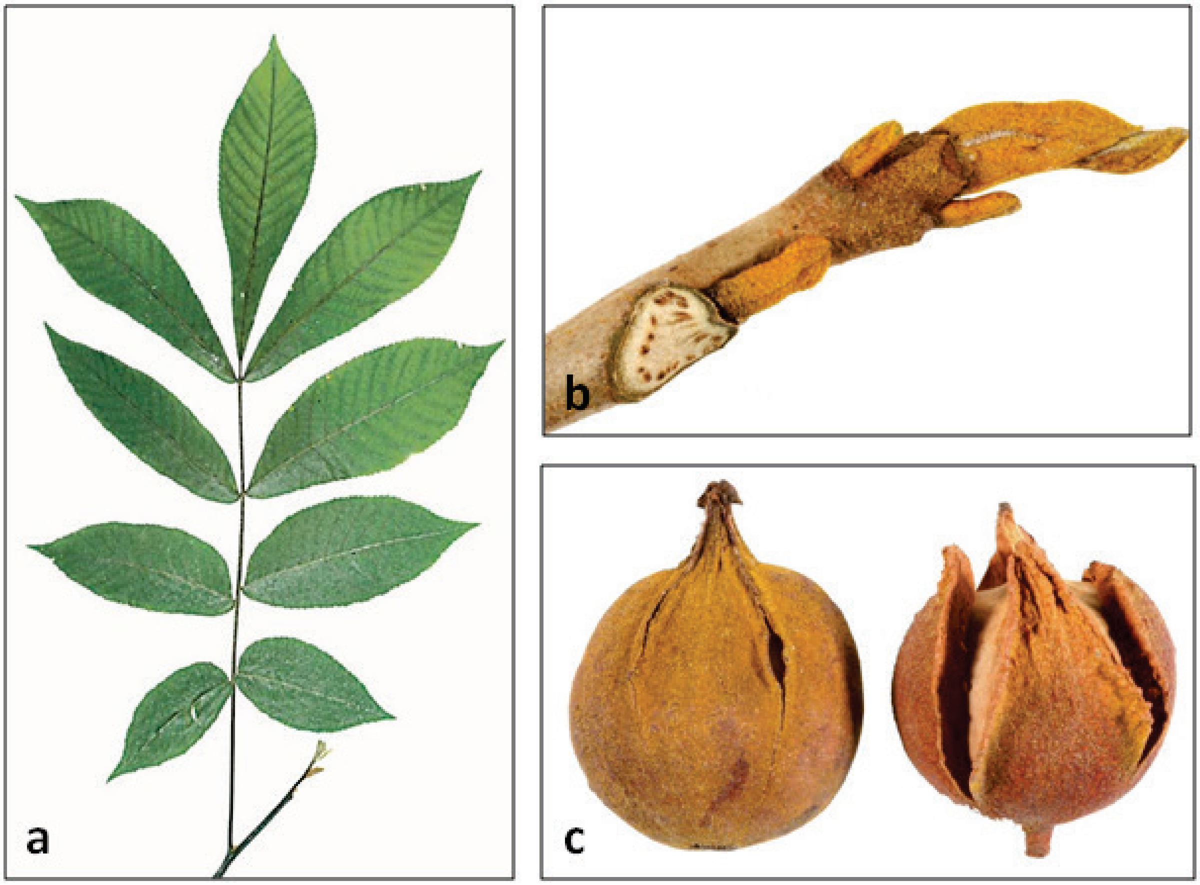
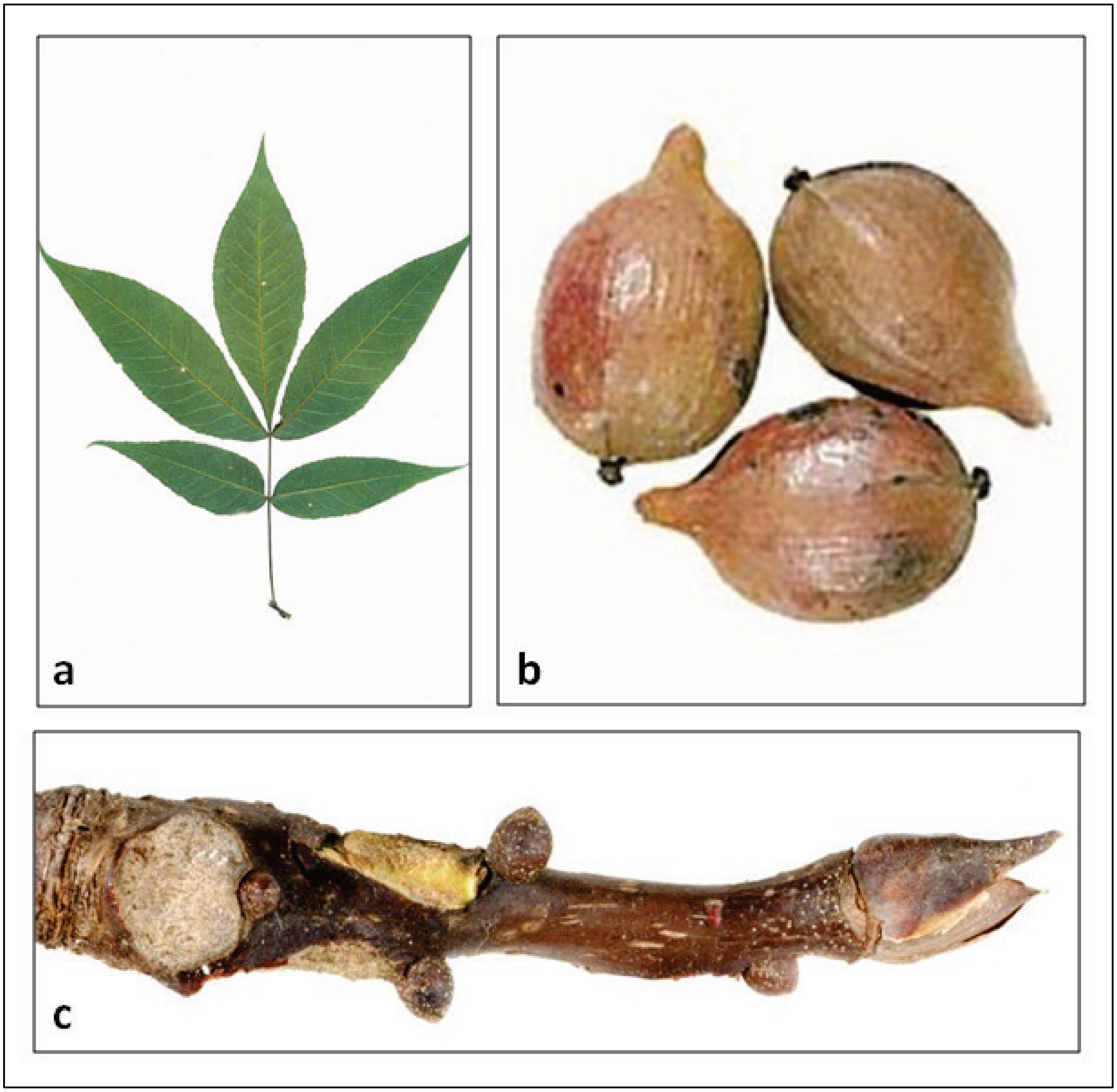


Figure C11. Pignut hickory (*Carya glabra*): (a) leaf; (b) fruit; (c) twig displaying leaf scar and leaf bud.



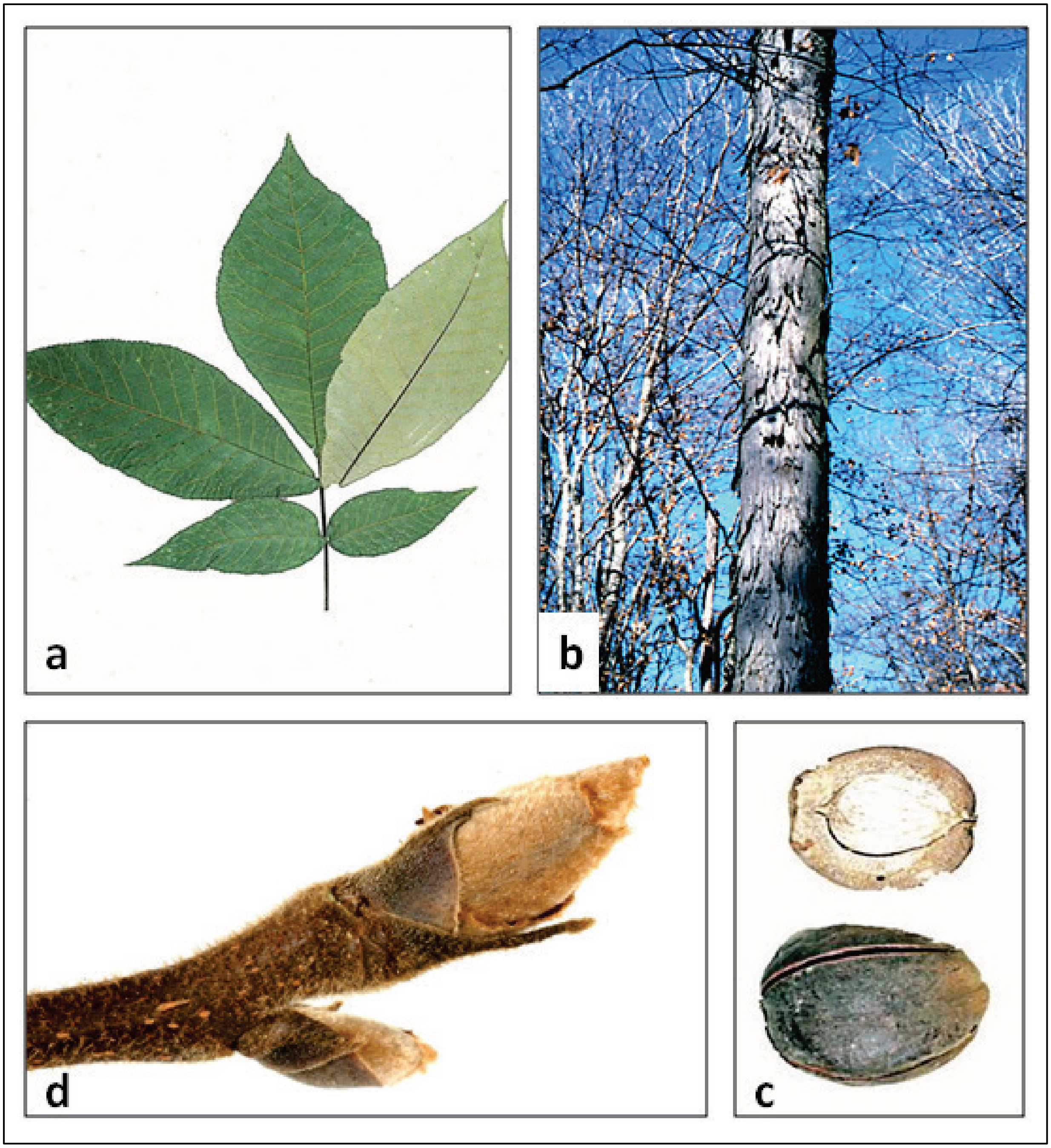


Figure C12. Shagbark hickory (*Carya ovata*): (a) leaf displaying five leaflets; (b) exfoliating bark; (c) open and closed fruit; (d) twig displaying leaf buds.

Figure C13. Mockernut hickory (*Carya tomentosa*): (a) leaf; (b) fruit; (c) splitting fruit displaying nut; (d) twig displaying leaf buds.

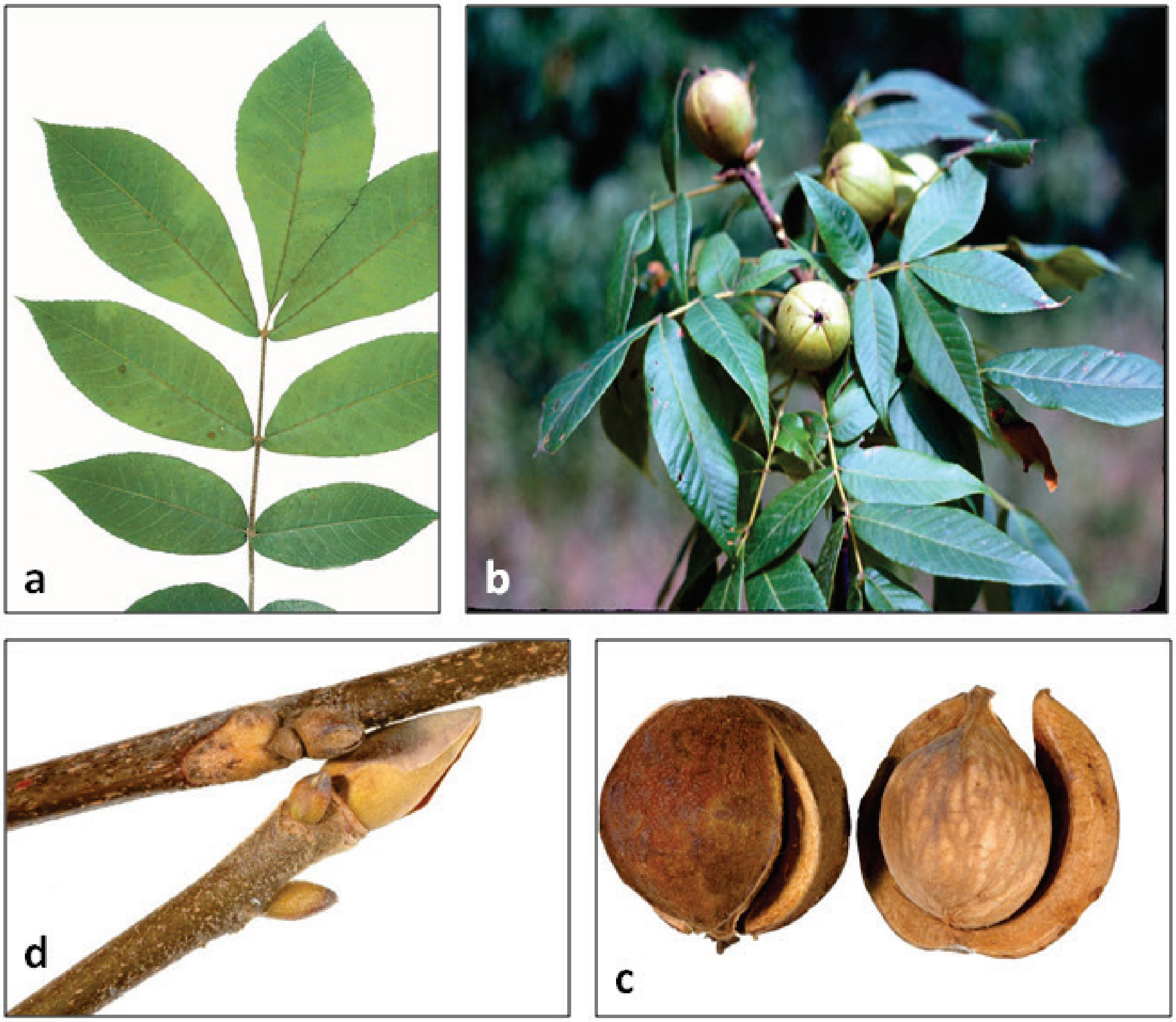


Figure C14. Flowering dogwood (*Cornus florida*): (a) leaves and flowers; (b) tree in flower; (c) twig displaying flower buds; (d) fruit.

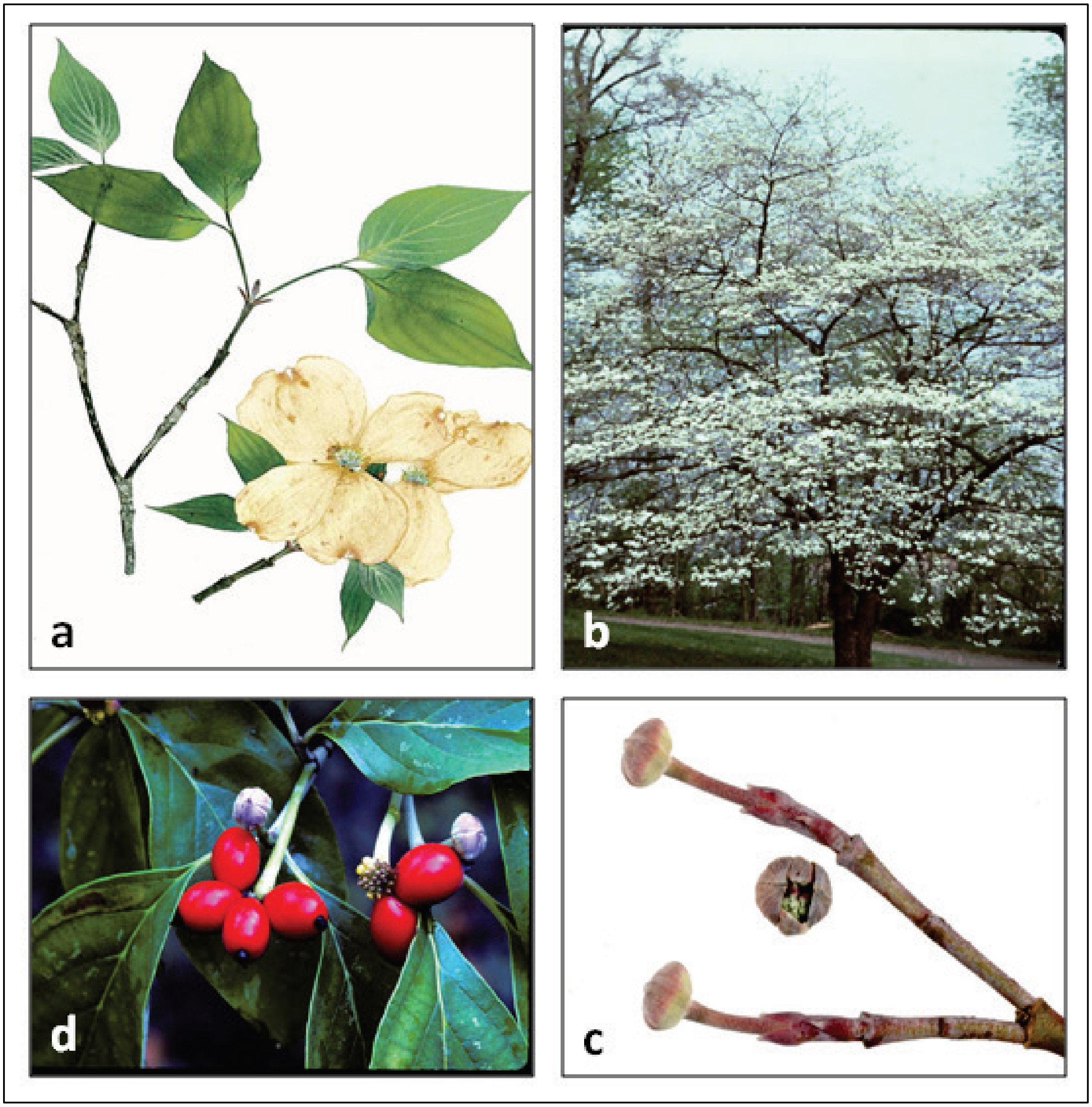


Figure C15. Autumn olive (*Elaeagnus umbellata*): (a) leaves and fruit; (b) branch; (c) fruit; (d) twig displaying leaf buds.

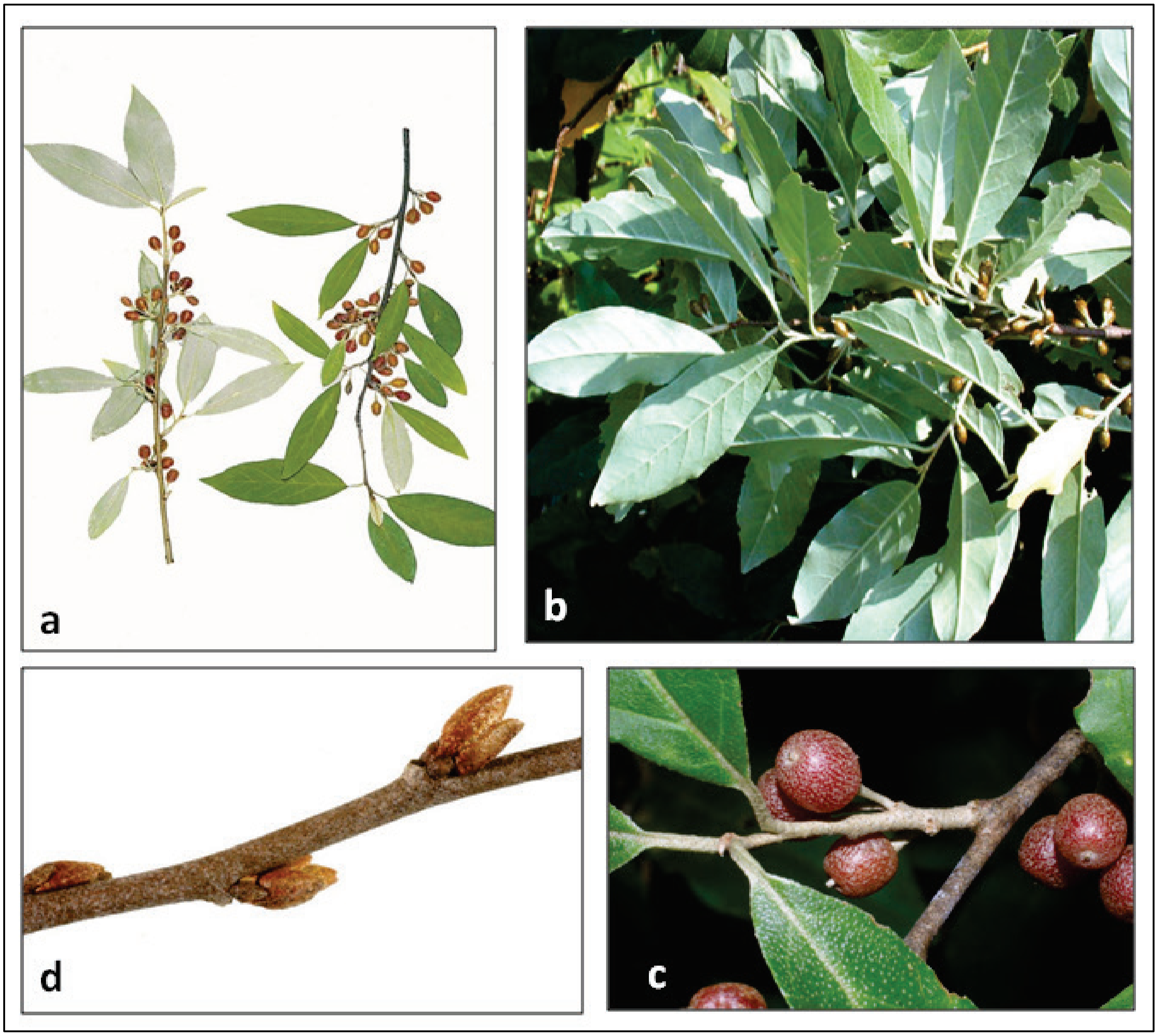


Figure C16. American beech (*Fagus grandifolia*): (a) leaves, fruit, and nuts; (b) bark displaying smooth, blue-gray appearance; (c) nut displaying three-angled shape; (d) twig displaying leaf bud.

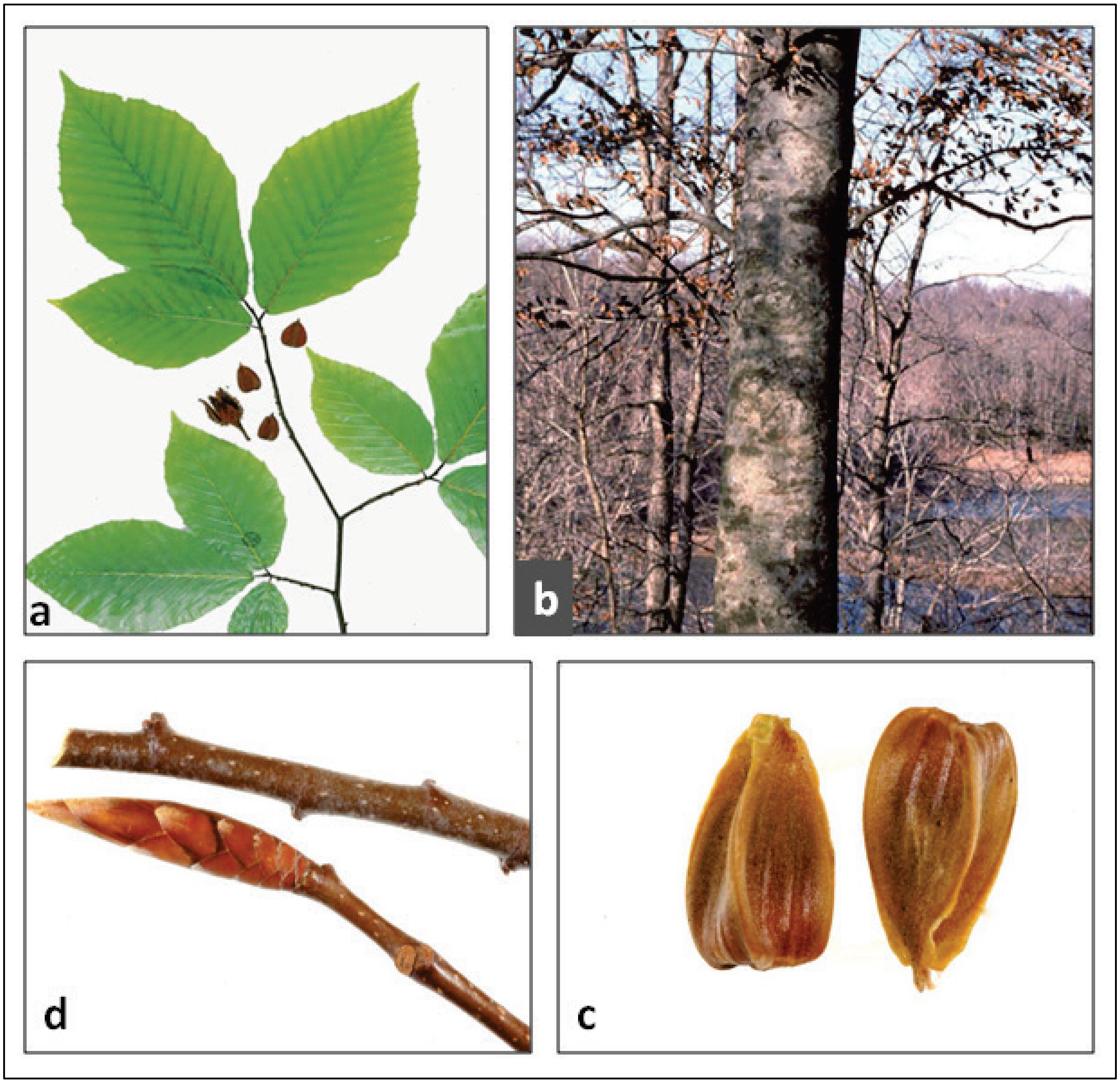


Figure C17. White ash (*Fraxinus americana*): (a) compound leaf and fruit; (b) branch; (c) bark; (d) twig displaying leaf buds at nodes.

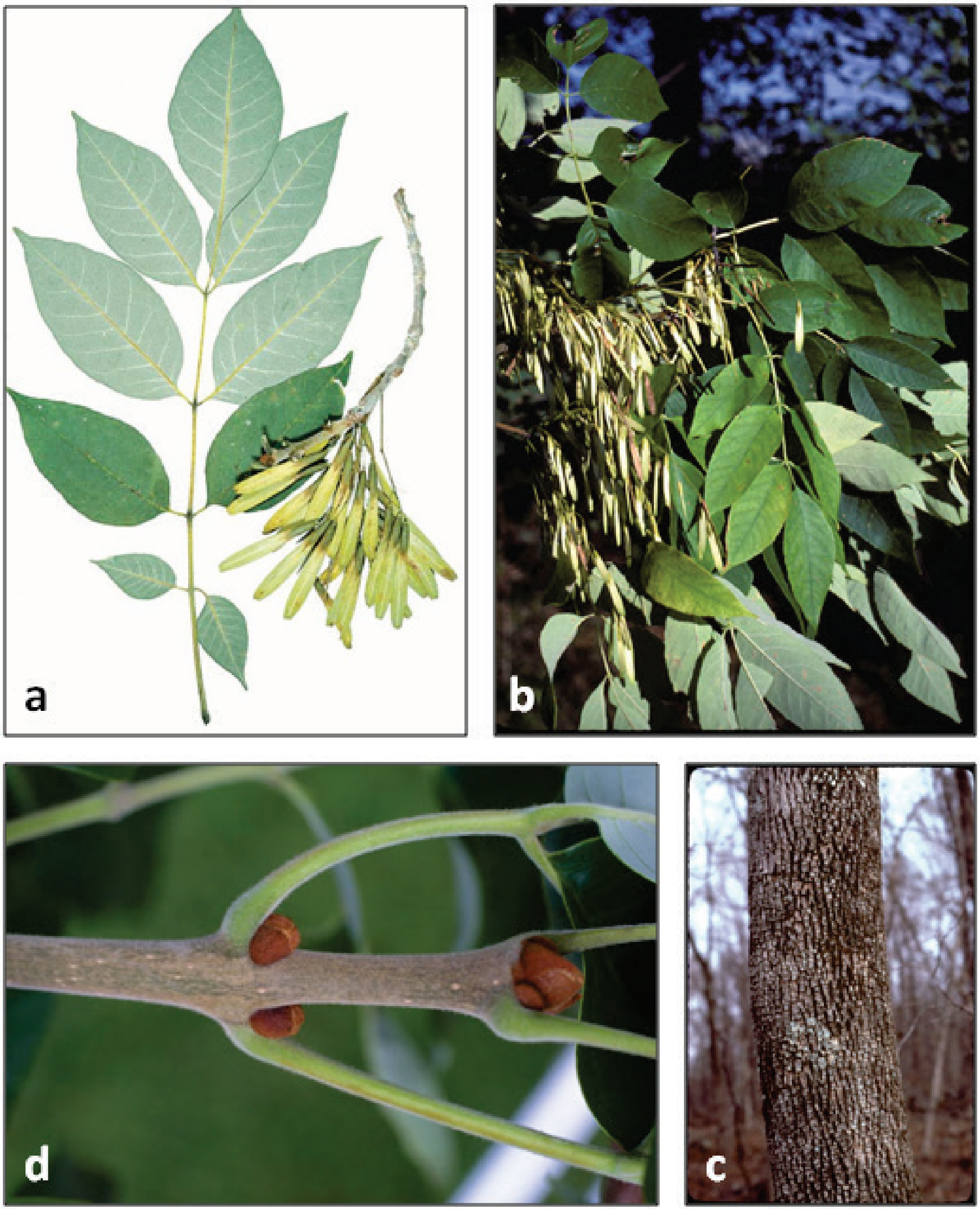


Figure C18. Tuliptree (*Liriodendron tulipifera*): (a) leaves, open fruit cluster, and samara; (b) flower; (c) twig displaying leaf bud.

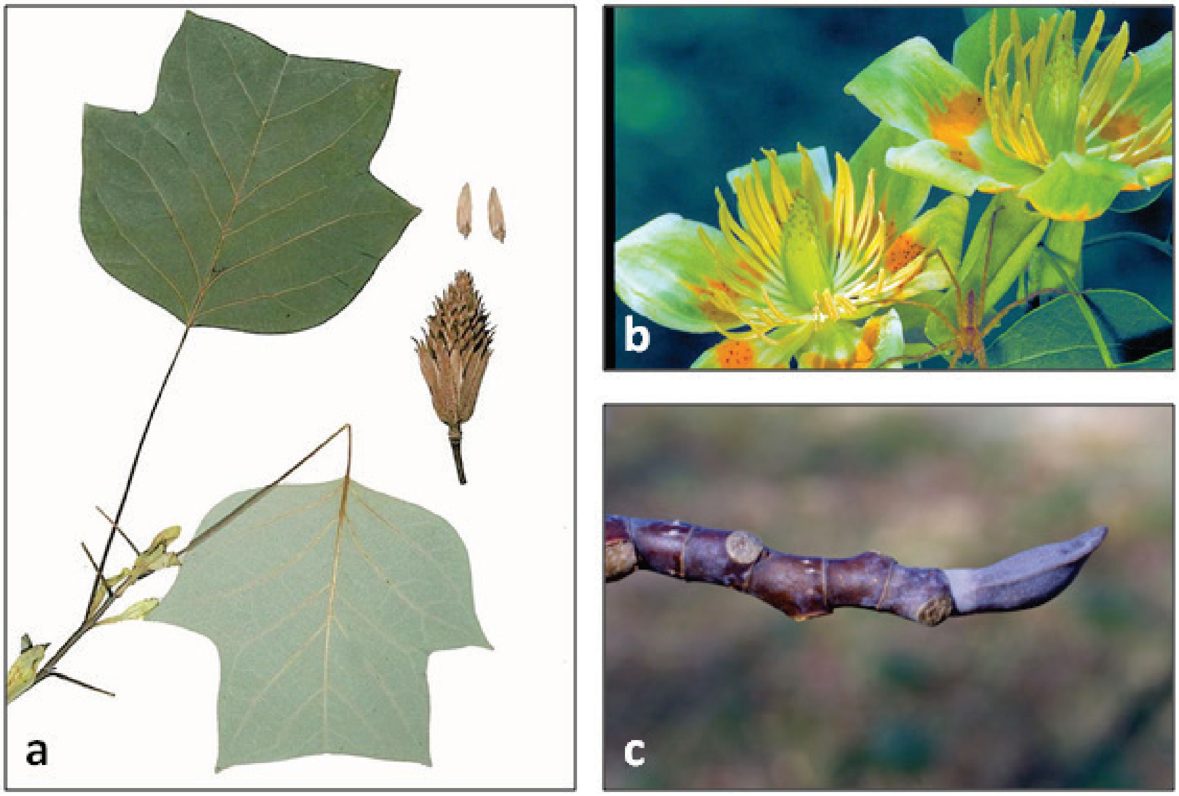


Figure C19. Cucumber tree (*Magnolia acuminata*): (a) leaves; (b) developing cone-like fruit aggregate; (c) twig displaying developing leaves; (d) twig displaying leaf bud.

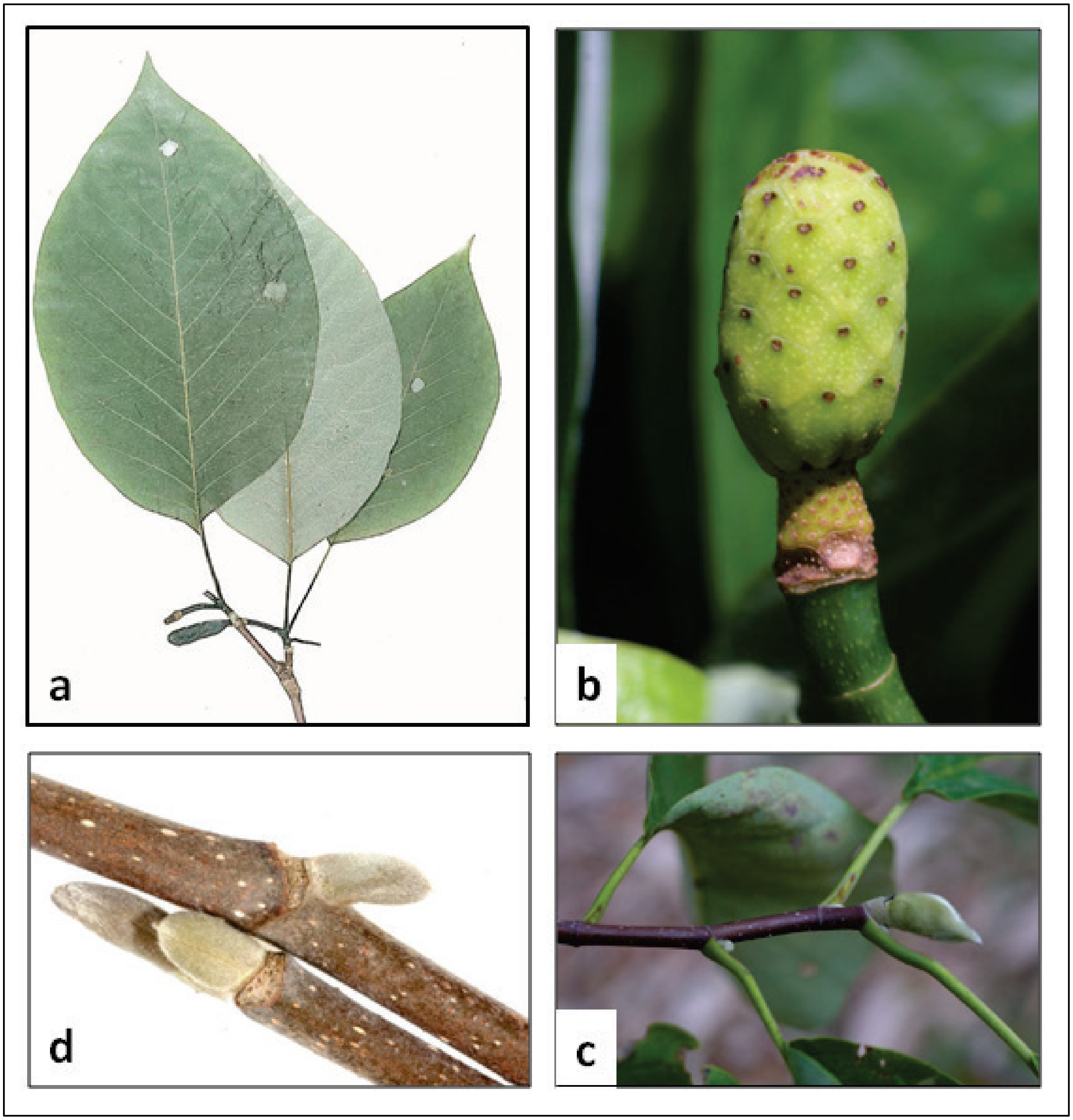


Figure C20. Umbrella-tree (*Magnolia tripetala*): (a) leaves; (b) flower; (c) cone-like fruit aggregate displaying pink color; (d) twig displaying leaf scar; (e) twig displaying leaf bud.

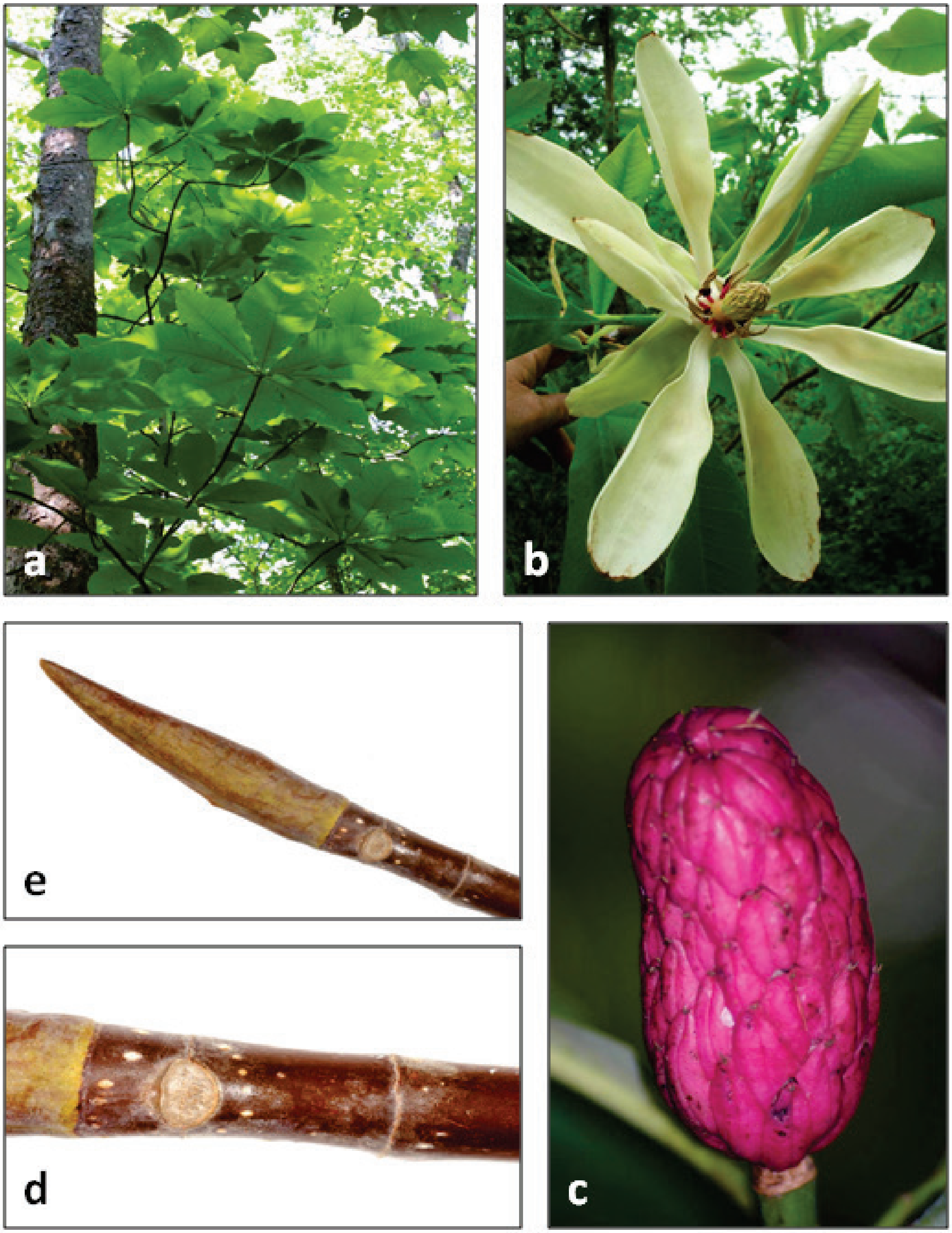


Figure C21. Blackgum (*Nyssa sylvatica*): (a) leaf and fruit; (b) flower; (c) fruit; (d) twig displaying leaf buds.

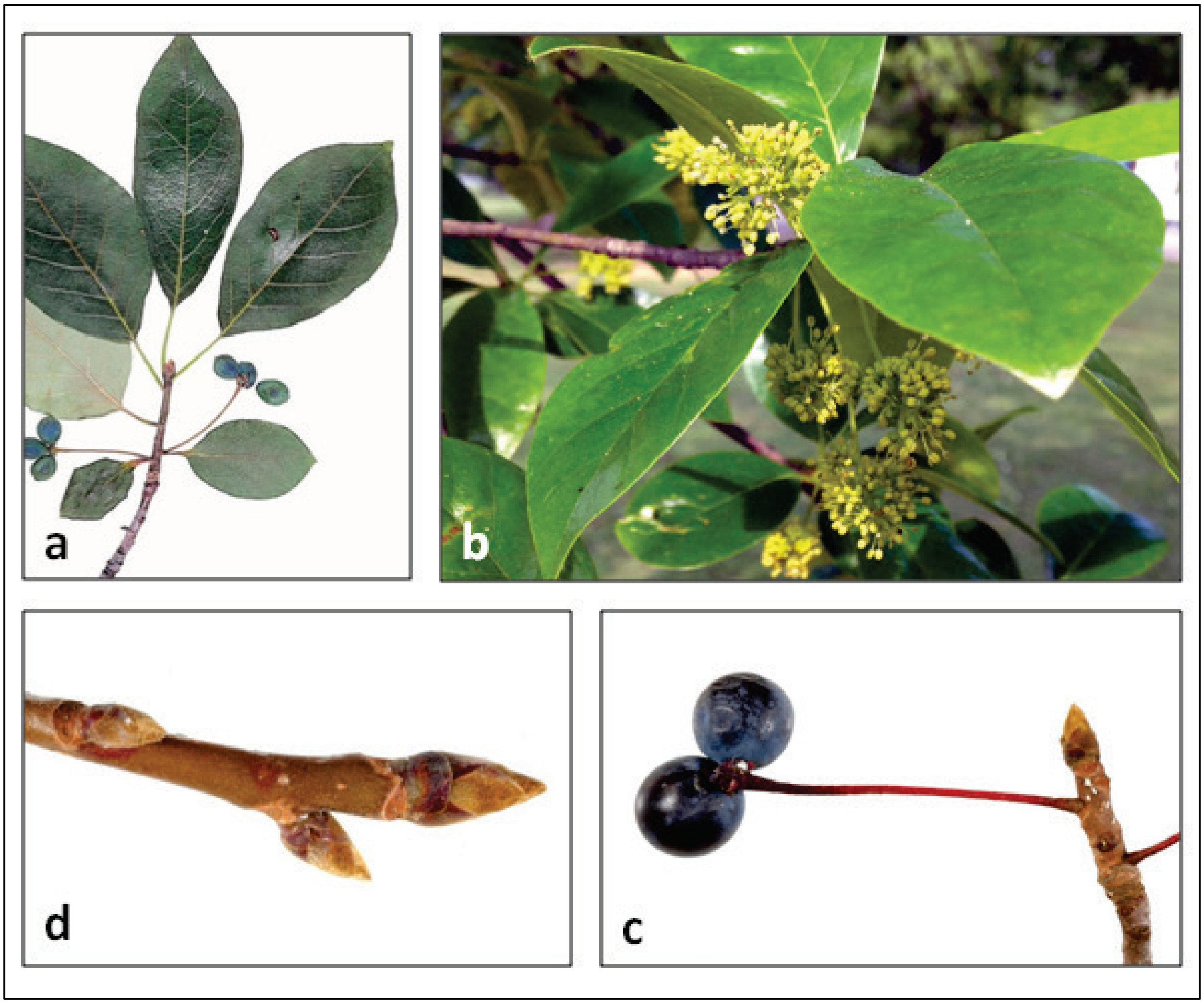


Figure C22. Sourwood (*Oxydendrum arboreum*): (a) leaf and fruits; (b) flowers; (c) fruits; (d) twig displaying leaf scars.

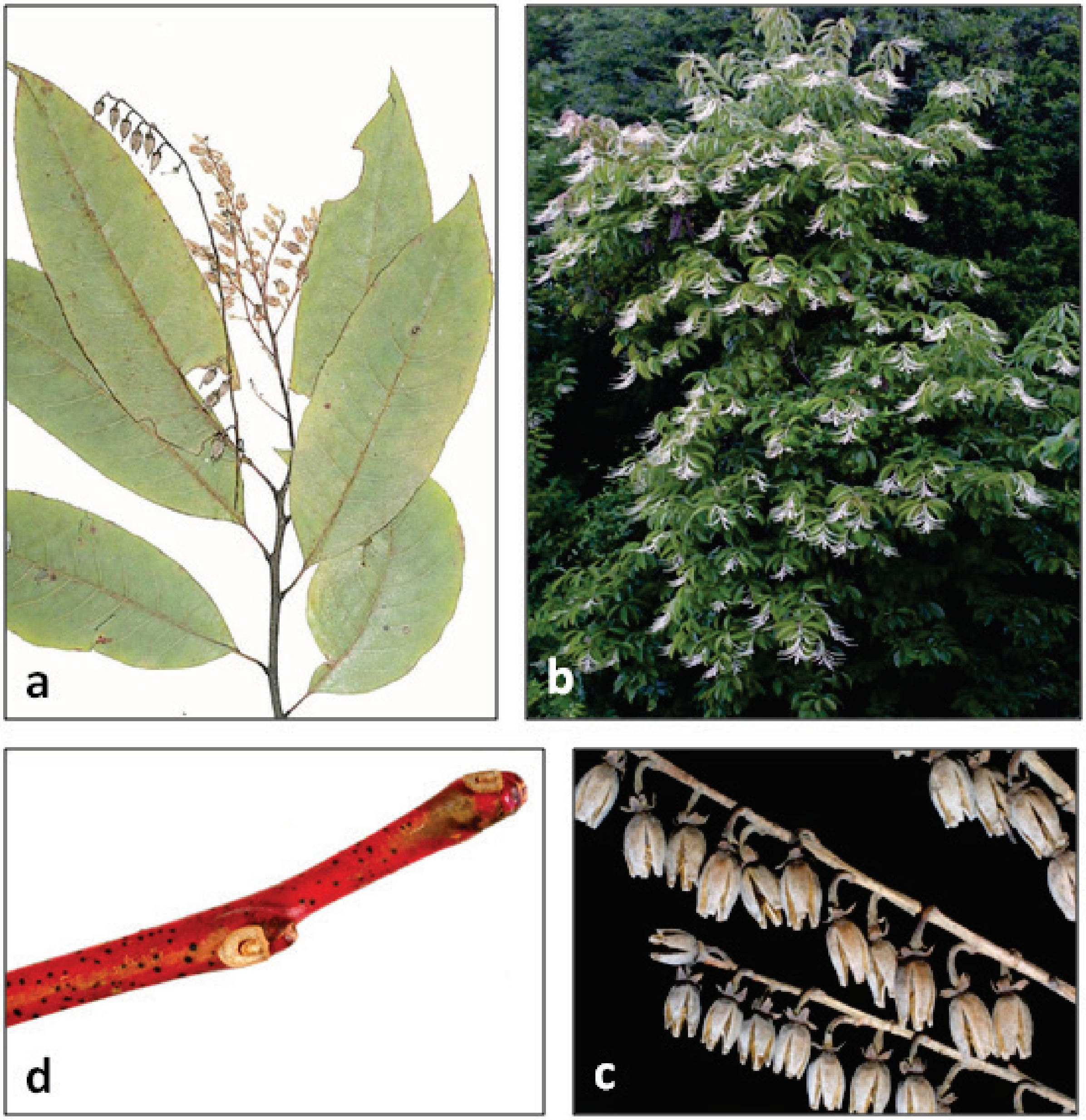


Figure C23. Princesstree (*Paulownia tomentosa*): (a) heart-shaped leaves and fruits; (b) stem displaying white lenticels and branches at nodes; (c) flower; (d) fruits.

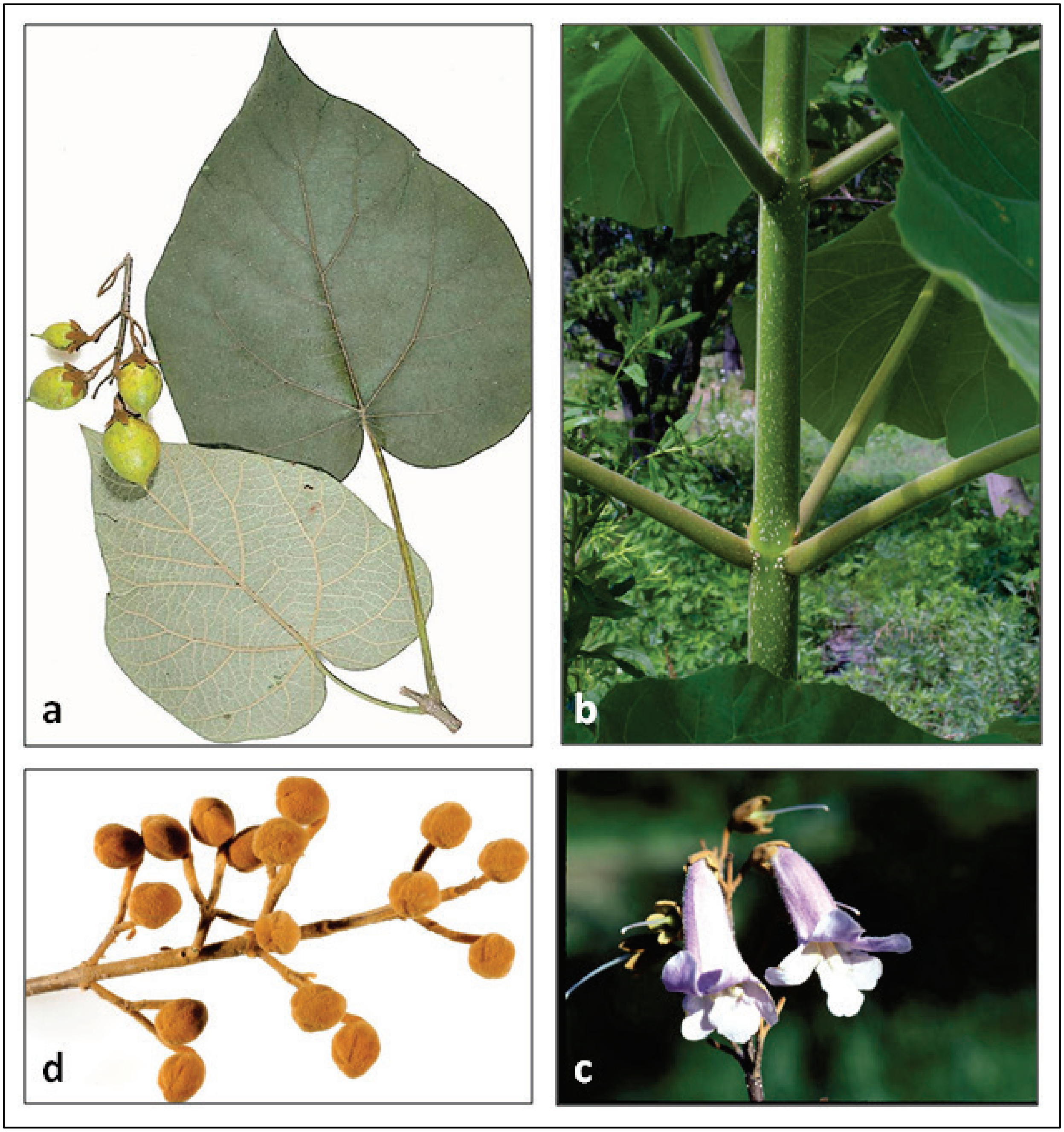


Figure C24. White pine (*Pinus strobus*): (a) needles in bundles of five; (b) closed cone; (c) pollen cones; (d) seed cones.

Figure C25. Black cherry (*Prunus serotina*): (a) leaf; (b) flowers; (c) fruits; (d) twig displaying white lenticels and leaf buds.

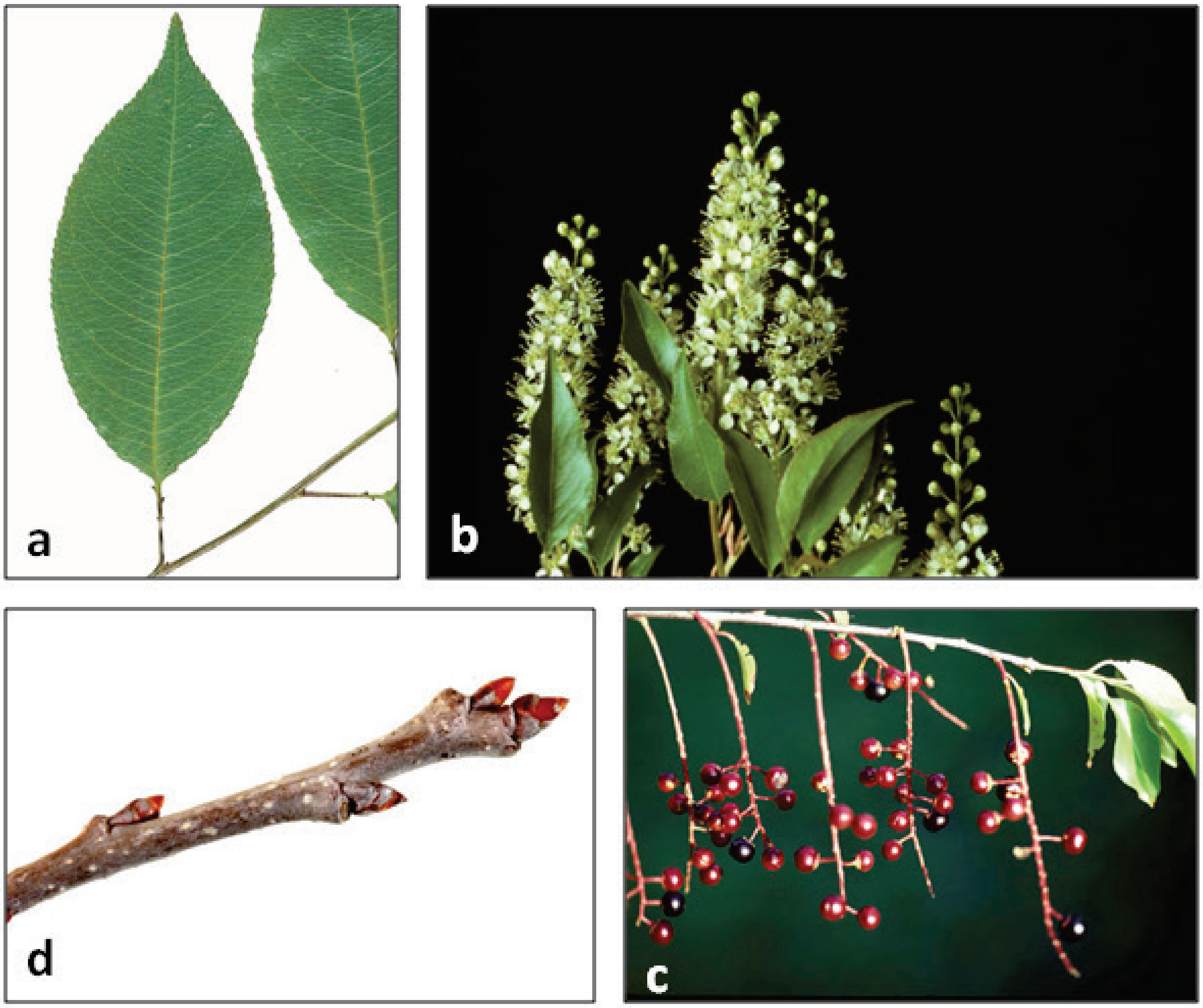


Figure C26. White oak (*Quercus alba*): (a) leaf and acorns; (b) acorns; (c) twig displaying terminal and lateral buds; (d) terminal buds.

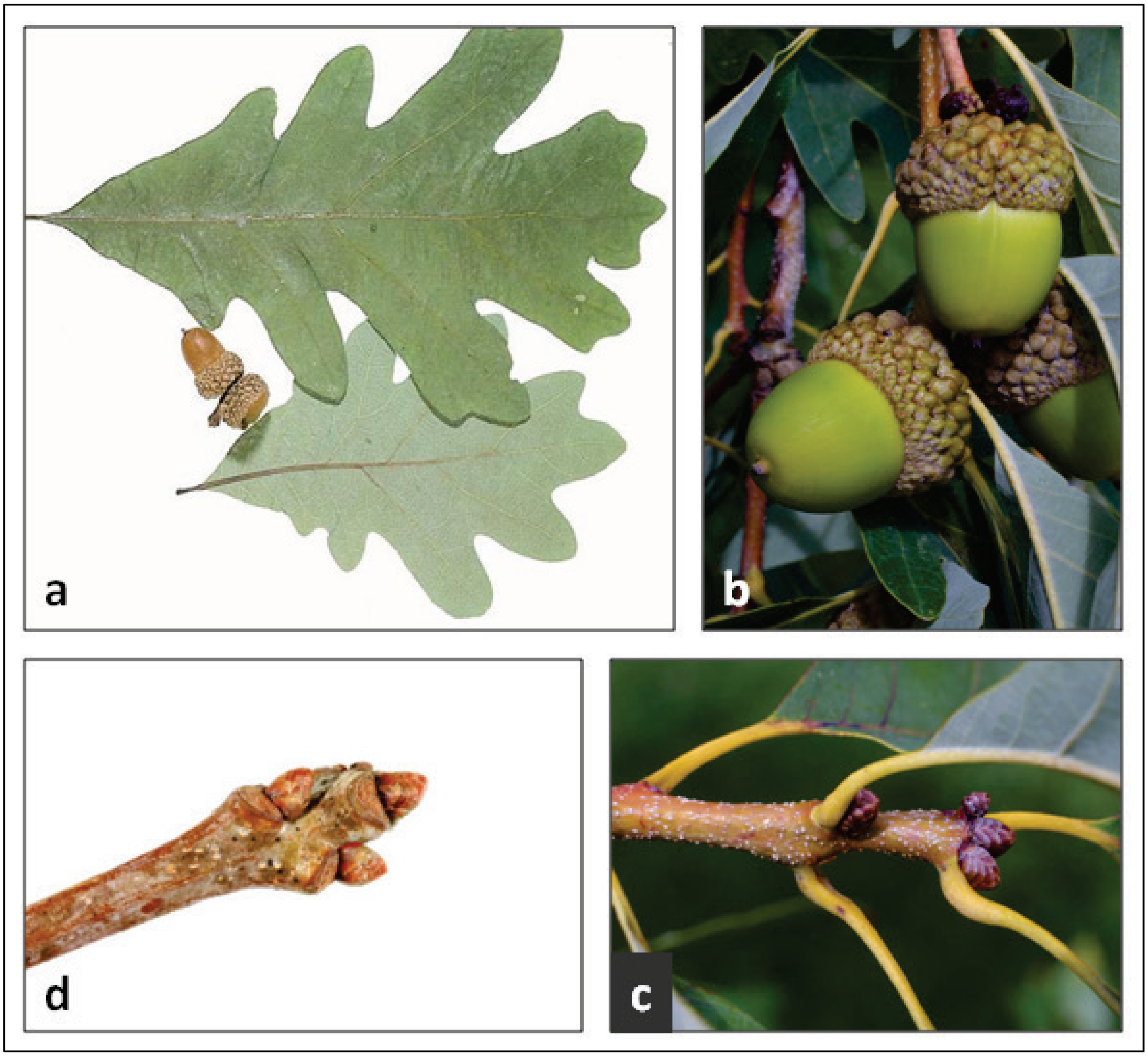


Figure C27. Scarlet oak (*Quercus coccinea*): (a) leaf and acorns; (b) terminal buds; (c) acorn; (d) twig displaying leaf scar and terminal buds.

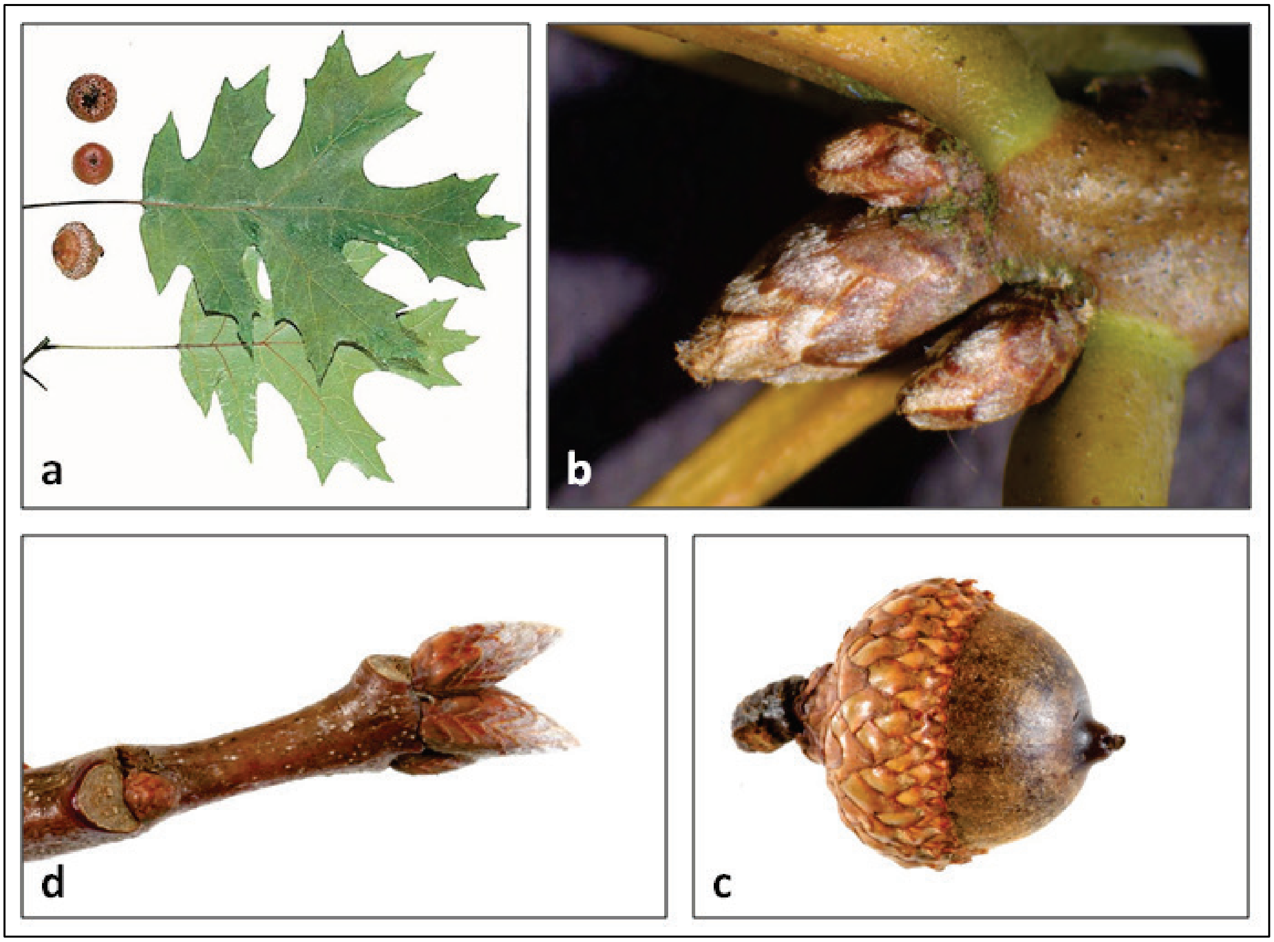


Figure C28. Shingle oak (*Quercus imbricaria*): (a) leaf and acorns; (b) oblong leaves; (c) acorn; (d) twig displaying leaf buds.

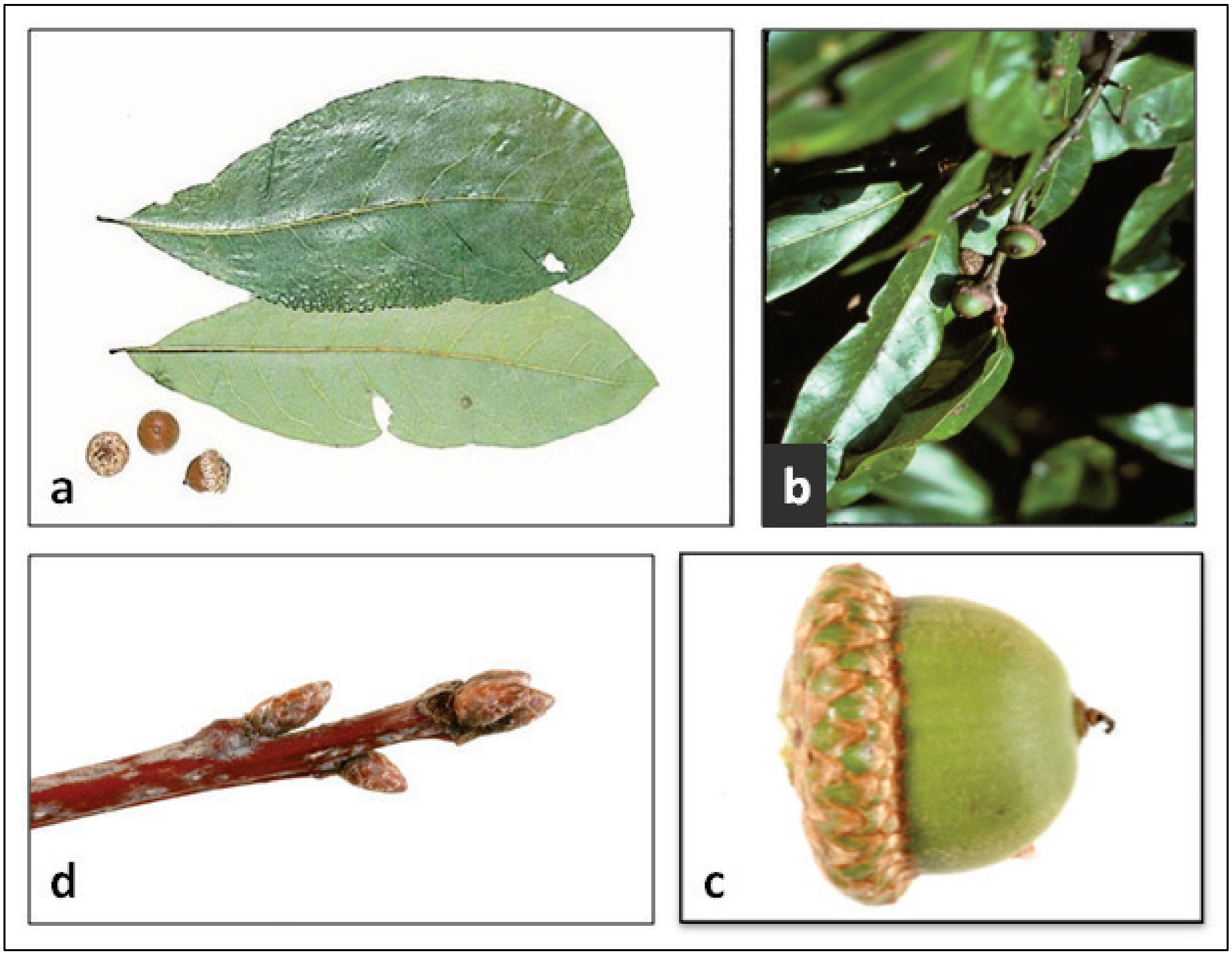


Figure C29. Chestnut oak (*Quercus montana*): (a) leaf and acorns; (b) acorn; (c) twig displaying leaf buds.

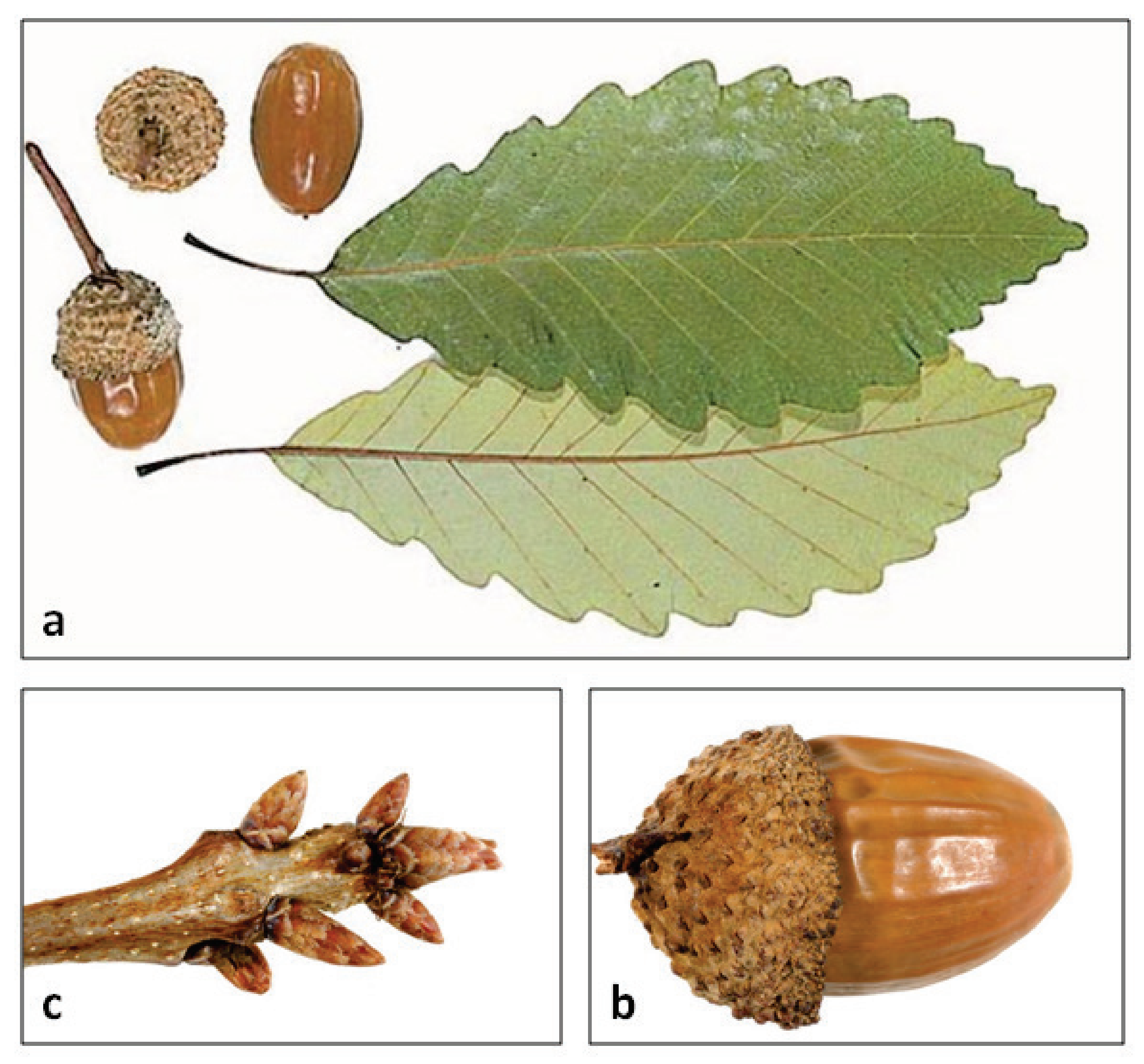


Figure C30. Northern red oak (*Quercus rubra*): (a) leaf and acorns; (b) branch and leaves; (c) acorn; (d) twig displaying hairless buds.

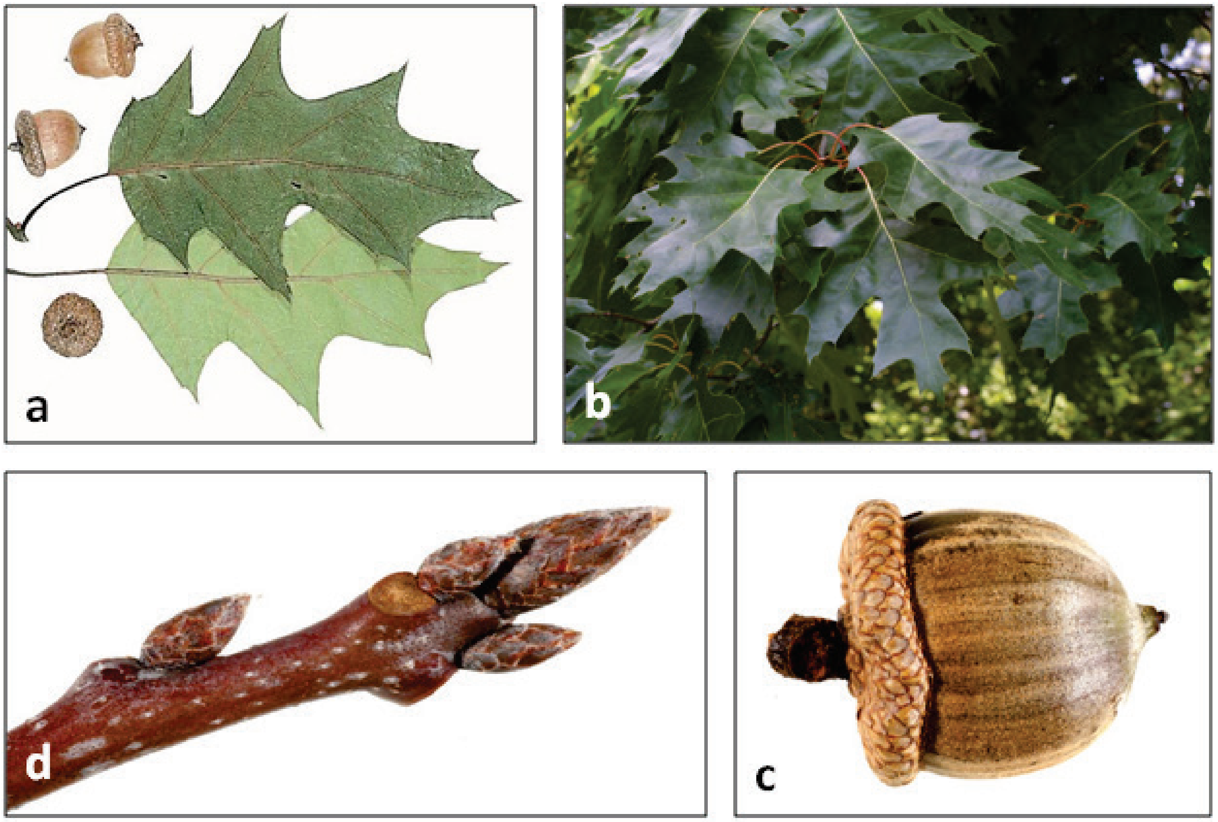


Figure C31. Black oak (*Quercus velutina*): (a) leaf and acorns; (b) twig displaying lateral buds; (c) hairy terminal buds; (d) acorns.

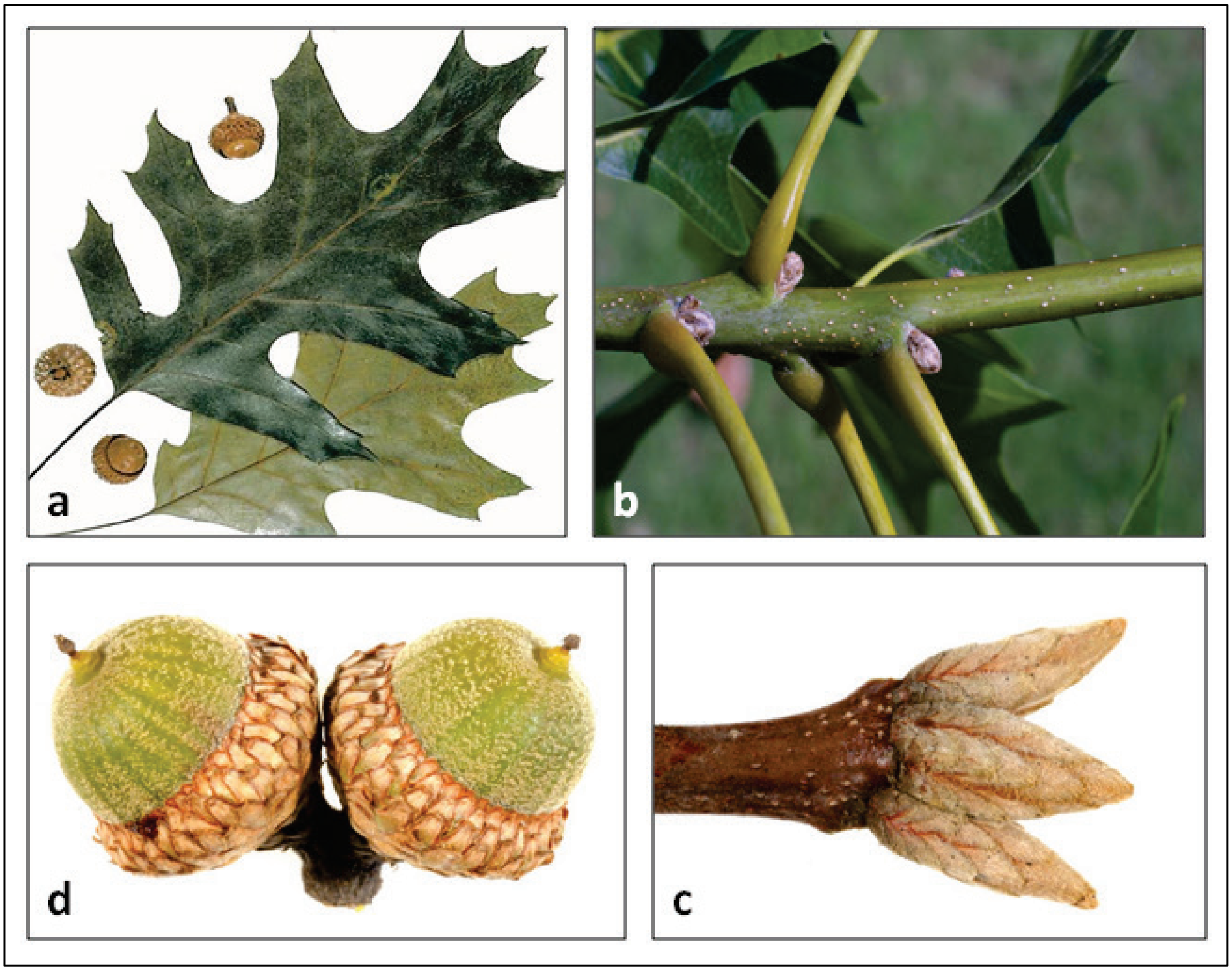


Figure C32. Sassafras (*Sassafras albidum*): (a) Common leaf shapes; (b) flowers; (c) fruits; (d) twig displaying leaf bud.

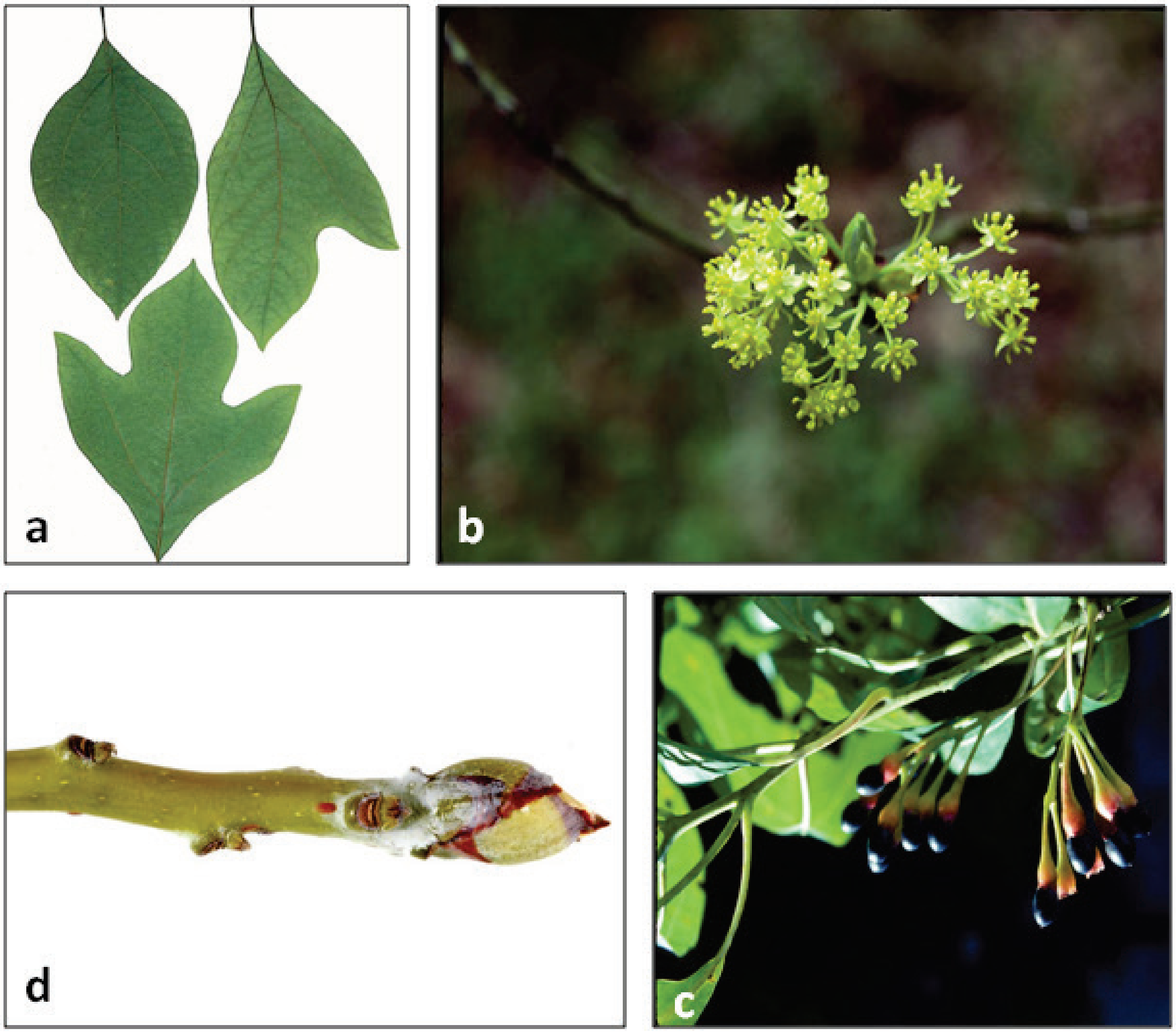


Figure C33. American basswood (*Tilia americana*): (a) Heart-shaped leaves; (b) twig displaying alternate leaf arrangement; (c) terminal buds.

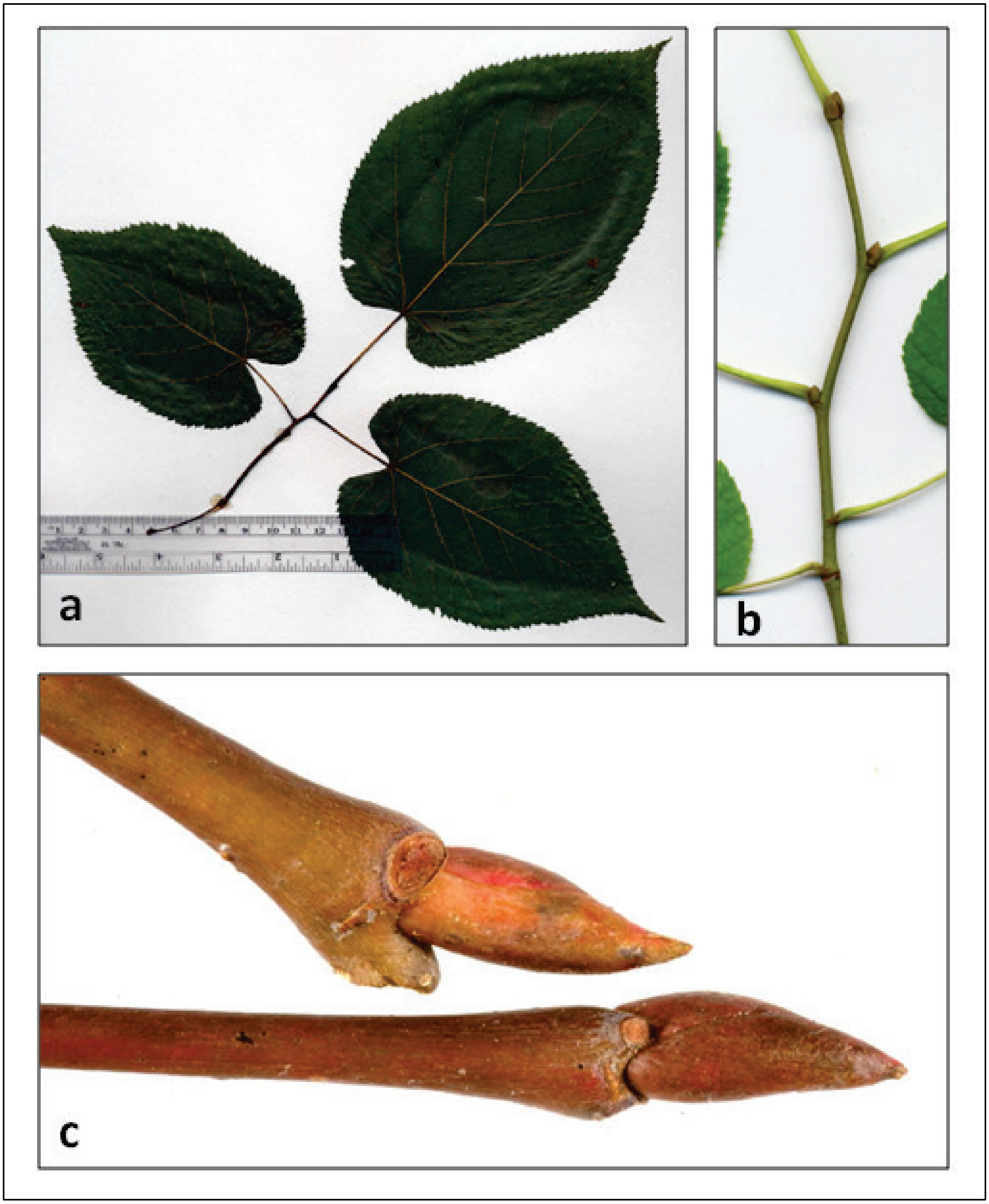


Figure C34. Eastern hemlock (*Tsuga canadensis*): (a) needles; (b) branch displaying closed pollen cones and open seed cones; (c) branch displaying small cones; (d) branch infested with hemlock wooly adelgid (*Adelges tsugae*).

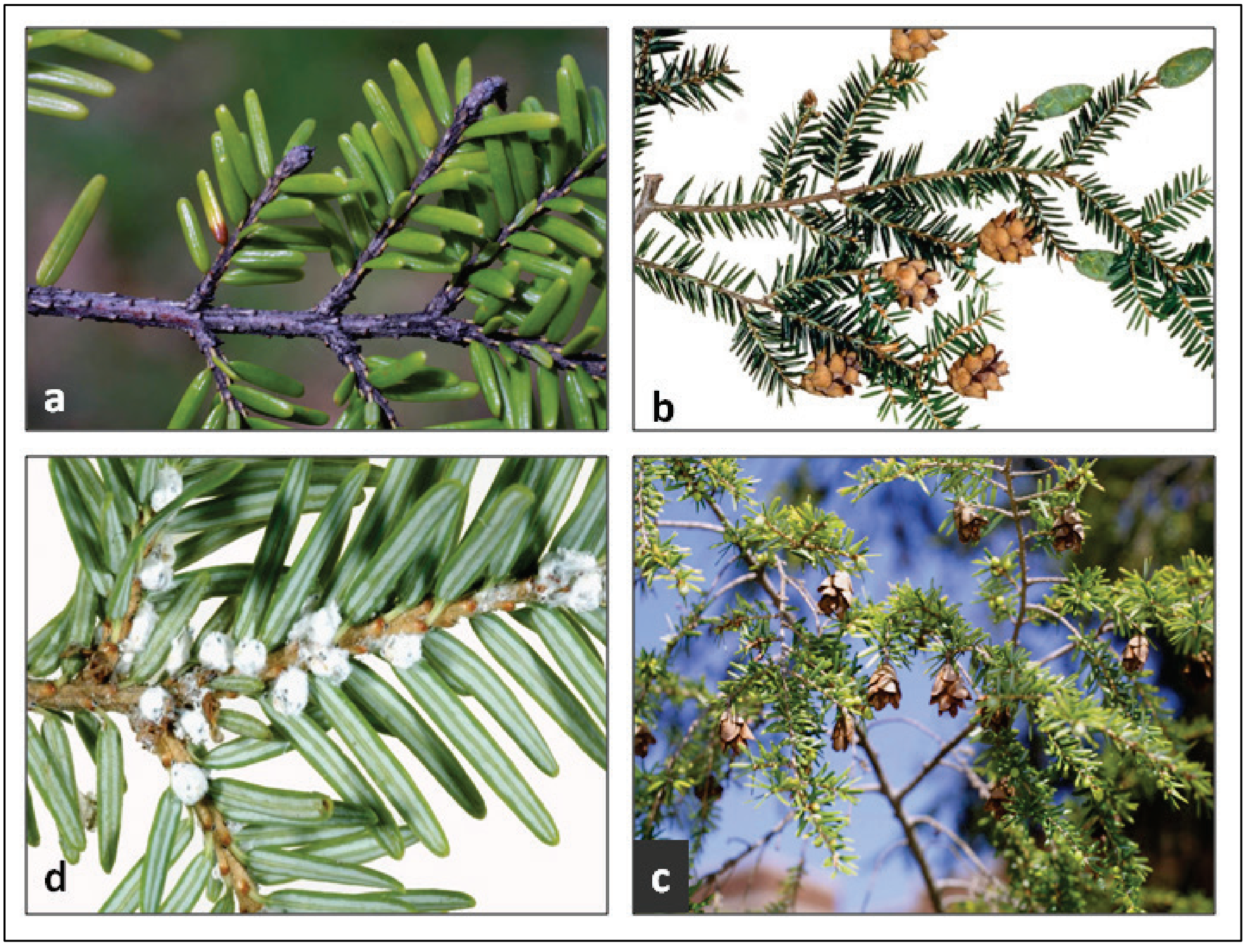
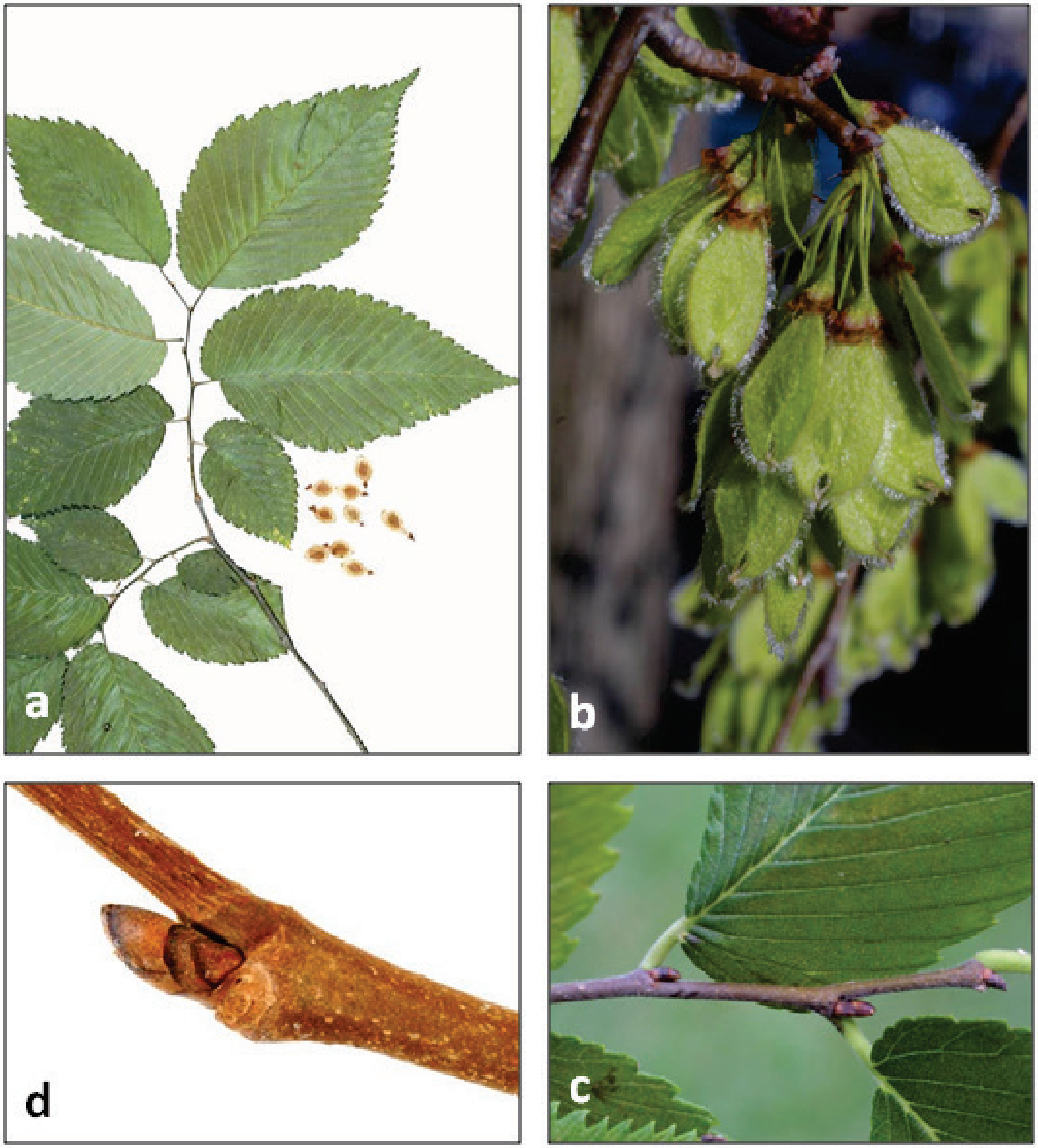


Figure C35. American elm (*Ulmus americana*): (a) alternate, parallel-veined leaves and flattened, winged samaras; (b) cluster of samaras; (c) twig displaying leaf arrangement and lateral buds; (d) twig displaying leaf bud.



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14. ABSTRACT

The HGM Approach is a method for developing functional indices and the protocols used to apply these indices to the assessment of ecosystem functions at a site-specific scale.

This report uses the HGM Approach to develop a Regional Guidebook to: (a) characterize high-gradient (greater than four percent channel slope) ephemeral and intermittent streams, known collectively as headwater streams, and wadeable, shadeable perennial streams with less than four percent slope, known as perennial streams, in the Appalachian region; (b) provide the rationale used to select functions for the headwater and perennial stream subclasses; (c) provide the rationale used to select assessment variables at the stream, riparian/buffer zone and watershed levels;(d) provide the rationale used to develop assessment equations; (e) provide data from reference streams and document their use in calibrating variables and assessment equations; and (f) outline the necessary protocols for applying the functional indices to the assessment of stream functions. The rapid assessments provided in this guidebook utilize structural components of streams and their watershed and can be used in conjunction with assessment of water quality and biotic communities if desired.

15. SUBJECT TERMS

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