Species Status Assessment Report
for the
Sicklefin Redhorse

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U.S. Fish and Wildlife Service
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Species Status Assessment Report For
Sicklefin Redhorse (*Moxostoma sp. 2*)

Prepared by the
U.S. Fish and Wildlife Service

EXECUTIVE SUMMARY

This species status assessment reports the results of the comprehensive status review for the Sicklefin Redhorse (Moxostoma sp. 2) and provides a thorough account of the species' overall viability and thus extinction risk. The Sicklefin Redhorse is a freshwater fish endemic to the Little Tennessee River and the Hiwassee River watersheds in North Carolina and Georgia. They occur in medium to large rivers and streams, moving upstream seasonally to spawn. To evaluate the biological status of the Sicklefin Redhorse both currently and into the future, we assessed a range of conditions to allow us to consider the species' resiliency, redundancy, and representation (together, the 3Rs). Sicklefin Redhorse need multiple resilient populations distributed widely across its range to maintain its persistence into the future and to avoid extinction. Several factors influence whether Sicklefin Redhorse populations will grow to maximize habitat occupancy, which increases the resiliency of a population to stochastic events. These factors are substrate conditions, water quality and water quantity. As we consider the future viability of the species, more populations with high resiliency distributed across the known range of the species are associated with higher overall species viability. Sicklefin Redhorse may have historically ranged throughout greater portions of the upper Tennessee River watershed, but a long history of land disturbance and habitat fragmentation has left the species confined to relatively short reaches of unimpounded habitat. Due to recent taxonomic distinction, there are few collection records for this species. The species is believed to have been reduced to only four substantial spawning aggregations that are believed to represent at least three genetically distinct populations. We have assessed the Sicklefin Redhorse's levels of resiliency, redundancy, and representation currently and into the future by assessing the condition of each population. Our qualitative assessment of the relative condition of each population is based on the knowledge and expertise of Service staff and other species experts, as well as published reports. Our analysis of the past, current, and future influences on what the Sicklefin Redhorse needs for long term viability revealed that there are three influences that pose the largest risk to future viability of the species. These risks are primarily related to the demographic health of the populations, habitat alteration and water quality changes due to changes in land use, and the potential long term effects of predation by invasive Blueback Herring. The remaining Sicklefin Redhorse populations are relatively small and barriers prevent sufficient gene flow to counter the stochastic loss of unique alleles in the populations. Projected human population increases and land development are expected to affect the quality of the habitat available to the Sicklefin Redhorse, while at the same time putting additional pressure on limited water resources. Climate change is an additional stressor that may affect the magnitude of other risks for this species. In an attempt to counter the future risk to this species, a dedicated

group of conservation partners have entered into a Candidate Conservation Agreement intended to conserve the species. The cumulative effects of these risks and the success of active management play a large role in the future viability of the Sicklefin Redhorse. Given our uncertainty regarding future conditions, we have attempted to frame our future projections as a contrast between a future where the species remains within its present range and a future where successful reintroduction to new habitats allows for increased viability.

Contents

Chapter 1. Introduction

The Sicklefin Redhorse (*Moxostoma* sp.) is a medium-size sucker, a fish of the family Catostomidae, endemic to the Hiwassee and Little Tennessee River basins of the upper Tennessee River drainage in North Carolina and Georgia. It is a species that has been of conservation concern since it was made a candidate for listing in 2005 by the U. S. Fish and Wildlife Service (Service) under the Endangered Species Act of 1973, as amended (Act) (70 FR 24870, May 11, 2005). The species is now being reviewed for listing as threatened or endangered under the Act. This Sicklefin Redhorse Species Status Assessment Report (SSA Report) is a summary of the information assembled and reviewed by the Service and incorporates the best scientific and commercial data available. This SSA Report documents the results of the comprehensive status review for the Sicklefin Redhorse.

For the purpose of this assessment, we define viability as the ability of a species to persist and avoid extinction over a period that is biologically meaningful for the species. Using the SSA framework, we consider what the species needs to maintain viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation as defined by the Service's Species Status Assessment Framework Version 3.2 (USFWS 2015):

- Resiliency is defined as the ability of populations to withstand stochastic events. We can measure resiliency based on metrics of population health, such as evidence of natural recruitment and the extent of occupied habitat. Healthy populations are more resilient and better able to withstand disturbances such as demographic stochasticity, environmental stochasticity, and the effects of anthropogenic activities.

- Representation is defined as the ability of a species to adapt to changing environmental conditions. Representation can be measured through the breadth of genetic diversity within and among populations and the ecological diversity (also called environmental variation or diversity) of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the case of the Sicklefin Redhorse, we evaluate representation based on the number of distinct populations and the genetic and ecological diversity contained within these populations.

- Redundancy is defined as the ability of a species to withstand catastrophic events. Redundancy is about spreading risk and can be measured through the duplication and distribution of resilient populations across the range of the species. The more resilient populations a species has, distributed over a larger landscape, the better it can withstand catastrophic events and localized degradation within the occupied range

To evaluate the long-term viability of the Sicklefin Redhorse we assessed all available information and potential future conditions to allow us to consider the species' resiliency, redundancy, and representation. This SSA Report provides an assessment of Sicklefin Redhorse biology and natural history, and assesses demographic risks, threats, and limiting factors in the context of determining the viability and risk of extinction for the species. This document is a compilation of the best available scientific and commercial information and a description of past, present, and likely future threats to the Sicklefin Redhorse.

The SSA Report is not a decision document issued by the Service on whether this species should be proposed for listing as threatened or endangered under the Act. That decision will be made by the Service after reviewing this and other documents in the context of all relevant laws, regulations, and policies, and will be announced in the Federal Register. This SSA Report provides a strictly biological review of the available information related to the viability of the Sicklefin Redhorse.

Chapter 2. Individual Needs: Life History and Biology

In this chapter we provide basic biological information about the Sicklefin Redhorse, including its taxonomy, morphological description, and known life history aspects. We then outline the known resource needs of individuals and populations based on present conditions.

2.1 Species Description

The Sicklefin Redhorse, a fish of the family Catostomidae, is recognizable by its long, sickle-shaped dorsal fin, which gives it its name. The Sicklefin Redhorse can grow to a length of approximately 650 millimeters (roughly 25.6 inches). It has an elongate, somewhat compressed body and a highly falcate (sickle-shaped) dorsal fin. Its body is olive-colored, with a coppery or brassy sheen; its lower fins (pectoral, pelvic, and anal fins) are primarily dusky to dark, often tinted yellow or orange and pale edged; the caudal fin (tail fin) is mostly red; and its dorsal fin is olive in color but becomes red and accentuated during the spawning season. Males develop prominent tuberculation on the anal and caudal fins during the breeding season. A more detailed description of the species is provided by Jenkins (1999, pp. 8–12).

2.2 Taxonomy

Modern fish biologists were slow to recognize the distinct morphological features of this species despite encountering it for several decades and prior to its recognition as a distinct taxon. The Sicklefin Redhorse is now known to have been collected in 1937 from the mouth of Forney Creek near its confluence with the Tuckaseegee River. This and subsequent collections were misidentified, often as hybrids of the Smallmouth Redhorse (*M. breviceps*) and the River Redhorse (*M. carinatum*), until 1992 when Dr. Robert Jenkins examined two specimens collected from the Little Tennessee River by Dr. Edward Menhinick in 1981 and 1982. Based on lower lip, dorsal fin, and pharyngeal teeth characters, Jenkins (1999, pp. 3–4, 9, and 13) recognized the fish as a distinct species. Subsequent genetic studies (Harris et. al. 2002, pp. 1433-1452) have concluded that the Sicklefin Redhorse is a distinct species. The Service is not aware of any challenges to the validity of this species.

2.3 Life History

The Sicklefin Redhorse is a potamodromous species, meaning that it makes a spawning run in fresh water. During spawning, the Sicklefin Redhorse moves from winter habitat in the lower portion of occupied rivers upstream to shoal areas suitable for spawning. The species appears to exhibit spawning-site fidelity, returning to their natal stream and possibly the same stream reaches each year to spawn (Favrot 2008, pp. 3, 9, 36, 41-42, 70, and 72). Studies indicate that upstream migration to spawning sites in the Hiwassee/Valley rivers and Little Tennessee/Tuckasegee rivers occurs in early spring. Favrot (2008, pp. 67) reported that the adults began their spawning migration when water temperatures reach 10.0-12.0 degrees Celsius (ºC) (50.0-53.6 º Fahrenheit [F]) and peak at water temperatures of 15.0-16.0 ºC (59.0-60.8 ºF). (Favrot 2008, p. 67, Stowe 2012, p. 26). Male fish develop turbercles on their paired pectoral and pelvic fins, and especially the anal fin and the ventral portion of the caudal fin, which they use to physically stimulate the female into ovipositing. Spawning typically occurs in shoals over clean cobble with usually only a small proportion of sand and gravel, in moderate to fast-flowing water in open areas and pockets formed by boulders and outcrops without attached vegetation (Jenkins 1999, p. 18; Favrot 2008, pp. 3, 8, 49, 56, 59-60, 84-85). The eggs are negatively buoyant and adhesive (Petty et al. 2013, p. 7). Sometime after hatching, yolk-sac stage larvae become buoyant, enter the water column, and are carried downstream as part of the stream drift to the mouths of streams or into reservoirs (Jenkins 1999, pp. 19–20; Stowe 2012, pp. 23, 29), where transition to a benthic existence likely occurs.

Juveniles apparently do not feed for over two weeks, based on a laboratory study (Petty et al. 2013, p. 7). How far they are capable of drifting is unknown, but in shorter river reaches they could conceivably reach a reservoir before beginning to feed. It is also possible that feeding behavior may not be developed until they transition to a benthic existence (presumably in reservoirs). Specific food habits of juvenile fish while in reservoirs are unstudied; if they begin to feed during their brief existence in the water column, they likely prey upon microcrustaceans and other foods characteristic of reservoir zooplankton communities. As benthic dwellers, they probably feed primarily on macroinvertebrates as do adults. Very little is known about the juvenile stage of Sicklefin Redhorse. Capture records indicate that juveniles are present in Fontana Lake and Hiwassee Lake, but their distribution and abundance is unknown. Juveniles occupying the lower reaches of rivers show a preference for moderate to deep pools with slow currents and large boulder-crevice cover (Stowe 2012, pp. vii and 18-19). Juvenile fish are believed to mature and begin to participate in spawning at around 5-8 years of age (males 5-7 years, females 7-8 years) (Jenkins 1999, p. 20), and appear to be relatively long-lived, with males living at least 20 years and females at least 22 years of age (Jenkins 1999, pp. 8–6).

Adult Sicklefin Redhorse occupy cool to warm, moderate-gradient creeks and rivers (Jenkins 1999, p. 19; Stowe 2012, p. vi). Adults are generally associated with moderate to fast currents, in riffles, runs, and well-flowing pools (Jenkins 1999, pp. 15, 17, and 19; Favrot 2008, pp. 49, 62-64, and 80). Adults are found over gravel, cobble, boulder, and bedrock substrates with no, or very little, silt overlay (Jenkins 1999, pp. 15, 17, and 19; Favrot 2008, pp. 49, 62-64, and 80). Post-spawn adults appear to generally move downstream to deeper waters and more suitable foraging areas (Favrot 2008, pp. 37, 47, 57, 58, 74-76, and 80); and to migrate further downstream to even deeper waters for the winter (Favrot 2008, pp. 38, 39, 57, 58, 63, 74, 82, and 84; Stowe 2012, p. 21). Except during migrations to and from spawning and wintering sites, the Sicklefin Redhorse appears relatively sedentary at its spawning, post-spawning, and wintering sites, travelling only short distances up and down stream within the occupied river reach (Favrot 2008, p. 72). Impounded habitat does not appear to be suitable habitat for adult Sicklefin Redhorse. Although a few adult Sicklefin Redhorse have been observed in the Hiwassee and Fontana Reservoirs, Favrot (2008, pp. 2 and 39) reported that he was unable to detect radio-tagged adult Sicklefin Redhorse utilizing Hiwassee Reservoir for other than brief periods, presumably while moving between winter and spawning habitat.

Observations and stomach analyses indicate that adult Sicklefin Redhorse are benthic foragers on macroinvertebrates, such as insect larvae, crustaceans, and snails (R. Jenkins, pers. comm. 2004). Distinct from the spawning habitat, the species has rarely been observed foraging on substrates with even a thin covering of silt (Jenkins 1999, p. 15). When feeding, the species exhibits a well-defined preference for coarse substrates with abundant riverweed (Podostemum ceratophyllum) (Favrot 2008, pp. 3, 48-50, 56-57, 59, 62, 64, and 80).

The habitat requirements of Sicklefin Redhorse vary with life stage. In some cases the needs of a particular life stage are not known with certainty, but must be inferred based on best judgment. The habitat needs of each life stage are summarized in Table 1.

Table 1. Habitat needs per life stage of the Sicklefin Redhorse.

Life Stage	Habitat Needs	References
Eggs – Emergence of Fry	• Spawning migration requires adequate spring time flows and water temperatures to reach 9.5–12.0 ºC (49.1–53.6 °F) during early spring. • Spawning requires cobble, with only a small portion of sand and gravel, in moderate to fast-flowing water in open areas and pockets formed by boulders and outcrops. • Eggs are adhesive (initially), fragile, and negatively buoyant requiring clean substrate to adhere to. • Developmental stages and behaviors likely temperature–dependent; in lab hatching begins after ~5 days and requires a temperature of 18–21°C, after which larvae require a few days of stable conditions before swimming up into the water column.	Favrot (2008, p. 67) Stowe (2012, p. 26) Jenkins (1999, p. 18) Favrot 2008, p. 84–85) Petty et al. (2013, p. 7) Petty et al. (2013, p. 7)
Fry	• Habitat usage/needs are unknown. Expected to require a period of larval drift at normal flows to allow the larvae to mature in the water column before maturing to benthic feeding as a juvenile around 17 days	Petty et al. (2013, p. 7)
Juveniles	• Habitat usage/needs are unknown. Expected to require stable pool habitat in the lower reaches of creeks and rivers and near-shore portions of reservoirs.	Jenkins (1999, p. 20); Stowe (2012, p. 23 and 29)
Adults	• Adults require cool to warm flowing water in moderate-gradient creeks and rivers that provide an abundance of benthic macroinvertebrates for foraging. • Observation of adult behavior suggests they require silt free coarse substrates with abundant riverweed. • Adults may require that their spawning sites remain suitable from year to year for successful spawning due to spawning site fidelity.	Jenkins (1999, p. 19) Stowe (2012, p. vi) Jenkins (1999, p. 15) Favrot (2008, pp. 37-–42 and 69—75)

Chapter 3. Species Status and Management Needs

In this chapter we consider the Sicklefin Redhorse's historical distribution, its current distribution, and environmental requirements in terms resiliency, redundancy, and representation, in addition to the management history and ongoing needs for the species.

3.1 Historical Range and Distribution

The Sicklefin Redhorse is a species endemic to the Hiwassee and Little Tennessee River basins of the upper Tennessee River drainage in North Carolina and Georgia. Jenkins (1999, p.3) noted that this small geographic range is odd for a large, migratory fish species and that other fish in the *Moxostoma* genus are generally widespread. It seems likely that Sicklefin Redhorse did at one time extend further downstream into the lower reaches of the Hiwassee and Little Tennessee Rivers prior to the damming of the rivers, but there is no information available to indicate where Sicklefin Redhorse might have been present in other rivers of the upper Tennessee River Basin. By the time of its discovery, the species' distribution had likely been significantly reduced. Based on past and recent collection records and the habitat requirements of the Sicklefin Redhorse, it is believed that the species once inhabited the majority of the rivers and large creeks in the Blue Ridge portion of the Hiwassee and Little Tennessee River systems in North Carolina and Georgia (Jenkins 1999, pp. 20-26). Jenkins estimated that the species' historic range of 353 river miles has been reduced to a present range of 147 river miles, a reduction of 58.4% (Jenkins 1999, p. 26). The most likely mechanism to explain the observed distribution within the upper Tennessee River is that the Sicklefin Redhorse evolved in either the Little Tennessee or Hiwassee River and was transferred between basins by stream capture, a geological process where a stream changes course and is diverted into an adjacent river basin (Jenkins 1999, p. 24). The implication is that the Sicklefin Redhorse has likely always been a narrowly distributed species, and its present distribution is a result of its naturally restricted historical range rather than broad scale extirpation from other rivers in the Blue Ridge. Within the Little Tennessee and Hiwassee Rivers, the range of Sicklefin Redhorse has likely been reduced by the creation of barriers and subsequent loss of the species in stream segments where natural re-establishment is not possible. Due to the long history of habitat alteration in the Little Tennessee and Hiwassee river drainages and the dearth of historical records attributable to the species, the extent of its historical range will likely never be completely known.

3.2 Current Range and Distribution

Currently, the Sicklefin Redhorse is only known to occupy two river systems; the Little Tennessee River and the Hiwassee River systems (Jenkins 1999, pp. 20-25 and 29, Figure 1). In the Hiwassee River system, Jenkins (1999, pp. 20-25 and 29) and Favrot (2008, pp. 33, 35-36, and 38-39) recorded the current known occupied range of the Sicklefin Redhorse as: (1) a relatively short reach (approximately 9.0 mi [14.5km]) of the main stem of the Hiwassee River, between Mission Dam and Hiwassee Lake, Cherokee County, North Carolina; (2) Brasstown Creek (approximately 16.9 mi [27.2 km]), a tributary to the Hiwassee River in Cherokee and Clay Counties, North Carolina, extending into Towns County, Georgia; (3) the main stem of the Valley River, between the community of Buffalo and backwaters of Hiwassee Lake (approximately 22.3 mi [35.9 km]), Cherokee County, North Carolina (Jenkins; Favrot); in addition, Favrot (2008, pp. 33, 35-36, and 38-39) provides recent records for the species in (4) Hanging Dog Creek (approximately 3.0 mi [4.8 km]), a tributary to Hiwassee River (at Hiwassee Lake) in Cherokee County, North Carolina; and, (5) a short reach of the Nottley River (approximately 2 mi [3.2 km]) between the cold water discharge from Nottely Reservoir and the backwaters of Hiwassee Reservoir in Cherokee County, North Carolina (Favrot 2008, pp. 33, 35-36, and 38-39). In addition, several juveniles have been collected from the near shore portions of Hiwassee Lake, Cherokee County, North Carolina (Jenkins pers. comm. 2003, 2004, and 2006). Also, as mentioned previously, a few adult Sicklefin Redhorse have been detected in Hiwassee Reservoir but these appear to have been moving from one stream to another (Favrot 2008, pp. 2 and 39).

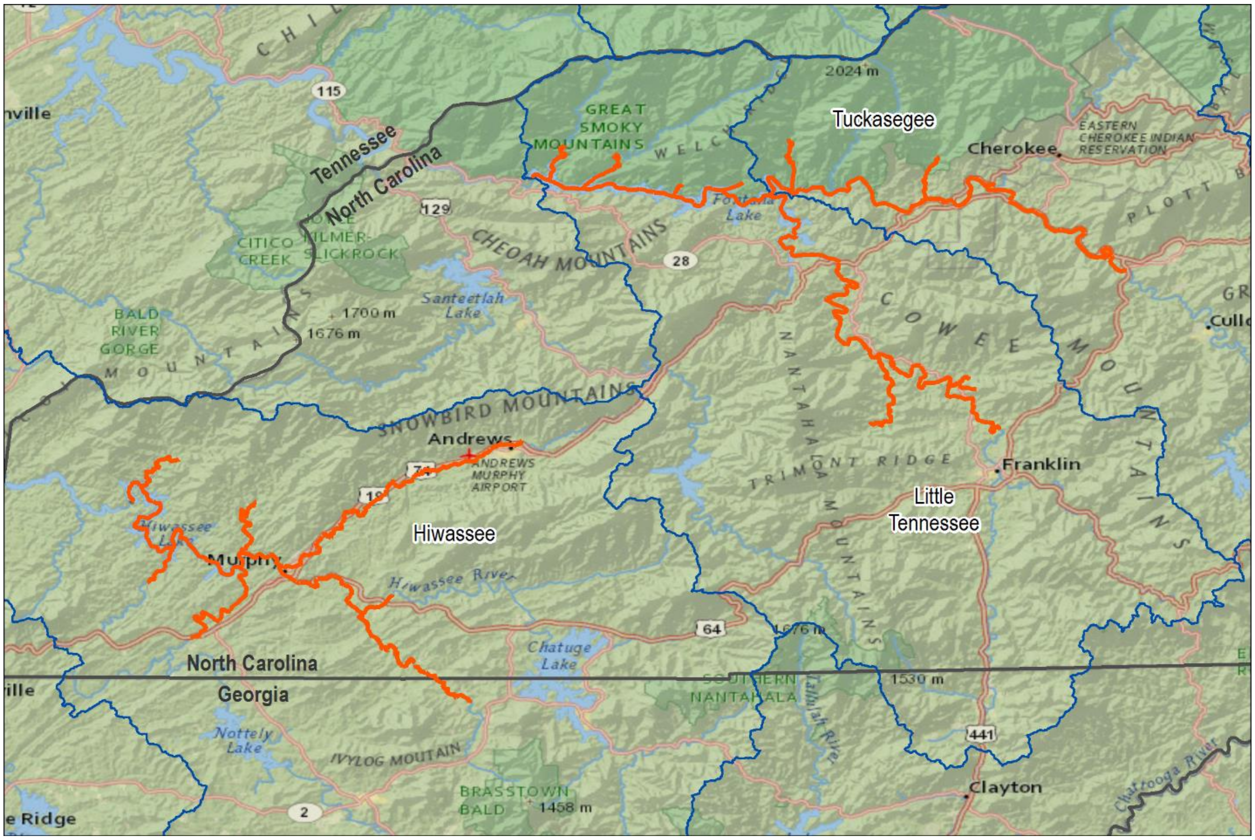
Estimated occupied stream habitat in the Hiwassee river systems totals about 53.0 mi (85.3 km) (adapted from Jenkins 1999, p. 26 and Favrot 2008, pp. 2, 33, 35-36, 38-39). However, use of various streams/stream reaches within this total appears to be seasonal. Available information indicates that the Sicklefin Redhorse uses Brasstown Creek, Hanging Dog Creek, Beaverdam Creek, Nottely River and the mid and upper reaches of the Valley River, primarily for spawning (Favrot 2008, pp. 2, 35-36, 51, and 69). No spawning or courting behavior was observed within the mainstem of the Hiwassee River (Favrot 2008, p. 69). The mid and lower Hiwassee River and lower reaches of the spawning tributaries are occupied from the post-spawning period through the fall and early winter (Favrot 2008 pp. 2, 36-39 and 75). Adults occupy the lower un-impounded reaches of the Hiwassee River (Favrot 2008, pp. 38 and 39) the lower Valley River, during the winter months (Favrot 2008, p. 38).

The Little Tennessee River system meta-population of the Sicklefin Redhorse includes a total of approximately 59.2 mi (95.3 km) of creek and river reaches plus near-shore areas of Fontana Reservoir, including: (1) the main stem of the Little Tennessee River in Macon and Swain Counties, North Carolina, between the Franklin Dam and Fontana Reservoir (approximately 23.2 mi [37.3 km]), and its tributaries, Burningtown Creek (approximately 5.5 mi [8.9 km]) and Iotla Creek (approximately 0.1 [0.16 km]) in Macon County, North Carolina; (2) the main stem of the Tuckasegee River in Swain and Jackson Counties, North Carolina, downstream to Fontana Reservoir (approximately 27.5 mi [44.3]), and its tributaries, Forney Creek (mouth of the creek), Deep Creek (approximately 2.4 mi [3.9 km]), and the Oconaluftee River below the Bryson Dam (also sometimes referred to as the Ela Dam) (approximately 0.5 mi [0.8 km]), in Swain County, North Carolina; and, (3) the near shore portions of Fontana Reservoir, Swain County, North

Carolina, where sub-adults of the species have been collected (Jenkins pers. comm. 2007; Thomas ("TR") Russ, NCWRC, Marion, NC, pers. comm. 2012).
Like Hiwassee Reservoir, current evidence indicates Fontana Reservoir likely serves only as maturation sites for sub-adult Sicklefin Redhorse, though additional research is needed to confirm this (Jenkins pers. comm. 2010; Stowe 2012 p. 23). Likely adult spawning, foraging, and/or wintering habitat in the Little Tennessee River system appears to be restricted to the Little Tennessee River and its tributaries, Burningtown Creek and possibly the lower Iotla Creek; and, the Tuckasegee River and its tributaries, the lower Oconaluftee River and possibly the lower reaches of Deep Creek (a single adult was observed in Deep Creek in 2000, but no Sicklefins have been observed in subsequent surveys) (Jenkins pers. comm. 2006).

The species has apparently been eliminated from roughly 50% of its presumed former range (adapted from Jenkins 1999, p. 26). This is a conservative estimate that: (1) includes several miles of Hiwassee and Fontana Reservoirs (totaling ~ 62.3 mi [100.3 km]) within the present range of the species (36% of the species' estimated present range) (although portions of these reservoirs appear to provide suitable habitat for juvenile Sicklefins, current evidence indicates they do not provide spawning, foraging, or wintering habitat for adults of the species; however, they likely did prior to impoundment); (2) does not include the higher reaches of some of the creeks where the Sicklefin Redhorse occurs in their lowermost reaches and which may have been part of the species' historic range; and, (3) does not include portions of the Cheoah River, Cullasaja River, Cartoogechaye Creek, and several other large tributaries in the Hiwassee and Little Tennessee River systems that may also have been part of the historical range of the Sicklefin Redhorse.

Figure 1. Presently occupied range of Sicklefin Redhorse is shown in red.



3.3 Current Condition of the Sicklefin Redhorse

As discussed in Chapter 1, for the purpose of this assessment, we define viability as the ability of the species to sustain populations in the wild over time. Using the SSA framework, we describe the species' viability by characterizing the status of the species in terms of its resiliency, redundancy, and representation (the 3Rs). Using current and projected levels of the 3Rs, we thereby describe the species' level of viability in the future.

3.3.1 Population Resiliency

For the Sicklefin Redhorse to maintain viability, its populations, or some portion of its populations, must be resilient. For the Sicklefin Redhorse we measure the resiliency of the population using metrics of population health. Due to the difficulty of sampling Sicklefin Redhorse, an estimate of effective population size (N_e), is used to assess population health. Larger populations tend to have a higher effective population size, which is a theoretical measure of the number of breeding adults in the population that contribute to the gene pool. Populations with a low effective population size are more likely to experience genetic drift and inbreeding and are less likely to adapt to changing environmental conditions. Defining minimal viable populations is a difficult challenge faced by conservation biologists. In small populations, stochastic factors (e.g., genetic, environmental, and demographic) can accelerate problems caused by deterministic events such as habitat loss or modification and overexploitation (Fagan & Holmes 2006). Therefore, predicting the fate of small populations requires incorporating both demographic and genetic information into realistic models of extinction (Lande 1988; Reed et al. 1988). Demographic data are often limited; therefore, general conservation goals based on genetic considerations are frequently established at an $N_e \geq 50$ to minimize inbreeding depression and an $N_e \geq 500$ to maintain sufficient evolutionary potential (Franklin 1980, entire; Franklin & Frankham 1998, entire). Estimates of effective population size for the Little Tennessee River are $N_e = 586$, Sample Size [n] = 245, 95% Confidence Interval [CI] = 279-∞; and for the Tuckaseegee River $N_e = 589$, n= 99, 95% CI = 218-∞ (USFWS Warm Springs Conservation Genetics Laboratory, unpublished data). Estimates of N_e for the Little Tennessee River and Tuckaseegee are above suggested threshold levels for inbreeding and maintenance of evolutionary potential; therefore, these findings suggest genetic factors are not of immediate concern for the persistence of Sicklefin Redhorse in these two rivers. However, the species is long-lived, breeds multiple times during its lifetime, and the effective population is near the recommended minimum of 500, therefore these populations should continue to be monitored for declines over time.

Less genetic sampling has been conducted in the Hiwassee River. At present, genetic samples are only available from the Brasstown Creek portion of the population in the Hiwassee River, leaving us unable to assess the population health of the Valley River, a significant portion of this population. Presently only 38 samples are available from Brasstown Creek. This number of samples is too few to obtain a statistically valid estimate, returning a value of infinity ($N_e = \infty$, n=38, 95% CI = 126-∞) (USFWS Warm Springs Conservation Genetics Laboratory, unpublished data). However; the lower end of the confidence interval, 126, does indicate that the population in Brasstown Creek is greater than the critical threshold to avoid inbreeding depression (≥50 breeding individuals;Franklin & Frankham 1998). Based on observations of substantial breeding populations in Brasstown Creek and the Valley River (Favrot 2009, p.25; Davis 2015, p. 12), we believe that additional samples are likely to confirm that the Hiwassee River population is comparable in size to the populations in the Little Tennessee and Tuckaseegee Rivers.

3.3.2 Species Representation

The Sicklefin Redhorse needs to have genetic and ecological diversity to have adequate representation. Maintaining representation in the form of genetic or ecological diversity is important to maintain the capacity of the Sicklefin Redhorse to adapt to future environmental changes.

Habitat diversity will be necessary for Sicklefin Redhorse to maintain sufficient representation for populations to remain viable. Spawning areas appear to be a limiting factor that affects recruitment in the population. Spawning areas are typically characterized as near-shore areas of moderate to swift runs and riffles with substrates of coarse gravel and small cobble (Favrot 2008, pp. 8-9). Sicklefin Redhorse have been shown to display fidelity to spawning tributaries (Favrot 2009, pp. 34-35), and have been recaptured at the same spawning shoal over periods of several years in the Little Tennessee River below Emory Dam (USFWS Asheville Field Office, unpublished data), indicating that spawning site fidelity may be important to successful reproduction. It is presently unknown how important spawning site fidelity is for Sicklefin Redhorse, but it has been shown to play an important role in the population dynamics of other fish species. For example, Northern Pike in a lake in Minnesota have been shown to exhibit strong spawning site fidelity, with only 1.3-4.8% of fish swapping spawning sites over 4 years of observation, despite their ranges overlapping. Genetic evaluation indicated low levels of gene flow between the populations and may indicate a reproductive isolating mechanism (Miller et al. 2001, entire). It is presently unknown how strong site fidelity is for Sicklefin Redhorse or how readily they can adapt to alternative spawning sites if their preferred spawning site is altered. Strong spawning site fidelity may make the Sicklefin Redhorse particularly vulnerable to population level disruptions resulting from degradation of spawning habitat. Juvenile and adult Sicklefin Redhorse require diverse seasonal habitats that provide sufficient prey items for growth and reproduction, as well as refugia from water level fluctuations. Alteration of habitat due to fragmentation, sedimentation, pollution, or climate change can reduce representation within the populations by affecting population size and recruitment rates, thereby reducing the ability of the population to respond to a changing environment.

Presently there appears to be an abundance of suitable habitat in four streams where Sicklefin Redhorse are known to spawn. There appear to healthy populations of adults making spawning runs in the Little Tennessee River, Tuckaseegee River (NCWRC, unpublished), Valley River (Favrot 2009, p.25) and Brasstown Creek (Davis 2015, p. 12). Sicklefin Redhorse are also known to seasonally occupy the lower portions of several smaller tributaries in both the Little Tennessee and Hiwassee watersheds (Jenkins 1999, p. 22, Favrot 2009, p. 34), but it is presently unknown if these minor habitats play a significant role in maintaining the populations.

Genetic diversity also affects a species level of representation. As part of efforts to manage populations of Sicklefin Redhorse through hatchery propagation and reintroduction, the USFWS Warm Springs Conservation Genetics Laboratory (WSCGL) conducted a genetic analysis using 10 microsatelite genes to compare the populations of Sicklefin Redhorse in the Little Tennessee, Tuckaseegee and Hiwassee River drainages. The results of this analysis indicate the Sicklefin Redhorse has high heterozygosity: 0.85, 0.84, and 0.766 in the Little Tennessee, Tuckaseegee and Hiwassee Rivers, respectively. However; allelic richness, the number of unique genes at a single locus, was relatively low compared to other redhorses: 5.27, 5.21, and 4.52 in the Little

Tennessee, Tuckaseegee and Hiwassee Rivers, respectively. The Hiwassee River population had the lower genetic diversity than the Little Tennessee and Tuckaseegee Rivers, but samples were not available from the Valley River, confounding the interpretation of the diversity in the Hiwassee population as a whole (WSCGL, unpublished data).

3.3.3 Species Redundancy

Species that are well-distributed across their range (i.e., having high redundancy) are less susceptible to extinction and more likely to be viable than species confined to a small portion of their range (Carroll et al. 2012, entire; Redford et al. 2011, entire). Genetic data from the Little Tennessee River, Tuckaseegee River, and Brasstown Creek indicate that there are at least three genetically distinct populations distributed in two primary watersheds, the Little Tennesee River and the Hiwassee River. Within each watershed there are two primary tributaries that provide redundancy. In the Little Tennessee River the Little Tennessee mainstem and the Tuckaseegee River are redundant. In the Hiwassee River, the Valley River and Brasstown Creek provide redundancy. In both watersheds there are also some minor creeks that are occupied seasonally and may provide additional redundancy, but the importance of these areas to the populations are presently unknown.

Table 2. Summary of current condition of Sicklefin Redhorse in occupied stream reaches.

River Basin	Stream Reach	Length Occupied	Effective Population Size Estimate	Relative Breeding Population Size
Little Tennessee	Little Tennessee River	37.6 mi (60.5 km)	586	Large
Little Tennessee	Tuckaseegee River	38.27 mi (61.6 km)	589	Large
Hiwassee	Brasstown Creek	21.6 mi (34.8 km)	> 126	Medium
Hiwassee	Valley River	20.1 mi (32.3 km)	Unsampled	Large
Hiwassee	Nottely River	5.3 mi (8.6 km)	Unsampled	Small
Hiwassee	Hanging Dog Creek	5.0 mi (8.0 km)	Unsampled	Small
Hiwassee	Beaverdam Creek	1.6 mi (2.7 km)	Unsampled	Small

3.4 Ongoing Management and Research

The Service has been working with Conservation Fisheries, Inc. (CFI), Warm Springs National Fish Hatchery (WSNFH), Eastern Band of Cherokee Indians (EBCI), NCWRC, and Tennessee Valley Authority (TVA) to propagate the Sicklefin Redhorse and reintroduce the species into currently unoccupied habitat within the historical range since 2007. From 2007–2015, approximately 80,000 juvenile Sicklefin Redhorse, reared by CFI (46,272 released) and by WSNFH (35,540 released) from broodstock collected from the Little Tennessee River, have been released into the Oconaluftee River above Bryson Dam and into the Tuckaseegee River upstream from the former Dillsboro Dam site. The Service and NCWRC have been holding annual stakeholder meetings since 2009 to coordinate conservation efforts, which include an annual sampling effort to collect animals for propagation and to collect data on the Sicklefin Redhorse populations. Additional propagation and reintroduction efforts, population monitoring, and studies of movement patterns, habitat use, and water quality requirements are planned to continue into the future, as necessary.

In 2010, as part of the Tuckasegee Cooperative Stakeholders Team Settlement Agreement with Duke Energy, LLC, the Dillsboro Dam, a small hydropower dam on the mainstem of the Tuckasegee River, was removed and stream bank restoration within the former impounded river reach was carried out. In 2013, a young male Sicklefin Redhorse, likely part of the stock of fingerlings used to augment the species in the Tuckaseegee River in 2007 or later, was captured by NCWRC and Service biologists in the formerly impounded area. Monitoring efforts on the species' potential expansion in this reach of the Tuckasegee River is on-going in an effort to determine if the fish continue to use this newly restored river reach.

The Service, NCWRC, and Georgia Department of Natural Resources (GADNR) have collaborated over the last decade to fund studies of Sicklefin Redhorse life history and occupancy that will help guide future management activities. In 2005, the GADNR began annual monitoring of the Sicklefin Redhorse breeding population in Brasstown Creek. In 2013, they contracted with Dr. Jonathan Davis of Young Harris College to develop a monitoring protocol based on visual observations and seining. This protocol was carried out between 2013 and 2015 and will be continued into the future. GADNR and Young Harris College have also carried out surveys in the upper Nottely and Hiwassee Rivers in search of undocumented populations of the Sicklefin Redhorse within its putative historical range. In 2008, a study was conducted on the reproduction and habitat ecology of adult Sicklefin Redhorse in the upper Hiwassee River basin (Favrot 2009, entire). In 2012, a study was completed on movement patterns and habitat use by juvenile and adult Sicklefin Sedhorse in the Tuckasegee River Basin (Stowe 2012, entire). In 2014, a study was initiated on the early life stages of the Sicklefin Redhorse and their interaction with the introduced predator, Blueback Herring. This study is presently underway and preliminary results from DNA barcoding have not identified Sicklefin Redhorse among the Blueback Herring gut contents.

3.4 Candidate Conservation Agreement

The Service has entered into a Candidate Conservation Agreement (CCA), signed February 23, 2016, with TVA, Duke Energy Carolinas, NCWRC, GADNR, and EBCI to maintain the viability of extant populations, improve its status by funding and executing a propagation and stocking strategy to expand populations where feasible, and to evaluate long-term genetic issues of its isolated populations. The terms of this agreement ensure funding to continue these activities for

10 years and is extendable in 5-year increments thereafter if stock assessment data indicate that the effort should continue. The actions carried out under this CCA will be guided by a larger working group of interested parties and stakeholders and the results of ongoing genetic and demographic monitoring.

Providing the species with additional habitat can also affect resiliency by increasing the carrying capacity which would allow for a greater effective population size, and improve the species' redundancy by decreasing the chances a population could be affected by demographic or environmental stochasticity. Expanding the species into currently inaccessible habitat will increase the species viability by providing access to greater ecological diversity and increasing the abundance of suitable habitat. It is hoped that greater diversity of habitat will help the species more effectively adapt to climate change and other stressors. Species conservation carried out under the CCA is intended to be adaptive and focused on ensuring that the species does not become threatened with extinction.

Chapter 4. Risk Factors

In this chapter, we evaluate the past, current, and future influences that are affecting what the Sicklefin Redhorse needs for long term viability. Current and potential future effects, along with current expected distribution and abundance, determine present viability and, therefore, vulnerability to extinction. Those risks that are not known to have effects on Sicklefin Redhorse populations, such as overutilization for commercial and scientific purposes and disease, are not discussed in this SSA report.

4.1 Demographic Risk

Estimates of Sicklefin Redhorse effective population size for the Little Tennessee River and Tuckaseegee River populations are above the recommended 500 minimum (Franklin 1980, entire; Franklin & Frankham 1998, entire) and these populations are likely to have sufficient population size to allow for evolutionary adaptation. Estimates of effective population size from the Hiwassee River are lower, but at present, too few samples have been analyzed to give a statistically relevant estimate of effective population size. Additionally, all samples from the Hiwassee River have been collected from Brasstown Creek. We are aware that the Valley River population is a major component of the Hiwassee River population and that fish have been observed using both rivers during a single spawning season (Favrot 2009, pp. 34-35). It is presently unknown if Brasstown Creek and Valley Rivers represent a single population of interbreeding adults, or two populations with ample opportunity for gene flow. In either case, the Sicklefin Redhorse in the Valley River represents a substantial portion of the Sicklefin Redhorse in the Hiwassee River watershed and likely contributes to greater genetic diversity than the available analysis would suggest. At this time we do not have information to assess how Sicklefin Redhorse in the other, smaller occupied streams within the Hiwassee River system are contributing genetically to the populations in the system (e.g., Nottely River; Beaverdam, Hanging Dog creeks), but their confirmed presence increases the opportunities for gene transfer and reduces long-term demographic risk.

Populations of Sicklefin Redhorse display high heterozygosity but may have low allelic richness when compared to other redhorses (see Section 3.3.1). This observation may indicate that the populations may have experienced a population bottle neck in the past (Greenbaum *et al*. 2104, entire). This is not surprising, considering the range contraction and habitat fragmentation that the species has experienced. A reduction in allele diversity decreases a population's ability to adapt to environmental changes and places them at greater risk of extinction due to a complex reinforcing mechanism known as the extinction vortex (Fagan and Holmes 2006, pp. 58–59). Gene flow between populations may be important to preserve the remaining allelic diversity from being lost due to genetic drift. Genetic data suggests limited gene flow occurs between the Little Tennessee River and the Tuckaseegee River populations, and observations suggest that gene flow may take place between the Valley River and Brasstown Creek. More information will be necessary to assess the effect that genetic drift and gene flow may have on the demographic health of the population in the future.

A primary component of management carried out under the CCA is to assess and manage the genetic health of the remaining Sicklefin Redhorse populations. Data available about the demographic health of the Sicklefin Redhorse populations suggest that with the present population size, there is enough diversity for the species to respond and evolve to changes in environmental conditions without substantial threat from inbreeding or substantial genetic loss due to genetic drift; however, the estimates are on the lower end of the recommended effective population size and it will be important to ensure that the populations do not decline below a level where genetic considerations become critical. One of the major benefits of the CCA is that the species will be aided in expansion into unoccupied habitat, with the intention of increasing the carrying capacity and the effective population size in the future, enabling the species to remain viable despite an evolving landscape. Genetic evaluation being conducted as part of the hatchery rearing of Sicklefin Redhorse will provide an effective means of monitoring genetic health. In the future, if additional genetic information reveals that increased gene flow between populations would be beneficial, this would be easily accommodated through the existing stocking program.

4.2 Changes in Land Use

Perhaps the most significant threat to Sicklefin Redhorse populations are the effects of land use change and human development on its habitat. Habitat suitability can be dramatically affected by changes in land use. Conversion of forested landscapes to agriculture, rural, or urban land uses increases erosion and sediment load, and impairs water quality with nutrients and chemical pollutants (Foley et. al. 2005, p. 571; U.S. Department of Agriculture 2013, p. 309). Indexes of biotic integrity, habitat metrics, and fish diversity have been shown to negatively correlate with the extent of agricultural and urban land use (Roth *et al*. 1996, p. 141; Kennen *et al.* 2005). The sicklefin redhorse has been observed feeding and spawning only in substrates with no or very little silt accumulation. Excessive siltation and suspended sediment, which can occur as a result of land disturbance activities with inadequate erosion and stormwater controls, affects the habitat of the sicklefin redhorse by: (1) eliminating breeding sites, which results in increased mortality of eggs and juveniles; (2) eliminating feeding areas; (3) reducing the ability to detect prey; (4) eliminating aquatic insect larvae and other food items from the sicklefin redhorse diet. Suspended sediment also irritates and clogs fish gills affecting their respiration (Waters 1995, pp. 53-117).

Harding (1998, entire) found the existing diversity in watersheds was better correlated with land use during the 1950's but not equally correlated with land use in the 1990's, indicating that the diversity loss caused by land use change is long-lived and does not rebound quickly on its own. Past land uses are likely to have had a dramatic effect on the present condition of Sicklefin Redhorse populations. Kirk (2009, entire) described a long history of landscape alteration in the range of Sicklefin Redhorse that began with widespread deforestation and conversion to agriculture in the late 19th and early 20th century. Agricultural extent peaked in 1910 and the regions total non-forested area peaked in the 1930's. In the 1940's, the arrival of railroads, mining and forestry industries, coupled with severe soil depletion, caused a shift away from agricultural practices and resulted in a trend of agricultural abandonment and reforestation (Otto 1989, entire). After the decline in agriculture, the forests within the watershed began to regrow and total forested area increased dramatically, peaking in the 1980's. From the 1980's to the present, the watersheds affecting Sicklefin Redhorse have experienced slow but steady rural development and modest growth of small towns in the watershed. From 1980 to the present, forested area is estimated to have been lost at a rate of 1.1% annually, mostly due to land development (Kirk 2009, pp. 105-111).

The period likely to have been most detrimental to the Sicklefin Redhorse populations was the period of intensive agricultural activity in the late 19th and early 20th century. Agricultural practices in the Appalachian Mountains before the beginning of the 20th century were primarily based on animal grazing and corn cultivation using a method known as forest fallowing. This primitive form of agriculture caused significant soil erosion and rapid depletion of soil nutrients, requiring most of the forested area to be converted to agricultural use at some time in the past. Due to the widespread erosion, sediment load in streams supporting Sicklefin Redhorse were likely to have been many times the background rate, causing substantial habitat degradation. An investigation of stream sedimentation rates in a watershed adjacent to the range of Sicklefin Redhorse indicated that during the late 19th century, sedimentation rates were 62 times higher in a watershed where 35% of the watershed was affected by forest fallowing compared to a similar forested watershed. In this study, sedimentation rates were as high as 155 tons of sediment per square kilometer of watershed area per year (tons/km^2/yr), compared to a background sedimentation rate of 2 tons/km^2/yr (Kennedy 2012, pp. 132-133). Sedimentation rates are likely to have remained high for a long period. Simmons (1993) reported high rates of suspended sediment yield in the range of Sicklefin Redhorse between 1970 and 1979. The Tuckaseegee River, Little Tennessee River, Oconaluftee River, Valley River and Cartoogechaye Creek were reported as having suspended sediment yields of 79.6, 86.5, 45.0, 90.0 and 65.8 tons/km^2/yr, respectively.

The trend of high suspended sediment yield in the range of Sicklefin Redhorse appears to have improved over the last few decades. Increasing environmental regulation, greater public awareness, and the actions of governmental and non-governmental organizations to improve water quality conditions have resulted in considerable improvements in suspended sediment rates. Measurements of suspended sediment yield in the Upper Little Tennessee River between 2000 and 2002 were much lower than those measured in the 1970s. The Little Tennessee had a yield of 18 tons/km^2/yr at Riverside, North Carolina and 5 tons/km^2/yr below Lake Emory. The Cullasaja River and Cartoogechaye Creek had 5 and 7 tons/km^2/yr, respectively (USGS 2003, p. 18). The author acknowledges that these data are confounded by the unusually low flow due to drought conditions during the 2001 year, but the study was altered to collect some data during high flow events in 2002 to address this shortcoming. Due to the drought conditions during the measurement, it is possible that the present average suspended sediment yields are somewhat higher than those measured during the 2001-2002 study, but the dramatic reduction compared to the 1970-1979 study likely represents a significant improvement in land use practices.

Improvements in land use practices are likely attributable to the modern regulatory environment that provides protection to the stream environment. The Fish and Wildlife Coordination Act of 1934, the North Carolina Environmental Policy Act of 1971, the Clean Water Act of 1972, the North Carolina Sediment and Pollution Control Act of 1973, the Georgia Erosion and Sedimentation Act of 1975, as well as other regulatory actions, were enacted to control the effects of land development and pollution on the aquatic environment. However, despite significant improvements, the human population within the species range is expected to continue to increase and associated land development may continue to affect habitat quality.   The average rate of growth for the 7 counties in the range of Sicklefin Redhorse is projected to be around 0.71 percent per year between 2010-2030 with most of the growth expected in Macon and Swain Counties, North Carolina and in Towns County, Georgia. The population growth in the counties where it may affect Sicklefin Redhorse is lower than the state wide average growth rates in North Carolina and Georgia, and is much lower than the rates of growth seen in larger metropolitan areas in these two states (Table 3).

The increasing population is likely to lead to increased conversion of forest land to developed land use types. Land use models were not available for all counties where Sicklefin Redhorse is found, but Macon County, where the majority of the Little Tennessee River Sicklefin Redhorse population is found, was modeled in detail by Kirk (2009). Modeling projections for Macon County through 2030 indicate that land use change will primarily be due to growth in residential and commercial development, representing a 47% increase in developed area, with a slight decrease in agricultural area and 3% decrease in forested area (Kirk 2009, p. 17). Macon County was 75% forested in 2009, and 45% of the county was publicly owned, with most public land being part of the Nantahala National Forest (Kirk 2009, p. 17). This model also predicts a decreasing rate of change across the landscape in the future, compared to rates of change experienced over the last century (Kirk 2009, pp. 33-34). Kirk (2009) also produced a larger scale analysis of landscape trends within a 21-county region, which encompasses all of the range of Sicklefin Redhorse in North Carolina, and shows a similar trend of increasing residential and commercial development accompanied by an average 12% decrease in agricultural area and 5% reduction in forest area 2010-2030 (Kirk 2009, p. 86).

Sustained human population growth and land use alteration within the Little Tennessee and Hiwassee River Basins has the potential to affect Sicklefin Redhorse habitat quality and is likely the most important factor affecting long term viability; however, we expect the effects will remain within a tolerable range due to several mitigating factors. The effects of population growth and development is likely to be minimized by the relatively small size of the present human population, lack of large metropolitan areas or interstate highways, existing regulations for land development and water quality, and a trend of diminishing agriculture in the area. Importantly, large portions of the watersheds are permanently protected by inclusion in the Nantahala and Chattahoochee National Forests. In the Little Tennessee and Tuckaseegee Rivers the Sicklefin Redhorse populations overlap with the federally endangered Appalachian Elktoe. In the Little Tennessee it overlaps with the federally threatened Spotfin Chub. Co-occurrence with these two federally listed species offers some protection to the habitat on which Sicklefin Redhorse depends on. The state of Georgia lists Sicklefin Redhorse as a state endangered species and North Carolina recognizes the Sicklefin Redhorse as threatened. State listed status protects the Sicklefin Redhorse from intentional take and provides a mechanism for the states to apply protective measures when reviewing permitted activities. The existing populations of Sicklefin Redhorse appear to have persisted through a long period of high intensity land disturbance resulting in severe sedimentation of its habitat in the past. With the protective regulations now in place to minimize sedimentation, and the ability of the Sicklefin Redhorse to persist through historical water quality challenges, we anticipate that they are likely to persist into the future even with the expected increase in rural development.

Table 3. Projected human population growth for NC and GA Counties within range of Sicklefin Redhorse

County, State	2010	2020	2030	% Annual Growth 2010-2030
Jackson, NC[1]	40,271	42,453	44,820	0.56
Swain, NC[1]	13,981	15,755	17,301	1.18
Graham, NC[1]	8,861	9,224	9,875	0.57
Clay, NC[1]	10,587	10,792	10,820	0.11
Cherokee, NC[1]	27,444	27,338	27,312	-0.02
Macon, NC	33,922	36,974	41,217	0.98
NC Total[1]	9,574,917	10,574,718	11,609,883	1.06
Towns, GA[2]	11,386	13,088	15,066	1.61
GA Total[2]	10,069,700	12,189,252	14,687,906	2.29

1. NC Office of Budget and Management http://www.osbm.nc.gov/demog/county-projections
2. GA Office of Planning and Budget, Georgia 2030 Population Projections http://www.georgialibraries.org/lib/construction/georgia_population_projections_march_2010.pdf

4.3 Water Quantity

The amount of water being transported by a stream is represented by a hydrograph (discharge magnitude vs. time). The hydrograph can be altered by changes in land use, water withdrawal, water discharge, dam operation, and consequences of climate change. Conversion of a forested landscape to non-forested uses within a watershed reduces the water retention capacity of the watershed and allows water to reach streams faster than it would in a forested watershed. The result of faster runoff is that the peak instantaneous discharge is both greater in volume and shorter in duration than the baseline condition, leading to stream instability and alteration of habitat (U.S. Department of Agriculture 2013, p. 309). Sicklefin Redhorse appear to be dependent on moderately-elevated flows for days to weeks during the spring to allow for upstream movement over shoals and other shallow areas. A hydrograph altered by deforestation can result in peak flows that are too high for migration which quickly recede to a flow that is too low for migration, thereby reducing the time when migration is possible, potentially reducing the number of fish that are able to make it to spawning shoals at the appropriate time for maximizing spawning success.

Hydropower operations may also alter the hydrograph by hydropeaking, quickly increasing and decreasing the flow rate as needed to provide power to the electric grid. It is possible that a river with hydropeaking will always have flow rates too high or too low for migration and spawning. In such a situation, Sicklefin Redhorse may not be able to spawn successfully. Newly hatched fry may not be able to remain in suitable pools due to frequent changes in water velocity. Sicklefin Redhorse in the Tuckaseegee River are subjected to daily hydropeaking and appear to be able to tolerate conditions in that river. In the Hiwassee River, daily hydropeaking and low temperatures from hypolimnetic discharge may be reducing the ability of fish to spawn in the river and necessitating the use of Brasstown Creek as a primary spawning area. The other occupied rivers, the Little Tennessee and Valley Rivers, are not affected by hydropeaking and have a more natural hydrograph.

The existing Sicklefin Redhorse populations appear to have adapted to the present conditions of hydropeaking and are expected to remain stable in the future. A slow increase in runoff rates due to changes in land use are expected in the future, but the magnitude and effect of these changes are unknown. Due to the large amount of publicly owned land and the relatively large size of the watersheds supporting Sicklefin Redhorse it is unlikely that increased runoff will reduce the viability of the populations.

4.4 Water Temperature

Changes in natural water temperatures may be attributable to changes in land use, climate change, or wastewater discharges. Sicklefin Redhorse appear to use warming water temperature as their trigger to begin their spawning migration in the spring and have been observed to spawn at temperatures between 11.0-21.1°C, with a mean spawning temperature of 17.5°C (Favrot 2009, p. 47). Warming may trigger fish to become gravid earlier in the year; though specific effects are unknown, this has the potential to affect spawning success or the development of eggs and larvae. Land use alteration, especially reduction of forested area and construction of impervious surface has been shown to raise the temperature of streams (Swift 1971, entire, Herb et al. 2008, entire). In the future temperatures could increase to a point where Sicklefin Redhorse populations are affected. It is presently unknown what temperature threshold would cause effects. Critical thermal maximum (temperature leading to loss of coordinated locomotion) for the Sicklefin Redhorse is not available, but data collected for other redhorse species have shown this temperature threshold to be around 35°C (Walsh *et al.* 1998, entire; Reash *et al.* 2000, entire). In 2013, maximum summer temperatures in the Little Tennessee River and Tuckaseegee River were measured to be 25.5°C and 24°C, respectively (J. Levine, NC State University, pers. comm. 2016), indicating that there is not an immediate threat due to temperature increases. The Sicklefin Redhorse occupies a network of streams with diverse characteristics that includes substantial gradients in stream size, elevation, temperature regime and development pressures that should allow them to find refuge during periods of elevated temperature.

Cold water discharges from reservoirs is an additional temperature related factor potentially affecting the future viability of Sicklefin Redhorse populations. Portions of the Tuckaseegee and Hiwassee Rivers are affected by hydropower operation that results in the discharge of water that may be too cold for successful spawning. In the Tuckaseegee River, cold water discharge from several reservoirs in the headwaters may influence the ability of the species to expand upstream beyond the recently removed Dillsboro Dam. In the Hiwassee River, there is no evidence of spawning in the main stem of the Hiwassee up to Mission Dam. Cold discharges from reservoirs may not allow water to warm to the appropriate temperature early enough in the year to induce Sicklefin Redhorse to spawn. Additionally, cold water may not allow for proper maturation of eggs and fry. Little is known about the ability of Sicklefin Redhorse to adapt to colder water conditions. Availability of cool water conditions may also provide a protective effect by increasing the potential for temperature refugia during periods of unusually hot conditions. Juveniles residing in reservoirs have access to additional habitat diversity associated with depth gradients and temperature gradients created where cold streams flow into warmer reservoirs.

As stated in Section 4.3, the current populations appear to have adapted to the baseline condition and are presently stable. The effect of cold water discharges is not expected to become worse in the future and may provide for additional habitat diversity. Populations may be affected by a long term warming trend, perhaps exacerbated by climate change, but we expect this effect to be very gradual, allowing time for the populations to adapt to changing conditions.

4.5 Climate Change

Due to uncertainty about the timing, magnitude or complex interactions involved in climate change, it is not possible to predict what effect climate change might have on Sicklefin Redhorse. Climate change is expected to have a long-term effect on annual maximum temperature and precipitation and is likely to increase the frequency of extreme weather events (IPCC 2014, pp. 10). The U.S. Geological Survey Climate Research and Development Program projects an annual maximum temperature increase of 3.4°C in the Little Tennessee, Tuckaseegee and Hiwassee River basins between 2050-2074 compared to recorded temperature from 1950-2005. Precipitation is expected to rise slightly during this time period with the Little Tennessee experiencing an annual increase of 111mm per year, and a 74mm per year increase in the Tuckaseegee and Hiwassee. The increased precipitation is expected to be primarily in the late summer and spring, with mid-summer precipitation remaining near present levels (USGS http://www.usgs.gov/climate_landuse/clu_rd/nccv/viewer.asp). Additional effects of climate change, such as drought and magnitude of high flows, may also affect the timing and success of spawning runs for Sicklefin Redhorse, but are less predictable. Presently, Sicklefin Redhorse already appear to tolerate year to year variation in temperature and stream flow conditions, and the effective population size of known populations appears sufficient to respond to changes in the environment. If changes in precipitation and temperature are relatively minor within the range of Sicklefin Redhorse, as predicted, we expect that climate change by itself will not affect the viability of this species. However; interactions between the effects of other threats and the effects of climate change could be greater than expected and can be monitored and addressed with species management.

4.6 Barriers to Migration

All known populations of Sicklefin Redhorse are affected by the presence of dams and reservoirs that limit their ability to naturally expand their present range. Dams block upstream migration to spawning sites, and cause spawning fish to concentrate into small, possibly suboptimal spawning areas. Dependence on reduced spawning areas make the fish more vulnerable to events that disrupt spawning behavior or affect the quality of the spawning habitat. Barriers to upstream or downstream migration might also affect the species' ability to adapt to changes in water temperature. The presence of a reservoir downstream of a spawning area alters the natural life history of this species in ways that are not fully understood. Newly hatched redhorse drift downstream for a period of weeks until they become strong enough to swim against the stream current. The length of stream between spawning areas and the reservoir downstream appears to be an important factor in recruitment and maintenance of the population. Small numbers of Sicklefin Redhorse have been observed in the Nottely River, Beaverdam Creek, and Hanging Dog Creek, all tributaries to Hiwassee Lake, but it is unknown if they are able to reproduce in these streams or if the reservoir is a barrier to movement among streams. In stream reaches that are too short the larvae may reach the reservoir before they have developed sufficiently to feed effectively and avoid predation in the altered lentic environment. Studies on larval development are underway which might help answer these and other questions about larval development.

Jenkins estimated that the species' historical range has experienced a reduction of around 58.4% (Jenkins 1999, p. 26), however; there is some uncertainty about how the impoundment of the Little Tennessee River by Fontana Dam and the Hiwassee River by Hiwassee Dam have affected the population dynamics within these two river systems. It is possible that the added nursery habitat provided by the reservoirs may have increased the number of juveniles surviving to reproductive age (R. Jenkins, Roanoke College, Roanoke, Virginia, pers. comm. 2016). It doesn't appear that adult Sicklefin Redhorse use the reservoirs as primary habitat, but collection of juveniles during reservoir sampling efforts suggests that the reservoirs are important to the rearing of juveniles. Impoundment of these rivers created large amounts of shoreline habitat and increased the volume of water available to juvenile Sicklefin Redhorse, at the expense of decreasing the downstream extent of their distribution. Nothing is known about the life history of juvenile Sicklefin Redhorse prior to the creation of reservoirs. We assume that they would have naturally drifted downstream to large pools and slower moving sections of river, perhaps extending into Tennessee, where the ridge and valley physiographic province allowed for more of this type of habitat. Presently, the reservoirs appear to be providing most or all of the available juvenile habitat. Impoundment of Fontana Lake inundated 28 river miles of habitat that was likely suitable for adult Sicklefin Redhorse, but created 248 miles of shoreline. It is unknown how this shift in habitat availability has affected the population as a whole, but the observation that Sicklefin Redhorse are common in the rivers feeding these two reservoirs, and that young juveniles are recruiting into the reproducing population hints that the present condition is allowing for stable, viable populations; however, opportunities for Sicklefin Redhorse to colonize new habitats, exchange genes with other populations, or seek new habitats in response to changing conditions in the future may be limited by barriers. A primary goal of previous management actions and the intent of the CCA is to address these issues by reintroducing this species into areas that are presently inaccessible. Due to the permanence of the existing reservoirs, conditions of their licensing and willingness from the operators of these facilities to participate in management, barriers are not likely to alter the viability of the existing populations.

4.7 Predation by Non-Native Fish

The introduction of Blueback Herring, a non-native predatory species, into Hiwassee Reservoir, and Fontana Reservoir, is an emerging threat that is being actively studied by the Service and other partners. Blueback Herring were first observed in Hiwassee Reservoir sometime around 1998, and in Fontana Reservoir in the spring of 2016. Their introduction caused immediate negative effects to the populations of Walleye and White Bass in Hiwassee Reservoir. Populations of these species declined by approximately 50% per year, leading to almost complete loss of natural recruitment in the early 2000's (A.P. Wheeler, NCWRC, pers. comm. 2015). It is presently unknown what effect predation by Blueback Herring has had on the Sicklefin Redhorse populations, but increased predation on juvenile redhorse could have long-term population effects. In order to evaluate the effect to Sicklefin Redhorse, the Service has been collaborating with NC State University to evaluate the gut contents of Blueback Herring from Hiwassee Reservoir for the presence of Sicklefin Redhorse juveniles and eggs. Preliminary data have confirmed the presence of juveniles and eggs of other species of redhorse, but so far no Sicklefin Redhorse have been detected among the prey items (T. Kwak, NCSU, pers. comm. 2016). Sicklefin Redhorse are very similar to other redhorse species present in the Valley River, and there is no obvious reason why Blueback Herring would choose not to prey on Sicklefin Redhorse. It is likely that Blueback Herring are feeding on Sicklefin Redhorse, but due to small sample size they have not yet been identified. The lack of Sicklefin Redhorse in the samples suggests that Sicklefin Redhorse are not being heavily preyed on by Blueback Herring. Recent observation of large numbers of Sicklefin Redhorse and other species of redhorse in the Hiwassee River population (Favrot 2009, p. 35; Davis 2015, p. 12; S.J. Fraley, NCWRC, pers. comm. 2015), including many young adult and late juvenile Sicklefins that were obviously spawned after the invasion, indicates that the populations of redhorses have not collapsed in the way that Walleye and White Bass did following introduction of Blueback Herring. It appears that redhorse may be able to minimize predation by Blueback Herring by spawning further upstream than typical foraging habitat for Blueback Herring (Thomas Ivasauskas, NCSU, pers. comm. 2016).

It is currently unknown how establishment of Blueback Herring in Fontana Lake will affect the population of Sicklefin Redhorse in the Little Tennessee and Tuckaseegee Rivers. The coexistence of Sicklefin Redhorse and Blueback Herring in the Hiwassee River makes it likely that Sicklefin Redhorse can persist in Fontana after establishment of Blueback Herring. We expect that the effect of Blueback Herring in Fontana Lake will be similar to the effect observed in Hiwassee Lake following introduction of Blueback Herring in 1999.

The available information does not indicate that Blueback Herring are affecting Sicklefin Redhorse population viability in the short term; however; the long-term effects of Blueback Herring are less certain. Increased predation rates caused by the introduction of Blueback Herring represent an additional stressor that should be monitored in the future.

4.8 Angling

The losses of adult Sicklefin Redhorse due to angling is another form of predation that has the potential to affect population dynamics. Presently, there is no information available to estimate the effect of angling on Sicklefin Redhorse. It is likely that redhorse are occasionally caught as bycatch when fishing for other species, but the presence of numerous intermuscular bones in the edible parts likely deters most anglers from keeping redhorse for table fare despite their palatable qualities. Snagging for fish, using a multi-barbed hook to hook fish in the body, is a method used in some rivers where redhorse make a spawning run. It is unlawful to use this method of fishing in North Carolina and Georgia. Redhorse may be targeted by hook and line fishing using most types of baits typical for other fish including worms, dough balls, minnows and cut bait, and are occasionally caught on flies and jigs. When fishing for redhorse in this manner, there are many other species of fish competing for these baits, so the occurrence of catching a Sicklefin Redhorse should be relatively infrequent. Most of the anglers in the range of Sicklefin Redhorse are likely to target game fish like trout and bass, with angling for non-game fish like redhorse accounting for only a small percentage of the fishing activity in the area. The Eastern Band of Cherokee Indians (EBCI) have a long history of using redhorse as a food source and have indicated their interest in preserving the tradition of fishing for redhorse, including Sicklefin Redhorse, as part of their cultural heritage. Presently, the practice does not appear to be widespread among tribe members (Mike Lavoie, EBCI pers. comm. 2015). The EBCI are a primary partner in restoration efforts for Sicklefin Redhorse and share a goal with the Service and other conservation partners that populations can be restored and managed sufficiently to create more robust recreational fishery. Accordingly, we believe that present angling pressure on redhorse is minimal and there is no indication that it is likely to effect viability of Sicklefin Redhorse in the future.

4.9 Other Factors Considered

The potential introduction of *Didymosphenia geminate*, commonly referred to as didymo and rock snot, into streams occupied by Sicklefin Redhorse poses a potential threat to the species. *D. geminate* is an invasive, colonial diatom (single-celled algae with silica cell walls). The historical distribution of *D. geminate* is poorly understood but is believed to include parts of northern Europe, northern Asia, and the far northern regions of North America. However over the last few decades, its range has expanded significantly and now inhabits scattered streams in parts of the western, central, and eastern continental United States. Didymo has recently been documented in the Tuckaseegee River. Colonies of *D. geminate* produce large amounts of extracellular stalk material which attaches to rocky stream-bottom substrates. It can form large mats, carpeting up to 100% of the stream substrate in infested reaches. This could affect the availability of Sicklefin Redhorse spawning and foraging habitat and reduce macro-invertebrate diversity and densities, affecting the prey base of the Sicklefin Redhorse. The mechanisms aiding in the spread of *D. geminate* from one stream to another are not fully understood; however, studies have shown it can survive and remain viable out of water in cool, moist conditions for at least 40 days. Waterfowl, wading birds, and contaminated fishing and survey gear (e g., waders, wading boots, and wet clothing) are likely or at least potential vectors (Spaulding and Elwell 2007, pp. 1-33). Current indications suggest that the pH of the Sicklefin Redhorse river systems may not be appropriate for this species or that high flow areas (including spawning areas) may be largely unaffected. Additionally, its presence may increase food availability in some areas. At this time didymo has not resulted in any known threat to Sicklefin Redhorse and any potential threat is only speculative. Under the CCA, this potential threat will continue to be monitored.

4.10 Summary

Our analysis of the past, current, and future factors influencing the viability of the Sicklefin Redhorse reveal that there are three primary factors that continue to pose a risk to the species. These risks are primarily related to the demographic health of the populations, habitat alteration and water quality changes due to changes in land use, and the potential long term effects of predation by invasive Blueback Herring. We did not assess overutilization for scientific and commercial purposes or disease, because these risks do not appear to be occurring at a level that affects Sicklefin Redhorse populations. We did not consider didymo introduction or the short term effects of blueback herring predation in the assessment to pose a risk to the species, because at this time it is unclear whether these are or will be stressors on the species. The long term effects of these potential stressors will continue to be monitored under the CCA.

Each of the threats considered could be exacerbated by climate change or by interaction with other threats. Our evaluation of the threats facing this species indicate that the existing populations are stable and are likely to remain stable in most plausible future scenarios. Uncertainty regarding the long term viability of the species is primarily due to their limited ability to adjust their range in response to changing environmental conditions. Due to this uncertainty, we believe that ongoing and future management carried out under the CCA is an important factor to ensure future viability.

Chapter 5. Management Actions Affecting Future Viability

This chapter is intended to provide a discussion of the future condition of Sicklefin Redhorse populations by evaluating how the present condition of Sicklefin Redhorse populations are likely to be affected by the combined risk factors in Chapter 4 and how management might be used to mitigate these risks. The Sicklefin Redhorse is a species whose future viability may be affected by its narrow distribution. The remaining populations are confined to the upper reaches of the Little Tennessee and Hiwassee River systems. In the Tuckaseegee, Little Tennessee, Hiwassee, and Nottely Rivers, there are large areas of habitat that appear to be suitable for Sicklefin Redhorse (Table 4.). Expansion of this species into these habitats will increase each of the 3R's and will increase long term viability.

The primary intent of the CCA is to manage existing populations of Sicklefin Redhorse and restore them to suitable portions of their historical range to insure long term viability of the species. The activities carried out under the CCA are intended to provide additional assurance that the species will be able to adapt to changes in the environment. Reintroduction of the species into unoccupied areas will provide access to greater habitat diversity. Greater habitat diversity and expanded range are expected to lead to greater resiliency of the populations and will provide additional assurance that the species can persist long into the future. As identified earlier, human population growth and land development are expected to be a primary factor affecting habitat quality in the range of the Sicklefin Redhorse. Many of the effects that accompany human population growth can be mitigated by conservation actions carried out under the CCA. Expanding the range of the Sicklefin Redhorse into the upper sections of the occupied watersheds will provide a greater variety of micro-habitat available to the species, allowing it to more easily adjust to temporary effects of construction and landscape alteration, and provides more opportunities to find areas of refuge during periods of adverse conditions, such as periods of high temperature or increased flow. Accessibility to more suitable habitat will increase the number of available spawning sites, increasing the opportunities for successful recruitment, and will provide alternative spawning areas should some spawning sites become unsuitable. Successful reintroduction will increase the carrying capacity of Sicklefin Redhorse by providing the species with additional riverine habitat as well as access to additional reservoirs to serve as juvenile rearing habitat.

Perhaps one of the most valuable aspects of CCA implementation is an ability to monitor and affect the demographic health of the populations. The hatchery program will allow fisheries managers to detect trends in the genetics of the populations that would not otherwise be detectable. Creation of new sub populations within the watersheds will allow for greater flexibility in managing gene flow between populations and should be beneficial in preserving the remaining allelic diversity within the populations.

Table 4. Projected Future Condition with and without CCA Implementation

Stream Reach	**Available Riverine Length without CCA**	**Potential Available Riverine Length with CCA**	**Available Reservoir Area Without CCA****	**Potential Reservoir Area with CCA****
Little Tennessee River	59.4 km (36.9 miles)	100.7 km (62.6 miles)	4,144 ha (10,240 acres)	4,214 ha (10,414 acres)
Tuckaseegee River	48.8 km (30.3 miles)	92.5 km (57.5 miles)	4,144 ha (10,240 acres)	4,144 ha (10,240 acres)
Oconaluftee River	0.9 km (.56 miles)	30.5 km (19.0 miles)	0 ha (0 acres)	15 ha (38 acres)
Brasstown Creek/ Hiwassee River	34.8 km (21.6 miles)	65.4 km (40.6 miles)	2,710 ha (6,697 acres)	5,257 ha (12,992 acres)
Valley River	32.3 km (20.1 miles)	32.3 km (20.1 miles)	2,710 ha (6,697 acres)	2,710 ha (6,697 acres)
Nottely River	8.6 km (5.3 miles)	30.7 km (19.1 miles)	2,710 ha (6,697 acres)	4,118 ha (10,176 acres)
Hanging Dog Creek	8.0 km (5 miles)	8.0 km (5 miles)	2,710 ha (6,697 acres)	2,710 ha (6,697 acres)
Beaverdam Creek	2.7 km (1.7 miles)	2.7 km (1.7 miles)	2,710 ha (6,697 acres)	2,710 ha (6,697 acres)
Total	**195.5 km (121.5 miles)**	**362.8 km (225.4 miles)**	**6,854 ha (16,936 acres)**	**10,894 ha (26,920 acres)**

*Totals may not sum due to rounding

** Includes duplication due to rivers sharing reservoirs, totals are calculated without duplication

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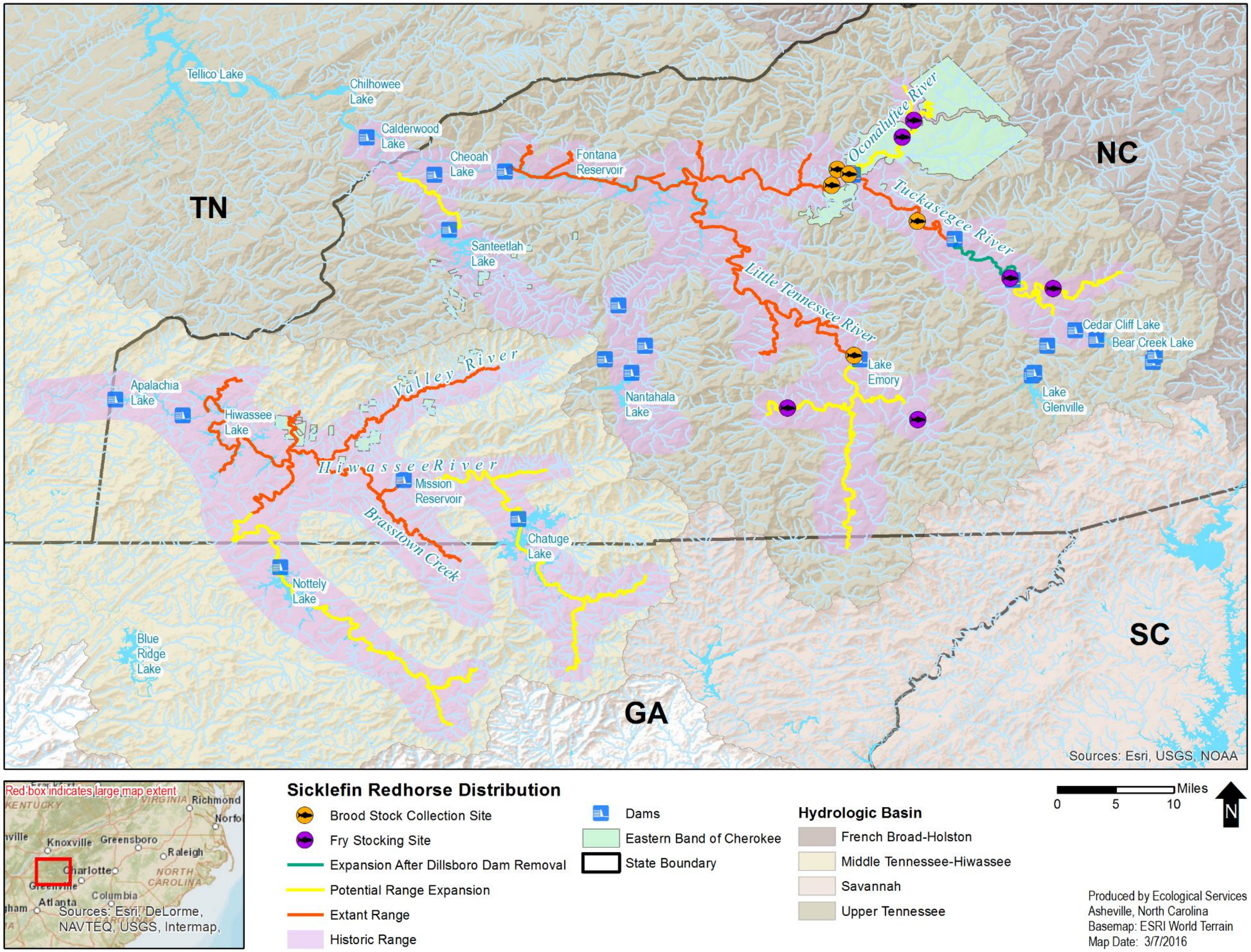
Appendix A


Tellico Lake
Chilhowee Lake
Calderwood Lake
Cheoah Lake
Fontana Reservoir
Santeetlah Lake
Oconaluftee River
Tuckasegee River
Little Tennessee River
Cedar Cliff Lake
Bear Creek Lake
Lake Emory
Lake Glenville
Nantahala Lake
Apalachia Lake
Hiwassee Lake
Valley River
Hiwassee River
Mission Reservoir
Brasstown Creek
Chatuge Lake
Nottely Lake
Blue Ridge Lake
TN
NC
GA
SC
Sources: Esri, USGS, NOAA
Red box indicates large map extent
KENTUCKY
VIRGINIA
Richmond
Norfolk
Knoxville
Greensboro
Raleigh
Charlotte
NORTH CAROLINA
Greenville
Atlanta
Columbia
Sources: Esri, DeLorme, NAVTEQ, USGS, Intermap,
Sicklefin Redhorse Distribution
Brood Stock Collection Site
Fry Stocking Site
Expansion After Dillsboro Dam Removal
Potential Range Expansion
Extant Range
Historic Range
Dams
Eastern Band of Cherokee
State Boundary
Hydrologic Basin
French Broad-Holston
Middle Tennessee-Hiwassee
Savannah
Upper Tennessee
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Produced by Ecological Services
Asheville, North Carolina
Basemap: ESRI World Terrain
Map Date: 3/7/2016

Appendix B

Current Condition

Measure	Little Tennessee	Tuckaseegee	Hiwassee/Brasstown	Valley	Hanging Dog	Beaverdam	Nottely
Current Effective Population Size, Estimate (Lower 95% Confidence Interval)	586 (279)	589 (218)	Undefined due to low sample size (126)	Unknown, but likely greater than Brasstown Ck. May represent a single population	Unknown, likely very low, small watersheds with limited habitat available, not likely to ever support a sizeable population		Unknown, but likely low, cold water discharge may prohibit large population in lower river
Water Temperature, Cold water is from reservoir discharges, baseline indicates natural water temperature	Baseline	Cold/Moderate	Cold in Hiwassee Mainstem, warm in Brasstown Ck.	Baseline	Baseline	Baseline	Cold
Daily flow fluctuation from reservoir discharges	0	1 (400-600CFS)	2 (8:00 am and 2:00pm; Hiwassee), 0 (Brasstown)	0	0	0	1:00 pm (1460 CFS)
Predation Risk from Blueback Herring	Blueback Herring not present in Fontana Lake, but likely in future	Blueback Herring not present in Fontana Lake, but likely in future	Blueback Herring Present in Hiwassee Lake	Blueback Herring Present in Hiwassee Lake	Blueback Herring Present in Hiwassee Lake	Blueback Herring Present in Hiwassee Lake	Blueback Herring Present in Hiwassee Lake
Occupied Area Riverine (km)	60.5	61.6	34.8	32.3	8.0	2.7	8.6
Lacustrine Area (acres)	10,240 (Fontana Lake)		6,016 (Hiwassee Lake)				

Future Conditions with No Action and CCA Implementation

Measure	Little Tennessee	Tuckaseegee	Hiwassee/Brasstown*	Valley*	Hanging Dog*	Beaverdam*	Nottely*
Current effective population size estimate (lower 95% CI)	586 (279)	589 (218)	Undefined due to low sample size (126)	Unknown, but likely greater than Brasstown Ck. May represent a single population	Unknown, likely very low, small watersheds with limited habitat available, not likely to ever support a sizeable population		Unknown, but likely low, cold water discharge may prohibit large population
Potential for population increase with CCA	High	High	Moderate	None	None	None	Moderate
Riverine expansion potential above baseline (km)	59.4 (Above Emory Lake)	79.7 (Oconaluftee River and expansion above Dillsboro Dam)	28.7 (Above Chatuge Lake)	None			30.7 (Above Nottely Lake)
Lacustrine expansion potential (acres)	174 (Emory Lake)	38 (Oconoluftee Lake)	6,976 (Chatuge Lake)	None	None	None	4,160 (Nottely Lake)
30 year projected occupied riverine length with no action (km)	60.5	76.9 (Includes natural expansion past Dillsboro Dam barrier removal)	34.8	32.3	8.0	2.7	8.6
30 year projected occupied riverine length with maximum successful reintroduction (km)	119.9	140.0	63.5	32.3	8.0	2.7	39.3
30 year % riverine length increase above baseline with maximum successful reintroduction	98%	82%	82%	0	0	0	357%