Cracking Pearlymussel
Hemistena lata (Rafinesque, 1820)

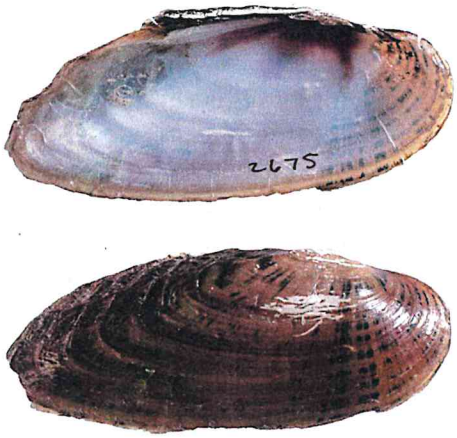

Photo by Tom Schirtz, McClung Museum of Natural History and Culture
66 mm length. UTMM Lot no. 2675

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
Southeast Region
Tennessee Ecological Services Field Office
Cookeville, Tennessee

5-YEAR REVIEW
Cracking Pearlymussel (*Hemistena lata*)

1. GENERAL INFORMATION

1.1. Methodology used to complete this review

Public notice of initiation of this 5-year review was provided in the *Federal Register* on May 7, 2018 (83 FR 20092), and a 60-day comment period was opened. During this comment period, we obtained information on the status of this species from several experts; additional data was also obtained from the recovery plan, peer-reviewed scientific literature, unpublished reports, and our State partners. Once all known literature and information was collected for this species, the review was drafted by Gerald Dinkins, McClung Museum of Natural History and Culture, University of Tennessee, and completed by Jessica Miller, lead biologist with the U.S. Fish and Wildlife Service. All literature and documents used for this review are on file at the Frankfort, KY Field Office. We sent the draft 5-year review to cooperating field offices (listed below) and submitted it to three mussel experts for peer review: Todd Amacker (Tennessee Valley Authority (TVA)), Don Hubbs (Tennessee Wildlife Resources Agency (TWRA)), and Jeff Garner (Alabama Department of Conservation and Natural Resources (ADCNR)). The Service evaluated and incorporated the comments received into this 5-year review (see Appendix A for further detail).

1.2. Reviewers

Lead Region - Southeast: Kelly Bibb (404) 679-7132

Lead Field Office – Cookeville, Tennessee: Jessica Miller (502) 695-0468

Cooperating Field Offices
Daphne, Alabama: Anthony Ford (251) 441-5838
Abingdon, Virginia: Jordan Richard (276) 623-1233; Jess Jones (540) 231-2266

Cooperating Regional Office – Martin Miller, Northeast Region, Hadley, MA, (413) 253-8615

1.3. Background

1.3.1. Federal Register Notice citation announcing initiation of this review:

May 7, 2018; 83 FR 20092

1.3.2. Species status:

Declining. The Cracking Pearlymussel historically occurred in much of the Ohio River system, including the mainstem and major tributaries in Alabama, Illinois, Indiana, Kentucky, Ohio,

Pennsylvania, Tennessee, and Virginia (Watters *et al.* 2009, Williams *et al.* 2008, Parmalee and Bogan 1998). It has been extirpated from nearly all of its historical range; most extirpations occurred decades ago (Watters *et al.* 2009, Haag and Cicerello 2016). The population in the Powell River, listed as extant in the 1991 Recovery Plan, is now considered extirpated (Jones 2019, pers. comm.). The species is currently believed to be extant only in the Tennessee River basin in a short reach of the Elk River near the Alabama and Tennessee state line and a short reach of the Clinch River near the Tennessee and Virginia state line (Jones *et al.* 2018, Hagg and Cicerello 2016, Williams *et al.* 2008).

1.3.3. Recovery achieved: 1 = 0-25 percent species recovery objectives achieved.

1.3.4. Listing history:

Original Listing

FR Notice: 54 FR 39850
Date Listed: September 28, 1989
Entity Listed: Species
Classification: Endangered

1.3.5. Associated rulemakings

Establishment of Nonessential Experimental Population (NEP) Status for 16 Freshwater Mussels and 1 Freshwater Snail (Anthony's Riversnail) in the Free Flowing Reach of the Tennessee River below the Wilson Dam, Colbert and Lauderdale Counties, AL, Final Rule; June 14, 2001; 66 FR 32250

Establishment of Nonessential Experimental Population (NEP) Status for 15 Freshwater Mussels, 1 Freshwater Snail, and 5 Fishes in the Lower French Broad River and in the Lower Holston River, Tennessee, Final Rule; September 13, 2007; 72 FR 52434

1.3.6. Review History

A recovery plan was completed for the species in 1991.

Each year, the Service reviews and updates listed species information for inclusion in the required Recovery Report to Congress. Through 2013, we submitted information for the annual recovery data call that included status recommendations like "Unknown" or "Declining" for the Cracking Pearlymussel. We continue to show this call as part of our 5-year reviews (1.3.2 above). The most recent evaluation for this mussel to inform the Recovery Report to Congress was completed in 2019.

A 5-year review for the Cracking Pearlymussel was completed on August 19, 2011 (Service 2011), and no change to the species' endangered status was recommended.

1.3.7. Species' Recovery Priority Number at start of review (48 FR 43098):

4 (high degree of threat and a low potential for recovery; the taxonomy is monotypic genus)

1.3.8. Recovery Plan

Name of plan: Recovery Plan for Cracking Pearlymussel (*Hemistena* (=Lastena) *lata*)
Date issued: July 11, 1991

2. REVIEW ANALYSIS

2.1. Application of the 1996 Distinct Population Segment (DPS) policy

The Endangered Species Act defines species as including any subspecies of fish or wildlife or plants, and any distinct population segment of any species of vertebrate wildlife. This definition limits listing DPSs to only vertebrate species of fish and wildlife. Because the species under review is an invertebrate, the DPS policy is not applicable.

2.2. Recovery Criteria

2.2.1. Does the species have a final, approved recovery plan containing objective, measurable criteria? Yes.

2.2.2. Adequacy of recovery criteria.

Do the recovery criteria reflect the best available and most up-to-date information on the biology of the species and its habitat? Yes.

Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria (and there is no new information to consider regarding existing or new threats)? Yes.

2.2.3. List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information

Cracking Pearlymussel will be considered for downlisting or reclassification from endangered to threatened status when the likelihood of the species becoming extinct in the foreseeable future has been eliminated by achievement of the following criteria:

(1) Through protection of existing populations and through successful establishment of reintroduced populations or the discovery of additional populations, a total of five distinct viable[1] populations exist. The populations shall be distributed throughout the Ohio River basin as follows: one in the upper Tennessee River system, one in the middle to lower Tennessee River system, one in the Cumberland River system, one in a Kentucky tributary to the Ohio River other than the Cumberland River, and one in the Wabash River system.

Status: *This criterion has not been met. Only two populations of the species are known to be extant: the Clinch River population, in the upper Tennessee River system, and the Elk River population, in the middle to lower Tennessee River system (Jones* et al. *2018, Hagg and Cicerello 2016, Williams* et al. *2008). Additional research is needed to determine if these two populations are large enough to meet the definition of viable as defined in the recovery plan.*

(2) One naturally reproduced year class exists within each of the five populations. The year class must have been produced within five years of the downlisting date. Within one year of the downlisting date, gravid females of the species and its host fish must be present in each river.

Status: *This criterion has not been met. Only two populations of the species are known to be extant. Surveys conducted in the past 10 years have demonstrated natural recruitment in both of these populations (Amacker 2019, pers. comm., Jones 2019, pers. comm.).*

(3) Biological and ecological studies have been completed, and the recovery measures developed and implemented from these studies are beginning to be successful, as evidenced by an increase in population density and/or an increase in the length of the river reach inhabited by each of the five populations.

Status: *This criterion has not been met. Only two populations of the species are known to be extant. Recent increases in overall mussel density have been observed at some sites in the Clinch River (Jones* et al. *2014); however, the mortality of thousands of mussels of various species have been documented in annual die-offs in a reach of the Clinch River in Tennessee from 2016-2019 (Richard 2019, pers. comm.). The mussel fauna in the Elk River has responded positively to changes in releases from Tims Ford Dam initiated in 2006 to 2008 (Howard 2017, pers.*

[1] A viable population is defined as a reproducing population that is large enough to maintain sufficient genetic variation to enable it to evolve and respond to natural habitat changes. The number of individuals needed to obtain a viable population will be determined as one of the recovery tasks.

comm.). Additional studies need to be conducted to understand the species' specific biological and ecological requirements to inform recovery measures.

Cracking Pearlymussel will be considered for removal from Endangered Species Act protection when the likelihood of the species becoming threatened in the foreseeable future has been eliminated by the achievement of the following criteria:

(1) Through protection of existing populations and successful establishment of reintroduced populations or the discovery of additional populations, a total of eight distinct viable populations exist. These populations must be separated to the extent that it is unlikely that a single event would eliminate or significantly reduce more than one of these populations. The populations shall be distributed throughout the Ohio River basin as follows: two in the upper Tennessee River system, two in the middle to lower Tennessee River system, one in the Cumberland River system, one in a Kentucky tributary to the Ohio River other than the Cumberland River, and two in the Wabash River system.

Status: *This criterion has not been met. See explanation above in status of downlisting criteria #1.*

(2) Two distinct naturally reproduced year classes exist within each of the eight populations. Both year classes must have been produced within 10 years, and one year class within five years, of the recovery date. Within one year of the recovery date, gravid females of the species and its host fish must be present in each river.

Status: *This criterion has not been met. See explanation above in status of downlisting criteria #2.*

(3) Studies of the mussel's biological and ecological requirements have been completed, and recovery measures developed and implemented from these studies have been successful, as evidenced by an increase in population density and/or an increase in the length of the river reach inhabited by each of the eight populations.

Status: *This criterion has not been met. See explanation above in status of downlisting criteria #3.*

(4) No foreseeable threats exist that would likely threaten the survival of any of these eight populations.

Status: *This criterion has not been met. Despite application of existing Federal and State laws and regulations, the species continues to be*

subjected to ongoing adverse effects from land use practices. Undetermined threats to the species' continued existence persist in the Clinch River population as evidenced by the annual die-off of thousands of mussels of various species from 2016-2019 (Richard 2019, pers. comm.). Knowledge of the species' biology, habitat requirements, and response to threats is incomplete. The two isolated populations of the species are extremely vulnerable to extirpation from stochastic or catastrophic events.

(5) Where habitat has been degraded, noticeable improvements in water and substratum quality have occurred.

Status: *This criterion has not been met. Conservation efforts have not resulted in noticeable improvements to mussel habitat in the Clinch River. Changes in releases from Tims Ford Dam initiated in 2006 to 2008 have improved conditions for mussels in the Elk River (Howard 2017, pers. comm.). Additional studies need to be conducted to understand the species' specific biological and ecological requirements to inform recovery measures.*

2.3. Updated Information and Current Species Status

2.3.1. Biology and Habitat

When the Recovery Plan was published in 1991, only very limited data on the species' life history existed. The species inhabits medium to large rivers where it is typically found buried in sand and gravel substrates in riffle habitat (Bates and Dennis 1985; Bogan and Parmalee 1983). No new information has become available regarding the habitat preferences for the Cracking Pearlymussel since the 2011 5-year review (Service 2011).

Like other freshwater mussels, Cracking Pearlymussel feeds by filtering food particles from the water. Its specific food habits are unknown, but it likely feeds on items similar to those consumed by other freshwater mussels: detritus, diatoms, phytoplankton, and zooplankton (Churchill and Lewis 1924).

Freshwater mussels have a complex reproductive cycle. Males release sperm into the water column. The sperm are taken in by the females through their incurrent apertures during feeding and respiration. The fertilized eggs are retained in the gills until the larvae (glochidia) fully develop. When the glochidia are released into the water, they attach and encyst on the gills or fins of a fish host. When metamorphosis is complete, they drop to the streambed as juvenile mussels.

The specific reproductive biology of the Cracking Pearlymussel was poorly understood at the time of listing, with observations supporting both short-term and long-term brooding strategies (Williams *et al.* 2008). The Recovery Plan (Service 1991) stated that unless the Cracking Pearlymussel's life history (especially its fish host requirements) and environmental requirements are defined, recovery efforts may be inconsequential or misdirected.

Recent propagation work has established that Cracking Pearlymussel is a short-term brooder and can have multiple broods (Lane 2019, pers. comm.). When the larvae are developed, the females release white, flattened conglutinates (gelatinous or mucous masses containing glochidia) (Lane 2019, pers. comm.). Some progress has been made in identifying the species' fish hosts. Laboratory host fish trials by researchers at Virginia Polytechnic Institute and State University documented marginal success with Banded Sculpin (*Cottus carolinae*), Central Stoneroller (*Campostoma anomalum*), Whitetail Shiner (*Cyprinella galactura*), Streamline Chub (*Erimystax dissimilis*), and Fantail Darter (*Etheostoma flabellare*) (Jones *et al.* 2003). Other species tested in those trials, Rockbass (*Ambloplites rupestris*), Margined Madtom (*Noturus insignis*), Striped Shiner (*Luxilus chrysocephalus*), Greenside Darter (*Etheostoma blennioides*), Bluebreast Darter (*Etheostoma camurum*), and Redline Darter (*Etheostoma rufilineatum*) did not successfully transform juvenile Cracking Pearlymussels. The Tennessee Wildlife Resources Agency's Cumberland River Aquatic Center successfully propagated Cracking Pearlymussel in 2019 using Logperch (*Percina caprodes*) and Greenside Darter as hosts (Hua 2019, pers. comm.). The Virginia Department of Game and Inland Fisheries' Aquatic Wildlife Conservation Center is currently in the middle of a two-year study to further investigate fish host suitability for the species and has had some preliminary success (Lane 2019, pers. comm.).

2.3.2. Abundance, population trends, demographic features, or demographic trends:

Several quantitative mussel surveys have been conducted in the Clinch River. When detected during surveys in 1979-2004 at three sites in Tennessee (Swan Island, Brooks Island, and Kyles Ford), the species occurred at 0.10-0.60 mussels/m^2 (Ahlstedt *et al.* 2016). In quantitative surveys at multiple sites in the Clinch River in Hancock County, TN, from 2004-2014, Cracking Pearlymussel occurred at a mean density of 0.15 mussels/m^2 and a mean species proportion of 0.52 for all years and sites (Jones *et al.* 2018). The species is naturally reproducing, and multiple year classes have been observed (Jones 2019, pers. comm.).

Because it occurs at such low densities, population trends for the species are difficult to delineate. Several years of quantitative surveys provide trends within the overall mussel fauna in the Clinch River. Within the Tennessee portion of the Clinch River, mussel densities of all species had increased at an annual rate of 2.3%, stabilizing at a mean density of 29 mussels/m^2 from 2004-2014 (Jones *et al.* 2018). However, total mussel abundance has declined by about 50% over the last few years in surveyed mussel beds near Kyles Ford, approximately 14 km downstream of the Tennessee and Virginia state boundary (Jones *et al.* 2014, Cope and Jones 2016). Jones *et al.* (2014), Ahlstedt *et al.* (2016), and Phipps *et al.* (2017, 2018) agree that overall mussel densities are lower in the Virginia portion of the Clinch River. The mean density from quantitative surveys around Pendleton Island in Virginia have declined from an estimated 25 mussels/m^2 in the late 1970s to 0.7 mussels/m^2 in 2009, and slightly increased to 1.1 mussels/m^2 in 2014 (Jones *et al.* 2014). Pendleton Island is located in a 68-km reach of the Clinch River in Virginia characterized by low mussel abundance, little to no recruitment, and a high proportion of older individuals (Jones *et al.* 2014).

In June 2016, a mussel die-off was observed at Kyles Ford and Frost Ford in the Clinch River, Tennessee (Richard 2019, pers. comm.). Similar mortalities were observed again during the late summer to early fall in 2017, 2018, and 2019 (Richard 2019, pers. comm.) (Figures 1-2). Approximately 3,500 freshly dead mussels were recovered by State and Federal agency biologists in 2016, and a comparable number in 2017. Ninety-six (96) Cracking Pearlymussels, representing several size classes, were found in the collection of freshly dead shells found after the 2016 die-off. The dead mussels found in 2017 are archived at the McClung Museum of Natural History and Culture for future reference and study, but have not yet been counted. Causes of the die-off and mussel population impacts are still being investigated at the time of this review (Richard 2019, pers. comm.).

TVA has conducted mussel surveys in the Elk River in 2008, 2012, 2015, and 2018. Cracking Pearlymussel was found during quantitative surveys in 2012, 2015, and 2018 with an abundance of 10, 5, and 5 individuals, respectively, at sites from RM 34.5 to RM 75.7 (Amacker 2019, pers. comm.). Juvenile individuals and multiple age classes were found in these surveys.

Figure 1. Recently dead freshwater mussels collected from the Clinch River at Wallen Bend, Tennessee in 2019 (photo by Meagan Racey, USFWS).

Figure 2. A dead mussel (fanshell (*Cyprogenia stegaria*)) in the Clinch River at Kyle's Ford (photo by Rose Agbalog, USFWS).

2.3.3. Genetics, genetic variation, or trends in genetic variation:

There is no new information available on genetics, genetic variation, or trends in genetic variation.

2.3.4. Taxonomic classification or changes in nomenclature:

A revised list of the freshwater mussels of the United States and Canada was recently published by Williams *et al.* (2017), incorporating changes in nomenclature and systematic taxonomy since publication of the previous checklist by Turgeon *et al.* (1998). No change was recommended for the Cracking Pearlymussel in Williams *et al.* (2017). Additionally, no nomenclature change is reflected in the Integrated Taxonomic Information System (ITIS 2019).

2.3.5. Spatial distribution, trends in spatial distribution, or historical range:

The Recovery Plan (Service 1991) describes the historical distribution of the Cracking Pearlymussel as widespread in the Ohio River system, from the mainstem and major tributaries in Alabama, Kentucky, Illinois, Indiana, Ohio, Pennsylvania, Tennessee, and Virginia. It occurred in the Ohio River from Ohio downstream to Illinois. In Indiana and Illinois, it was historically known from the White, Wabash, and Tippecanoe Rivers; in Kentucky from the Upper Cumberland, Big South Fork, Green, and Kentucky Rivers; in Tennessee from the Tennessee, Cumberland, Powell, Clinch, Holston, Elk, Duck, and Buffalo Rivers; from Alabama in the Elk and Tennessee Rivers; and in Virginia from the Powell, Clinch, and Holston Rivers (refer to Table 1).

In the last few decades, the species has only been found in the Elk and Clinch Rivers. The Recovery Plan listed the species as extant in the Powell River, based on a 1979 survey. The species is now believed to be extirpated from the Powell River (Jones 2019, pers. comm.). Cracking Pearlymussel is believed to be extant only in the Clinch and Elk Rivers (Jones *et al.* 2018, Hagg and Cicerello 2016, Williams *et al.* 2008). In the Clinch River, it occurs in approximately 41 miles of the main channel, from Swan Island, Hancock County, TN, (Clinch River Mile 172) upstream to Clinchport, Scott County, VA, (Clinch River Mile 213) (Hubbs 2019, pers. comm.; Jones *et al.* 2018). In the Elk River, it occurs in approximately 42 miles of the main channel, from approximately one river mile downstream of the Tennessee and Alabama state line, Limestone County, AL (Elk River Mile 34) to Harms Mill, Lincoln County, TN, (Elk River Mile 76) (Hubbs 2019, pers. comm.). No new populations have been successfully established, and no new populations have been discovered.

2.3.6. Other:

Successful propagation is necessary to augment existing populations and reestablish the species in other streams within its historical range. In response to mussel losses from a chemical spill in 1998, the Virginia Department of Game and Inland Fisheries' Aquatic Wildlife Conservation Center and the Virginia Polytechnic Institute and State University's Freshwater Mollusk Conservation Center propagated the species and produced juvenile mussels of 34 freshwater mussel species to release into the Clinch and Powell Rivers (Hyde and Jones 2019). None of the 148 individual Cracking Pearlymussels produced from 2010-2018 survived to six months. The facility is currently in the middle of a two-year propagation study and has had some preliminary success (Lane 2019, pers. comm.). The Tennessee Wildlife Resources Agency's Cumberland River Aquatic Center successfully propagated Cracking Pearly mussel in 2019; 18 of 278 individuals had survived 4 to 5 months at the time of this review (Hua 2019, pers. comm.). Additional research is needed to refine propagation techniques to support recovery actions.

2.4. Five Factor Analysis (threats, conservation measures and regulatory mechanisms).

As shared in our 2011 5-Year Review and based on information gathered since that review, the most significant threat to the species continues to be Factor A (destruction, modification, curtailment of habitat or range) caused by a variety of human-induced impacts to its habitat. The species is also threatened by the inadequacy of existing regulatory mechanisms in protecting against habitat alteration or destruction (Factor D) and its restricted range and small population size (Factor E). More studies are needed to understand the potential effects of disease on the species (Factor C).

2.4.1. Factor A: Present or threatened destruction, modification, or curtailment of its habitat or range:

The Recovery Plan (Service 1991) listed habitat loss from impoundments, water quality deterioration attributed to coal mining and other land use practices, and chemical spills as reasons for the decline of the Cracking Pearlymussel. Its status is still attributable to the continued impacts of these ongoing threats.

The creation of reservoirs reduced the amount of habitat available for Cracking Pearlymussel and has ongoing effects on the range of the species. Dams convert upstream habitat to unsuitable lentic conditions; additionally, a river's flow regime (changing quantity and timing of water flows throughout the course of a year) and water temperature is influenced by dam operations. The Recovery Plan specifically notes that the mussel fauna in the Elk River is reduced because of the cold-water

releases from Tims Ford Reservoir. Cracking Pearlymussel is confined to suitable habitat between the lower reach of the influence of the cold-water releases and the upper limits of Wheeler Reservoir. Operational changes were initiated at the Tims Ford Dam in 2006 to 2008 to improve habitat below the dam for threatened and endangered fish and mussels. In response to this, improvements to overall mussel species density and recruitment were observed below the dam during monitoring starting in 2012 (Howard 2017, pers. comm.).

Non-point source pollution that affect Cracking Pearlymussel habitat include domestic sewage (through septic tank leakage or straight pipe discharges); agricultural pollutants such as fertilizers, pesticides, herbicides, and animal waste; and chemicals associated with oil and gas development and coal mining. These pollutants can cause excess nutrification (increased levels of nitrogen and phosphorus), excessive algal growth, instream oxygen deficiencies, increased acidity and conductivity, and other changes in water chemistry that can seriously impact aquatic species.

Because of its rich mussel fauna and recent declines, a number of recent studies have researched the water quality in the Clinch River. Coal mining activity has decreased in the Clinch River watershed in recent years; however, current and previous mining in the Powell River watershed still impacts water quality in that watershed (Zipper *et al.* 2014, 2016; Phipps 2019). New research is beginning to shed light on the specific chemical constituents primarily responsible for declines in freshwater mussels, such as the Cracking Pearlymussel. In sites impacted by coal mining or natural gas extraction, total recoverable metals, polycyclic aromatic hydrocarbons (PAHs), major ions, or a combination of the three likely have contributed to sediment toxicity and mussel declines in the Upper Tennessee and Cumberland River systems (Wang *et al.* 2013, Cope and Jones 2016). Oil and gas wastewater from both conventional and unconventional wells have been shown to be a risk to aquatic organisms due to halide and ammonium levels in waters, even after brine treatment (Harkness *et al.* 2015).

Price *et al.* (2011) indicated that concentrations of total dissolved solids have continued to rise in the Clinch River. Price *et al.* (2014) and Zipper *et al.* (2016) found a temporal increase of dissolved solids in the Clinch River between 1964 and 2010 that corresponds to declining mussel densities in the Virginia portion. In addition, water-column ammonia and sediment metals have occurred at levels likely contributing to the decline of freshwater mussels in the Virginia portion (Price *et al.* 2014). The increased levels of ammonia, metals, and dissolved solids were seen in watersheds with both agricultural activity and coal mining; however, mussel declines are greater in close proximity to and downstream of

watersheds impacted by coal mining (Guest River, a tributary to the Clinch River) (Price *et al.* 2014).

Johnson *et al.* (2014) found higher turbidity and specific conductance in Clinch River reaches with low quality mussel assemblages when compared to reaches with high quality mussel assemblages. Additionally, higher concentrations of major ions and metals were also observed in reaches with low quality mussel assemblages (Johnson *et al.* 2014, Zipper *et al.* 2016). The low quality mussel assemblages were spatially associated with tributary inflows from systems draining Pennsylvanian shale and coal geologic formations and were diluted by tributaries with no mining (Johnson *et al.* 2014).

Land cover analyses of the Clinch River watershed between Clinchport and Artrip, Virginia, (Cope and Jones 2016) indicate that developed land cover and impervious surfaces increased by approximately 40 percent between 2001 and 2011. This area has been described as a "Zone of Decline" for freshwater mussels, with expected stressors including wastewater and stormwater discharges, industrial and commercial discharges, oil and gas operations, and surface coal mining operations (Jones *et al.* 2014, Cope and Jones 2016). A combination of factors appears to be impacting this reach of the Clinch River; however, polycyclic aromatic hydrocarbons (PAHs) were consistently prevalent at sites within the Zone of Decline, and there were consistent concentrations when comparing mussel tissues and samples of sediment and surface water (Cope and Jones 2016). The PAH sources within the study reach are thought to be tributaries associated with mining, such as the Guest River and Dumps Creek (Cope and Jones 2016). Furthermore, their observations show that the PAH levels (and most metals tested) in tissues are the result of recent rather than long-term exposure (Cope and Jones 2016). The PAHs might have a chronic lethal effect on mussels, while metals have a sub-lethal effect on the growth of mussels; however, conductivity, turbidity, and other environmental stressors likely interact in unpredictable ways to impact mussel health and survival (Cope and Jones 2016). Cope and Jones (2016) also observed that ammonia and manganese were detrimental to mussel survival and biomass, particularly in sediments from the Guest River and Copper Creek. The source of these pollutants appears to be surface coal mining activities in the Guest River watershed, while agriculture is the predominant land use in the Copper Creek watershed. The source of the high levels of manganese in Copper Creek are unknown at this time (Cope and Jones 2016).

2.4.2. Factor B: Overutilization for commercial, recreational, scientific or educational purpose:

Overutilization for commercial, recreational, scientific or educational purposes was not considered to be a limiting factor in the Recovery Plan

(Service 1991) or the last 5-year review (Service 2011). We have no new information to indicate that this has changed.

2.4.3. Factor C: Disease and predation:

The Recovery Plan (Service 1991) and the last 5-year review (Service 2011) did not indicate that disease or predation were limiting factors for this species. However, new information suggests that disease may be affecting mussels in the Clinch River. The species specificity, timing, intensity, and spatial distribution during the 2016-2019 mussel die-offs in the Clinch River have led researchers to investigate disease as a causative factor (Richard 2019, pers. comm.). Preliminary data show a strong correlation between dead and dying mussels with the presence of particular viruses, bacteria, and parasites (Richard 2019, pers. comm.). Research is ongoing to investigate the effects of these potential pathogens.

2.4.4. Factor D: Inadequacy of existing regulatory mechanisms:

The Cracking Pearlymussel and its habitats are afforded some protection from water quality and habitat degradation under the Clean Water Act of 1977 (33 U.S.C. 1251 et seq.), Surface Mining Control and Reclamation Act of 1977 (30 U.S.C. 1234-1328), Alabama's Water Quality Program (ADEM Admin. Code r. 335-6), Tennessee's Water Quality Control Act of 1977 (T.C.A. 69-3-101), and Virginia's State Water Control Act (§ 62.1). While these laws and corresponding regulations, which focus on point-source discharges, have resulted in some improvements in water quality and stream habitat for aquatic life, they have been inadequate to halt population declines and degradation of habitat for the Cracking Pearlymussel. Effects from sedimentation and other nonpoint-source pollutants continue to be a significant problem that is not adequately addressed by regulatory mechanisms.

The Cracking Pearlymussel is designated as an endangered species in Virginia (VDGIF 2018), a designation that conveys no legal protection. It is also designated as an endangered species in Tennessee (TWRA 2015; TDEC 2016). Under the Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (Tennessee Code Annotated §§ 70-8-101-112), "...it is unlawful for any person to take, attempt to take, possess, transport, export, process, sell or offer for sale or ship nongame wildlife, or for any common or contract carrier knowingly to transport or receive for shipment nongame wildlife." Further, regulations included in the Tennessee Wildlife Resources Commission Proclamation 00-15 Endangered Or Threatened Species state the following: except as provided for in Tennessee Code Annotated, Section 70-8-106 (d) and (e), it shall be unlawful for any person to take, harass, or destroy wildlife listed as threatened or endangered or otherwise to violate

terms of Section 70-8-105 (c) or to destroy knowingly the habitat of such species without due consideration of alternatives for the welfare of the species listed in (1) of this proclamation, or (2) the United States list of Endangered fauna. While this regulation provides for the consideration of alternatives, it does not require the level of project review afforded by the Act. Cracking Pearlymussel is also listed under the Alabama Invertebrate Species Regulation (Alabama Administrative Code 220-2-.98) that "make[s] it unlawful to take, capture, kill, or attempt to take, capture, or kill; possess, sell, trade for anything of monetary value, or offer to sell or trade for anything of monetary value, the listed invertebrate species (or any parts of reproductive products of such species) without a scientific collection permit or written permit..."

Since listing, section 7 of the Act has required Federal agencies to consult with the Service when projects they fund, authorize, or carry out may affect the species. However, the lack of Federal authority over the many actions likely affecting Cracking Pearlymussel habitat has become apparent. Many of the threats (including those identified at the time of listing, during recovery planning, and in our last 2011 5-year review) involve activities that likely do not have a Federal nexus (such as water quality changes resulting from development, water withdrawals, or indiscriminate logging) and, thus, may not require section 7 consultation. Although the take prohibitions of section 9 of the Act do apply to these types of activities and their effects on the Cracking Pearlymussel, enforcement of the section 9 prohibitions is difficult, at best. The Service is not informed when many activities are being considered, planned, or implemented and, therefore, has no opportunity to provide input into the design of the project or to inform project proponents of the need for a section 10 permit. Unlike higher profile species, the public may not be aware that listed mussel species exist in nearby waters, making them less likely to report habitat destruction.

2.4.5. Factor E: Other natural and manmade factors affecting its continued existence:

Invasive Species

The Recovery Plan (Service 1991) discusses the potential for nonnative *Corbicula* to negatively affect native mussel species by consuming a significant amount of their sperm. It is unknown whether this is influencing the reproductive success of Cracking Pearlymussel.

Restricted Range and Isolation

The Clinch and Elk Rivers, where the only two extant Cracking Pearlymussel populations remain, are separated by approximately 285 river miles. Additionally, the reaches of these rivers occupied by the

species are separated by five TVA dams: Guntersville, Nickajack, Chickamauga, Watts Bar, and Norris. Each of these two disjunct populations is extremely vulnerable to extirpation from catastrophic events (e.g., accidental toxic chemical spills), progressive degradation from land surface runoff (nonpoint-source pollutants, release of chemicals used in agricultural or residential applications), and natural stochastic events (e.g., floods, drought). The Recovery Plan mentions two mussel kills in the Clinch River caused by spills from a coal-fired power plant. Since the Recovery Plan was published, at least eight more spills or accidental releases have occurred in the Clinch and Powell River watersheds (Ahlstedt *et al.* 2016).

The level of isolation seen in the Cracking Pearlymussel makes natural recovery of extirpated populations virtually impossible without human intervention. Propagation techniques have only recently began to show some success. Additionally, there is the likelihood of decreased fitness from reduced genetic diversity. Species that are restricted in range and population size are more likely to suffer loss of genetic diversity due to genetic drift, potentially increasing their susceptibility to inbreeding depression, decreasing their ability to adapt to environmental changes, and reducing the fitness of individuals (Soule 1980, Hunter 2002, Allendorf and Luikart 2007). The long-term viability of a species is founded on the conservation of numerous local populations throughout its geographic range (Harris 1984). These separate populations are essential for the species to recover and adapt to environmental change (Noss and Cooperrider 1994, Harris 1984).

Climate Change

In its Fifth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) concluded that warming of the climate system is unequivocal (IPCC 2014). Numerous long-term climate changes have been observed including changes in arctic temperatures and ice, widespread changes in precipitation amounts, ocean salinity, wind patterns and aspects of extreme weather including droughts, heavy precipitation, heat waves, and the intensity of tropical cyclones (IPCC 2014). Climate change has the potential to increase the vulnerability of the Cracking Pearlymussel to random catastrophic events (McLaughlin *et al.* 2002, Thomas *et al.* 2004).

Thomas *et al.* (2004) report that frequency, duration, and intensity of droughts are likely to increase in the Southeast as a result of global climate change. According to Kaushal *et al.* (2010), stream temperatures in the Southeast have increased roughly 0.2–0.4°C (0.4–0.7°F) per decade over the past 30 years, and as air temperature is a strong predictor of water temperature, stream temperatures are expected to continue to rise. Estimates of the effects of climate change using available climate models

typically lack the geographic precision needed to predict the magnitude of effects at a scale small enough to discretely apply to the range of a given species. However, data on recent trends and predicted changes for Kentucky and Tennessee (Girvetz et al. 2009), and, more specifically, the Cumberland and Tennessee River drainages (Alder and Hostetler 2019), provide some insight for evaluating the potential threat of climate change to the Cracking Pearlymussel. Alder and Hostetler (2019) use different emission scenarios to calculate estimates of average annual increases in maximum and minimum temperature, precipitation, snowfall, and other variables. These scenarios, called "representative concentration pathways" (RCPs) are plausible pathways toward reaching a target radiative forcing (the change in energy in the atmosphere due to greenhouse gases) by the year 2100 (Moss et al. 2010). According to this model, air temperatures and precipitation are expected to increase in the Cumberland and Tennessee River drainages (Alder and Hostetler 2019).

There is uncertainty about the specific effects of climate change (and their magnitude) on the Cracking Pearlymussel; however, species with limited ranges, fragmented distributions, and small population size are thought to be especially vulnerable to the effects of climate change (Byers and Norris 2011). Thus, we consider climate change to be a potential threat to the Cracking Pearlymussel.

2.5. Synthesis

Historically, the Cracking Pearlymussel was a widespread species, endemic to the Ohio River drainage. It occurred in the Ohio River main channel and many of its large tributaries in Alabama, Pennsylvania, Illinois, Indiana, Ohio, and Kentucky. It has been extirpated from most historical locations (Watters *et al.* 2009, Haag and Cicerello 2016). Currently, the species is extant only in a few miles of the Elk River near the Alabama and Tennessee state line and in a short reach of the Clinch River near the Tennessee and Virginia state line. In both rivers, the species is mostly restricted to Tennessee and barely extends past the state borders.

The Recovery Plan listed habitat loss from impoundments, water quality deterioration attributed to coal mining and other land use practices, and chemical spills as reasons for the decline of this species. The effects of impoundments and water quality deterioration from land use practices persist within the current range of the Cracking Pearlymussel. Past chemical spills have resulted in Cracking Pearlymussel declines, and the threat of future events remains. Disease likely represents a new threat to the Cracking Pearlymussel based on data from the recent die-offs in the Clinch River. The relationship of the die-offs to potential pathogens continues to be investigated. The species' occurrence in only two isolated populations makes it especially vulnerable to extirpation and extinction.

In the most recent 5-year review for the Cracking Pearlymussel, it was stated that in order to achieve the recovery criteria for these species, it will be necessary to successfully propagate juveniles and raise those juveniles to a size at which they can be introduced into historic habitat with the maximum potential for survival. Species propagation has had limited success to date. Propagation techniques and understanding of the reproductive biology must be improved to create a successful program. Moreover, we need to increase our understanding of the species' specific habitat needs and response to threats to inform species introductions.

Therefore, based on our status review, threats analysis, and evaluation of conservation measures, we believe that the Cracking Pearlymussel continues to meet the definition of endangered under the Endangered Species Act.

3. RESULTS

Recommended Classification: Remain endangered.

The recovery criteria listed in Section 2.2 above have not been met for delisting or downlisting the species. Cracking Pearlymussel occurs in two isolated populations and continues to be vulnerable to severe threats. Our knowledge of the biology of the species is insufficient to understand the species' specific habitat needs and its response to threats. Species population reintroductions within its historical range will be necessary to meet recovery criteria. Some successful propagation of the species has occurred, but there is currently no propagation program in place to accomplish this. For these reasons, we believe that the species continues to meet the definition of endangered (in danger of extinction throughout all or a significant portion of its range).

4. RECOMMENDATIONS FOR FUTURE ACTIONS

The following actions are generally ordered based on priority, with the higher priority actions listed towards the top.

- Conduct additional studies to investigate the cause of the mussel die-offs in the Clinch River.
- Refine propagation techniques and conduct additional fish host studies to support population reintroductions and augmentations.
- Continue efforts to monitor and expand the population in the Clinch River upstream and downstream of its current distribution. Reassess the need to augment these populations by reintroducing the species to currently unoccupied reaches of both rivers.

- Continue efforts to monitor and expand the population in the Elk River upstream of its current distribution. The Elk River becomes impounded by backwaters of Wheeler Reservoir a short distance downstream of the TN/AL border so it is unlikely that its current downstream distribution can be expanded.
- Take appropriate actions to eliminate or greatly diminish threats to this species in the Elk and Clinch Rivers. Regulations that apply to non-point pollution need to be strictly enforced to prevent the loss of these populations.
- Reintroduce and reestablish viable populations in other streams within the historical range that have suitable habitat and water quality. The Cumberlandian Region Mollusk Restoration Committee (2010) recommended the following as priority rivers for reintroduction: the Nolichucky River (TN), the Duck River (TN), and the Big South Fork of the Cumberland River (KY, TN). The following were also identified as having potential for reintroductions: the Tennessee River main stem tailwaters (Wilson, AL and Pickwick Landing, TN), lower French Broad/Holston (TN), upper French Broad (TN), upper Holston (TN), and Buffalo (TN). Consider other potential reintroduction sites within the historical range of the species, such as the Green River.
- Augment the population in the Elk River through introduction of propagated juveniles (as recommended by the Cumberlandian Region Mollusk Restoration Committee (2010)).
- Continue to educate the public about water quality and freshwater mussels.

5. REFERENCES

Ahlstedt, S.A., M.T. Fagg, R.S. Butler, J.F. Connell, and J.W. Jones. 2016. Quantitative monitoring of freshwater mussel populations from 1979-2004 in the Clinch and Powell Rivers of Tennessee and Virginia, with miscellaneous notes on the fauna. Freshwater Mollusk Biology and Conservation 19:1-18.

Alder, J.R. and S.W. Hostetler. 2019. USGS National Climate Change Viewer. US Geological Survey website, *https://www2.usgs.gov/climate_landuse/clu_rd/nccv.asp*. Summary of Tennessee Region (06) (*http://regclim.coas.oregonstate.edu/NEX-DCP30_app/ data/huc2_20160309/summaries//06/06_en.pdf*) and Summary of Cumberland (0513) (*http://regclim.coas.oregonstate.edu/NEX-DCP30_app/data/huc4_20160309/summaries//0513/0513_en.pdf*)(accessed 11/07/2019).

Allendorf, F.W. and G. Luikart. 2007. Conservation and the genetics of populations. Malden, Massachusetts, Blackwell Publishing. 642 pp.

Amacker, T.M. 2019. Personal communication (email correspondence) regarding mussel surveys in the Elk River. Tennessee Valley Authority, Knoxville, Tennessee.

Bates, J. M., and S. D. Dennis. 1985. Mussel resource survey - State of Tennessee. Tennessee Wildlife Resources Agency Technical Report No. 85-3. 125 pp.

Bogan, A. E., and P. W. Parmalee. 1983. Tennessee's rare wildlife, volume II: the mollusks. Tennessee Wildlife Resources Agency and Tennessee Department of Conservation. 123 pp.

Byers, E. and S. Norris. 2011. Climate change vulnerability assessment of species of concern in West Virginia. West Virginia Division of Natural Resources, Elkins, West Virginia. 72 pp.

Churchill, E. P., Jr., and S. I. Lewis. 1924. Food and feeding in freshwater mussels. Bulletin of the United States Bureau of Fisheries. 39:439-471.

Cope, W.G., and J.W. Jones. 2016. Recent precipitous declines of endangered freshwater mussels in the Clinch River: an in situ assessment of water quality stressors related to energy development and other land-use. Final completion report submitted to U.S. Fish and Wildlife Service, Abingdon, Virginia and Cookeville, Tennessee.

Cumberlandian Region Mollusk Restoration Committee. 2010. Plan for the population restoration and conservation of imperiled freshwater mollusks of the Cumberland Region. V + 145 pp.

Garner, J. 2019. Personal communication (email correspondence) regarding Cracking Pearlymussel distribution in the Elk River. Alabama Department of Conservation and Natural Resources, Huntsville, Alabama.

Girvetz E.H., C. Zganjar, G.T. Raber, E.P. Maurer, P. Kareiva, and J.L. Lawler. 2009. Applied Climate-Change Analysis: The Climate Wizard Tool. PLoS ONE 4:1-19. e8320. doi:10.1371/ journal.pone.0008320.

Haag, W. R. and R. R. Cicerello. 2016. A distributional atlas of the freshwater mussels of Kentucky. Kentucky State Nature Preserves Commission, Scientific and Technical Series, No. 8. 299 pp.

Harkness, J.S., G.S. Dwyer, N.R. Warner, K.M. Parker, W.A. Mitch, and A. Vengosh. 2015. Iodide, bromide, and ammonium in hydraulic fracturing and oil and gas wastewaters: environmental implications. Environmental Science and Technology 49:1955-1963.

Harris, L.D. 1984. The fragmented forest. University of Chicago Press. 211 pp.

Howard, C.S. 2017. Personal communication (email correspondence) regarding mussel surveys in the Elk River. Tennessee Valley Authority, Knoxville, Tennessee.

Hua, D. 2019. Personal communication (email correspondence) regarding propagation. Tennessee Wildlife Resources Agency, Nashville, Tennessee.

Hubbs, D. 2019. Personal communication (email correspondence) regarding species occurrence in the Elk River. Tennessee Wildlife Resources Agency, Camden, Tennessee.

Hunter, M.L., Jr. 2002. Fundamentals of conservation biology, second edition. Blackwell Science, Inc. Malden, Massachussetts. 547 pp.

Hyde, J.M. and J.W. Jones. 2019. Annual report for 2018: assessment of the Certus, Inc. and Lone Mountain Processing, Inc. natural resource damage assessment and restoration cases to restore mussels in the Clinch and Powell Rivers in Virginia and Tennessee. Report for Office of Restoration and Damage Assessment, Department of Interior. 95 pp.

Intergovernmental Panel on Climate Change (IPCC). 2014. Climate change 2014 synthesis report. Available at *http://ipcc.ch/report/ar5/.*

Integrated Taxonomic Information System (ITIS). 2019. Integrated Taxonomic Information System website, https://www.itis.gov/ (accessed 11/08/2019).

Johnson, G.C., J.L. Krstolic, and B.J.K. Ostby. 2014. Influences of water and sediment quality and hydrologic processes on mussels in the Clinch River. Journal of the American Water Resources Association. 50:1-20.

Jones, J.W. 2019. Personal communication (email correspondence) and attached comments on draft document. U.S. Fish and Wildlife Service, Blacksburg, Virginia.

Jones, J.W., R. Mair, and R.J. Neves. 2003. Annual progress report for 2002: life history and artificial culture of endangered mussels. Report submitted to Tennessee Wildlife Resources Agency, Nashville, Tennessee. 80 pp.

Jones, J., S. Ahlstedt, B. Ostby, B. Beaty, M. Pinder, N. Eckert, R. Butler, D Hubbs, C. Walker, S. Hanlon, J. Schmerfeld, and R. Neves. 2014. Clinch river freshwater mussels upstream of Norris Reservoir, Tennessee and Virginia: a quantitative assessment from 2004 to 2009. Journal of the American Water Resources Association 50:820-836.

Jones, J., T. Lane, B. Ostby, B. Beaty, S. Ahlstedt, R. Butler, D. Hubbs, and C. Walker. 2018. Collapse of the Pendleton Island mussel fauna in the Clinch River, Virginia: setting baseline conditions to guide recovery and restoration. Freshwater Mollusk Biology and Conservation 21:36-56.

Kaushal, S.S., G.E. Likens, N.A. Jaworski, M.L. Pace, A.M. Sides, D. Seekell, K.T. Belt, D.H. Secor, and R.L. Wingate. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment 8: 461-466.

Lane, T. 2019. Personal communication (email correspondence) regarding propagation. Virginia Department of Game and Inland Fisheries, Marion, Virginia.

McLaughlin, J.F., J.J. Hellmann, C.L. Boggs, and P.R. Ehrlich. 2002. Climate change hastens population extinctions. Proceedings of the National Academy of Sciences of the United States of America 99(9):6070-6074.

Noss, R.E. and A.Y. Cooperrider. 1994. Saving nature's legacy: protecting and restoring biodiversity. Island Press, Washington, D.C. 416 pp.

Moss, R.H., J.A. Edmonds, K.A. Hibbard, M.R. Manning, S.K. Rose, D.P. vanVuuren, T.R. Carter, S. Emori, M. Kainuma, T. Kram, G.A. Meehl, J.F.B. Mitchell, N. Nakicenovic, K. Riahi, S.J. Smith, R.J. Stouffer, A.M. Thompson, J.P. Weyant, and T.J. Wilbanks. 2010. The next generation of scenarios for climate change research and assessment. Nature, Vol 463:747-756. doi:10.1038/nature08823.

Parmalee, P. W. and A. E. Bogan. 1998. The freshwater mussels of Tennessee. The University of Tennessee Press, Knoxville. 328 pp.

Phipps, A., M. Hyde, and J. Jones. 2017. Monitoring freshwater mussels at population restoration sites in the upper Tennessee River Basin, Tennessee and Virginia. Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia and U.S. Fish and Wildlife Service, Blacksburg, Virginia. Draft final report submitted to the U. S. Fish and Wildlife Service, Ecological Services, Cookeville, Tennessee and Abingdon, Virginia. 62 pp.

Phipps, A., M. Hyde, and J. Jones. 2018. Monitoring freshwater mussels at population restoration sites in the upper Tennessee River Basin, Tennessee and Virginia. Department of Fish and Wildlife Conservation, Virginia Polytechnic Institute and State University, Blacksburg, Virginia and U.S. Fish and Wildlife Service, Blacksburg, Virginia. Final report submitted to the U. S. Fish and Wildlife Service, Ecological Services, Cookeville, Tennessee and Abingdon, Virginia. 61 pp.

Phipps, A. 2019. Evaluation of the effects of mining related contaminants on freshwater mussels (Bivalvia: Unionidae) in the Powell River of Virginia and Tennessee. Master of Science Thesis, Virginia Tech University. 102 pp.

Price, J.E, C.E. Zipper, J.W. Jones, and C.T. Franck. 2014. Water and sediment quality in the Clinch River, Virginia and Tennessee, USA, over nearly five decades. Journal of the American Water Resources Association 1-22.

Price, J.E., C.E. Zipper, J.W. Jones, and C. Franck. 2011. Water sediment quality in the Clinch and Powell Rivers of Virginia and Tennessee, 1964 – 2010: Final Project Report.

Richard, J. 2019. Personal communication (email correspondence) regarding mussel die-offs in the Clinch River. U.S. Fish and Wildlife Service, Abington, Virginia.

Soule, M.E. 1980. Threshold for survival: maintaining fitness and evolutionary potential. Pages 151-169 *in*: M.E. Soule and B.A. Wilcox, eds. Conservation Biology. Sinauer Associates, Inc., Sunderland, Massachusetts.

Tennessee Department of Environment and Conservation (TDEC). 2016. A guide to the rare animals of Tennessee. Division of Natural Areas, Natural Heritage Program, Nashville, Tennessee. 89 pp.

Tennessee Wildlife Resources Agency (TWRA). 2015. Tennessee State wildlife action plan 2015. TWRA, Nashville, Tennessee. 194 pp.

Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M Ferreira de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427:145-148.

Turgeon, D.D., J.F. Quinn, A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks, second edition. American Fisheries Society, Special Publication 26. 526 pp.

U.S. Fish and Wildlife Service (Service). 2011. Birdwing Pearlymussel (*Conradilla caelata [=Lemiox rimosus]*), Dromedary Pearlymussel (*Dromus dromas*), Cracking Pearlymussel (*Hemistena (=Lastena) lata*). 5-year review: summary and evaluation. Southeast Region, Cookeville Ecological Service Field Office, Cookeville, Tennessee. 27 pp.

U.S. Fish and Wildlife Service (Service). 1991. Recovery Plan for Cracking Pearlymussel (*Hemistena (=Lastena) lata*). Atlanta, Georgia. 25 pp.

Virginia Department of Game and Inland Fisheries (VDGIF). 2018. Special status faunal species in Virginia. 20 pp.

Wang, N., C.G. Ingersoll, J.L. Kunz, W.G. Brumbaugh, C.M. Kane, R.B. Evans, S. Alexander, C. Walker, and S. Bakaletz. 2013. Toxicology of sediments potentially contaminated by coal mining and natural gas extraction to the unionid mussels and commonly tested benthic invertebrates. Environmental Toxicology and Chemistry 32:207-221.

Watters G.T., Hoggarth M.A. & Stansbury D.H. 2009. The freshwater mussels of Ohio. Ohio State University, Columbus, Ohio.

Williams, J. D., A. E. Bogan, R. S. Butler, K.S Cummings, J. T. Garner, J. L. Harris, N. A. Johnson, and G. T. Watters. 2017. A revised list of the freshwater mussels (Mollusca: Bivalvia: Unionida) of the United States and Canada. Freshwater Mollusk Biology and Conservation 20:33–58.

Williams, J. D., A. E. Bogan and J. T. Garner. 2008. Freshwater mussels of Alabama and the Mobile Basin in Georgia, Mississippi and Tennessee. University of Alabama Press, Tuscaloosa, Alabama. 908 pp.

Zipper, E.E., B. Beaty, G.C. Johnson, J.W. Jones, J.L. Krstolic, B.J.K. Ostby, W.J. Wolfe, and P. Donovan. 2014. Freshwater mussel population status and habitat quality in the Clinch River, Virginia and Tennessee, USA: a featured collection. Journal of the American Water Resources Association 50:807-819.

Zipper, C.E, P.F. Donovan, J.W. Jones, J. Li, J.E. Price, and R.E. Stewart. 2016. Spatial and temporal relationships among watershed mining, water quality, and freshwater mussel status in an eastern USA river. Science of the Total Environment 541:603-615.

Table 1. Summary of historical distribution of Cracking Pearlymussel (*Hemistena lata*).

Waterbody	State(s)	County(s)	Status
Tennessee River	Alabama, Tennessee	Lauderdale, Colbert (AL); Hardin (TN)	Extirpated
Elk River	Alabama, Tennessee	Limestone (AL); Giles, Lincoln (TN)	Extant
Wabash River	Illinois, Indiana	Wabash, White (IL); Knox, Posey, Tippecanoe (IN)	Extirpated
White River	Indiana	Marion	Extirpated
Tippecanoe River	Indiana	White	Extirpated
Cumberland River	Kentucky, Tennessee	Cumberland, Hart, Pulaski, Russel (KY); Davidson (TN)	Extirpated
Big South Fork Cumberland River	Kentucky	McCreary	Extirpated
Scioto River	Ohio	Franklin, Pickaway	Extirpated
Tuscarawas River	Ohio	Coshocton, Tuscarawas	Extirpated
Ohio River	Ohio, Kentucky	Meigs, Jefferson, Hamilton, Washington (OH); Jefferson, Carroll, Kenton (KY)	Extirpated
Paint Creek	Ohio	Ross	Extirpated
Allegheny River	Pennsylvania	Armstrong	Extirpated
Clinch River	Tennessee, Virginia	Anderson, Grainger, Hancock (TN); Russel, Scott, Wise (VA)	Extant
Duck River	Tennessee	Maury	Extirpated
Holston River	Tennessee	Knox	Extirpated
Buffalo River	Tennessee	Perry	Extirpated
Powell River	Virginia	Lee	Extirpated
Green River	Kentucky	Butler, Hart	Extirpated
Kentucky River	Kentucky	Unknown	Extirpated

Data from museum records from Carnegie Museum of Natural History, Chicago Academy of Science, Delaware Museum of Natural History, Eastern Kentucky University, Field Museum of Natural History, Florida Museum of Natural History, Illinois Natural History Survey, Naturalis Biodiversity Center, North Carolina Museum of Natural Sciences made available online in Invertebase (http://www.invertebase.org/portal/ collections), McClung Museum of Natural History and Culture, University of Tennessee, Parmalee and Bogan (1998), Williams et al. (2008), Watters et al. (2009), Haag and Cicerello (2016), Hubbs (pers. comm, 2019), and Garner (pers. comm. 2019).

U.S. FISH AND WILDLIFE SERVICE
5-YEAR REVIEW of Cracking Pearlymussel (*Hemistena lata*)

Current Classification: Endangered
Recommendation resulting from the 5-Year Review:

__X__ No change is needed

Review Conducted By: Gerald Dinkins, University of Tennessee and Jessica Miller, Kentucky Ecological Services Field Office

FIELD OFFICE APPROVAL:

Lead Field Supervisor, U.S. Fish and Wildlife Service

Approve: VIRGIL ANDREWS Digitally signed by VIRGIL ANDREWS Date: 2019.11.14 11:20:30 -05'00' Date: 11/14/19

REGIONAL OFFICE APPROVAL:

Cooperating Regional Director, U.S. Fish and Wildlife Service, Northeast Region

__X__ Concur _____ Do Not Concur

Signature: Paula Tocchi Date: 12/5/2019

APPENDIX A: Summary of peer review for the 5-year review of the Cracking Pearlymussel (*Hemistena lata*)

A. Peer Review Method: The draft document was peer-reviewed by Todd Amacker (Tennessee Valley Authority), Don Hubbs (Tennessee Wildlife Resources Agency), and Jeff Garner (Alabama Department of Conservation and Natural Resources).

B. Peer Review Charge: Angela Boyer in the Service's Ohio Field Office assisted in completing the peer review and asked peer reviewers to read the 5-year review and provide any comments, both editorial and content related. The Service did not ask peer reviewers to comment on the recommendation regarding listing status.

C. Summary of Peer Review Comments/Report: The peer reviewers considered the revised 5-year review to be biologically sound and generally agreed with the species' status information and proposed conservation actions. They agreed that the 5-year review was based on the best available scientific information. One peer reviewer (Don Hubbs) provided information about Cracking Pearlymussel propagation achieved by the Tennessee Wildlife Resource Agency's (TWRA) Cumberland River Aquatic Center. Another peer reviewer (Jeff Garner) commented that the State of Alabama has the "Invertebrate Species Regulation" that provides some protection to the Cracking Pearlymussel.

D. Response to Peer Review: We added the new information about TWRA's propagation to our discussion about the biology of the species (see section 2.3.1). We added Alabama's "Invertebrate Species Regulation" in our discussion of Factor D in our Five Factor Analysis.