AGENCY DRAFT RECOVERY PLAN

for

Endangered Fat Threeridge (*Amblema neislerii*), Shinyrayed Pocketbook (*Lampsilis subangulata*), Gulf Moccasinshell (*Medionidus penicillatus*), Ochlockonee Moccasinshell (*Medionidus simpsonianus*), Oval Pigtoe (*Pleurobema pyriforme*)

and

Threatened Chipola Slabshell (*Elliptio chipolaensis*), and Purple Bankclimber (*Elliptoideus sloatianus*)

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Literature citation should read as follows:

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EXECUTIVE SUMMARY

The eastern Gulf Slope streams draining the Apalachicolan Region are defined as streams from the Escambia to the Suwannee River systems. Occurring in southeast Alabama, west-central and southwest Georgia, and north Florida, these river systems collectively form one of the largest drainage areas in the eastern Gulf Coastal Plain. Historically, these rivers were known for their rich freshwater mussel populations. However, the fat threeridge (*Amblema neislerii*), shinyrayed pocketbook (*Lampsilis subangulata*), Gulf moccasinshell (*Medionidus penicillatus*), Ochlockonee moccasinshell (*Medionidus simpsonianus*), oval pigtoe (*Pleurobema pyriforme*), Chipola slabshell (*Elliptio chipolaensis*), and purple bankclimber (*Elliptoideus sloatianus*) mussels have all undergone significant reduction in total range and abundance.

Current Status: The fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, and oval pigtoe were federally listed as endangered species; and the Chipola slabshell and purple bankclimber were federally listed as threatened species under the Endangered Species Act of 1973, as amended (ESA), on March 16, 1998 (63 FR 12664). These mussel species are vulnerable to extinction due to significant habitat loss, range restriction, and population fragmentation and size reduction. Three (Gulf moccasinshell, oval pigtoe, Chipola slabshell) of the five species that once occurred in Alabama are considered extirpated from that State. Only one (purple bankclimber) of the species remains in the Chattahoochee River main stem, having recently been rediscovered after a nearly 150-year absence from collection records. There is little evidence of recent recruitment in most of the subpopulations of these species. The restricted distribution of these seven species also makes localized subpopulations susceptible to toxic chemical spills and the deleterious effects of genetic isolation.

Recovery Objective: Delisting.

Recovery Criteria: The goal of this recovery plan is to restore viable populations of the fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, oval pigtoe, Chipola slabshell, and purple bankclimber within a significant portion of their historical ranges, and to eliminate or reduce threats to their continued survival so that their protection under the ESA is no longer required.

Recovery in the near future is unlikely for the seven mussels addressed in this plan because of the extent of their decline, the relative isolation of their remaining subpopulations, their potential sensitivity to common pollutants, and continued threats to their habitats (see “Reasons for Decline”). Securing their extant subpopulations and occupied habitats, therefore, is the most immediate recovery priority (see “Narrative Outline of Recovery Tasks, Task 1"). Securing these subpopulations and their occupied habitats can best be achieved at the watershed level through voluntary community conservation awareness and stewardship as outlined under “Conservation Measures.”

The Service will consider the fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, and oval pigtoe for reclassification to threatened status when each species has: (1) shown an increase in current range to reflect occupation of at least 50 percent of the total historical habitat; (2) at least 3 viable subpopulations in each of the watersheds (listed in Table 8) that currently supports the species (e.g., Econfina Creek, lower Flint River); and (3) at least 10 viable subpopulations in the large river basins (i.e., Apalachicola-Chattahoochee-Flint, Ochlockonee, and Suwanee Rivers) within the historical range of the species, for at least 10 years or 3 generations, whichever is longer. The Service will consider delisting the five endangered mussels, the Chipola slabshell, and purple bankclimber when biennial monitoring shows that an increase of the current number of subpopulations/sites and/or extent of occurrence is enough to ensure population viability, reduce isolation among populations, and increase the potential for genetic exchange. Specific increases in subpopulations needed to delist are currently unknown and will be determined by tasks outlined in this recovery plan. To downlist and delist these seven mussels, all necessary subpopulations must be viable and secure, and all current and foreseeable threats must be identified and reduced; and the Listing/Recovery Factors have to be addressed.

Actions Needed:

1. Preserve extant subpopulations and currently occupied habitats and ensure subpopulation viability.
2. Search for additional subpopulations of the species and suitable habitat.
3. Determine through research and propagation technology the feasibility of augmenting extant subpopulations and reintroducing the species into historical habitat.
4. Develop and implement a program to evaluate efforts and monitor subpopulation levels and habitat conditions of existing subpopulations, as well as newly discovered, introduced, or expanding subpopulations.
5. Develop and implement cryogenic techniques to preserve the species' genetic material until such time as conditions are suitable for reintroduction.
6. Develop and utilize a public outreach and environmental education program.
7. Assess the overall success of the recovery program and recommend actions.

Cost ($000s):

Year	Action 1	Action 2	Action 3	Action 4	Action 5	Action 6	Action 7	Total
2004	830	70	98	48	0	25	4	1,075
2005	810	60	93	180	60	20	4	1,227
2006	830	55	68	45	102	20	4	1,124
2007	715	55	50	180	102	20	4	1,126
2008	735	55	50	45	60	20	4	969
Total	3,920	295	359	498	324	105	20	5,521

The cost estimates provided above are based on the Implementation Schedule and identify foreseeable expenditures that could be made to implement the specific recovery tasks during a 5-year period.

Date of Recovery: Downlisting and delisting dates cannot be estimated at this time. A time period of at least 10 years or three generations, which ever is longer, is needed to document the long-term viability of mussel populations. Tasks outlined in the Implementation Schedule address the monitoring component of the recovery plan to ensure that these data will be collected and evaluated in order to estimate downlisting and delisting dates.

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PART I

INTRODUCTION

The Endangered Species Act of 1973, as amended (ESA), establishes policies and procedures for identifying, listing, and protecting species of wildlife that are endangered or threatened with extinction. The ESA defines an "endangered species" as "any species which is in danger of extinction throughout all or a significant portion of its range." A "threatened species" is defined as "any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range."

The fat threeridge (*Amblema neislerii* [Lea, 1858]), shinyrayed pocketbook (*Lampsilis subangulata* [Lea, 1840]), Gulf moccasinshell (*Medionidus penicillatus* [Lea, 1857]), Ochlockonee moccasinshell (*Medionidus simpsonianus* [Walker, 1905]), and oval pigtoe (*Pleurobema pyriforme* [Lea, 1857], were federally listed as endangered species and the Chipola slabshell (*Elliptio chipolaensis* [Walker, 1905]) and purple bankclimber (*Elliptoideus sloatianus* [Lea, 1840]) were federally listed as threatened species under the ESA, on March 16, 1998 (Service 1998).

The Secretary of the Interior is responsible for administering the ESA's provisions as they apply to these species. Day-to-day management authority for endangered and threatened species under the Department of the Interior's jurisdiction has been delegated to the Service. To help identify and guide species recovery needs, section 4(f) of the ESA directs the Secretary to develop and implement recovery plans for listed species or populations. Such plans are to include: (1) a description of site-specific management actions necessary to conserve the species or population; (2) objective measurable criteria which, when met, will allow the species or populations to be removed from the List; and (3) estimates of the time and funding required to achieve the plan's goals and intermediate steps. Section 4 of the ESA and regulations (50 CFR Part 424) have been promulgated to implement listing provisions and to set forth the procedures for reclassifying and delisting species on the Federal lists. A species can be delisted if the Secretary of the Interior determines that the species no longer meets the endangered or threatened status based upon these five factors listed in Section 4(a)(1) of the ESA:

(1) the present or threatened destruction, modification, or curtailment of its habitat or range;
(2) overutilization for commercial, recreational, scientific, or educational purposes;
(3) disease or predation;
(4) the inadequacy of existing regulatory mechanisms; and
(5) other natural or manmade factors affecting its continued existence.

Further, a species may be delisted, according to 50 CFR Part 424.11(d), if the best scientific and commercial data available substantiate that the species or population is neither endangered nor threatened for one of the following reasons: (1) extinction; (2) recovery; or (3) original data for classification of the species were in error.

These seven freshwater mussels, all members of the family Unionidae, are endemic (restricted in distribution) to eastern Gulf Slope streams draining the Apalachicolan Region, defined as streams from the Escambia to the Suwannee River systems (Butler 1989), and occurring in southeast Alabama, west-central and southwest Georgia, and north Florida. These seven species are presently found only in streams draining the eastern portion of the Apalachicolan Region (from Econfina Creek east to the Suwanee River) (Figure 1). The fat threeridge is endemic to the Apalachicola-Chattahoochee-Flint River system (ACF). Historically, it occurred in the main stems of the Apalachicola, Flint, and Chipola Rivers. This species has apparently been extirpated from the Flint River, which included most of its historical range, and now occurs sporadically at only a few sites in the Apalachicola and lower Chipola Rivers. The shinyrayed pocketbook historically occurred in the ACF Basin and Ochlockonee River systems. This mussel continues to occur at scattered localities in tributary streams of the ACF Basin and in the Ochlockonee River system, having apparently been extirpated from the primary main stems in the ACF Basin except for the Flint River. The Gulf moccasinshell historically occurred in Econfina Creek and in the ACF Basin. Apparently extirpated from the Apalachicola and Chattahoochee River main stems, this species currently occurs sporadically in Econfina Creek, the Flint and Chipola River main stems, and in several ACF Basin tributaries. The Ochlockonee moccasinshell occurred historically in the Ochlockonee River system. Only three live specimens are known to have been collected since 1974 in this river system despite concerted efforts by numerous investigators. The oval pigtoe was historically found in Econfina Creek, throughout the ACF Basin, and in the Ochlockonee and Suwannee River systems. It has been extirpated from the main stems of the Apalachicola, Chattahoochee, and Suwannee Rivers. Current sites of occurrence include Econfina Creek, Flint and Chipola Rivers, and various tributary streams throughout its range. The Chipola slabshell occurred historically in the Chipola River system and one site in the Chattahoochee River system. It is currently known sporadically from just the middle portion of the Chipola River system. The purple bankclimber historically occurred in larger streams throughout the ACF and Ochlockonee River systems. Apparently extirpated from the Chipola River, this species currently occurs sporadically in the Apalachicola, Flint, and Ochlockonee Rivers, and from single sites in the Chattahoochee River and a Flint River tributary.

These seven mussels were eliminated from much of their historical range by anthropogenic activities, such as impoundments, channelization, pollution, sedimentation, and other factors. The decline of some of the species was evident decades ago. The fat threeridge, Gulf moccasinshell, oval pigtoe, and purple bankclimber were recognized in lists of rare species compiled in the early 1970s (Athearn 1970, Stansbery 1971). Low population levels and restricted ranges now render these mussels vulnerable to toxic chemical spills and other catastrophic events, and the deleterious effects of genetic isolation. Presently, there is also little evidence of recent recruitment in most of the subpopulations of these species. This agency draft recovery plan outlines the recovery objectives and criteria for the seven federally listed mussels and the tasks needed to conserve and recover the species so they no longer require the protection afforded by the ESA.

BACKGROUND

North America harbors the world's greatest diversity of freshwater mussels (Williams and Neves 1995, Neves 1999a), with about 300 recognized species (Turgeon et al. 1998). Over 90 percent of the species inhabit the southeastern United States (Neves et al. 1997), with the vast majority of these species endemic to this area. There is evidence that mussel populations throughout the central and eastern part of the United States remained relatively unchanged for centuries prior to European settlement, despite the consumption and utilization of huge numbers of mussels by Native Americans from numerous regional streams (Parmalee et al. 1982). Modern civilization began to exploit mussel resources by the late 1800s for pearls, as did Native Americans (Kunz 1898, Kunz and Stevenson 1908, Myer 1914); buttons (Lefevre and Curtis 1912); and even fish bait, hog feed, and occasionally human consumption (Davis 2000). Although mussel exploitation proved locally destructive, it was the significant anthropogenic alteration of aquatic habitats that fostered the early collapse of our native mussel resources on a grand scale (Lewis 1868, Kunz 1898, Kunz and Stevenson 1908, Ortmann 1909a, van der Schalie 1938).

No other wide-ranging faunal group in North America is as imperiled as freshwater mussels (Stein and Flack 1997, Abell et al. 2000). Two assessments of the continent's entire mussel fauna recommended conservation status for 67 percent (Stein and Flack 1997) and 72 percent (Williams et al. 1993) of the taxa. As many as 36 taxa (13 percent) are presumed extinct (Howells et al. 1997, Neves et al. 1997, Neves 1999a), and 70 taxa (23 percent) are classified as federally listed, endangered or threatened species, with some of these latter species considered extinct (Neves 1999a). Over one-third of the continent's mussel fauna became extinct during the past century or were federally listed since 1973. The primary cause of this decline is loss of suitable habitat caused by impoundments, channelization, pollution, sedimentation, and other factors (Ortmann 1909a, Fuller 1974, Williams et al. 1993, Williams and Neves 1995).

The general trend of increasing mussel imperilment has also been documented on a global scale (Bogan 1993, Kay 1995). Several experts have postulated that many additional mussel taxa are "circling the drain;" these taxa are functionally extinct or are expected to become extinct in the foreseeable future (Neves 1993, 1997; Shannon et al. 1993; Ricciardi et al. 1998). Nott et al. (1995) noted that North American mussels and fishes have suffered recent extinction rates in the "kilo-death" range, or three orders of magnitude higher than the rates that have been estimated for species over geological time. They predict a major increase in the global extinction rate in the near future for freshwater mussels and other mollusks compared with the past global extinction rate. The level of imperilment in the southeastern mussel fauna (75 percent) exceeds that of the continent as a whole (Lydeard and Mayden 1995, Neves et al. 1997, Neves 1999a).

The Apalachicolan Region is known for its high level of endemism (van der Schalie 1938, Abell et al. 2000), with approximately 25 of 55 mussel species being endemic (Heard 1979, Butler 1989, Brim Box and Williams 2000). The Nature Conservancy (TNC) ranked the Apalachicolan Region (as Florida Gulf) fifth in number of imperiled mussel and fish species (Master et al. 1998). Several species of Apalachicolan Region mussels were considered rare at mid-century (Clench and Turner 1956). The further decline of the fauna was noted by subsequent investigators (Athearn 1970; Heard 1970, 1975; Stansbery 1971; Williams and Butler 1994). Currently, 56 percent of the Apalachicolan Region mussel fauna is in need of conservation measures (Williams et al. 1993). At least four (see "Species Descriptions and Taxonomy," Gulf moccasinshell account) Apalachicolan Region species are now considered extinct: Ochlockonee arcmussel (*Alasmidonta wrightiana* [Walker 1901]), winged spike (*Elliptio nigella* [Lea 1852]), lined pocketbook (*Lampsilis binominata* [Simpson 1900]), and Apalachicola ebonyshell (*Fusconaia apalachicola* [Williams and Fradkin 1999]) (Heard 1975, Butler 1994, Turgeon et al. 1998, Williams and Fradkin 1999, Brim Box and Williams 2000). The latter species, described solely from archeological material, probably survived in the main stem of the Chattahoochee and Apalachicola Rivers until early habitat modifications occurred in the ACF Basin (Williams and Fradkin 1999).

SPECIES DESCRIPTIONS AND TAXONOMY

General Information

The following species descriptions based on shell characteristics were generally derived from Williams and Butler (1994). Brim Box and Williams (2000) also outlined various aspects of the soft anatomy of the six ACF Basin listed species (minus the Ochlockonee moccasinshell). Brim Box and Williams (2000) provided the only published color photographs of these six species, while the unpublished report of Johnson et al. (2000) also has color photographs of these same species. In addition to the original descriptions, several other studies have published black and white photographs or illustrations of these species (van der Schalie 1940, Clench and Turner 1956, Burch 1975, Johnson 1977, Heard 1979, Williams and Butler 1994). Brim Box and Williams (2000) and Clench and Turner (1956) also present complete synonymies (taxonomic history of name changes) of the six species represented in the ACF Basin.

Fat threeridge

The fat threeridge is a medium-sized to large, subquadrate, inflated, solid, and heavy-shelled mussel that reaches a length of 4.0 inches (in) (10.2 centimeters (cm)). Large specimens are so inflated that their width approximates their height. The umbos (bulge or beak that protrudes near the hinge of a mussel) are in the anterior quarter of the shell. The dark brown to black shell is strongly sculptured with seven to eight prominent horizontal parallel plications (ridges). As is typical of the genus, no sexual dimorphism is displayed in shell characters. Internally, there are two subequal pseudocardinal teeth in the left valve and typically one large and one small tooth in the right valve (shell half). The lateral teeth are heavy, long, and slightly arcuate (curved like a bow), with two in the left valve and one in the right valve. The inside surface of the shell (nacre) is bluish white to light purplish and very iridescent.

This taxon was assigned to the genera *Quadrula* and *Crenodonta* by Simpson (1914) and Clench and Turner (1956), respectively. Subsequent investigators (e.g., Turgeon et al. 1998) have placed the fat threeridge in the genus *Amblema*. The Service considers *Unio neislerii* (Lea, 1858), to be a synonym of *Amblema neislerii.*

Shinyrayed pocketbook

The shinyrayed pocketbook is a medium-sized mussel that reaches approximately 3.3 in (8.4 cm) in length. The shell is subelliptical, with broad, somewhat inflated umbos and a rounded posterior ridge. The shell is fairly thin but solid. The surface is smooth and shiny, light yellowish brown in color with fairly wide, bright emerald green rays over the entire length of the shell. Older specimens may appear much darker brown with obscure rays. Female specimens are more inflated postbasally, whereas males appear to be more pointed posteriorly. Internally, the pseudocardinal teeth are double and fairly large and erect in the left valve, with one large tooth and one spatulate tooth in the right valve. The lateral teeth are relatively short and straight, with two in the left valve and one in the right valve. The nacre is white, with some specimens exhibiting a salmon tint in the vicinity of the umbonal cavity. The Service recognizes *Unio subangulatus* (Lea, 1840), and *Unio kirklandianus* (Wright, 1897), as synonyms of *Lampsilis subangulata.*

Heard (1977, 1979) and Williams and Butler (1994) assigned this species to the genus *Villosa* based on the lack of a true mantle flap, which is characteristic of the genus *Lampsilis* (Ortmann 1912). Turgeon et al. (1998), however, retained the shinyrayed pocketbook under the latter genus. Superconglutinate producers (see “General Reproductive Biology”) probably warrant their own genus. This was hypothesized over 25 years ago by Fuller and Bereza (1973) for a sister species of the shinyrayed pocketbook, southern sandshell (*L. australis* [Simpson, 1900]), but for reasons (i.e., soft anatomy) other than the production of superconglutinates.

Gulf moccasinshell

The Gulf moccasinshell is a small mussel that reaches a length of about 2.2 in (5.6 cm), is elongate-elliptical or rhomboidal in outline, fairly inflated, and has relatively thin valves. The ventral margin is nearly straight or slightly rounded. The posterior ridge is rounded to slightly angled and intersects the end of the shell at the base line. Females tend to have the posterior point above the ventral margin and are somewhat more inflated. Sculpturing (ridges/bumps on a shell caused by natural processes) consists of a series of thin, radially-oriented plications along the length of the posterior slope. The remainder of the surface is smooth and yellowish to greenish brown with fine, typically interrupted green rays. The left valve has two stubby pseudocardinal and two arcuate lateral teeth. The right valve has one pseudocardinal tooth and one lateral tooth. Nacre color is smoky purple or greenish and slightly iridescent at the posterior end.

Much confusion has clouded the taxonomy of *Medionidus* species in the Apalachicolan Region (Brim Box and Williams 2000). In the Chipola River system, van der Schalie (1940) recorded two species of *Medionidus*: *M. kingii* (Wright, 1900) and *M. penicillatus*. Clench and Turner (1956) synonymized *M. kingii* and two other species, the Ochlockonee moccasinshell and

Suwannee moccasinshell, *M. walkeri* (Wright, 1897), under the Gulf moccasinshell, an arrangement also followed by Burch (1975). Johnson (1970) erroneously reported both the Gulf moccasinshell and Suwannee moccasinshell from the ACF Basin and the Suwannee moccasinshell from the Ochlockonee and Suwannee Rivers as well. In his *Medionidus* monograph, Johnson (1977) later recognized the validity of the Gulf moccasinshell, Ochlockonee moccasinshell, and Suwannee moccasinshell from Apalachicolan Region streams based on shell characters. The validity of the three allopatrically distributed Apalachicolan Region *Medionidus* species is also recognized by Turgeon et al. (1998). The Service recognizes *Unio penicillatus* Lea, 1857, and *Unio kingii* Wright, 1900, as synonyms of *Medionidus penicillatus*.

Ochlockonee moccasinshell

The Ochlockonee moccasinshell is a small species, generally under 2.2 in (5.6 cm) in length. It is slightly elongate-elliptical in outline, the posterior end obtusely rounded at the median line, and the ventral margin broadly curved. The posterior ridge is moderately angular and covered in its entire length with well developed, irregular plications. Sculpture may also extend onto the disk below the ridge. The periostracum (outside surface of the shell) is smooth. The color is light brown to yellowish green, with dark green rays formed by a series of connected chevrons or undulating lines across the length of the shell. Internal characters include thin straight lateral teeth and compressed pseudocardinal teeth. There are two pseudocardinals and two laterals in the left valve and one pseudocardinal and one lateral in the right valve. The nacre is bluish white.

The taxonomic confusion that has surrounded the genus *Medionidus* is summarized in the Gulf moccasinshell account above. The Service considers *Unio simpsonianus* Walker, 1905, to be a synonym of *Medionidus simpsonianus*.

Oval pigtoe

The oval pigtoe is a small to medium-sized mussel that attains a length of about 2.4 in (6.1 cm). The shell is suboviform and compressed. The periostracum is shiny smooth; yellowish, chestnut, or dark brown; rayless; and with distinct growth lines. The posterior slope is biangulate and forms a blunt point on the posterior margin. The umbos are slightly elevated above the hingeline. No sexual dimorphism is displayed in *Pleurobema* shell characters. Internally, the pseudocardinal teeth are fairly large, crenulate (bumpy/notched), and double in each valve. The lateral teeth are somewhat shortened, arcuate, and also double in each valve. Nacre color varies from salmon to bluish white and is iridescent posteriorly.

Variation in this species has led to the description of various nominal species. Williams and Butler (1994) recognized *Pleurobema reclusum* (Wright, 1898) as a distinct species (the Florida pigtoe, distributed in the Ochlockonee and Suwannee River systems) following Simpson (1914), however Turgeon et al. (1998) recognizes only *P. pyriforme*. A recent study using molecular genetic techniques to determine genetic distinctiveness concluded that *P. reclusum* may indeed warrant specific status (Kandl et al. 2001). Brim Box and Williams (2000) asserted that preliminary findings by Kandl et al. (1997) suggested instead that *P. reclusum* and *P. pyriforme* were synonymous. For the purpose of this recovery plan, however, the two taxa are considered as one, *Pleurobema pyriforme*, the oval pigtoe. The Service currently recognizes *Unio pyriformis* Lea, 1857, *Unio modicus* Lea, 1857, *Unio bulbosus* Lea, 1857, *Unio amabilis* Lea, 1865, *Unio harperi* Wright, 1899, *Unio reclusus* Wright, 1898, and *Pleurobema simpsoni* Vanatta, 1915, as synonyms of *Pleurobema pyriforme*.

Chipola slabshell

The Chipola slabshell is a medium-sized species reaching a length of about 3.3 in (8.4 cm). The shell is ovate to subelliptical, somewhat inflated, and with the posterior ridge starting out rounded, but flattening to form a prominent biangulate margin. The periostracum is smooth and chestnut colored. Dark brown coloration may appear in the umbonal region and the remaining surface may exhibit alternating light and dark bands. The umbos are prominent, well above the hingeline. As is typical of all *Elliptio* mussels, no sexual dimorphism is displayed in shell characters. Internally, the umbone cavity is rather deep. The lateral teeth are long, slender, and slightly curved, with two in the left and one in the right valve. The pseudocardinal teeth are compressed and crenulate, with two in the left and one in the right valve. Nacre color is salmon, becoming more intense dorsally and somewhat iridescent posteriorly. The Service currently recognizes *Unio chipolaensis* Walker, 1905, as a synonym of *Elliptio chipolaensis*.

Purple bankclimber

The purple bankclimber is a very large, heavy-shelled, strongly-sculptured mussel reaching lengths of 8.0 in (20.5 cm). A well-developed posterior ridge extends from the umbo to the posterior ventral margin of the shell. The posterior slope and the disk just anterior to the posterior ridge are sculptured by several irregular plications that vary greatly in development. The umbos are low, extending just above the dorsal margin of the shell. No sexual dimorphism is displayed in purple bankclimber shell characters. Internally, there is one pseudocardinal tooth in the right valve and two in the left valve. The lateral teeth are very thick and slightly curved, with one in the right valve and two in the left valve. Nacre color is whitish near the center of the shell becoming deep purple towards the margin, and very iridescent posteriorly. Fuller and Bereza (1973) described aspects of its soft anatomy, and characterized *Elliptoideus* as being an "extremely primitive" genus.

Elliptoideus sloatianus was included in the genus *Elliptio* until Frierson (1927) erected the subgenus *Elliptoideus* based on the presence of glochidia in all four gills instead of two gills, a characteristic of the genus *Elliptio* (Ortmann 1912). Clench and Turner (1956) overlooked the work of Frierson (1927), placing the species under *Elliptio.* Subsequent investigators (e.g., Turgeon et al. 1998) have elevated the subgenus, creating the monotypic genus *Elliptoideus.* The Service recognizes *Unio sloatianus* Lea 1840, *Unio atromarginatus* Lea, 1840, *Unio aratus* Conrad, 1849, and *Unio plectophorus* Conrad, 1850, as synonyms of *Elliptoideus sloatianus*.

DISTRIBUTIONAL HISTORY AND RELATIVE ABUNDANCE

General Information

The fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, oval pigtoe, Chipola slabshell, and purple bankclimber are endemic to streams draining the Apalachicolan Region. These seven mussels, however, are all presently restricted to the eastern portion of the Apalachicolan Region (Figure 1). The fact that regional endemics are distributed either in the eastern or western portions of the Apalachicolan Region, but not both (see Gulf moccasinshell account), seems to indicate that the tri-state area of Alabama, Florida, and Georgia contains at least two distinct biogeographic regions for mussels (Brim Box and Williams 2000).

The majority of the Apalachicolan Region drains the Coastal Plain Physiographic Province. Only the uppermost portion of the ACF Basin (i.e., Chattahoochee and Flint River systems) occurs above the Fall Line in the Piedmont, and to a limited degree the Blue Ridge (i.e., Chattahoochee River), Physiographic Provinces. The Dougherty Plain, part of the Coastal Plain, is an area of karst topography that comprises the lower Flint River system extending southwest to the upper Chipola River system. The Floridan Aquifer is a shallow body of groundwater that underlies the Dougherty Plain. This area coincides with the best remaining subpopulations of the shinyrayed pocketbook, Gulf moccasinshell, oval pigtoe, and Chipola slabshell.

Brim Box and Williams (2000) delineated the historical and current distributions of six of these species. The fat threeridge and the Chipola slabshell are endemic to the ACF Basin; the shinyrayed pocketbook and the purple bankclimber are restricted to the ACF and Ochlockonee River systems; the oval pigtoe is known from Econfina Creek, and the ACF, Ochlockonee, and Suwannee River systems; and the Gulf moccasinshell is known from Econfina Creek and the ACF Basin. The Ochlockonee moccasinshell is endemic to the Ochlockonee River system (Williams and Butler 1994). Among the six ACF Basin species, at least the shinyrayed pocketbook and Gulf moccasinshell once occurred in the vicinity of Atlanta in the upper Chattahoochee River (Brim Box and Williams 2000). Otherwise, these species are primarily distributed from the lower Piedmont in the general vicinity of the Fall Line south onto the Coastal Plain. The fat threeridge, Ochlockonee moccasinshell, and Chipola slabshell are restricted to the Coastal Plain portion of the region.

The freshwater mussel fauna of the Apalachicolan Region has been the subject of relatively few zoogeographic studies (see Brim Box and Williams [2000] for a detailed history of ACF Basin mussel collections). References to Apalachicolan mussels in the 19th century were limited to numerous species descriptions and species lists, which generally had vague, if any, distributional information. Walker (1905a) published the first list of Apalachicolan mussels from two Florida sites, one on the Chipola River, the other on Moccasin Creek (Econfina Creek system, Bay County). van der Schalie (1940) reported on numerous collections of mussels in the Chipola River system, which represented the first attempt at a thorough mussel survey in the Apalachicolan Region. These collections from 1915 to 1918 were made by local residents familiar with the river who were commissioned by the distinguished malacologist, Bryant Walker, through the training, guidance, and supervision of H.H. Smith, Alabama Geological Survey (AGS). Smith collected at several other sites in the ACF Basin in the early 1900s (Brim Box and Williams 2000).

A plan by the U.S. Army Corps of Engineers (Corps) to build a major impoundment on the Apalachicola River just below the confluence of the Chattahoochee and Flint Rivers prompted a survey of mussels to be impacted by reservoir construction and at numerous other sites in the ACF Basin. This study, published by Clench and Turner (1956), also included previously unreported museum collections from streams throughout the Apalachicolan Region, and represented the first published documentation of the regional fauna. Numerous articles with distributional records and species lists of Apalachicolan Region mussels were published in the 1960s and 1970s (Athearn 1964, 1970; Johnson 1965, 1967a, 1968, 1969, 1970, 1972, 1977; Fuller and Bereza 1973). Uchee, Little Uchee, and Halawakee Creeks in the Chattahoochee River system, Alabama, were sampled in 1972 at 21 sites (Jenkinson 1973). Heard (1975) surveyed 32 sites in the eastern portion of the Apalachicolan Region and assessed the endangered status of the mussel fauna. He later generated a list of 26 mussel species inhabiting the ACF Basin (Heard 1977). Heard (1979) also published a compilation of mussels in Florida, providing the first composite species list of mussels inhabiting the State by drainage. From the 1950s to early 1990s, other investigators made collections (primarily unpublished) at numerous sites in the region (Brim Box and Williams 2000; J.D. Williams, U.S. Geological Survey [USGS] and R.S. Butler, [Service], unpublished [unpub.] data).

During the past decade or so, Apalachicolan mussel distributions have been more thoroughly explored. Butler (1989) published numerous new drainage records in the region. Williams and Butler (1994) assessed the status of imperiled Florida mussels including these seven species. Howard (1997) resurveyed Jenkinson's (1973) sites in the middle Chattahoochee River system during 1996, finding most of the stations devoid of mussels. Stringfellow and Stanton (1998) surveyed 45 sites in 5 Chattahoochee River system tributaries in the Fall Line Hills, west-central Georgia, during 1995 to 1996, but found none of the species addressed in this plan. Johnson et al. (2000) surveyed 46 sites in 12 tributary streams of the lower Flint River system on the Coastal Plain in 1999. Several new site and tributary records were reported for the shinyrayed pocketbook, Gulf moccasinshell, and oval pigtoe, while their continued occurrence at other sites was confirmed (P. Johnson, Joseph W. Jones Ecological Research Center [JERC], unpub. data). Blalock-Herod (2000) examined one site in the New River (Suwannee River drainage) to determine if one species, oval pigtoe, had experienced recent recruitment. Blalock-Herod and Williams (2001) surveyed 26 sites in the Suwannee River basin to determine if the oval pigtoe was still extant at historical sites and to attempt to locate new subpopulations.

Comprehensive surveys of the ACF Basin (Brim Box and Williams 2000) and Ochlockonee River (J.D. Williams, USGS, unpub. data) systems were conducted by researchers at the USGS lab in Gainesville, Florida, from 1991to 1993. A total of 324 ACF Basin sites and 74 Ochlockonee River system sites were sampled. Over 2,600 museum records from approximately 260 sites in the ACF Basin in Alabama, Georgia, and Florida were compiled by

Brim Box and Williams (2000), which represent a significant portion of the records reported in the distributional history tables (Tables 1 through 7). The information garnered from the ACF and Ochlockonee River systems was compiled by Butler (1993), and represented the status survey upon which these seven mussels were listed (Service 1994, 1998). These faunal studies collectively form the basis upon which the distributional history of these species are outlined.

Distributional History and Relative Abundance of the Seven Species

In compiling the vast amount of distributional information on the seven species in this section, numerous details should be explained for the reader. Footnotes have been used liberally in Tables 1 through 7 in an effort to clarify erroneous, ambiguous, or otherwise complex records in these species' long distributional histories (Clench and Turner 1956, Stringfellow and Stanton 1998, Brim Box and Williams 2000). Note that the authority for a particular occurrence is not necessarily exclusive, but that the same occurrence may have been represented by multiple authorities. For instance, most of Brim Box and Williams' (2000) museum collection references for 1954 and 1955 probably refer to collections made by Clench and Turner (1956), although the latter failed to date respective collections in their paper. Personal communications (pers. comm.) with mussel researchers active in the Apalachicolan Region have served as the authority for more recent records of these species.

Many of the museum lots published by Brim Box and Williams (2000) represent split collections, as it was common for researchers in the first half of the 20^{th} century to divide their field material between two or more institutions. Duplicate lots may also appear in the same institution, such as at the Florida Museum of Natural History, Gainesville, Florida, whose collections include material that once was housed at the Alabama Museum of Natural History, Tuscaloosa, Alabama. Therefore, large historical lot sizes stated in the following species accounts may exceed the largest individual lot sizes recorded by Brim Box and Williams (2000). When considering historical vs. current information, it should also be noted that Brim Box and Williams (2000) considered collections made pre-1990 as historical.

Records in Tables 1 through 7 are for live or fresh dead shell material unless specimens were considered to be relic or of archeological age or origin. Relic shells had nacre that lacked the luster of fresh dead specimens, and were considered dead for at least several months if not years or decades. Archeological records represent specimens collected from archeological sites or specimens that are subfossil in appearance (e.g., flaky periostracum, chalky nacre, brittle shell); such material is generally construed as having been dead centuries. In general, 1985 represented the rather arbitrary cutoff date for determining whether a species was considered extant or extirpated from a stream. Exceptions to these assumptions are to be expected with further survey data. Common and scientific names follow Turgeon et al. (1998). Brim Box and Williams (2000) include dot distribution drainage maps for the historical and current occurrences, respectively, of the six species that occur in the ACF Basin. Williams and Butler (1994) included Florida dot distribution drainage maps for all seven species.

Fat threeridge

The type locality of the fat threeridge is the Flint River, Macon County, Georgia (Table 1). Records for this species are limited to the ACF River system main stems of the Flint, Apalachicola, and Chipola Rivers in southwest Georgia and north Florida (Clench and Turner 1956, Williams and Butler 1994), all below the Fall Line (Brim Box and Williams 2000). This species has never been recorded from the Chattahoochee River, and thus is absent from Alabama. Two historical records from the Escambia River (van der Schalie 1940, Heard 1979) are considered erroneous (Williams and Butler 1994). Brim Box and Williams (2000) reported 56 historical museum collections from 21 sites in the ACF Basin.

The fat threeridge was added to a list of regionally rare mussels compiled in 1971 (Stansbery 1971). The Service (1989) made it a candidate for Federal listing in 1989. In two separate reports, Williams et al. (1993) assigned the fat threeridge mussel a status of endangered rangewide, while Williams and Butler (1994) assigned it a status of threatened in Florida.

Apparently, the fat threeridge has been extirpated from the main stem of the Flint River (and thus from Georgia), and from Dead Lake in the Chipola River. Few sites continue to harbor the fat threeridge. The fat threeridge is thought to persist only in Florida at eight scattered main stem sites on the Apalachicola River and lowermost portion of the Chipola River (Table 1).

Concerning its historical abundance, van der Schalie (1940) reported only 17 fat threeridge specimens from 2 of 25 Chipola River system sites collected from 1915 to 1918. The majority of the sampling sites he reported were in the upper half of the system where this species has never been reported. Van Hyning (1925) considered it "rare," having spent some money sent by L.S. Frierson to acquire specimens in 1918 "several times over since then in the endeavor to locate them." It took several years of effort on his part before a "nice little lot" of fat threeridge was secured from the lower Chipola River (see footnote 1, Table 1). Clench and Turner (1956) described it as being a "rather rare species [but]. . . locally abundant." They reported it common from an Apalachicola River site (56 specimens collected in 1954) now submerged in the reservoir created by Jim Woodruff Dam (Brim Box and Williams 2000). An exceptional subpopulation, reported at densities of 0.9 to 1.4 specimens per square foot along a 600+ foot stretch of shoreline, was documented by Clench and Turner (1956) from Dead Lake, a natural flow-through, lake-like section of the lower Chipola River. Several museum lots containing a total of 102 specimens dated September 3, 1954, probably refer to their collection from this subpopulation. Dead Lake was impounded in 1960 by a low-head dam (Brim Box and Williams 2000). Although the dam was removed in 1987, Dead Lake has aggraded with sediment, which may have contributed to the localized extirpation of the fat threeridge. Heard (1975) considered this species rare throughout its range and in danger of extinction, and noted its decline in the Apalachicola River from abundant to rare over a seven-year period. Eight of 56 historical collections contained 10 or more fat threeridge specimens (Brim Box and Williams 2000).

The status survey (Service 1998) produced an average of 6.4 live specimens of the fat threeridge from six sites of occurrence in the ACF Basin. Brim Box and Williams (2000) reported a subpopulation of approximately 100 specimens located on the Chipola River below Dead Lake in 1988. Relatively large subpopulations are currently known in the lower Apalachicola River, where scores of specimens could be found in the mid-1990s (J. Brim Box, USGS, pers. comm., 1994); and a distributary (a side channel whose origin is the river main stem), Swift Slough. The latter site apparently serves as a nursery; 17 specimens, 1.0 to 2.0 in (2.5 to 5.0 cm) long, were discovered in 2000 (J.D. Williams, USGS, personal. comm., 2000). Limited quadrat sampling at one main stem site (six 2.7-square feet samples) conducted by Richardson and Yokley (1996) determined the fat threeridge to be the second most abundant of four species encountered (25 percent relative abundance). Although their data are unclear, it would appear that this species occurred at a density of less than 0.4 specimens per square foot in this bed (Richardson and Yokley 1996), in what may represent the largest known subpopulation.

The Corps has completed mussel surveys at potential dredged material disposal sites (Miller 1999). As a result of these surveys, the fat threeridge comprised 23.5 percent of the fauna and were found in 20.9 percent of the samples at nine locations. At the Chipola River cutoff (nautical mile 41.6) a "dense band" of mussels, of which more than 60 percent were fat threeridge, was located.

Shinyrayed pocketbook

The shinyrayed pocketbook was described from the Chattahoochee River, Columbus, Muscogee County, Georgia. Historically, this species was widely distributed in streams in the ACF and Ochlockonee River systems in Alabama, Georgia, and Florida (Heard 1977, Williams and Butler 1994, Brim Box and Williams 2000). van der Schalie (1940), Clench and Turner (1956), and Burch (1975) erroneously reported it from the Choctawhatchee River system; their records were actually based on the closely related southern sandshell (Williams and Butler 1994). Museum collections of the shinyrayed pocketbook from the ACF Basin number 126 from 55 sites (Brim Box and Williams 2000). Numerous collections are known from the Ochlockonee River system (J.D. Williams, USGS, unpub. data) (Table 2).

The Service (1989) made the shinyrayed pocketbook a candidate for Federal listing in 1989. In separate reports, Williams et al. (1993) assigned this mussel a status of threatened rangewide, while Williams and Butler (1994) assigned it a status of special concern in Florida.

This species has apparently been extirpated from the Chattahoochee River main stem (although relic specimens were found in 1999; see Table 2) and several of its tributaries, including Mill, Little Uchee, and Cowikee Creeks. Historically, 23 collections were known from this subsystem (Brim Box and Williams 2000). Several streams in the Flint River system have also presumably lost their shinyrayed pocketbook subpopulations, including Patsiliga, Gum, Aycocks, and Dry Creeks. The shinyrayed pocketbook has apparently been extirpated in Mosquito Creek, a tributary to the Apalachicola River. In the Chipola River system, subpopulations are no longer known from Big, Cowarts, Spring (near Marianna; see footnote 6, Table 2), and Rocky Creeks. Although Brim Box and Williams (2000) reported no live specimens from the Chipola River main stem during the early 1990s status survey; Service personnel documented living shinyrayed pocketbooks at 4 Chipola River main stem sites in 2000 (J. Ziewitz, Personal Observation [pers. obs.]). The Ochlockonee River system subpopulation reported from the Little River has also apparently been extirpated (Table 2).

Uchee Creek has the last remaining subpopulation known from Alabama, while Sawhatchee Creek is the only other shinyrayed pocketbook subpopulation known from the entire Chattahoochee River system. This mussel persists in the uppermost Flint River main stem, and in Line, Whitewater, Swift, Jones, Abrams, Mill, Muckalee, Kinchafoonee, Ichawaynochaway, Chickasawhatchee, Coolewahee, and Spring Creeks. Small subpopulations are also known from the upper half of the Chipola River main stem and its tributaries Waddells Mill, Baker, and Dry Creeks. Ochlockonee River system subpopulations are known from the upper half of the main stem, the Little Ochlockonee River, and Barnetts Creek (Table 2). However, this species is extirpated from the Little River and from the lower Ochlockonee River below Talquin Dam. Overall, the shinyrayed pocketbook is thought to persist at 36 sites in seven different watersheds.

Relative subpopulation size for the shinyrayed pocketbook is generally low. van der Schalie (1940) reported a total of 94 specimens from 8 of 25 sites in the Chipola River system (average of 11.8 specimens per site of occurrence). Sizable museum collections with the same localities and dates were historically documented from several sites. These include Cowikee Creek (40 specimens collected in 1955); Cooleewahee Creek (54, 1958); two sites on the middle Chipola River (55 and 27, 1918 and 1954, respectively) (van der Schalie 1940, Brim Box and Williams 2000); and two collections from the same site on the upper Ochlockonee River (34 and 22, 1930 and 1933, respectively) (J.D. Williams, USGS, unpub. data). This species was once common in the main stems of both the Flint and Chipola Rivers (Brim Box and Williams (2000). Fourteen of the 126 historical collections from the ACF Basin reported by Brim Box and Williams (2000) contained at least 12 specimens.

An average of 2.9 live specimens of the shinyrayed pocketbook were found at each of 23 sites during the status survey (Service 1998). O'Brien and Brim Box (1999) recorded adult densities of the largest known subpopulation of the shinyrayed pocketbook (Cooleewahee Creek) to be 0.02 specimens per square foot in a bed measuring 59 x 26 feet. Densities of shinyrayed pocketbooks at four other sites where quantitative work was conducted in the Flint and Chipola Rivers yielded no more than 0.01 specimens per square foot (J. Brim Box, USGS, unpub. data). At four sites within approximately a two-mile stretch of the Chipola River, 27 shinyrayed pocketbooks were documented in 2000 (J. Ziewitz, Service, pers. obs.).

Gulf moccasinshell

The type locality for the Gulf moccasinshell was originally recorded as three sites in the ACF Basin in Georgia--the Chattahoochee River near Columbus and near Atlanta, and the Flint River near Albany (Table 3). According to Johnson (1977), Clench and Turner (1956) erroneously restricted the type locality to the first of these three localities, "Chattahoochee River, near Columbus," when actually the figured holotype was from the "Flint River, near Albany" locality (see footnote 9, Table 3). Historically, this species was known in Alabama, Georgia, and Florida from the main stems and tributaries throughout the ACF Basin and Econfina Creek (Johnson 1977, Butler 1989, Williams and Butler 1994, Brim Box and Williams 2000). Brim Box and Williams (2000) reported 93 museum collections of the Gulf moccasinshell from 52 sites in the ACF Basin.

Brim Box and Williams (2000) considered the Gulf moccasinshell to be restricted to the ACF Basin and Econfina Creek "based on zoogeographic considerations." A decade earlier, Butler (1989) stated that *Medionidus penicillatus* was the only Apalachicolan Region endemic that spanned the divide formed between the ACF Basin/Econfina Creek (east) and Choctawhatchee River (west) (but see Bogan and Hoeh 1993-94). This divide is also a well known break in the distribution of numerous fish taxa (Lee et al. 1980). The *Medionidus* recorded from the Choctawhatchee River west (Johnson 1977, Butler 1989, Williams and Butler 1994, Service 1994, 1998) is therefore Alabama moccasinshell (*Medionidus acutissimus* [Lea, 1831]) or an undescribed species (Williams et. al., in review). The Service adheres to the position of Brim Box and Williams (2000) concerning the present taxonomy and distribution of the Gulf moccasinshell.

The Gulf moccasinshell was recognized in lists of rare species published in the early 1970s (Athearn 1970, Stansbery 1971). In separate reports, Williams et al. (1993) assigned this species a status of endangered rangewide, while Williams and Butler (1994) assigned it a status of threatened in Florida.

Subpopulation losses have been substantial for the Gulf moccasinshell. The species is no longer found in the Chattahoochee River main stem (Brim Box and Williams 2000) and is now considered extirpated from Alabama (*contra* Lydeard et al. 1999). ACF Basin streams where the Gulf moccasinshell has apparently been extirpated include Mulberry, Uchee, and Little Uchee Creeks in the Chattahoochee River system; Line, Patsiliga, Turkey, Sandy Mount, Gum, Cedar, Jones, Abrams, Mill, Ichawaynochaway, and Spring Creeks, all tributaries to the Flint River; the Apalachicola River main stem; and Big, Marshall, Cowarts, Dry, Rocky, and both Spring Creeks (see footnote 16, Table 3) in the Chipola River system. This species has also been eliminated from most of the Flint and Chipola River main stems.

Generally small subpopulations of the Gulf moccasinshell persist in ACF Basin streams. These include Sawhatchee and Kirkland Creeks (Chattahoochee River system); Whitewater, Swift, Muckalee, Kinchafoonee, and Chickasawhatchee Creeks (Flint River system); single main stem localities in the Flint and Chipola Rivers; and Baker and Waddells Mill Creeks in the latter system. The Gulf moccasinshell also persists in Econfina Creek (Table 3). This mussel, overall, is found in 21 subpopulations in 6 different watersheds.

The Gulf moccasinshell once occurred in significant numbers at several sites in the ACF Basin. Sizable museum collections with the same localities and dates represented the Flint River system, including two Flint River sites (25 and 26 specimens collected in 1954), and Mill Creek (23, 1978), although collections from other ACF Basin streams appear to be smaller (Johnson

1977, Brim Box and Williams 2000). van der Schalie (1940) reported 166 specimens from 11 of 25 sites (average of 15.1 per site of occurrence) in the Chipola River system. Large subpopulations were noted at sites in Cowarts (67 specimens collected in 1916), and Spring (see footnote 16) (63, 1915 to 1918) Creeks. Sizable historical collections were also reported by Brim Box and Williams (2000) from two Chipola River sites (46 and 21, 1954), and Marshall Creek (23 and 26, 1954 and date unknown, respectively). Heard (1975) considered it to be rare throughout its range and in danger of extinction. Fifteen of the 93 historical museum collections reported by Brim Box and Williams (2000) contained a dozen or more specimens of this species.

During the status surveys, an average of 1.4 Gulf moccasinshell specimens was found per site of occurrence (eight sites), although new and larger subpopulations were subsequently discovered (Service 1998). The subpopulation in Waddells Mill Creek, where dozens of specimens can be found, is thought to be the largest remaining (D.N. Shelton, Alabama Malacological Research Center [AMRC], pers. comm., 1998). Recent quantitative sampling using sieves from 50 quadrat samples (2.7 square feet each) in Chickasawhatchee Creek recorded a density of 0.044 specimens per square foot of substrate (R.S. Butler, unpub. data).

Ochlockonee moccasinshell

The Ochlockonee moccasinshell was described from the Ochlockonee River, Calvary, Grady County, Georgia (Table 4). This Ochlockonee River system endemic mussel was known historically from the main stem in Georgia and Florida, and the Little River (Johnson 1977, Butler 1993, Williams and Butler 1994). Williams et al. (1993) assigned the Ochlockonee moccasinshell a status of endangered rangewide. In Florida, Williams and Butler (1994) assigned it a status of endangered.

Museum records for the Ochlockonee moccasinshell indicate that it was historically common, including two Ochlockonee River sites (21 and 24 specimens collected twice from a single site in the early 1930s, 19 from another collected in 1969) (J.D. Williams, USGS, unpub. data). Even as late as the early 1970s this species was found in some numbers above Talquin Reservoir, Florida (W.H. Heard, Florida State University [FSU], pers. comm., 1994). This species may now be the rarest mussel currently inhabiting the Apalachicolan Region and is one of the rarest mussels nationwide. Only three live specimens are known to have been collected since 1974 despite concerted efforts by numerous investigators (J.D. Williams, USGS, unpub. data). The most recent live specimen was collected during the status survey in 1 of 4 hand-picked 97-square foot quadrats (J. Brim Box, USGS, unpub. data). Currently, the species persists in only a relatively short reach of the Ochlockonee River above Talquin Reservoir (Table 4).

Oval pigtoe

The oval pigtoe was described from the Chattahoochee River, near Columbus, Muscogee County, Georgia (Table 5). This species historically occurred in four major stream systems in

Alabama, Georgia, and Florida: Econfina, ACF, Ochlockonee, and Suwannee, (Brim Box and Williams 2000). Brim Box and Williams (2000) reported 96 historical records from 57 localities in the ACF Basin. Blalock-Herod and Williams (2001) found records from 11 localities in the Suwannee River basin. Dozens of other records are known from sites in the other two stream systems within its range (J.D. Williams, USGS, unpub. data).

The oval pigtoe was recognized in lists of rare species published in the early 1970s (Athearn 1970, Stansbery 1971). Stansbery (1976) considered it threatened in Alabama. Williams et al. (1993) assigned the oval pigtoe a status of endangered rangewide. Williams and Butler (1994), restricted the oval pigtoe to the ACF Basin, assigned it a status of threatened in Florida (*contra* Brim Box and Williams 2000). They split *Pleurobema reclusum*, the Florida pigtoe (Ochlockonee and Suwannee River systems subpopulations), from the oval pigtoe and assigned the Florida pigtoe a status of special concern in Florida (see "Species Descriptions and Taxonomy").

All four stream systems still harbor the oval pigtoe, but numerous subpopulations have been lost. Stream extirpations in the ACF Basin are thought to include the Chattahoochee River main stem and three tributaries, Randall, Uchee, and Little Uchee Creeks; most of the Flint River main stem and its tributaries Patsiliga, Little Patsiliga, Sandy Mount, Gum, Cedar, Chokee, Abrams, Mill, Little Pachitla, and Dry Creeks; the Apalachicola River main stem; and several Chipola River tributaries including both Spring (see footnote 28, Table 5), Rocky (Houston County, Alabama), Marshall, Big, and Cowarts Creeks. The oval pigtoe is probably extirpated from Alabama (*contra* Lydeard et al. 1999). The oval pigtoe was recently found extant at only three sites within Suwannee River drainage, two in the New River, and one in the Santa Fe River (Blalock-Herod and Williams 2001). This species is no longer known from the Suwannee River main stem and the Sampson River (Table 5) and its range is greatly reduced in the Santa Fe River (Blalock-Herod and Williams 2001).

The oval pigtoe is currently known from Econfina Creek; Sawhatchee Creek (the only Chattahoochee River system locality remaining); Flint River, Decatur County, Georgia; the upper-most main stem of the Flint River and its tributaries Line, Red Oak, Turkey, Swift, Jones, Muckalee, Kinchafoonee, Cooleewahee, Chickasawhatchee, and Spring Creeks; the upper Chipola River main stem, and Baker, Waddells Mill, Dry, and Rocky (Jackson County, Florida) Creeks; the upper Ochlockonee River main stem and Barnetts Creek; and the New and Santa Fe Rivers in the Suwannee River system (Table 5). This wide ranging mussel presently persists in a 36 subpopulations, overall.

Clench and Turner (1956) document the oval pigtoe as being "relatively rare...perhaps only locally abundant." According to van der Schalie (1940), the 9 of 25 sites in the Chipola River system from which this species was collected from 1915 to 1918 produced a total of 470 specimens (average of 52.2 per site of occurrence). A subpopulation considered extirpated in Cowarts Creek, Alabama, yielded 295 specimens of oval pigtoe (van der Schalie 1940). Other large museum collections representing single sites and dates include Rocky Creek, Chipola River system, Alabama (64 specimens collected in 1916); Jones (44, 1933) and Mill (25, 1933)

Creeks in the Flint River system (Brim Box and Williams 2000); and the Ochlockonee River system (68, 1933); New (129, 1974); and Santa Fe (Suwannee River basin) (127, 1916) Rivers (J.D. Williams, USGS, unpub. data). Heard (1975) considered it rare but widespread in the ACF Basin. Twenty-one of the 96 historical collections reported by Brim Box and Williams (2000) contained at least 12 specimens.

Nearly all known subpopulations are presently comprised of relatively small numbers of oval pigtoe, with the exceptions of sites on the Chipola River and Chickasawhatchee Creek (Brim Box and Williams 2000). Rangewide, an average of 5.2 specimens per site of occurrence (24 sites) were recorded during the status survey (Service 1998). More recent quantitative sampling using sieves at two sites (Chickasawhatchee Creek, 50 samples 2.7-square feet each; and New River, 75 samples 2.7-square feet each) found 8 specimens in Chickasawhatchee Creek and 3 in New River for densities of 0.059 and 0.015 per square feet of substrate, respectively (R.S. Butler, unpub. data). Blalock-Herod (2000) reported an overall density of 0.003 per square foot (15 specimens in 2,000 samples 2.7-square feet each) in sieved samples and found no recruitment at a study site on the New River (Suwannee River drainage). Only one specimen was detected after searching for two hours at another site on the New River (Blalock-Herod and Williams 2001).

Chipola slabshell

The type locality is Chipola River, Marianna, Jackson County, Florida (Table 6). The Chipola slabshell was thought to be endemic to the Chipola River system (van der Schalie 1940, Clench and Turner 1956, Burch 1975, Heard 1979, Williams and Butler 1994) until Brim Box and Williams (2000) located a museum lot (single specimen) from Howards Mill Creek, a Chattahoochee River tributary in southeastern Alabama. The historical range of this ACF Basin endemic is centered throughout much of the Chipola River main stem and several of its headwater tributaries. The Chipola slabshell is one of the most narrowly distributed species in the Apalachicolan Region. Brim Box and Williams (2000) located 37 historical museum collections from 17 sites. Williams et al. (1993) assigned the Chipola slabshell a status of threatened rangewide. Williams and Butler (1994), who erroneously considered it endemic to Florida, also assigned it a status of threatened.

The Chipola slabshell is no longer known from Howards Mill Creek. Likewise, this species is probably extirpated from Dead Lake on the lower main stem of the Chipola and in two Chipola River tributaries, Cowarts and Spring (see footnote 30, Table 6) creeks, and thus is considered extirpated from Alabama (Lydeard et al. 1999). Currently, 6 subpopulations of Chipola slabshell remain in Marshall and Dry Creeks, and from the upper two-thirds of the Chipola River main stem (Table 6). The largest remaining subpopulation appears to be on the Chipola River main stem in the vicinity of (but not in) Dead Lake, where the species remains relatively common (J.D. Williams, USGS, unpub. data).

Relative abundance of this species has always been low for the Chipola slabshell. Clench and Turner (1956) considered it to be "rather rare, though it does occur throughout most of the length of the river proper and its smaller tributaries." van der Schalie (1940) reported 31 specimens of this species from 6 of 25 sites (average of 5.2 per site of occurrence). The largest museum collections with the same localities and dates were from Cowarts Creek, Houston County, Alabama (28 specimens collected in 1916) and Chipola River (22, 1954). The former record represents the only occurrence of the Chipola slabshell from the Alabama portion of the Chipola River system (Brim Box and Williams 2000), and was apparently overlooked by van der Schalie (1940). Heard (1975) reported this species as being relatively uncommon but that it could be locally abundant. An average of 3.7 Chipola slabshell specimens per site of occurrence (3 sites) were found during the status survey (Service 1998).

Purple bankclimber

The type locality of the purple bankclimber was restricted to the Chattahoochee River, Columbus, Georgia, by Clench and Turner (1956) (Table 7). This large species is virtually restricted to ACF Basin main stems and the Ochlockonee River in Florida and Georgia (Clench and Turner 1956, Williams and Butler 1994, Brim Box and Williams 2000). Generally distributed in the Flint, Apalachicola, and Ochlockonee Rivers, it was also known from the lower halves of the Chattahoochee and Chipola Rivers, and from two tributaries in the Flint River system. Heard (1979) erroneously reported it from the Escambia River system (Williams and Butler 1994). Brim Box and Williams (2000) located 68 historical museum collections from 25 sites in the ACF Basin alone. Fossil material is also known from the Suwannee River main stem and the Hillsborough Bay system in peninsular Florida (Brim Box and Williams 2000, Bogan and Portell 1995). The latter site has been dated from the early Pleistocene (Bogan and Portell 1995).

The purple bankclimber was recognized in lists of rare species published in the early 1970s (Athearn 1970, Stansbery 1971). Williams et al. (1993) assigned this species a status of threatened rangewide, while Williams and Butler (1994) assigned it a status of threatened in Florida.

Subpopulations from the Chattahoochee River have apparently been extirpated save for a single live specimen found in 2000 (L. Andrews, Service, pers. comm., 2000). In addition, it is no longer known from Line and Ichawaynochaway Creeks, and has not been seen live in the Chipola River since 1988. Within portions of the Flint and Ochlockonee Rivers, the purple bankclimber occurs more sporadically than it did historically. Most occurrences in the Ochlockonee River are above Talquin Reservoir. An anomalous small stream occurrence (a single specimen from an unnamed tributary of Mill Creek, Flint River system) was discovered during the status survey (Table 7) (Service 1998). Overall, 30 subpopulations of purple bankclimber currently persist.

van der Schalie (1940) did not record it from the Chipola River, but the 1915-18 collections he based his survey on canvassed the upper portion of the system more thoroughly than the lower main stem. The purple bankclimber was noted as being a "relatively rare species" by Clench and Turner (1956). Heard (1975) considered this species to be common in the Apalachicola

River in the 1960s, but that population sizes by the mid-1970s, particularly below Jim Woodruff Dam, had been "drastically reduced." Based on museum records, however, this species was relatively common in the lower Flint, upper Apalachicola, and upper Ochlockonee Rivers (Brim Box and Williams 2000; J.D. Williams, USGS, unpub. data). The largest museum collections with the same localities and dates were from the upper Apalachicola River (36 specimens collected in 1954) and lower Flint River (17, 1954). Since this is a very large species, museum collections may have under represented its abundance at certain sites where it was common as large numbers of specimens pose a logistical problem in processing and storage.

During the status survey, an average of 54 specimens of the purple bankclimber was recorded from 41 sites rangewide (Service 1998), 30 sites occurring in the ACF Basin (Brim Box and Williams 2000). Limited quantitative sampling for the purple bankclimber has been conducted in the upper Apalachicola and Ochlockonee Rivers. Six 2.7-square feet quadrat samples taken below Jim Woodruff Dam on the former river revealed approximately one specimen per square foot of substrate when sieved (Richardson and Yokley 1996). Four 97-square foot quadrat hand-picked samples in the Ochlockonee River in 1993 recorded purple bankclimber densities averaging 0.34 per square foot (J. Brim Box, USGS, unpub. data).

HABITAT

General Information

Adult mussels are ideally found in localized patches (beds) in streams and almost completely burrowed in the substrate with only the area around the siphons exposed (Balfour and Smock 1995). The composition and abundance of mussels are directly linked to bed sediment distributions (Neves and Widlak 1987, Leff et al. 1990). Physical qualities of the sediments (e.g., texture, particle size) may be important in allowing the mussels to firmly burrow in the substrate (Lewis and Riebel 1984). These and other aspects of substrate composition, including bulk density (mass/volume), porosity (ratio of void space to volume), sediment sorting, and the percentage of fine sediments, may also influence mussel densities (Brim Box 1999, Brim Box and Mossa 1999). Water velocity may be a better predictor than substrate for determining where certain mussel species are found in streams (Huehner 1987). In general, heavy-shelled species occur in stream channels with currents, while thin-shelled species occur in more backwater areas.

Stream geomorphic and substrate stability is especially crucial for the maintenance of diverse, viable mussel beds (Vannote and Minshall 1982, Hartfield 1993, Di Maio and Corkum 1995). Where substrates are unstable, conditions are generally poor for mussel habitation. See "Past and Present Threats" for a detailed discussion on how various activities cause channel instabilities that result in substrate conditions that are not conducive to mussels. Although several studies have related adult habitat selection with substrate composition, most species tend to be habitat generalists (Tevesz and McCall 1979, Strayer 1981, Hove and Neves 1994, Strayer and Ralley 1993), with few exceptions (Stansbery 1966).

Habitat and stream parameter preferences for juveniles are largely unknown (Neves and Widlak 1987). This is possibly due to a prevalent lack of evidence of recruitment, inadequate sampling methods, or reproductive failure (Coon et al. 1977; Strayer 1981; Moore 1995; McMurray et al. 1999a, b). Isley (1911) stated that juveniles may prefer habitats that have sufficient oxygen, are frequented by fish, and are free of shifting sand and silt accumulation. Neves and Widlak (1987) suggested that juveniles inhabit depositional areas with low flow, where they can feed pedally (see "Food Habits") and siphon water from interstitial spaces among substrate particles (Yeager et al. 1994). Juvenile mussels of certain species stabilize themselves by attaching to rocks and other hard substrates with a byssus (protein threads) (Frierson 1905, Isley 1911, Howard 1922).

Strayer (1999a) demonstrated in field trials that mussels in streams occur chiefly in flow refuges, or relatively stable areas that displayed little movement of particles during flood events. Flow refuges conceivably allow relatively immobile mussels to remain in the same general location throughout their entire lives. He thought that features commonly used in the past to explain the spatial patchiness of mussels (e.g., water depth, current speed, sediment grain size) were poor predictors of where mussels actually occur in streams.

Neves and Widlak (1987) summarized stream parameter preferences of habitat, substrate, current velocity, and presence of other bivalves for juvenile unionids. Initially, juveniles were clumped in runs and riffles, occurred primarily behind boulders, and were significantly correlated with fingernail clam presence. They surmised that the habitat of older juveniles (i.e., ages 2 and 3 years) was similar to that of adults. Nevertheless, it remains unknown if juveniles of most species experience differential survival rates among different habitat parameters, if they remain in the habitat of the host fish, or if they exhibit any habitat preference (Neves and Widlak 1987).

Williams and Butler (1994) examined descriptive habitat parameter preferences including stream size, substrate, and current velocity for the seven mussels in this recovery plan. In compiling their status survey, Brim Box and Williams (2000) and Blalock-Herod (2000) included more specific information on habitat, particularly substrate, preferences for all but the Ochlockonee moccasinshell. Following is a summary of this information.

Fat threeridge

The fat threeridge inhabits the main channel of small to large rivers in slow to moderate current. Substrate used by this mussel varies from gravel to cobble to a mixture of sand and sandy mud (Williams and Butler 1994). Brim Box and Williams (2000) found 60 percent of the specimens were located in a sandy silt substrate.

Shinyrayed pocketbook

The shinyrayed pocketbook inhabits medium-sized creeks to rivers in clean or silty sand substrates in slow to moderate current (Williams and Butler 1994). Specimens are often found in the interface of stream channel and sloping bank habitats, where sediment particle size and current strength are transitional. Clench and Turner (1956) noted it preferred small creeks and spring-fed rivers. During the status survey in the ACF Basin, 45 percent of the specimens were found in a sand/rock substrate, while 38 percent were associated with a predominance of sand/clay or sandy substrates (Brim Box and Williams 2000).

Gulf moccasinshell

The Gulf moccasinshell inhabits the channels of medium-sized creeks to large rivers with sand and gravel or silty sand substrates in slow to moderate currents (Williams and Butler 1994). Approximately 46 percent of the ACF Basin specimens located during the Basin's status survey were in a substrate of sand/rock (Brim Box and Williams 2000).

Ochlockonee moccasinshell

The Ochlockonee moccasinshell inhabits large creeks and the Ochlockonee River main stem in areas with current. Typical substrates are sand with some gravel (Williams and Butler 1994).

Oval pigtoe

The oval pigtoe occurs in medium-sized creeks to small rivers where it inhabits silty sand to sand and gravel substrates, usually in slow to moderate current (Williams and Butler 1994). Stream channels appear to offer the best habitat for this species. The ACF Basin status survey located 85 percent of the specimens in sandy substrates associated with either detritus, or clay, or silt, or cobble (Brim Box and Williams 2000). In the Suwannee River drainage, specimens of the oval pigtoe were associated with sandy mud and coarse sand sediments with little to no detritus (Blalock-Herod 2000).

Chipola slabshell

The Chipola slabshell inhabits silty sand substrates of large creeks and the main channel of the Chipola River in slow to moderate current (Williams and Butler 1994). Specimens are generally found in sloping bank habitats. Nearly 70 percent of the specimens found during the status survey were associated with a sandy substrate (Brim Box and Williams 2000).

Purple bankclimber

The purple bankclimber inhabits small to large river channels in slow to moderate current over sand or sand mixed with mud or gravel substrates (Williams and Butler 1994). Over 80 percent of the specimens located during the ACF Basin portion of the status survey were found at sites with a substrate of sand/limestone (Brim Box and Williams 2000). ACF Basin collections were often in waters over 10 feet in depth.

LIFE HISTORY

Food Habits

Adult freshwater mussels are filter-feeders, orienting themselves in the substrate to facilitate siphoning of the water column for oxygen and food (Kraemer 1979). Mussels have been reported to consume detritus, diatoms, phytoplankton, zooplankton, and other microorganisms (Coker et al. 1921, Churchill and Lewis 1924, Fuller 1974). According to Ukeles (1971), phytoplankton is the principal food of bivalves. However, other food sources (e.g., bacteria, organic detritus, assimilated organic material, phagotrophic protozoans) may also play an important role (Neves et al. 1996). Churchill (1916) concluded that mussels could absorb various sources of fat, protein, and starch dissolved in the water. According to Baldwin and Newell (1991), bivalves feed on an entire array of naturally available particles (e.g., heterotrophic bacteria, phagotrophic protozoans, phytoplankton). Based on the findings of studies such as Baldwin and Newell (1991) and Neves et al. (1996), an omnivorous opportunistic diet would allow mussels to take advantage of whatever food type happens to be abundant.

Juvenile mussels employ foot (pedal) feeding, and are thus suspension feeders (Yeager et al. 1994). Video observations of rainbow mussel (*Villosa iris* [Lea, 1829]) by Yeager et al. (1994) revealed juveniles occupy the top 0.4 in (1.0 cm) of sediment and employed two types of feeding mechanisms: 1) collecting organic and inorganic particles that adhere to the foot and conveying them to the pedal valve gape with sweeping motions; and 2) extending the foot anteriorly pulling themselves along while picking up organic and inorganic particles on the foot. These methods of suspension feeding have been termed pedal sweep feeding and pedal locomotory feeding, respectively (Reid et al. 1992).

Foods of juveniles up to two weeks old include bacteria, algae, and diatoms with amounts of detrital and inorganic colloidal particles (Yeager et al. 1994). In juvenile freshwater mussel feeding experiments, Neves et al. (1996) found that algae was a suitable food and Gatenby et al. (1997) determined that a tri-algal (three algae species) diet high in lipids mixed with fine sediment resulted in better growth. Silt provided some nutritional value, which was also observed by Hudson and Isom (1984), but bacteria in riverine sediments was not essential to growth and survival (Neves et al. 1996).

Growth and Longevity

Growth rates for freshwater mussels tend to be relatively rapid for the first few years (Chamberlain 1931, Scruggs 1960, Negus 1966), then slows appreciably (Bruenderman and Neves 1993, Hove and Neves 1994). The relatively abrupt slowing in growth rate occurs at sexual maturity, probably due to energies being diverted from growth to gamete production. Growth rates vary among species; heavy-shelled species grow slowly relative to thin-shelled species (Coon et al. 1977, Hove and Neves 1994). Under shoal habitat conditions, where high water velocities in river shallows are characterized by increased oxygen levels and food availability per unit time, growth rates are probably higher (Bruenderman and Neves 1993).

As a group, mussels are extremely long-lived, with maximum life spans of 100 to 200 years for certain species (Neves and Moyer 1988, Bauer 1992, Mutvei et al. 1994). Heavy-shelled species, which include many riverine forms, tend to reach higher maximum ages (Stansbery 1961). No age specific information is available for these seven species. However, some Virginia subpopulations of Cumberland moccasinshell (*Medionidus conradicus*) and Tennessee clubshell (*Pleurobema oviforme* (species related to those considered in this recovery plan)) were found to have individuals up to 24 and 56 years old, respectively (Moyer and Neves 1984).

Multiple age classes within a subpopulations are necessary to ensure adequate densities of mature adults are present to produce enough recruitment to maintain a stable population. Haag and Warren (2003) found that in a stable mussel subpopulations in the Tallahatchie River, Mississippi and Sipsey River, Alabama, new recruits comprised an average of 11 percent of the subpopulation. Using stochastic stage-based matrix population models, Haag and Warren (2003) estimated that to maintain a stable or increasing subpopulation minimum mean annual recruitment must be greater than 5 to 12 percent depending on species.

General Reproductive Biology

Following is a summary of freshwater mussel reproduction (see Watters [1994] for an annotated bibliography of mussel reproduction). Freshwater mussels generally have separate sexes, although hermaphroditism is known for some species (van der Schalie 1970, Downing et al. 1989). The age of sexual maturity for mussels is variable, usually requiring from three (Zale and Neves 1982) to nine (Smith 1979) years, and may be sex dependent (Smith 1979). Males expel clouds of sperm into the water column, although some species expel spermatozeugmata (sperm balls), which are comprised of thousands of sperm (Barnhart and Roberts 1997). Females draw in sperm with the incurrent water flow. Fertilization takes place in the suprabranchial chamber of the female, and the resulting zygotes develop into specialized parasitic larvae, termed glochidia, in water tubes of the gills.

Three subfamilies are generally recognized within the family Unionidae (Ortmann 1919, Parmalee and Bogan 1998): Unioninae (or Ambleminae) (e.g., *Amblema*, *Elliptio*, *Elliptoideus*, *Pleurobema*); Anodontinae (e.g., *Alasmidonta*, *Pyganodon*); and Lampsilinae (e.g., *Lampsilis*, *Medionidus*). Depending upon the subfamily, all four gills (Unioninae), the entire outer pair of gills (Anodontinae, some Unioninae), or discreet portions of the outer pair of gills (Lampsilinae), are used as marsupia or brood chambers for glochidia, although Heard and Guckert (1970) argue that some unionines (e.g., *Elliptio*, *Pleurobema*) that use only the outer gills as marsupia may warrant a fourth subfamily, the Pleurobeminae. Spawning appears to be temperature dependent (Zale and Neves 1982, Bruenderman and Neves 1993), but may also be influenced by stream discharge (Hove and Neves 1994). Fertilization rates are dependent on spatial aggregation of reproductive adults (Downing et al. 1993).

Mussels are generally categorized as either short-term summer brooders (tachytictic) or long-term winter brooders (bradytictic) (Neves and Widlak 1988). Tachytictic species have a spring fertilization period, then the glochidia are incubated for a few months and expelled during the summer or early fall. Bradytictic species have a late summer or early fall fertilization period with the glochidia incubating overwinter, and expelled the following spring or early summer.

The fact that some species have glochidia that overwinter on hosts (see "Reproductive Biology of the Seven Species") indicates that they do not clearly fall into either the tachytictic or bradytictic reproductive strategy. This has led Watters and O'Dee (2000) to believe that glochidial release is more a function of water temperature. They have coined new terms to better coincide with actual reproductive strategies of mussels. Winter releasers expel glochidia when water temperatures dip below a threshold level, while summer releasers expel glochidia when water temperatures rise above a threshold level. The reproductive strategy where glochidia have been released in the autumn or winter to parasitize hosts (winter releasers) is termed host overwintering. This is in contrast with the strategy of parent overwintering, whose species are summer releasers. Although parent overwintering is typically associated with bradyticty, species that are strictly tachytictic may also be summer releasers (Watters and O'Dee 2000).

After a variable incubation period, mature glochidia, which may number in the tens of thousands to several million (Surber 1912, Coker et al. 1921, Yeager and Neves 1986), are expelled into the water column. The temporal release of glochidia is thought to be behavioral rather than developmental (Gordon and Layzer 1993). Glochidia must come into contact with specific species of fish whose gills and fins they temporarily parasitize, although two species have been shown to possibly utilize amphibian hosts (Howard 1915, 1951; Watters 1997a). Some mussel species, such as (green floater (*Lasmigona subviridis* [Conrad, 1835]), squawfoot (*Strophitus undulatus* [Say, 1817]), and paper pondshell (*Utterbackia imbecillis* [Say, 1829]) may not require a host fish to complete their life cycle (Lefevre and Curtis 1912, Howard 1914; G.T. Watters, Ohio Biological Survey, pers. comm., 1998). Glochidia failing to come into contact with a suitable host will drift through the water column, surviving for only a few days at most (Sylvester et al. 1984, Neves and Widlak 1988, Jansen 1990, O'Brien and Williams in press).

Glochidia are generally released individually in net-like mucoid strands that entangles fish (Haag and Warren 1997), or as discreet packets termed conglutinates, which represent all the glochidial contents (and sometimes eggs) of a single water tube packaged in a mucilaginous capsule (Ortmann 1910, 1911). A newly described method, termed a "superconglutinate" by Williams and Butler (1994), involves the expulsion of the sum of the conglutinates from discreet portions of both outer gills that are packaged in a single glochidial mass (Haag et al. 1995, Hartfield and Butler 1997, O'Brien and Brim Box 1999).

Each of the three basic methods of glochidial expulsion and glochidial shape facilitates attachment to specific host fish and to specific fish structures (fin vs. gill), respectively (Lefevre and Curtis 1910, 1912). Although supported by field observations (Lefevre and Curtis 1912, Neves and Widlak 1988), the fish structure parasitized may in some cases be due to fish behavior rather than morphology (Gordon and Layzer 1989). Species in the subfamily Anodontinae are generally bradytictic (Zale and Neves 1982), broadcasting masses of hooked glochidia in net-like mucoid strands (Haag and Warren 1997), that generally parasitize the fins of fishes (Clarke 1981, Haag and Warren 1997).

Species in the subfamily Unioninae are generally tachytictic and package their glochidia in a conglutinate, which are expelled out of the excurrent aperture (Neves and Widlak 1988). Conglutinates often resemble colorful fish prey items (e.g., worms, insect larvae, fish fry) (Chamberlain 1934, Luo 1993, Hartfield and Hartfield 1996), and researchers have demonstrated that conglutinates are actively foraged by fish (Ortmann 1911, Neves and Widlak 1988, Weiss and Layzer 1995, Haag and Warren 1997). Unionine glochidia are hookless and generally parasitize gills (Neves et al. 1985).

The Lampsilinae are generally bradytictic (Zale and Neves 1982), they utilize discreet portions of the outer pair of gills as marsupia (Ortmann 1911), and employ two methods of glochidial release. Lampsilines that have mantle modifications (e.g., *Lampsilis*, *Medionidus*) to attract fish generally do not release conglutinates, rather they expel loose masses of glochidia out openings in the ends of the water tubes (Ortmann 1910, Neves and Widlak 1988, Richard et al. 1991). Mantle modifications include flaps or villi (elongate papilla-like structures) exhibiting bright colors, rhythmic movements, and/or actual mimicry of fish prey items (e.g., worms, insect larvae, fish fry complete with eyespot) that serve to attract host fish (Ortmann 1911, Coker et al. 1921, Chamberlain 1934, Kraemer 1970, Zale and Neves 1982, Hartfield and Hartfield 1996, Barnhart and Roberts 1997). The swollen marsupialized gills are often extruded well beyond the edge of the shell margins between the mantle “lures” (Kraemer and Swanson 1985). Light sensitive areas on the mantle may be stimulated by the shadow of a passing fish (Kraemer 1970, Jansen 1990, Weiss and Layzer 1995). When the mantle lure is attacked by a fish, a cloud of hookless glochidia is released into the buccal cavity, thus facilitating gill infestation. Lampsilines that lack mantle modifications (e.g., *Ptychobranchus*, *Obliquaria*, *Cyprogenia*) expel their glochidia as conglutinates as do the Unionines as outlined above.

A small group of lampsilines expel superconglutinates (Haag et al. 1995, Hartfield and Butler 1997; Blalock-Herod et al., 2002), and includes the shinyrayed pocketbook (O’Brien and Brim Box 1999). The superconglutinate, which is tethered by a secreted, transparent mucilaginous strand that may reach eight feet in length, resembles a fish in size, shape, and coloration, complete with stripes and eyespot. The length of the modified conglutinate ranges from 0.6 to 1.2 in (1.5 to 3.0 cm). During the production of the superconglutinate, the water currents move the fish mimic in motions that are similar to a small fish (Haag et al. 1995, Hartfield and Butler 1997). Once detached from the female, the fate of the superconglutinate depends on the chance that the current will wrap it around a rock, branch, or any structure in the stream where it will continue to mimic prey for a piscivorous host fish (Haag et al. 1995).

As few as 1 to as many as 25 fish species are known to serve as suitable hosts for particular species of mussels (Fuller 1974, Trdan and Hoeh 1982, Gordon and Layzer 1989, Hoggarth 1992). Host specificity appears to be common in mussels (Neves 1993), with most species utilizing only a few host fishes (Lefevre and Curtis 1912, Zale and Neves 1982, Yeager and Saylor 1995). Research on these seven species seems to corroborate this assertion (see "Reproductive Biology of the Seven Species").

There are two types of fish immunity to glochidial infestation: natural and acquired (Watters and O'Dee 1996). Natural immunity is believed to be a tissue response (Bauer and Vogel 1987), where attempts to parasitize non-host fish will result in rejection and glochidial death by the host's immune system, usually within 11 days (Neves et al. 1985, Yeager and Neves 1986, Waller and Mitchell 1989). However, chemically induced metamorphosis (which may prove to be a useful artificial propagation tool in cases where the host fish is not known) has been accomplished in certain species (Kirk and Layzer 1997). In the case of acquired immunity, even a suitable host fish will display decreased transformation rates with subsequent infections (Arey 1932, Bauer and Vogel 1987, Luo 1993). The number of exposures needed to initiate glochidial sloughing is highly variable (Watters and O'Dee 1996).

The parasitic stage generally lasts a few weeks (Neves et al. 1985, O'Brien and Williams in press), but possibly much longer (Yeager and Saylor 1995, Haag and Warren 1997), and is temperature dependent (Watters and O'Dee 2000). After dropping from fish hosts, newly metamorphosed juveniles passively drift with currents and ultimately settle in depositional areas with other suspended solids (Neves and Widlak 1987, Yeager et al. 1994). Juveniles must, however, come into contact with suitable habitat to begin their free-living existence (Howard 1922). Survival rates for a glochidium to metamorphosis ranges from 0.000001 to 0.0001 percent, not factoring in predation after metamorphosis (Watters and Dunn 1993-94).

Glochidial parasitism serves as a means of dispersal for this relatively sedentary group (Neves 1993). The intimate relationship between mussels and their host fish has therefore played a major role in mussel distributions on both a geographic (Watters 1992) and community (Haag and Warren 1998) scale. Haag and Warren (1998) determined that mussel community composition was more a function of fish community pattern variability than of microhabitat variability, and that the type of strategy used by mussels for infecting host fishes was the determining factor. Host-generalist mussels without elaborate host-attracting mechanisms (e.g., anodontines) and host-specialized mussels with elaborate host-attracting mechanisms (e.g., lampsilines) were independent of host-fish densities. Conversely, host-specialist mussels without elaborate host-attractant mechanisms (e.g., unionines) were dependent on densities of host fishes. Stable numbers of hosts therefore appear to be critical for determining where unionines (e.g., fat threeridge, oval pigtoe, Chipola slabshell, purple bankclimber) are able to persist (Haag and Warren 1998).

Knowledge about the reproductive biology of many freshwater mussels remains incomplete (Jansen 1990). For example, according to Watters (1994), host fish for only 25 percent of the 300 mussel species in North America have been identified, although subsequent studies are gradually expanding that number (e.g., Luo 1993, Weiss and Layzer 1995, Yeager and Saylor 1995, Haag and Warren 1997, Howells 1997, Keller and Ruessler 1997, Roe and Hartfield 1997, O'Dee and Watters 2000). Host fish information is lacking most in the Southeast where over 90 percent of the freshwater mussel species occur (Neves et al. 1997).

Reproductive Biology of the Seven Species

Fat threeridge

O'Brien and Williams (2002) studied various aspects of the life history of the fat threeridge. A tachytictic species, it appears to be gravid in Florida when water temperatures reached 75.2°F, in late May and June. This release period would suggest that this species is a summer releaser. Unlike most unionines, fat threeridge glochidia are released in a white, sticky, web-like mass, which expands and wraps around a fish, thus facilitating attachment. Viability is maintained for two days after release (O'Brien and Williams 2002). The glochidia were described and figured by O'Brien and Williams (2002).

Five potential host fishes were identified: weed shiner (*Notropis texanus*), bluegill (*Lepomis macrochirus*), redear sunfish (*L. microlophus*), largemouth bass (*Micropterus salmoides*), and blackbanded darter (*Percina nigrofasciata*). Transformation of the glochidia on host fishes required 10 to 14 days at 73.4 ± 2.7°F (O'Brien and Williams 2002).

Shinyrayed pocketbook

O'Brien and Brim Box (1999) summarized the reproductive biology of the shinyrayed pocketbook. This species is one of four lampsiline species known to produce a superconglutinate to attract potential fish hosts. Gravid females are found from December through August and superconglutinates are released from late May to early July at water temperatures of 71.6 to 74.3°F. Although apparently mature glochidia are present in the marsupia after the end of the superconglutinate "season," they could not get them to transform during a single test trial with largemouth bass (see below). They suggested that nearly an entire year is needed by the incubating glochidia to reach full maturity. This indicates that the shinyrayed pocketbook is a parent overwintering, summer releasing species. They also described and figured glochidial morphology.

Primary host fishes for the shinyrayed pocketbook based on their laboratory infections appear to be largemouth bass and spotted bass (*Micropterus punctulatus*) (100 percent transformation rates on fishes tested), although transformations also occurred in low percentages on eastern mosquitofish (*Gambusia holbrooki*), bluegill, and the nonindigenous guppy (*Poecilia reticulata*) that were tested. Glochidia metamorphosed in 11 to 16 days on the basses at a temperature of 72.5 ± 4.5°F.

Gulf moccasinshell

Gulf moccasinshell glochidia are released in early to late spring, while gravid females were found in March, April, September, and November (O'Brien and Williams 2002). The presence of gravid specimens of this lampsiline species in late summer and fall months suggests that the Gulf moccasinshell is a parent overwintering, summer releasing species. Gravid specimens were observed lying upside down (i.e., umbos down) on top of gravel and sand substrates in mid-March and flapping their mantle margins (Brim-Box and Williams 2000). This host-attractant behavior has been noted in the Alabama moccasinshell (*M. acutissimus* Lea, 1831) during the spring in northern Alabama (W.R. Haag, U.S. Forest Service [USFS], pers. comm., 1995). Glochidial morphology was described and figured first by Lea (1858b), and then by O'Brien and Williams (2002).

Primary fish hosts for the Gulf moccasinshell in the ACF Basin appear to include the blackbanded darter and the brown darter (*Etheostoma edwini*) (O'Brien and Williams 2002). Laboratory tests reveal that 100 percent of the fish of these two species transformed the glochidia that were exposed to them. Glochidia metamorphosed in 29 to 33 days for the blackbanded darter and 30 to 37 days for the brown darter. Two other fishes, the eastern mosquitofish and guppy, also transformed glochidia, but at lower percentage rates. All tests were conducted at 70.7 ± 2.7°F (O'Brien and Williams 2002).

Ochlockonee moccasinshell

The extreme rarity of the lampsiline Ochlockonee moccasinshell has precluded any opportunities to explore its life history. It can only be assumed that this species has similar reproductive biology traits of its congener, the Gulf moccasinshell (see above). Therefore, it may be a parent overwintering, summer releasing species that probably utilizes darters as hosts, as does the Gulf moccasinshell (see above), Alabama moccasinshell (Haag and Warren 1997), and Cumberland moccasinshell (Lea, 1834) (Zale and Neves 1982).

Oval pigtoe

Ortmann (1909b) considered *Pleurobema* species to have a short, summer breeding season (tachytictic). Gravid oval pigtoe were collected from the ACF Basin from March through July at water temperatures of 55.4 to 77.0°F (O'Brien and Williams 2002). This indicates that this unionine is a summer releasing, but not necessarily a parent overwintering species, as fertilization may take place in late winter or early spring. Females readily aborted their conglutinates in the laboratory, which contained both ova and glochidia in several stages of development. The structures are elongate, white to pinkish, approximately 0.2 in (0.5 cm) long, and one layer thick (O'Brien and Williams 2002). Once released, the glochidia remained viable for three days. The morphology of the glochidia was described and figured by O'Brien and Williams (2002).

Based on laboratory infections, juvenile specimens transformed on the gills of the sailfin shiner (*Pteronotropis hypselopterus*), eastern mosquitofish, and guppy (O'Brien and Williams 2002). Only the sailfin shiner was considered to be a primary host as it was the only species upon which the glochidial transformation rate exceeded 50 percent. Glochidia metamorphosed in 20 to 25 days at a temperature of 70.7 ± 2.7°F (O'Brien and Williams 2002).

Chipola slabshell

Little is known about the life history of the Chipola slabshell. A unionine, it is suspected that this species expels conglutinates and is a tachytictic summer releaser. Southeastern congeners of the Chipola slabshell have been documented to use centrarchids (sunfishes) as host fish (Keller and Ruessler 1997), although a relationship between cyprinids and tachytictic brooders has been documented (Bruenderman and Neves 1993).

Purple bankclimber

Females of the purple bankclimber with viable glochidia were found in the Ochlockonee River from February through April when water temperatures ranged from 46.4 to 59.0°F (O'Brien and Williams 2002). This indicates that it is a late winter-early spring releaser that may or may not be a parent overwintering species, dependent upon when fertilization takes place. Females expelled narrow lanceolate-shaped conglutinates (0.4 to 0.6 in (1.0 to 1.5 cm) long) that remain viable for three days after release. The white structures, which are two-glochidia thick, are generally released singly although some are paired, being attached at one end (O'Brien and Williams 2002). Rigid when aborted prematurely (containing only eggs), conglutinates with mature glochidia easily disintegrate presumably facilitating host infection. Glochidial morphology was described and figured by O'Brien and Williams (2002).

The eastern mosquitofish, blackbanded darter, and guppy transformed glochidia of the purple bankclimber during laboratory infections. Only the eastern mosquitofish was effective at transforming glochidia (100 percent transformation rate), with the percentages for the other two species being under 33 percent. Transformation on eastern mosquitofish occurred in 17 to 21 days at temperatures of 68.9 ± 5.4°F (O'Brien and Williams 2002). Considering that the purple bankclimber is more of a channel species (Williams and Butler 1994) while the eastern mosquitofish occupies stream margins in slower (or slack) currents (Lee et al. 1980), the primary host species for this mussel remains unknown (O'Brien and Williams 2002).

REASON FOR DECLINE

Past and Present Threats

Two general categories of factors have impacted freshwater mussel resources for the past 500 years in eastern North America: exploitation and habitat alteration. The former category primarily includes activities associated with the post-Mississippian Culture, such as pearling, the mussel button industry, and more recently, the cultured pearl industry. The latter category includes a variety of anthropogenic activities prevalent during the past two centuries.

<u>Exploitation</u>

Native Americans

The Mississippian Culture and Native American peoples that followed in the Southeast utilized mussels in a variety of ways (Parmalee and Bogan 1998, Davis 2000). They made decorative shell jewelry such as gorgets worn by chieftains and drilled pearl necklaces; fashioned scrapers, hoes, utensils, and other tools from shells; and incorporated crushed shells in clay as a way of strengthening their pottery. But the foremost use of mussels by this culture, and previous ones, was as a food source (Parmalee et al. 1982). Archaeological evidence suggests that mussels were commonly steamed open for consumption (Morrison 1942). Shell "middens" excavated from parts of the Southeast have contained hundreds of thousands of valves (Parmalee and Bogan 1998). As Davis (2000) stated, "[t]he survival of [post-]Mississippian material culture--at least as practiced during the sixteenth century--was therefore closely linked to the mussels' presence and availability." However, he believed that "overcollecting was socially discouraged or at least minimized to insure a continued harvest."

Pearling

Pearling has its roots hundreds, if not thousands, of years ago. The post-Mississippian Cultures of the Southern Appalachian region traded pearls with the Spanish in the early 1500s (Davis 2000). Caches of pearls in southeastern Native American villages weighing over a hundred pounds have been documented. In the latter half of the eighteenth century, pearling made a resurgence in various areas, usually being sparked by the fortuitous discovery of a large, valuable specimen (Parmalee and Bogan 1998). Considering that perhaps only 1 in 10,000 mussels may produce a commercially valuable pearl (McGregor and Gordon 1992), it may be safe to assume that hundreds of thousands, if not millions, of mussels were sacrificed in regional streams by individuals hoping to "get rich quick." Large specimens of the thick-shelled fat threeridge may have been among the species locally exploited for pearls. Major impoundments in the Southeast effectively sealed the fate of the pearling industry in the early part of the 20^{th} century (Neves 1999b, Davis 2000).

Pearl Buttons and Cultured Pearls

Two industries, the pearl button and cultured pearl, utilized the shells of specific mussel species as a raw material. Parmalee and Bogan (1998), and Neves (1999b) provide a detailed summary of these two industries. The making of pearl buttons began commercially in 1891 and flourished for half a century before the advent of plastic buttons doomed this industry. Another industry, cultured pearls, soon found utility for large numbers of freshwater mussel shells. Spherical beads fashioned from mussel shells have served as nuclei for pearls cultured from Pacific Basin oysters since the 1920s. Globally, cultured pearls represent a multi-billion dollar industry (B. Torrey, Editor, *Pearl World*, pers. comm., 2000).

Summary

Occasional harvest of Apalachicolan Region species for commercial purposes has been documented in the past (Service 1994). Harvest stemmed primarily from demand by biological supply houses (purple bankclimber), and possibly for pearl buttons (fat threeridge). Small numbers of at least the purple bankclimber have been used for the polished chip (jewelry) industry (Robert S. Butler [RSB], Service, pers. obs.). However, it is doubtful that the seven species addressed in this recovery plan have ever been overly exploited for pearling, pearl buttons, cultured pearls, or any other exploitative activity.

Habitat Alteration

Resource managers should realize that in the majority of cases, mussel resources were widely sustained during human interactions throughout history despite the widespread, prolonged, and sometimes dramatic exploitation events outlined in the previous section. Rather, the collapse of the mussel fauna outlined in the "Background" section of this plan is by and large the result of the second broad category of impacts: habitat loss from anthropogenic degradation (Williams et al. 1993, Neves 1993). Principle causes include impoundments, channelization, pollution, and sedimentation that have altered or eliminated those habitats that are essential to the long-term viability of many riverine mussel populations. Neves et al. (1997) and Watters (1997b) summarized many of these major categories of impacts, while Richter et al. (1997) identified specific stressors that threatened imperiled mussels and other aquatic species. The mussel fauna of the Apalachicolan Region is no exception to this long-standing and general status trend (Butler 1993). Brim Box and Williams (2000) thoroughly outlined the history of impacts to the ACF Basin. The histories of anthropogenic impacts to the Econfina, Ochlockonee, and Suwannee river drainages have not been summarized.

Impoundments

The effects of dams, hydrologic disturbances, and other instream alterations of habitat have been reviewed by numerous authors, including Ellis (1942), Baxter (1977), and Yeager (1993, 1994). Neves et al. (1997) and Watters (1997b) reviewed the specific effects of impoundments on freshwater mollusks. Ortmann (1909a) may have been the first biologist to correctly assess, but significantly underestimate (Stansbery 1970), the impact of dams on the aquatic biota. Impoundments have significantly altered riverine ecosystems (Baxter and Glaude 1980, Williams et al. 1992, Allan and Flecker 1993, Ligon et al. 1995, Sparks 1995, Blalock and Sickel 1996), and have been a major causal factor in the high extinction rate of freshwater mollusks (Johnson 1978, Lydeard and Mayden 1995, Neves et al. 1997).

Impoundments result in the elimination of riffle and shoal habitats and subsequent loss of mussel resources (van der Schalie 1938; Scruggs 1960; Neel 1963; Stansbery 1970, 1973; Schmidt et al. 1989; Williams et al. 1992; Layzer et al. 1993; Parmalee and Hughes 1993; Lydeard and Mayden 1995; Sickel and Chandler 1996; Watters 1996). By stalling water that would otherwise move, impoundments disrupt the many ecological processes driven by the variable flow of water, sediment, nutrient, and energy, as well as, increasing depth and sediment deposition (Williams et al. 1992, Ligon et al. 1995, Sparks 1995). Most riverine species are unable to successfully reproduce and recruit under impounded conditions (Fuller 1974, Neves et al. 1997), including these seven mussels (Butler 1993).

In addition to the loss of riverine habitat within an impoundment, dams can seriously alter downstream water quality and riverine habitat (Allan and Flecker 1993, Ligon et al. 1995, Collier et al. 1996), and adversely affect tailwater mussel populations (Cahn 1936, Ahlstedt 1983, Miller et al. 1984, Layzer et al. 1993, Heinricher and Layzer 1999, McMurray 1999b, Vaughn and Taylor 1999). Impacts on stream biota include thermal alterations (Neves 1993), and a variety of changes in channel characteristics, habitat availability, and flow regime (Krenkel et al. 1979, Allan and Flecker 1993). Habitat alterations result in fish community shifts (Brim 1991) that favor colonization by fewer native and more nonindigenous mussel species (Williams and Neves 1992). Extreme daily discharge fluctuations, bank sloughing, seasonal oxygen deficiencies, coldwater releases, turbulence, high silt loads, and altered host fish distribution have contributed to limited mussel recruitment and skewed demographics (Sickel 1982, Ahlstedt 1983, Miller et al. 1984, Layzer et al. 1993, McMurray et al. 1999b).

There are 16 main stem impoundments in the ACF Basin that were constructed between 1834 and 1975 (Brim Box and Williams 2000). The Chattahoochee River alone has 14 dams (9 major ones), including 3 locks and dams along its lower half that facilitate navigation from Columbus, Georgia, downstream. The lowermost mainstem of the Chattahoochee River is now permanently inundated for approximately 250 miles (mi). An additional 50 mi of mainstem habitat are impounded upstream of Atlanta, making approximately 300 mi of the Chattahoochee's 435 mi total length (69 percent) impounded. An additional 110 mi (or 29 percent of 370 mi) of main stem riverine habitat in the Flint River have been permanently altered by impoundments. Talquin Reservoir inundated approximately 20 mi of riverine habitat (or 12 percent of 172 mi) of main stem in the middle portion of the Ochlockonee River and the lowermost 3 mi of the Little River, its largest tributary. The lowermost portion of numerous other tributaries are also permanently flooded throughout these reservoirs. Smaller impoundments on other streams (e.g., Dead Lake, Chipola River; Deer Point Reservoir, Econfina Creek) may also have been detrimental to mussels (Watters 1996). Although the dam was removed in 1987, Dead Lake continues to be highly sedimented and currently provides habitat only for silt tolerant species (R. Butler, pers. obs.). Impoundments, as barriers to dispersal, contribute to losses of local subpopulations by blocking postextirpation recolonization (Luttrell et al. 1999). Apalachicolan Region impoundments have contributed to the decline of these seven species (Butler 1993). Quantitative sampling using sieves for juvenile mussels failed to document recruitment immediately below Jim Woodruff Dam on the Apalachicola River (Richardson and Yokley 1996). Several subpopulations of these seven species have been isolated due to impoundments (see "Patterns of Imperilment" and "Narrative Outline," Recovery Task 1.3.6, for a discussion of the consequences of population fragmentation).

Channelization

Dredging and channelization activities have profoundly altered riverine habitats nationwide; effects on streams have been summarized by Simons (1981), Bhowmik (1989), and Hubbard et al. (1993). DeHaan (1998) provides an annotated bibliography of sediment transport and deposition in large rivers. Hartfield (1993) and Neves et al. (1997) reviewed the specific effects of channelization on freshwater mollusks. Channelization affects a stream's physical (e.g., erosion rates, depth, habitat diversity, geomorphic stability, riparian canopy) and biological (e.g., species composition and abundance, biomass, and growth rates) characteristics (Stansbery and Stein 1971, Hartfield 1993, Hubbard et al. 1993). Channel construction for navigation has been shown to increase flood heights (Belt 1975), which exacerbates the impacts of flood events that convey large quantities of sediments and contaminants in streams. Channel maintenance may also result in downstream impacts (Stansbery 1970), such as increases in turbidity and sedimentation, which may smother benthic organisms. The volume of literature documenting on-site and off-site environmental and economic consequences of dredging for navigation and flood control is substantial (Smith and Patrick 1991).

The navigational history of the ACF Basin dates to 1829 when Congress appropriated funds to aid navigation in the Apalachicola River (Thurston 1973). Later, Congress approved a plan by the Corps in 1873 to provide a 100-foot-wide channel by 4 feet deep in the Chattahoochee (from Columbus downstream) and Flint (from Bainbridge downstream) Rivers, and a channel six feet deep in the Apalachicola River. Miles of mussel shoal habitat were destroyed in the process of pursuing navigation goals (Brim Box and Williams 2000). A navigation channel is currently maintained on the Chattahoochee and Apalachicola Rivers from Columbus, Georgia, 200 mi to the Gulf Coast, and about 30 mi of the lower Flint River. As none of these mussels occur in the navigation channels of the Chattahoochee or Flint Rivers, maintenance activities will not be affected there. Since present maintenance dredging activities on the Apalachicola River remove primarily unstable bed materials that are unsuitable mussel habitat, it is likely that extant populations are being only minimally impacted by current maintenance dredging activities (see "Conservation Measures").

Gravel Mining

Instream gravel mining has been implicated in the destruction of mussel populations (Stansbery 1970, Yokley and Gooch 1976, Grace and Buchanan 1981, Hartfield and Ebert 1986, Schuster et al. 1989, Hartfield 1993, Howard 1997). Lagasse et al. (1980), Kanehl and Lyons (1992), and Roell (1999) reviewed the physical and biological effects of mining sediments from streams. Negative impacts include riparian forest clearing (e.g., mine site establishment, access roads, lowered floodplain water table); stream channel modifications (e.g., geomorphic instability, altered habitat, disrupted flow patterns including lowered elevation of stream flow, sediment transport); water quality modifications (e.g., increased turbidity, reduced light penetration, increased temperature); macroinvertebrate population changes (e.g., elimination, habitat disruption, increased sedimentation); and changes in fish populations (e.g., impacts to spawning and nursery habitat, food web disruptions) (see "Sedimentation"). Once mussels have been eliminated from an area, a decade or more may pass before recolonization occurs (Stansbery 1970, Grace and Buchanan 1981). Substrate disturbance and siltation impacts can also be realized for considerable distances downstream (Stansbery 1970) and possibly upstream (Hartfield 1993).

Gravel mining activities have probably played a significant role in eliminating the Gulf moccasinshell and oval pigtoe from the Uchee Creek system (Howard 1997), and mining activities continue to threaten the shinyrayed pocketbook subpopulation there. This subpopulation represents the only subpopulation of the five species in this plan that remains in a tributary system within the State of Alabama (*contra* Lydeard et al. 1999).

Contaminants

Contaminants contained in point and non-point discharges can degrade water and substrate quality and adversely impact if not destroy mussel populations (Horne and McIntosh 1979, Neves and Zale 1982, McCann and Neves 1992, Havlik and Marking 1987). Although chemical spills and other point sources of contaminants may directly result in mussel mortality, "widespread decreases in density and diversity may result in part from the subtle, pervasive effects of chronic, low-level contamination" (Naimo 1995). The effects of heavy metals and other contaminants on freshwater mussels was reviewed by Fuller (1974), Havlik and Marking (1987), Naimo (1995), Keller and Lydy (1997), and Neves et al. (1997).

Mussels appear to be among the most intolerant organisms to heavy metals (Keller and Zam 1991), several of which are lethal, even at relatively low levels (Havlik and Marking 1987). Cadmium appears to be the heavy metal most toxic to mussels (Havlik and Marking 1987), although copper, mercury, chromium, and zinc also negatively affect biological processes (Jacobson et al. 1993, Naimo 1995, Keller and Zam 1991, Keller and Lydy 1997). Most metals are persistent in the environment (Miettinen 1977), remaining available for uptake, transportation, and transformation by organisms for long periods (Hoover 1978). In laboratory experiments, mussels suffered mortality when exposed to 2.0 parts per million (ppm) cadmium, 12.4 ppm chromium, 19.0 ppm copper, and 66.0 ppm zinc (Mellinger 1972, Havlik and Marking 1987). Metals stored in mussel tissues indicate recent or current exposure (Havlik and Marking 1987), while concentrations in shell material indicate past exposure (Imlay 1982, Mutvei et al. 1994). Highly acidic pollutants such as metals are capable of contributing to mortality by dissolving mussel shells (Stansbery 1995).

Among other pollutants, arsenic trioxide has been shown to be lethal to mussels at concentrations of 16.0 ppm and ammonia at concentrations of 5.0 ppm (Havlik and Marking 1987). Arsenic is commonly used in the poultry industry as a food additive for enhancing growth, while ammonia is often associated with animal feedlots, nitrogenous fertilizers, and the effluents of older municipal wastewater treatment plants. In stream systems, it is most prevalent at the substrate/water interface (Frazier et al. 1996). Due to its high level of toxicity and the fact that the highest concentrations occur in the microhabitat where mussels live, ammonia should be considered among the factors potentially limiting survival and recovery of mussels at some locations (Augspurger et al. in prep.).

Certain adult species may tolerate short-term exposure to contaminants (Keller 1993). However, the effects of heavy metals and other toxicants are especially profound on juvenile mussels (Robison et al. 1996), and on glochidia, which appear to be very sensitive to toxicants such as ammonia (Goudreau et al. 1993). Low levels of some metals may inhibit glochidial attachment (Huebner and Pynnönen 1992). Juvenile mussels may inadvertently ingest contaminated silt particles while feeding (see "Food Habits"). Mussel recruitment may be reduced in habitats with low but chronic heavy metal and other toxicant inputs (Yeager et al. 1994, Naimo 1995, Ahlstedt and Tuberville 1997), which may have contributed to the decline of these seven species.

Contaminants associated with urban areas, particularly those from industrial and municipal effluents, may include heavy metals, ammonia, chlorine, phosphorus, and numerous organic compounds. Runoff from urban areas tend to have the highest levels of many pollutants, such as phosphorus and ammonia, when compared to other catchments (Mueller et al. 1995). Collectively, these pollutants may cause decreased dissolved oxygen levels, increased acidity, and other water chemistry changes that may be lethal to mussels (Horne and McIntosh 1979, Rand and Petrocelli 1985, Sheehan et al. 1989, Keller and Zam 1991, Dimock and Wright 1993, Goudreau et al. 1993, Jacobson et al. 1993, Keller 1993).

Sediment samples from various ACF Basin streams tested for heavy metals that are known to be deleterious to mussels had concentrations markedly above background levels (Frick et al. 1998), among these were copper (throughout the Piedmont), and cadmium (large Coastal Plain tributaries of the Flint River). Past episodes of significant heavy metal contamination of ACF Basin streams may continue to impact mussel faunas. An estimated 950 million gallons of chemical-laden rinse, stripping, cleaning, and plating solutions were discharged indirectly into the Flint River (P. Laumeyer, Service, pers. comm., 1994) over a several year period. Concentrations of heavy metals (e.g., chromium and cadmium) in Asian clam, *Corbicula fluminea* (Müller 1774), and sediment samples were elevated downstream from two abandoned battery salvage operations on the Chipola River (Winger et al. 1985). Chromium concentrations found in sediments from Dead Lake downstream in the Chipola River (Winger et al. 1985) are known to be toxic to mussels (Havlik and Marking 1987).

Agricultural sources of contaminants in the ACF and Suwannee basins include nutrient enrichment from poultry farms and livestock feedlots, and pesticides and fertilizers from row crop agriculture (Couch et al. 1996, Frick et al. 1998, Berndt et al. 1998). Nitrate concentrations are particularly high in surface waters downstream of agricultural areas (Mueller et al. 1995; Berndt et al. 1998). A study by the U.S. Soil Conservation Service (SCS; now the Natural Resources Conservation Service [NRCS]) in the Flint River system determined that between 72 and 75 percent of the nutrients entering Lake Blackshear were derived from agricultural sources (SCS 1993). Stream ecosystems are impacted when nutrients are added at concentrations that cannot be assimilated (Stansbery 1995). Pesticides in stream sediments and aquatic biota were reviewed by Nowell et al. (1999). The effects of pesticides on mussels may be particularly profound (Fuller 1974, Havlik and Marking 1987, Moulton et al. 1996). Organochlorine pesticides are still detected in streams and aquatic organisms decades after their use has been banned. Erosion from areas of past use is a continuing source of these pesticides in some streams. Organochlorine pesticides were found at levels in ACF Basin streams that often exceeded chronic exposure criteria for the protection of aquatic life (Buell and Couch 1995, Frick et al. 1998). Once widely used in the ACF Basin (Buell and Couch 1995), these highly toxic compounds are persistent in the environment, and are found in both sediments and the lipid reservoir of organisms (Day 1990, Burton 1992). Commonly used pesticides have been directly implicated in a North Carolina mussel dieoff (Fleming et al. 1995). Cotton is raised extensively in much of the Apalachicolan Region inhabited by these mussels. One of the most important pesticides used in cotton farming, malathion, is known to inhibit physiological activities of mussels (Kabeer et al. 1979) that may decrease the ability of a mussel to respire and obtain food. This chemical may pose a continuing threat to some populations of these mussels.

Nutrients from aquaculture ponds may also have an impact on stream water quality. A large catfish farm is located in the floodplain of lower Cooleewahee Creek. Discharges of enriched pond water could negatively affect an oval pigtoe subpopulation, as well as the largest known subpopulation of the shinyrayed pocketbook, which occur in that stream.

Eight percent of the ACF Basin is developed (Frick et al. 1998). Although still a small portion of the watershed, residential development in Georgia is resulting in the conversion of farmland to subdivisions in areas relatively distant from cities, especially in the Albany, Atlanta, and Columbus metropolitan areas. The majority of the Suwannee basin is in silviculture or agriculture (Berndt et al. 1998). Many pollutants in the ACF Basin originate from urban stormwater runoff, developmental activities, and municipal waste water facilities, primarily in the Piedmont (Frick et al. 1998). Urban catchments in Piedmont drainages have higher concentrations of nutrients, heavy metals, pesticides, and organic compounds than do agricultural or forested ones (Lenat and Crawford 1994, Frick et al. 1998), and at levels sufficient to significantly affect fish health (Ostrander et al. 1995). Within the Suwannee River basin, nutrient concentrations were greater in agricultural areas and nitrates were found to exceed U.S. Environmental Protection Agency (EPA) drinking water standards in 20 percent of the surficial aquifer groundwater samples (Berndt et al. 1998). Pesticide concentrations were found to exceed criteria for protection of aquatic life mostly in urban areas. There are discharges from 137 municipal waste water treatment facilities in the ACF Basin alone (Couch et al. 1996). Although effluent quality has improved with modern treatment technologies and a phosphate detergent ban, hundreds of miles of streams in the ACF and Ochlockonee basins in Alabama, Florida, and Georgia, as identified in reports prepared by the water quality agencies of these states under Section 305(b) of the Clean Water Act (CWA), do not meet water use classifications.

Sedimentation

Sedimentation has been implicated as the principal cause of water quality impairment in the U.S. (EPA 1990). Although the specific associations of mussels with stream substrates are poorly understood (Brim Box and Mossa 1999), sedimentation is widely thought to have contributed to the decline of stream mussel populations (Kunz 1898; Ellis 1931, 1936; Imlay 1972; Coon et al. 1977; Marking and Bills 1979; Wilber 1983; Dennis 1985; Aldridge et al. 1987; Schuster et al. 1989; Wolcott and Neves 1991; Houp 1993; Richter et al. 1997; Brim Box 1999). Biological effects of sediments in streams were reviewed by Waters (1995), while Mount (1995) provided an overview of the effects of various land uses on stream systems. Brim

Box and Mossa (1999) specifically reviewed how mussels are affected by sediments and discussed land use practices that may impact mussels.

Specific biological impacts on mussels from excessive sediments include reduced feeding and respiratory efficiency from clogged gills, disrupted metabolic processes, reduced growth rates, increased substrata instability, limited burrowing activity, and physical smothering (Ellis 1936, Stansbery 1971, Markings and Bills 1979, Kat 1982, Vannote and Minshall 1982, Aldridge et al. 1987, Waters 1995). Brim Box (1999) showed that burying adult ACF Basin mussels under 5.5 in of sediment significantly decreased their chances of surviving. Intuitively, much thinner layers of sedimentation may result in juvenile mortality. Such studies tend to indicate that the primary impacts of excess sedimentation on mussels are sublethal, with detrimental effects not immediately apparent (Brim Box and Mossa 1999). The impacts of sediments on mussels range from direct effects to a multitude of indirect effects via alterations of stream morphology (Brim Box and Mossa 1999). Mussels are potentially directly affected by changes in suspended sediment load, bed sediment load, and bed sediment composition; which may indirectly affect them as well by altering channel geometry and stability. Sediment filling pools reduces channel capacity, which causes increased bank erosion rates, widening channels, increasing light penetration, and altering thermal regimes. Mussels are adversely affected by actively aggrading (filling) or degrading (scouring) channels. Abrupt shifts in channel position may leave mussels stranded (Vannote and Minshall 1982, Kanehl and Lyons 1992, Hartfield 1993, Brim Box and Mossa 1999; see "Gravel Mining").

Interstitial spaces in mixed substrates of streams may become clogged when sediment input to streams is excessive (Gordon et al. 1992). Reduced interstitial spaces and interstitial flow rates, also reduces habitat for juvenile mussels and some adults alike (Brim Box and Mossa 1999). Interstitial spaces are relatively free of sediments in the Tennessee portion of the upper Clinch River, whereas upstream in Virginia, interstitial spaces were clogged with sediments (R. Butler, pers. obs.). At the former site, small juvenile mussels were found in some abundance (oftentimes 4 to 6 in (10 to 15 cm) deep in the substrate), but were generally lacking at Virginia sites (S.A. Ahlstedt, USGS, unpub. data). Salomons et al. (1987) and National Research Council (1992) indicated that sediments may act as vectors in delivering contaminants such as nutrients and pesticides to streams. As previously mentioned under "Contaminants," juveniles can readily ingest contaminants adsorbed to silt particles during normal feeding activities (see "Food Habits"). These factors may help explain in part why so many mussel populations appear to be experiencing recruitment failure.

Host fish-mussel interactions may be indirectly affected by changes in stream sediment regimes through three mechanisms (Brim Box and Mossa 1999). First, fish abundance (Berkman and Rabeni 1987), diversity (Waters 1995), and reproduction (Muncy et al. 1979) may be reduced with increased sedimentation. Second, excessive sedimentation likely impedes host fish attractant mechanisms (e.g., mantle flaps, conglutinates, superconglutinates that mimic fish prey items; see "General Reproductive Biology") (Haag et al. 1995, Burkhead et al. 1997). Third, sedimentation on shoal substrates may interfere with the ability of some species' adhesive conglutinates to adhere to rock particles (Hartfield and Hartfield 1996).

Many southeastern streams have increased turbidity levels due to siltation (van der Schalie 1938). These seven mussels attract host fishes with visual cues, luring fish into perceiving that their glochidia are prey items (see "Reproductive Biology of the Seven Species"). Such a reproductive strategy depends on clear water during the critical time of the year when mussels are releasing their glochidia (Hartfield and Hartfield 1996). Turbidity is a limiting factor impeding sight-feeding fishes (Burkhead and Jenkins 1991), and may have contributed to population declines in some of these species. In addition, mussels may be indirectly affected when turbidity levels significantly reduce light available for photosynthesis and the production of unionid food items (Kanehl and Lyons 1992).

Water-borne sediments are produced by the erosion of stream banks, channels, plowed fields, unpaved roads, road-side ditches, upland gullies, and other soil disturbance sites (Brim Box and Mossa 1999). These sediments result from poorly designed and executed agricultural, silvicultural, and roadway activities; clearing of riparian vegetation for agricultural, silvicultural, roadway construction, and flood control activities; gravel mining; and those developmental and other practices that allow erosion to occur. Physical characteristics of stream channels are affected when large quantities of sediment are added or removed (Allan 1995, Waters 1995). These changes include formation of channel bars, erosion of banks, obstruction of flow, increase of flooding events, and shifting of the channel bottom.

Agricultural activities produce a significant amount of stream sediments including chemical runoff, affecting 72 percent of impaired river miles in the country (Neves et al. 1997). Crop farming has been implicated in producing roughly 40 percent of the erosion in the United States (Meade et al. 1990), and that 60 percent of the approximately 8,880 x 10^6 tons of soils lost annually from cropland is deposited in surface waters (U.S. Department of Agriculture [USDA] 1989). Reducing tillage not only reduces soil exposure, but also the nutrients and other contaminants that eroded soils carry into streams (National Research Council 1992). Since approximately 29 percent of the ACF Basin is in agriculture (Frick et al. 1998), sedimentation from agricultural sources is probably significant. According to SCS (1993), 89 percent of the sediments entering Lake Blackshear on the Flint River are derived from agricultural sources. The lower Flint River system serves as the heart of five of these seven species' range and is a major agricultural center. This area has experienced "severe losses of topsoil and nutrient additions to local streams due to agriculture" (Neves et al. 1997), and has profoundly affected the biota of surface and ground waters there (Patrick 1992). Despite the implications, only a few studies (e.g., Cooper 1987, Stewart and Swinford 1995) have specifically attributed changes in mussel populations to sediments derived from agricultural practices.

The effects of livestock grazing on riparian and stream ecosystems was reviewed by Armour et al. (1991). Unrestricted access by livestock is a significant threat to streams (Trimble and Mendel 1995) on a localized scale in the Apalachicolan Region. Grazing may reduce infiltration rates and increase runoff and erosion (Brim Box and Mossa 1999). Trampling causes or accelerates stream bank erosion, and grazing reduces a bank's resistance to erosion (Armour et al. 1991, Trimble and Mendel 1995). In addition, livestock may add nutrients to streams at levels that are not easily assimilated, particularly during low-flow conditions, resulting in over-enrichment. The proliferation of dairies in the Suwannee basin and localized areas of unrestricted livestock access potentially threaten mussel populations in regional streams. Within the Suwannee basin, predominant sources of nutrient enrichment were inorganic fertilizers and animal wastes (Crandall 1996). A herd of cattle several score in size was observed to have direct access to a large spring and spring run adjacent the Chipola River just upstream of Florida Caverns State Park during the summer of 2000 (R.S. Butler, pers. obs.). Although anecdotal, shinyrayed pocketbook and oval pigtoe were found live during mussel sampling in the Chipola River upstream of the mouth of this spring run, but not downstream.

Erosion from silvicultural activities is probably more attributable to logging roads than to the actual harvest of timber (Brim Box and Mossa 1999). Annual runoff and peak flow volumes increase with timber harvests, particularly during the wet season (Allan 1995). This was partially due to the construction of logging roads, and vegetation removal tends to compact soils, reduce infiltration rates, and increase soil erosion. Timber harvesting also results in stream channel changes (Brim Box and Mossa 1999) that may ultimately affect mussel beds.

Urban development changes sediment regimes by creating impervious surfaces and drainage system installations (Brim Box and Mossa 1999). The highest erosion rates are generally associated with construction activities, which can contribute sediments at a rate 300X greater than from forested land (USDA 1977). Impervious surfaces reduce sediment inputs to streams and increase the rate and magnitude of stormwater runoff events, causing in-channel changes that may ultimately result in bank erosion and bed scouring (Brim Box and Mossa 1999). Stream channel erosion contributes up to two-thirds of the total sediment yield in urbanized watersheds (Trimble 1997).

Brim Box and Williams (2000) provide a detailed account of the sedimentation history in the ACF Basin. Light to moderate levels of siltation are common in many Apalachicolan Region streams (van der Schalie 1938), particularly in the Piedmont, which is known for its highly erodible soils (Trimble 1972). The decline of the rich mussel fauna of the Chattahoochee River was attributed in part to erosion from intensive farming before the Civil War (van der Schalie 1938, Clench 1955), although erosion continued to represent a severe problem for several more decades (Glenn 1911, Trimble 1972).

Maintaining vegetated riparian buffer zones adjacent to stream banks is a well-known method of reducing stream sedimentation and other runoff (Allan and Flecker 1993, Lenat and Crawford 1994). Buffers reduce impacts to fish and other aquatic faunas (Armour et al. 1991, Naiman et al. 1988, Osborne and Kovacic 1993, Belt and O'Laughlin 1994, Penczak 1995, Rabeni and Smale 1995), and are particularly crucial for mussels (Neves et al. 1997). A review of riparian buffer widths, extent, and vegetation, focusing on recent refereed scientific articles primarily in Georgia, was compiled by Wenger (1999). Schultz and Cruse (1992) evaluated their effectiveness as nutrient and sediment filters. Riparian forest removal in southeastern streams and subsequent sedimentation has been shown to be detrimental to fish communities (Burkhead et al. 1997, Jones et al. 1999). Particularly affected in the study by Jones et al. (1999) were benthic-dependent species (e.g., darters, benthic minnows, sculpins), which were found to decrease in abundance with longer deforested patches of riparian area. Benthic-dependent fishes, themselves disproportionately imperiled (Burkhead et al. 1997), commonly serve as hosts for numerous imperiled mussel species (Watters 1994), including at least the Gulf moccasinshell and probably Ochlockonee moccasinshell (see "Reproductive Biology of the Seven Species").

Deadhead Logging

In Florida, "deadhead logging" has the potential to affect mussel communities by altering habitat. Timber cut approximately 100 years ago, then accidently sunk during log "drives," is salvaged from stream bottoms. Because of their age and quality, these logs now have high commercial value, principally as flooring material. The removal of deadhead logs may result in localized damage to mussels by resuspending fines and disrupting stable substrates associated with partially buried logs. Deadhead logging is currently being conducted at several locations in northern Florida under permits from the State Department of Environmental Protection. These permits all include several general conditions to avoid impacts to mussels and other aquatic life, such as prohibiting log removal from banks.

Water Withdrawal

Water quantity is becoming more of a concern in maintaining mussel habitat in the Apalachicolan Region. Extensive agricultural cropland areas, primarily planted in cotton, peanuts, corn, and soybeans, rely heavily on irrigation using groundwater, particularly in the Dougherty Plain (see "Distributional History and Relative Abundance"). Pumping of groundwater from the Floridan Aquifer is contributing to decreased spring outflows and lowered stream levels. Approximately 425,000 acres (ac) of cropland were being watered in 1999 with center pivot irrigation in a 16-county area of the lower Flint River system, with an additional 75,000 ac irrigated with surface waters (Litts, et al. 2001). Center pivot utilizes a well around which a radially oriented sprinkler system slowly rotates, thus irrigating a circle (or portion thereof). Several hundred gallons of water may be used each minute, and many center pivots run around the clock during the five-month growing season.

The potential impacts to mussels, their host fishes, and their respective habitats from ground water withdrawal may be profound. Lowering of the water table results in decreased stream flows, which is exacerbated by commonly aggraded stream channels. In addition, during periods of drought, streams may cease to flow entirely; be reduced to isolated pools of hot water, low dissolved oxygen (DO), low food resources, and concentrated contaminants; or dry up completely for long stream stretches. In the ACF River basin in Georgia, one study indicated that 8 of 37 streams (7 of which support listed mussels) examined were highly sensitive to water withdrawal and that during droughts these streams may go dry (Albertson and Torak 2002). Many other smaller streams that support listed mussels, could go dry at lower withdrawal rates (Albertson and Torak 2002). Water withdrawal for irrigation has been implicated in the decline of fish populations in other parts of the country (Luttrell et al. 1999). Within the Flint River basin, decreases in flow velocity and dissolved oxygen were highly correlated to mussel mortality (Johnson, et al. 2001). Maintaining adequate water levels in streams is particularly important during the reproductive season for mussels. Drought-related responses could affect the long-term viability of mussel populations in the lower Flint River basin by decreasing the effectiveness of lures and interrupting the life cycle by hindering the process of glochidial release and attachment. For instance, superconglutinates of the shinyrayed pocketbook have been observed lying on the river bottom due to low flow rates (Johnson, et al. 2001). Superconglutinates need to be suspended in current for their erratic "swimming" motions to attract the proper host fish (see "General Reproductive Biology").

Approximately 150 and 90 specimens of the shinyrayed pocketbook and oval pigtoe, respectively, were salvaged live from drought-ravaged segments of Spring Creek, Miller County, Georgia, during the summer 2000 drought (L. Andrews, Service; and R.S. Butler, pers. obs.). Large numbers of both species were also found fresh dead in the dried stream bed, in mud holes, and in shrinking pools of water. Low DO conditions in stagnating stream pools due to drought conditions are having a disastrous effect on these species. Mussel mortality increases dramatically as DO decreases below 5 mg/L (Johnson, et al. 2001). Rare species (e.g., shinyrayed pocketbook, oval pigtoe, and Gulf moccasinshell) were more susceptible to drought-related mortality within the Flint River basin and had the highest mortality rates from hypoxic conditions (Johnson, et al. 2001). Additionally, glycogen (the main form of enery storage in bivalves) levels were examined for another unionid species, fluted elephantear (*Elliptio mcmichaeli* [Clench and Turner, 1956]) before and during drought situations (J. J. Herod, USFWS, pers. comm.). During the drought conditions, glycogen levels were reduced to those similar to experimental specimens that were under nutritive stress in laboratory conditions. Unless water quantity and biological needs issues for mussels are addressed, more and more mussel populations may be experiencing the potentially catastrophic effects of prolonged low or zero-flow conditions in area streams.

Predation and Parasitism

The different life stages of mussels are preyed upon by a variety of invertebrate and vertebrate predators and infested by various parasites as part of natural ecosystem dynamics. Both groups of organisms normally have minimal impacts upon the fauna (Parmalee and Bogan 1998). Although muskrats (*Ondatra zibethicus*) have been shown to be detrimental to listed mussels (Neves and Odum 1989), they do not occur with populations of these seven mussels.

Alien Species

Alien species refers to those species "carried outside their original ranges by human activities" (Strayer 1999b). Invasions by alien aquatic species are a factor in streams throughout most of the continent. Impacts from alien species on mussels were reviewed by Neves et al. (1997) and Strayer (1997, 1999b).

Nonnative aquatic species invasions, whose impacts upon mussels was reviewed by Neves et al. (1997) and Strayer (1997), are a factor in streams throughout most of the continent. The nonindigenous Asian clam, *Corbicula fluminea*, was first reported from the ACF Basin in 1963 (Heard 1964). This species has been implicated as a competitor with native mussels for resources such as food, nutrients, and space (Heard 1977, Kraemer 1979, Clarke 1986), particularly as juveniles (Neves and Widlak 1987). However, specific impacts upon native mussels remain largely unresolved (Leff et al. 1990, Strayer 1997). Dense populations of Asian clams may ingest large numbers of unionid sperm, glochidia, and newly-metamorphosed juveniles. They also actively disturb sediments, so dense populations may reduce habitable space for juvenile native mussels. Lastly, periodic Asian clam dieoffs may produce ammonia in concentrations sufficient to consume enough oxygen to kill native mussels.

Yeager et al. (2000) determined that high densities of Asian clams negatively impacted survival and growth of newly metamorphosed juvenile mussels and thus reduced recruitment. They proved from laboratory experiments that Asian clams readily ingested glochidia. Clam density and juvenile mussel mortality were positively correlated, growth rates were reduced with the presence of clams, and that juvenile mussels were displaced in greater numbers downstream in tests with clams. Yeager et al. (2000) summarized that "[a]fter eons of speciation and adaptation by native unionids...particularly in the Southeast, it is highly improbable that all available niches for bivalve filter-feeders were not filled by the native assemblage. There was no grand niche left vacant, such that the non-indigenous Asian clam could invade, achieve high densities, dominate in benthic biomass, and yet have no significant adverse effect on native unionids." Resource managers may have underestimated the potential impact of *Corbicula* on native species in many southeastern stream systems.

Densities of Asian clams are sometimes heavy in Apalachicolan Region streams (Stringfellow and Stanton 1998), with estimates from approximately 9 per square foot (Flint River, Sickel 1973) to over 195 per square foot (Santa Fe River, Bass and Hitt 1974). In the New River (Suwannee River drainage), Blalock and Herod (1999) found an overall density of 8 Asian clams per square foot in the same study area where oval pigtoe density was 0.003 per square foot (Blalock-Herod 2000). In the Apalachicola River below Jim Woodruff Dam, the substrate has changed from homogenous silty sand or sand (W.H. Heard, FSU, pers. comm., 1994) to one with a gravel-like component comprised of huge numbers of live and dead Asian clams in concentrations up to 4 in (10 cm) deep. (R.S. Butler, pers. obs.).

Another nonnative bivalve, the zebra mussel, *Dreissena polymorpha* (Pallas 1773), poses a potential threat to the Apalachicolan Region's mussel fauna if it colonizes these rivers. The fat threeridge and purple bankclimber subpopulations in the Apalachicola River are probably the most at risk from zebra mussels as riverine invasions have generally occurred in navigation channels (Johnson and Carlton 1996). Zebra mussels in the Great Lakes have attached in large numbers (up to 10,000 per unionid) to the shells of live native mussels (Schloesser and Kovalak 1991), and have been implicated in the loss of mussel beds (Hunter and Bailey 1992, Masteller et al. 1993, Schloesser and Nalepa 1995). Mussel extinctions are expected as the result of the continued spread of zebra mussels in the eastern United States (Ricciardi et al. 1998).

The black carp (*Mylopharyngodon piceus*) may also pose a threat to these mussel species. Nico et al. (2001) prepared a risk assessment of the black carp, and summarized all known aspects of its ecology, life history, and intentional introduction (since 1970s) into North America. A molluscivore (mollusk eater), the black carp has been proposed for widespread use by aquaculturists to control snails, the intermediate host of a trematode (flatworm) parasite affecting catfish in ponds in the Southeast. One of several Asian carp species intentionally brought to the U.S., black carp are known to eat clams (*Corbicula* spp.) and unionid mussels in China in addition to snails. They are the largest of the Asiatic carp species, reaching over 4 feet in length and achieving a weight in excess of 150 pounds (Nico et al. 2001). Catfish farming is present in at least the ACF Basin and culture ponds commonly occur in flood-prone areas (see "Contaminants"). For this reason, conservation biologists believe that non-sterile black carp will inevitably escape into the wild (Mississippi Interstate Cooperative Resource Association 2000), and that they could wreak havoc on already stressed native mussel populations in the area.

Summary

Many of the impacts discussed above occurred in the past as unintended consequences of human development in the Apalachicolan Region. Improved understanding of these consequences has led to regulatory actions (e.g., CWA), voluntary landowner measures (e.g., best management practices [BMPs] for agricultural, silvicultural, and construction activities), and improved land use practices (e.g., maintaining riparian buffers, practicing no-till agriculture). These activities and others discussed under "Conservation Measures" are contributing to reduce threats to these mussels. Nonetheless, currently the seven species are highly restricted in distribution, occur in generally small subpopulations, and show little evidence of recovering from historical habitat losses without significant positive human intervention.

Patterns of Imperilment

The fate of freshwater mussel populations is influenced by a number of complex biological and ecological factors that are in turn ultimately affected by anthropogenic forces (Neves 1993). In addition, the elaborate life cycle of mussels increases the probability that weak links in their life history will preclude successful reproduction and recruitment. Following is an attempt to explain the consequences of the many factors that have contributed to the decline of mussel populations.

Reproductive Biology

Egg formation and fertilization are critical phases in the life history, as many mussels fail to form eggs (Downing et al. 1989), or fertilization is incomplete (Matteson 1948). A study of eastern elliptio (*Elliptio complanata* [Lightfoot 1786]) in a Canadian lake, Downing et al. (1993) found that fertilization success was strongly correlated with spatial aggregation, which influenced the rate of egg formation, or fertilization, or both. Complete fertilization failure occurred at densities of < 0.9 mussels per square foot. Not until densities reached 3.7 mussels per square foot were fertilization rates 100 percent. This study suggests that in lentic (lake) environments, fertilization success of sparse populations of species having separate sexes (i.e., non-hermaphroditic) is probably extremely low, and where fertilization does occur, recruits may be more homozygous (i.e., less genetically diverse) than those in denser populations. Reproductive success of sparse populations would further decline over time due to senescence. The occurrence of large numbers of gonad destroying trematode parasites in old specimens of some mussel species (Zale and Neves 1982) might indicate senescence is partially a result of gonadal infestation. Additionally, unnatural temperature regimes, created from releasing water from below the thermocline in reservoirs, can prohibit some species from producing gametes thereby eliminating reproduction at a cellular level.

It is likely that density has a lesser, but still significant influence on reproductive success in riverine ecosystems where as stream flow may disperse sperm over long distances. There is some evidence that hermaphroditism in certain mussel species may allow even minuscule populations to achieve some level of reproductive viability (R.J. Neves, USGS, pers. comm., 1996); however, hermaphroditism has not yet been observed in the seven species addressed by this plan.

Host Fish Connection

Host fish availability and density are a significant factors influencing locations where certain mussel populations can persist (Haag and Warren 1998). Any perturbation that decreases host fish abundance or fish community composition; limits fertilization rates; reduces glochidial, juvenile, or adult survivability; and/or alters density, aggregation, or size distribution (i.e., demographics) of mussel populations is detrimental to population viability and ultimately the species as a whole (Downing et al. 1993, Neves 1993, Neves et al. 1997).

The apparently inefficient reproductive cycle involving obligate fish hosts would appear to be a weak link in population recruitment (Bogan 1993). Despite the high number of glochidia produced, contact between glochidia and host fish is a low-probability event (Neves et al. 1997), promoted by the respiratory and feeding behavior of fishes (Dartnall and Walkey 1979, Neves et al. 1985), and the behavioral characteristics of some mussel species (Davenport and Warmuth 1965, Kraemer 1970). Infestation rates are therefore generally low for riverine mussels (Neves and Widlak 1988, Bruenderman and Neves 1993), but with exceptions (Michaelson and Neves 1995). Although glochidia may initially attach to many fish species, immune system incompatibility results in unsuitable fish hosts quickly sloughing off the parasites (see "General Reproductive Biology").

Recruitment Failure

Despite the dearth of available quantitative information, the evidence is overwhelming that individual and combined stressors resulting from anthropogenic forces have been responsible for the decline of mussel faunas (Havlik and Marking 1987, Bogan 1993, Neves et al. 1997).

Gradual reductions in recruitment and survival of vulnerable mussel species occur when anthropogenic factors act insidiously in altering sediment and water quality (Fleming et al. 1995).

Susceptibility of glochidia and host fish to altered and degraded habitats coupled with the chance encounter between glochidia and host can contribute to periodic recruitment failures (Zale and Neves 1982, McMurray et al. 1999a) and relic populations dominated by cohorts of older adults (Neves 1993, Stansbery 1995). Juveniles appear to be more susceptible to perturbations than adults (Ortmann 1909a) and are hypothesized to be more susceptible to competitive interactions with the Asian clam for space or food (Neves and Widlak 1987). Lack of recent recruitment is apparent in many mussel populations (Richardson and Yokley 1996; Blalock-Herod 2000, McMurray et al. 1999a, b). It is probable that pedal feeding juveniles ingesting contaminated sediments (see "Contaminants" and "Sedimentation") are precluding recruitment in some otherwise reproducing mussel populations. Unfortunately, many mussel populations are characterized by large, old, and spatially separated specimens that are commonly on their way towards extirpation (Stansbery 1995).

Mussel recolonization of impacted river reaches is achieved by dispersal of newly metamorphosed juveniles via infected host fish, passive adult movement downstream (Neves 1993), and active migration or passive movement downstream by juveniles (Kat 1982). Due to slow growth and relative immobility, however, the establishment of self-sustaining subpopulations requires decades of immigration and recruitment, even where suitable habitat exists for common species that may occur in high densities (Neves 1993). Mussel recruitment is typically low and sporadic, with population stability and viability being maintained by numerous, slow-growing cohorts and occasionally good year-classes (Neves and Widlak 1987). Only when a significant number of viable subpopulations have been verified should that species be considered stable (A.E. Bogan, North Carolina State Museum of Natural Sciences (NCSMNS), in litt., 1995).

Due to their extreme longevity, direct effects of some anthropogenic factors on mussels may not be evident for years, and unfortunately in some cases, not until the species has disappeared or experienced significant range reduction (A.E. Bogan, NCSMNS, in litt., 1995). Studies suggest that although individual impacts may be minor, cumulative effects may become lethal over time (Bogan 1993).

Determination of the relative rarity of species has been divided into three factors by Rabinowitz et al. (1986): geographic range, habitat specificity, and population abundance. Based simply on the fact that these seven mussels are highly restricted in range and generally occur in small subpopulations, their imperilment is made more acute.

Population Fragmentation and Genetic Considerations

Principles of population genetics give valuable insight into the heightened imperilment of rare species (see Neves [1993, 1997] for a thorough summary of genetic considerations in freshwater mussel conservation). Genomic heterogeneity is lost when the natural interchange of genetic material between populations is prohibited (Neil et al. 1975, Allendorf and Leary 1986). Population genetics has emphasized the profound negative effects the loss of genomic heterogeneity has on overall population viability of species with restricted and fragmented ranges (Chesser 1983, Gilpin and Soulé 1986). Such isolation can eventually lead to inbreeding depression (Avise and Hambrick 1996), which can be a major detriment to a species' recovery (Frankham 1995). Inbreeding may result in decreased fitness of multiple life stages, and the loss of genetic heterozygosity results in significantly increased risk of extinction in localized natural populations (Saccheri et al. 1998).

The effect of reduced heterozygosity on extinction risk is most noticeable in small, isolated populations (Saccheri et al. 1998). However, even in populations exhibiting more intermediate levels of isolation, extinction risk increases dramatically with decreasing heterozygosity in the smallest populations. Unfortunately, it is likely that some of the extremely small and geographically isolated populations of these seven mussel species may already be below their effective population size (EPS; Soulé 1980), or the level required to maintain long-term genetic viability (see "Narrative Outline," Recovery Task 1.3.6, for further discussion). The fragmentation of populations is of paramount importance when considering the likelihood of long-term survival of narrowly distributed species (Burkhead 1993). The fragmented distribution and imperiled status of most populations of these seven species in the Apalachicolan Region may be indicative of the detrimental bottleneck effect resulting when the EPS is not attained.

At one time, sizeable populations of the shinyrayed pocketbook, Gulf moccasinshell, oval pigtoe, and purple bankclimber occurred throughout significant portions of the large river main stems and tributary systems comprising the eastern Apalachicolan Region (see "Distributional History and Relative Abundance"). Historically, there were no natural absolute barriers to genetic interchange among their tributary subpopulations and those of their host fishes. With the completion of numerous main stem dams, populations in long stream reaches were soon extirpated, effectively isolating the remaining populations into subpopulations. Small isolated tributary subpopulations of imperiled short-lived species (e.g., most fishes) may theoretically have died out within a decade or so after, and as a direct result of, impoundment. This scenario is predicted by the hypothesis of disrupted source/sink populations (Pulliam 1988). Long-lived mussel species may potentially take decades for their subpopulations to expire post-impoundment, or possibly longer if other factors were at play in their ultimate demise. This latter scenario is predicted by Levins' (1970) metapopulation model, in which reservoirs originally contributed to extirpations by disrupting the extinction/recolonization population dynamics. The date of extirpation in Levins' model does not correlate with reservoir construction, but rather with other detrimental factors.

Without the level of genetic interchange these species experienced historically (because of anthropogenic factors discussed in "Past and Present Threats"), many small isolated subpopulations that are now comprised predominantly of adult specimens may be slowly dying out. This may in part account for the relatively recent demise of numerous tributary subpopulations, particularly in the Chattahoochee River system (see "Distributional History and Relative Abundance"). Even given the improbable absence of the impacts addressed in the "Past and Present Threats" section, we may lose smaller isolated subpopulations of these species to the devastating consequences of below-threshold EPS (see "Narrative Outline," Recovery Task 1.3.6, for further discussion). In reality, degradation of these isolated stream reaches resulting in ever decreasing patches of suitable habitat is invariably contributing to the decline of the seven species. Populations appear viable only where there are relatively large metapopulations in relatively extensive habitat patches (e.g., shinyrayed pocketbook, Gulf moccasinshell, and oval pigtoe in portions of the lower Flint River system).

Summary

In summary, mussels decline in range or abundance as a result of any factor that reduces glochidial or juvenile survivorship, adult spawning stocks, and host fish abundance (Neves 1993). Any perturbation that chronically limits fertilization rates and survivability of glochidia; decreases host fish abundance; decreases fish community composition; and/or alters density, aggregation, or size distribution of mussel subpopulations is detrimental to population viability and, ultimately, the species as a whole (Downing et al. 1993, Neves 1993, Neves et al. 1997). Many, if not all, of the factors addressed in this and the previous section have probably played, and some may continue to play, roles in the decline of the seven mussels addressed in this recovery plan.

CONSERVATION MEASURES

Ecosystem management is the most effective method of protecting the greatest number of species (Doppelt et al. 1993, Shute et al. 1997). The Service, other government agencies, conservation organizations, and local watershed protection groups have implemented ecosystem management programs to conserve, restore, and recover Federal trust resources and other rare aquatic species and their habitats nationwide. Ecosystem teams have been organized by the Service, including the Northeast Gulf and North Florida Ecosystems in the range of these seven species, to better manage each ecosystem's biota in a cross-program manner (Rappaport Clark 1999). This holistic approach to the management of biotic resources is deemed much more effective than managing single species in a complex natural and political environment. Shute et al. (1997) summarized the ecosystem approach to the management of imperiled aquatic resources, provided a literature review on the subject, and recommended a series of steps for developing and implementing an ecosystem management program. These include prioritizing ecosystems in need of protection, identifying and partnering with all potential agencies and organizations with watershed interests, prioritizing ecosystem threats, identifying strategies to minimize or eliminate threats, and educating ecosystem inhabitants and other stakeholders.

The Freshwater Mollusk Conservation Society was formed to conserve this highly imperiled fauna. Founding members of this organization have published a national strategy to address mussel conservation (National Native Mussel Conservation Committee, 1998). Its goals are to conserve native species; ensure their continued survival; and maintain their ecological, economic, and scientific values to our society (Neves 1997).

Governmental Activities

The ESA directs the Service to develop and implement recovery plans (Section 4); provides for possible land acquisition (Section 5); through cooperation with the States, provides funding to effect recovery activities (Section 6); requires Federal agencies to evaluate their actions with respect to any listed species (Section 7); and protects listed species from illegal taking (Sections 9, 10, and 11).

The implementation of several other Federal statutes may also contribute to the recovery of the seven mussels. The Clean Water Act (CWA), administered by the EPA, has taken great strides in reducing point discharge pollutants into streams (Neves et al. 1997). Municipalities and industries have improved wastewater treatment facilities with grants and aid from the EPA and State environmental protection departments. Non-point source pollution is dealt with in a number of ways under the CWA, including providing funds through its Section 319 non-point source pollution program to improve water quality and reduce nutrient loading, sedimentation, and the likelihood of other pollutants entering streams. In addition, EPA and USGS have assessed and monitored water quality in streams throughout much of the Southeast (e.g., Frick et al. 1998). The Fish and Wildlife Coordination Act (FWCA) is intended to protect fish and wildlife resources and their habitats by coordinating with natural resource agencies on their projects. Programs under the USDA, particularly those administered by NRCS (e.g., Conservation Reserve Enhancement Program [CREP], Environmental Quality Incentives Program, Wetland Reserve Program, Fish and Wildlife Habitat Incentives Program), are increasingly addressing restoration of impaired streams with imperiled species. For example, a proposed 10-year CREP project on the upper Green River system in Kentucky plans to earmark $110 million dollars to farmers volunteering to take tens of thousands of riparian acres out of agricultural production, restoring habitat, and establishing conservation easements. The NRCS is routinely adopting animal waste management plans to reduce nutrient and sediment input into streams throughout the country (SCS 1993).

The Corps is working with the Service in developing a plan in which their navigation channel maintenance activities in the Apalachicola River minimize impacts to the fat threeridge and purple bankclimber, and in prioritizing sites for mussel surveys to determine suitability for their continued protection. Accordingly, disposal sites are classified as “red” (sites which provide habitat for protected mussels and for which additional Section 7 consultation is required prior to use); “yellow” (sites which have not been used since 1991, and which must be surveyed prior to their use to determine if protected mussels are present); or “green” (sites which have been used since 1991 and/ or have been surveyed, have been determined not to harbor protected mussel species). Results of mussel surveys of yellow sites are continuously being coordinated with the Service prior to reclassification for protection as a red site, or approval for future use as a green site.

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA) was the first legislation authorizing the Service and the National Oceanic and Atmospheric Administration to issue regulations preventing the unintentional introduction of aquatic nuisance species. On February 3, 1999, the President issued Executive Order 13112 (EO) on Invasive Species. The EO places increased emphasis on efforts to prevent the introduction of invasive species and to provide for their control, and to minimize the economic, ecological, and human health impacts which invasive species cause. Regulations under the NANPCA and the EO will help prevent the incidental importation of other mollusks harmful to native species. The Service has developed four priorities under the title "Director's Priorities FY 1999-2000." One of the priorities is to develop and implement an aggressive program to enhance the Service's capability and leadership role to respond effectively to present and future invasive species problems and issues. All Service offices and ecosystem teams will focus efforts via three goal statements: enhance leadership, take direct action, and raise public awareness.

Water withdrawal for agricultural (primarily center pivot) irrigation from the Floridan Aquifer has become a major issue regarding water quantity for the lower Flint River system and the needs of resident aquatic and human resources. The Georgia Department of Natural Resources (GDNR), which issues groundwater withdrawal permits, has recently implemented a moratorium on new center pivot applications. Early in 2000, the Georgia Legislature passed the Flint River Drought Protection Act (FRDPA). This act authorizes the State to establish a drought abatement program for the Flint River watershed. Included under FRDPA are compensating permittees of irrigation systems for abstaining from irrigating cropland during periods of declared drought, providing methods of enforcement and penalties, and requiring a letter of concurrence or a permit from the GDNR for the construction of certain irrigation wells. The agricultural community realizes that groundwater withdrawals are unsustainable at the rate the aquifer is being depleted. Several partners, including the agricultural community, natural resource agencies, and academia, are experimenting with ways in which farmers can better conserve water resources. Research at facilities in the lower Flint River watershed includes experimenting with the utilization of less water dependent strains of crops, developing better technology to efficiently irrigate crops, and researching other aspects of irrigation and water conservation in southwest Georgia (E. Blood, JERC, pers. comm., 2000). These types of actions will help reduce future impacts to several of these listed mussels during severe droughts such as the two-year drought which continued through the Fall of 2000.

Certain Apalachicolan Region streams, some of which harbor subpopulations of these seven mussels, receive a level of State protection by being designated as outstanding resource waters, or are publicly owned and managed as wildlife management areas, parks, preserves, and historic areas. The States of Alabama, Georgia, and Florida, have collectively formed an interstate compact for the ACF Basin, approved by Congress and signed into Federal law (P.L. 105-104) November, 1997, to deal with interstate water issues. The Commission formed under this compact is currently negotiating a water allocation formula "for equitably apportioning the surface waters of the ACF Basin among the states while protecting the water quality, ecology, and biodiversity of the [basin]." The Service is actively engaged in promoting three general approaches for water management under the ACF Basin Compact that would protect and further the recovery of the six listed species occurring there. First, the Service is communicating the evidence for the ecological benefits of operating the water management system in ways that minimize departures from natural flow regimes in the remaining unimpounded river reaches of the basin. Second, the Service is encouraging alternatives to the construction of new dams to meet the growing consumptive water demands of the basin. Third, the Service is working with the States to identify measures that the Compact might facilitate to reduce the many point and non-point sources of pollution in the basin. Incorporating all three of these approaches into an ACF Basin water allocation formula and into the administration of the Compact would realize many conservation opportunities for the listed mussels.

In 1981, the Florida legislature established the "Save Our Rivers" program, providing funding for riparian lands acquisition in several streams in north Florida by both the Northwest Florida and Suwannee River Water Management Districts (NWFWMD and SRWMD, respectively). These agencies have purchased (fee simple) riparian lands and other wetlands in the following watersheds within the range of these species: Econfina Creek (37,301 ac), upper Chipola River main stem and its tributaries Marshall and Cowarts Creeks (7,378 ac), Apalachicola River (35,509 ac) (NWFWMD 1999), and over 100,000 riparian ac and 300 mi of river frontage in the Suwannee River system (R. Mattson, SRWMD, pers. comm., 2000). Additional lands are slated for acquisition, including 7,000 ac on the lower Chipola River and 5,000 ac on the Ochlockonee River (NWFWMD 1999). Although these lands may ultimately be managed for timber, no logging of riparian hardwoods has occurred in the NWFWMD to date. The purchase of these riparian lands will aid in the conservation, protection, and restoration of water resources and aquatic ecosystems in the region.

Priority Watersheds for Protection

Priority drainage regions in the United States based on numbers of at-risk fish and mussel species have been assessed by Master et al. (1998). The Florida Gulf region, which corresponds to the Apalachicolan Region minus the Suwannee River system, ranks 5th of 48 regions nationwide in this category. Small drainages in the Apalachicolan Region with subpopulations of three to four species of listed mussels (e.g., Sawhatchee, Swift, Muckalee, Kinchafoonee, Chickasawhatchee, Baker, Waddells Mill, and Dry Creeks in the ACF Basin; upper Ochlockonee River) should rank high for watershed-based restoration efforts. Studies conducted at JERC have further prioritized specific reaches of streams in the lower Flint River system critical for the conservation of mussel resources (P. Johnson, JERC, unpub. data). The high diversity remaining in these Coastal Plain streams can partially be attributed to the fact that they have relatively undisturbed riparian zones, which reduce the input of pesticides, nutrients, and helps maintain relatively undisturbed fish communities (Frick et al. 1998). The current high quality conditions of these streams will facilitate long-term protection and management of their imperiled mussel faunas.

Recently, TNC established a Freshwater Initiative with a Southern Rivers Director located in Chattanooga, Tennessee, to develop conservation strategies on focus streams in a multi-state area, based primarily on their study of critical watersheds for protecting biodiversity (Master et al. 1998). World Wildlife Fund (WWF) recently completed a conservation assessment of freshwater ecosystems in North America (Abell et al. 2000). Both WWF and American Rivers, another conservation organization promoting the welfare of rivers, have also stationed regional representatives in Chattanooga to work with partners in targeting high-biodiversity streams in the Southeast for protection and restoration.

Grassroots Support at the Watershed Level

Numerous stakeholders have realized that wise stream management, which involves restoring and protecting riparian habitat, improves water quality (Osborne and Kovacic 1993), enhances habitat for fishes (Belt and O'Laughlin 1994, Penczak 1995, Rabeni and Smale 1995), and is crucial for mussels (Neves et al. 1997). Numerous grassroots organizations have sprung up to initiate community-based, watershed restoration projects in the region. These groups, comprised of local citizenry, band together to promote water quality and aquatic habitat issues in their focus areas. In Alabama alone, the Alabama Rivers Alliance (ARA) has identified nearly 50 "grassroots watershed guardians" (ARA 1998). The ARA and their constituent watershed groups work at various levels to address a broad array of conservation issues. The importance of grassroots organizations cannot be overstressed in the conservation of riverine resources.

Various Service field offices have been forming partnerships with a legion of stakeholders to initiate several watershed-based riparian habitat restoration projects on streams having diverse mussel faunas in other parts of the Southeast (Butler et al. 1999). Seed money provided by the Service's Partners for Fish and Wildlife Program, which aids private landowners in restoring habitat, and other funding sources have been particularly instrumental in getting individual restoration programs started. TNC and other key partners have proven extraordinarily proficient at leveraging funds many times over for on-the-ground projects and other related restoration and environmental outreach endeavors. Such efforts should be implemented for the benefit of listed mussels in the Apalachicolan Region. A focus should be on agricultural watersheds, which are critical for the protection of water quality and aquatic life (Master et al. 1998).

During the past decade, TNC has played a pivotal role in establishing and coordinating community-based, watershed restoration projects throughout the United States. Demonstrating a strong commitment to imperiled aquatic resources, they have established bioreserves and other community-based, watershed restoration projects on high diversity streams. Field representatives hired by TNC or NRCS work closely with landowners and other stakeholders to conduct riparian and aquatic habitat restoration activities. The TNC has been working with the States of Alabama, Georgia, and Florida, and with the Service to protect river flows and biodiversity throughout the ACF Basin.

The Georgia Chapter of TNC recently purchased 15,105 ac of Chickasawhatchee Swamp, one of the largest freshwater swamps remaining in the Southeast. This significant wetland parcel will be managed through a land acquisition agreement with the State of Georgia. Second in size in Georgia only to Okefenokee Swamp, it is one of the priority watersheds for conservation and recovery for the shinyrayed pocketbook, Gulf moccasinshell, and oval pigtoe (see "Priority Watersheds for Protection"). In addition, it is a major recharge area for the Floridan Aquifer, and thus will benefit mussels in adjacent watersheds to the south. Purchased from The St. Joe Company, a timber company, this accomplishment demonstrates the willingness of private businesses to work with conservation organizations in the protection of our natural resources.

Riparian Habitat Restoration

The full protection of forested stream buffers is possibly the most important conservation action riparian landowners can make (Service 1980, Allan and Flecker 1993). Forested buffers are absolutely critical for maintaining healthy benthic-dependent fish communities (Armour et al. 1991, Jones et al. 1999) including mussel populations (Neves et al. 1997).

Restoration activities in priority watersheds conducted by community-based groups, TNC, and other stakeholders have helped improve riverine habitat in agricultural and other settings in many ways. Typical among these are reducing erosion by stabilizing stream banks and using no-till agricultural methods; controlling nutrient enrichment by carefully planning heavy livestock-use areas; establishing buffer zones by erecting fencing and revegetating riparian areas; developing alternative water supplies for livestock; and implementing voluntary BMPs to control run-off for a variety of agricultural, silvicultural, and construction activities. BMPs vary from state to state, as does the level of participation by landowners. For instance, Florida forestry guidelines allow a 50 percent thinning in riparian areas. In order to increase their effectiveness in protecting aquatic resources, mussels and their habitats in particular, certain BMPs should be improved, and a higher level of landowner participation should be encouraged.

Despite their current level of imperilment, Neves (1999a) remains optimistic that nearly every stream with historically or currently significant mussel populations will become suitable for restoration if impacts are reduced. Perhaps the greatest accomplishment of all is that riparian landowners and other stakeholders are proving that they can be good stewards of the land by taking increased interest and pride in aquatic resources.

Propagation, Augmentation, and Reintroduction

Water and stream habitat quality improvements in parts of the Southeast have made it possible for mussel populations to expand in certain river reaches. Such improvements in habitat conditions have come to fruition through the concerted efforts of the Corps, Tennessee Valley Authority, EPA, and other Federal agencies; State water resource and natural resource agencies; industries; municipalities; conservation organizations; and concerned citizens.

State and Federal agencies and the scientific community have cooperatively developed mussel propagation and reintroduction techniques and conducted associated research that has facilitated the augmentation of existing populations and the reintroduction of mussels into historical and/or restored habitats (Watters 1994, Neves 1997, Garner 1999). These breakthroughs have enabled natural resource managers to plan major mussel reintroduction projects (e.g., Tennessee River system). Propagation and reintroduction research will be needed to bring about recovery of the seven mussels. The Service is initiating efforts at propagating these species. Furthermore, studies are underway to better understand and eliminate threats to mussels from contaminants, aquatic nuisance species, and other environmental perturbations, which could ultimately open up new areas for mussel translocation efforts.

Public Outreach and Environmental Education

Several Federal (e.g., USFS, NRCS, EPA, USGS, Corps) and other government agencies, conservation organizations, and grassroots groups have accomplished much in the field of public outreach and environmental education, and should be commended for their collective achievements. Environmental education center pamphlets, stakeholder guides, and other outreach materials are common components of public outreach in project watersheds in many areas of the Southeast. A concerted effort needs to be expended in the Apalachicolan Region to further the case of mussel protection and recovery through public outreach and environmental education channels.

PART II

RECOVERY

A. Recovery Objectives

The goal of this recovery plan is to restore viable populations of the fat threeridge (*Amblema neislerii*), shinyrayed pocketbook (*Lampsilis subangulata*), Gulf moccasinshell (*Medionidus penicillatus*), Ochlockonee moccasinshell (*Medionidus simpsonianus*), oval pigtoe (*Pleurobema pyriforme*), Chipola slabshell (*Elliptio chipolaensis*), and purple bankclimber (*Elliptoideus sloatianus*) to the point where their protection under the ESA is no longer required.

Downlisting and delisting dates cannot be estimated at this time. A time period of at least 10 years or three generations, which ever is longer, is needed to document the long-term viability of mussel populations. Therefore, recovery in the near future is unlikely for the seven mussels addressed in this plan because of the extent of their decline, the relative isolation of their remaining subpopulations, their potential sensitivity to common pollutants, and continued threats to their habitats (see "Reasons for Decline"). Protecting their extant subpopulations and occupied habitats, therefore, is the most immediate recovery priority (see "Narrative Outline of Recovery Tasks, Task 1"). Securing these subpopulations and their occupied habitats can best be achieved at the watershed level through voluntary community conservation awareness and stewardship as outlined under "Conservation Measures."

This section of the plan includes (A) objective and measurable criteria for recognizing recovery, (B) a narrative outline of tasks for achieving recovery, and (C) Literature Cited. The recovery criteria define the conditions that must exist for the Service to consider reclassifying the five endangered species to threatened status and for delisting all seven mussels. The recovery tasks describe the management actions that are necessary to achieve the plan's goal. Both the recovery criteria and the recovery tasks address the five statutory listing/recovery factors given in Section 4(a)(1) of the ESA (see page 1).

Subpopulation criteria for downlisting to threatened status and delisting:

Table 8 lists the historic extent of occurrence, the current extent of occurrence, and the number of extant subpopulations (for purposes of this plan, subpopulations are mussels in relatively close proximity that represent a potentially reproducing group) for each species, which may or may not represent viable demographic units at present. Table 8 is a baseline for the three criteria by which we will measure recovery progress: 1) extent of occurrence in stream miles; 2) number of subpopulations/sites; and 3) viability of subpopulations. Stream miles, number of subpopulations/sites, and viability measures that are necessary for recovery vary between the species based on life-history, biogeographical, and genetic differences.

For purposes of this recovery plan, we define a viable subpopulation as some number of mussels in a particular stream reach that contains: 1) multiple age classes; 2) gravid females during the appropriate season; 3) newly recruited (not artificially propagated) juveniles; and 4) sufficient genetic variability to evolve in response to natural habitat changes without further human intervention. Ensuring the viability of the current number of subpopulations and of any additional subpopulations in the future resulting from natural recolonization or human-assisted reintroduction or augmentation is essential to the recovery of all seven mussels and protects all existing genetic variation. The number of individuals, reproductive characteristics, and genetic variability necessary for the viability of a subpopulation are currently unknown and will be developed specific to each species under task 1.3.6 and 1.3.7.

Reductions in historical extent of occurrence, number of subpopulations, and questionable subpopulation viability for each species were criteria that led to the protection of these species under the ESA. Each of the five species listed as endangered occurs in less than 50 percent of its historical extent of occurrence. While the two species listed as threatened occur in more than 50 percent of their historical range. To prevent further extirpation and extinctions, at least 50 percent of habitats for species should be protected (Soulé and Terborgh1999). Therefore, the Service will consider the fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, and oval pigtoe for reclassification to threatened status when each species has: (1) shown an increase in current range to reflect occupation of at least 50 percent of their total historical habitat; (2) at least 3 viable subpopulations in each of the watersheds (listed in Table 8) that currently supports the species (e.g., Econfina Creek, lower Flint River); and (3) at least 10 viable subpopulations in the large river basins (i.e., Apalachicola-Chattahoochee-Flint, Ochlockonee, and Suwanee Rivers) within the historical range of the species, for at least 10 years or 3 generations, whichever is longer. The subpopulation criteria were established to decrease isolation of subpopulations, avoid potential inbreeding depression, and to protect the species at the extremes of their ranges and from catastrophic events.

The increase in range and number of viable subpopulations may occur by any combination of: 1) discovering previously unknown subpopulations; 2) reintroducing subpopulations within each species' historical range; or 3) augmenting the numbers of extant subpopulations. The Service will consider the fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, oval pigtoe, Chipola slabshell, and the purple bankclimber for removal from from the *Federal List of Endangered and Threatened Wildlife and Plants* when biennial monitoring shows that an increase of the current number of subpopulation/sites and extent of occurrence is enough to ensure population viability, reduce isolation among populations, and increase the potential for genetic exchange will be necessary. Specific increases to delist are unknown currently and will be determined by completing Tasks 1.3.6, 1.3.7, and 1.3.8. To downlist and delist these seven mussels, all necessary subpopulations must be viable and secure, and all current and foreseeable threats must be identified and reduced; and the Listing/Recovery Factors have to be addressed.

The Service arrived at the extent of occurrence and number of viable subpopulations criteria primarily by considering the known historical and current distribution, the amount of existing potential habitat, the amount of habitat that is irreversibly lost for the foreseeable future, number of existing subpopulations/sites of each species, and existing scientific data and literature included in this recovery plan, regarding reproductive biology, ecology, and distribution. Tasks 1.3.6, 1.3.7, and 1.3.8 will evaluate the population biology and the extent of range that are necessary for recovery of these species to determine if the criteria are adequate. Tasks 4.2 and 7.2 will facilitate evaluation of these recovery criteria and will allow for adaptive management if these criteria are determined to be inadequate.

Fat threeridge

The fat threeridge once occupied 308 river miles (rm) within the ACF river basin but now is known to occupy only 42 percent of its historical range (128 rm, see Table 8). Its viability at eight extant sites is doubtful. These eight sites are distributed across all of its historical extent of occurrence in the Chipola and Apalachicola rivers; however, the fat threeridge has been extirpated from the Flint River, which represented over half of its historic range (see Table 1). Reintroduction of viable subpopulations to the Flint would reduce the risks of extinction, from a catastrophic event, to the majority of the existing subpopulations located in the Apalachicola River. An increase of 26 rm in the Flint River basin is needed to achieve a current extent of occurrence that is 50 percent of the total historical occurrence (from 128 to 154 rm). An increase from 0 to 3 subpopulations in the Flint River basin is necessary to support the range increase and to establish a minimum of 3 subpopulations per watershed.

Shinyrayed pocketbook

The range of the shinyrayed pocketbook once occupied 1,248 rm within the ACF and Ochlockonee river basins. It still persists at 36 sites spread over 463 rm in seven watersheds (Table 8); however, this represents a range reduction of 63 percent. An increase of 161 rm (from 463 to 624 rm) is necessary to achieve occurrence in 50 percent of its historical range. An increase in subpopulations by 8 (from 36 to 44) is necessary to meet the minimum number of subpopulations per watershed and large basin.

Gulf moccasinshell

The Gulf moccasinshell once occurred in1,142 rm in Econfina Creek and the ACF river basin, and has lost 80 percent of its historic range (Table 8). It is currently found in 21 subpopulations spread over 234 rm in 6 watersheds (Table 8). A 337 rm increase (from 234 to 571 rm) is necessary to achieve occurrence in 50 percent of its historical range. An increase of subpopulations by 4 (from 21 to 25) is necessary to meet the minimum number of subpopulations per watershed and large basin.

Ochlockonee moccasinshell

It is unknown whether any subpopulations of the Ochlockonee moccasinshell persist. In Table 8, we list the possibility of one extant subpopulation and we base the tentative 34 rm extent of occurrence on the collection of shell material at two sites in the early 1990s. An increase in tentative current range by 21 rm (from 34 to 55 rm) is necessary to achieve 50 percent of its historical range. The discovery, reintroduction, or augmentation of 9 additional subpopulations is necessary in order to achieve the minimum number of 10 viable subpopulations within a large river basin.

Oval pigtoe

Like the shinyrayed pocketbook and Gulf moccasinshell, the oval pigtoe is a wide-ranging species (1,412 rm in 11 watersheds) that has lost 73 percent of its historic extent of occurrence, but still persists in 386 rm of several watersheds (Table 8). Unlike the other two wide-spread species, one entire basin of the oval pigtoe's distribution, the Suwannee River, is disjunct from the rest, and may represent genetic differences at the species level. An increase of 320 rm (from 386 to 706 river miles) is needed to achieve occurrence in 50 percent of its historical range. An increase in subpopulations by 18 (from 36 to 54) is necessary to meet the recommended number of subpopulations per watershed and large river basin.

Chipola slabshell

The threatened Chipola slabshell currently persists in most of its historic extent of occurrence (83 of 113 rm), but is reduced to 6 subpopulations of doubtful viability within that range (Table 8). An increase in the number of subpopulations by 4 (from 6 to 10) is necessary to achieve the minimum number of subpopulations needed per large river basin. Additional subpopulations and or extent of occurrence may be necessary to delist based on results generated from Tasks 1.3.6, 1.3.7, and 1.3.8.

Purple bankclimber

The threatened purple bankclimber once occurred in 737 rm with the ACF and Ochlockonee river basins. It has lost 39 percent of its range (from 737 to 453 rm). An increase in the number of subpopulations by 9 (from 30 to 39) is necessary to achieve the minimum number of subpopulations needed per watershed and large river basin. Additional subpopulations and or extent of occurrence may be necessary to delist based on results generated from Tasks 1.3.6, 1.3.7, and 1.3.8.

Listing/Recovery Factor Criteria

The following criteria (Factors A through E) apply equally to downlisting the endangered species and to eventually delisting all seven mussels. These criteria are linked to specific recovery tasks and shall serve to measure progress in removing threats to the species that is sufficient, in combination with the population criteria, for the Service to consider downlisting or delisting the species.

Factor A: The present or threatened destruction, modification, or curtailment of a species' habitat or range. To provide assurance of subpopulation stability when any of the seven species increase to the levels specified under the population criteria, threats to their habitat must be reduced as specified under this factor. Populations of the seven species have declined in response to a wide variety of impacts upon streams and watersheds (see "Reasons for Decline, Habitat Alterations"). Therefore, reducing threats to their habitat must be accomplished through a broad application of measures for protecting water quality and quantity, and through restoration of stable natural stream channels and riparian zones as buffers from various developmental activities. Effective watershed conservation will not only serve to reduce habitat threats to the listed mussels, but will benefit all other native components of the aquatic ecosystem, including the host-fish species essential for completing the mussels' life cycles. The following criteria shall serve to indicate a reduction in habitat threats:

1) Water quality and quantity are fully supporting a designated use of fishing or fish and wildlife habitat (as reported by the States under Section 305(b) of the CWA) in all stream reaches where the seven mussels occur. Special consideration to "biocriteria" used in assessing water quality (e.g., Index of Biotic Integrity) is given. Tasks 1.1, 1.2, 1.3.4, and 3.4 will contribute towards achieving this criterion.

2) Sub-basins currently supporting subpopulations of the seven mussels and those needed for recovery are not further fragmented by new dams, water withdrawals, or other habitat alterations that may preclude the movement of host fish species between occupied sites. The sub-basins that are listed in Table 8 are the areas of relatively unfragmented habitat that the Service regards as separate watersheds for the listed mussels for management purposes, because host fishes are potentially able to move between all occupied sites within those sub-basins. Any status surveys shall assess whether new barriers to fish passage have developed since listing that have genetically separated occupied sites within a sub-basin. Tasks 1.1, 1.2, 1.3.5, 2.1, 2.2, 3.4, 4.2 will contribute towards preventing such separation.

3) Stream channels at all sites occupied by the seven mussels are stable (not actively aggrading or degrading or undergoing excessive bank erosion) and adjacent riparian zones are adequately vegetated. Task 4.1 will develop a protocol for assessing this listing/recovery criterion as part of range-wide status surveys that will collect data for the population criteria. Tasks 1.2, 1.3.3, 1.3.5, 2.1, 3.4.1, 3.5, 4.2 will contribute towards achieving this criterion.

Factor B: Overutilization for commercial, recreational, scientific, or educational purposes. There are no data that indicate that harvest was historically a limiting factor; however, harvest could be detrimental to the species at current population level. To provide assurance of population stability when any of the seven species increase to the levels specified under the population criteria, overutilization for commercial, recreational, scientific, or educational purposes that threaten their continued existence must be reduced as specified under this factor. Commercial harvest of mussels is a heavily regulated venture in parts of the Southeast and Midwest. Primarily, mussels are harvested for their shells to produce nuclei for the cultured pearl industry. The fat threeridge is a potential target species for this endeavor. However, it is now believed that with the tremendous drop in shell price for culture pearl shell nuclei in the past several years, harvest for this industry is no longer considered a current threat (see "Listing/Recovery Factor D"). Secondarily, mussels in the Apalachicolan Region have been utilized for biological supply houses for dissection in academic institutions. The purple bankclimber and possibly the fat threeridge have been used for this purpose in past years. Harvest of mussels to serve as laboratory specimens for dissection is also thought to no longer pose a threat to any of these seven species now that protection has been provided under the Act. The increasing rarity of these seven species may make them more appealing to shell collectors. This potential threat is not considered to be a significant enough problem to alter listing/recovery criteria outlined in this section. Therefore, at this time overutilization for commercial, recreational, scientific, or educational purposes is not considered a threat (see "Listing/Recovery Factor D"), thus no reclassification (downlisting or delisting) criteria are necessary. Any change that may lead to overutilization would require a change in this factor.

Factor C: Disease or predation. At this time, there are no data indicating that disease or predation are limiting factors, thus no reclassification (downlisting or delisting) criteria are necessary.

Factor D: The inadequacy of existing regulatory mechanisms. To provide assurance of population stability when any of the seven species increase to the levels specified under the population criteria, any inadequacy of existing regulatory mechanisms that threaten their continued existence must be reduced as specified under this factor. Commercial harvest of mussels, now regulated in all three states where these seven species occur, was the only regulatory mechanism that was stated in the final rule (see "Listing/Recovery Factor B"). Commercial harvest must continue to be prohibited for these species for delisting. Other existing authorities, such as the CWA, may not be fully utilized in the protection of aquatic systems. Task 1.1 will address these needs. Current numerical criteria for pollutants such as ammonia may not be protective of mussels (Augspurger et al. in prep.). Continuing research on other threats to these species may identify areas where existing regulatory mechanisms are inadequate for their protection. Tasks 1.3.3, 1.3.4, and 1.3.5 will address these concerns. Any change that may lead to overutilization due to the inadequacy of existing regulatory mechanisms would require a change in this factor.

Factor E: Other natural or man-made factors affecting its continued existence. To provide assurance of population stability when any of the seven species increase to the levels specified under the population criteria, several natural and man-made threats to their continued existence must be reduced as specified under this factor. These threats include the presence and potential introduction of non-indigenous species (especially zebra mussel and black carp), insufficient densities of host-fish species in streams supporting the seven species, inbreeding depression and other genetic considerations, and possible weak links in the species' life cycles (see "Reasons for Decline, Patterns of Imperilment"). The following criteria shall serve to indicate a reduction in natural and other man-made threats: 1) zebra mussels and black carp are not introduced nor established in the sub-basins supporting the seven species (Task 6.1); 2) relatively stable, non-imperiled populations of host fish present in each sub-basin (Task 1.4); 3) genetic diversity sufficient within sub-basins (1.3.6 and 1.3.7); and 4) weak links in life cycle of each species are identified and remedied through research, habitat improvement, propagation, translocation, or other means (all tasks).

B. Narrative Outline

1. **Preserve extant subpopulations and currently occupied habitats and ensure subpopulation viability.** To begin recovery for these seven species, it is necessary to first stem their decline by removing threats from the sites where they persist.

    1.1 **Continue to use existing legislation, regulations, and programs (e.g., the Act, CWA, FWCA, USDA, Land and Water Conservation Fund, wetland and water quality regulations, stream alteration regulations, Federal Energy Regulatory Commission relicensing) to protect the species and their habitats.** Prior to and during implementation of this recovery plan, it is critical to the species' survival that Federal and State agencies continue to protect extant subpopulations with those existing laws and regulations that address protection and conservation of water quality and quantity, the species, their intentional and unintentional harvest, and their habitats. Where current numerical criteria of certain pollutants (e.g., ammonia, Augspurger et al. in prep) may not be protective of mussels, these standards should be adjusted to better conserve mussel resources.

    1.2 **Solicit help in protecting and conserving the species and their essential habitats through the development of cooperative partnerships (e.g., community-based watershed restoration projects) with Federal and State agencies, local governments, agricultural groups, conservation organizations, landowners, and other stakeholders.** Section 7 consultation under the ESA, FWCA, and other laws and regulations can assist in the protection of species when Federal programs are involved, but implementation of these programs alone cannot recover the species. The assistance of various stakeholders working at the ecosystem and watershed level will be essential for the conservation and restoration of imperiled mussel subpopulations (Williams and Neves 1995; see "Conservation Measures"). More importantly, the support of the local community, including agricultural, silvicultural, mining, construction, and other developmental interests; local individuals; and landowners will be essential in order to meet these recovery goals. Without a partnership with the people who live and work in these watersheds and who have an influence on habitat quality, recovery efforts will be futile.

        1.2.1 **Meet with State and local government officials and regional and local planners to inform them of our strategy to recover these species and request their support.** For State and local governments to take actions and monitor recovery of these mussels, they must be informed about their recovery needs and existing opportunities.

1.2.2 Meet with private landowners and agricultural, silvicultural, mining, construction, road maintenance, and other developmental interests and try to elicit their support in implementing protection and conservation actions. The support of these groups is essential. They should be informed of current, but strictly voluntary, BMPs that could be implemented to minimize the impact of their activities on aquatic resources. Their assistance should be attained in reaching contaminant levels that are appropriate for species recovery. Where BMPs fail to adequately prevent significant impacts to mussels, they should be improved (see “Conservation Measures”). These interest groups should be encouraged to promote the safe mixing, application, storage, and disposal of pesticides, herbicides, and fertilizers; and to comply with current water quality regulations. In addition, landowners should be encouraged to consider alternative pest management approaches that do not use synthetic pesticides. County road maintenance staff should be trained in BMPs that reduce sediment input to streams.

1.2.3 Develop cooperative ventures with private landowners, and federal, state and local governments, to restore stream channels and riparian habitat. Federal and State natural resources agencies and conservation organizations, in cooperation with willing landowners, have begun to implement programs to restore riparian and aquatic habitat (see “Conservation Measures”). Programs like the Service’s Partners for Fish and Wildlife and those administered by the USDA are designed to benefit both the landowner and natural resources, and should be pursued with willing landowners to help minimize soil erosion and toxic run-off and enhance habitat for these mussel species. Additionally, the Corps has authorities under Section 1135 of the 1986 Water Resources Development Act (as amended) to conduct project modifications for improvements to the environment and conduct aquatic ecosystem restoration projects under Section 206 of the 1996 Water Resources Development Act.

1.2.4 Continue to encourage the states to incorporate conservation approaches into an ACF Basin water allocation formula, particularly as it relates to water quantity and flow rates in streams with listed mussels. The Service is communicating the evidence for the ecological benefits of operating the water management system in ways that minimize departure from natural flow regimes in the remaining unimpounded river reaches of the ACF Basin. For instance, the Service is encouraging alternatives to the construction of new dams to meet growing consumptive water demands, and is working with the States of Alabama, Georgia, and Florida, to identify measures that the compact might facilitate to reduce the many point and non-point sources of pollution in the basin. Incorporating the above approaches into a water allocation formula and into the administration of an ACF Basin Compact would realize many conservation opportunities for the listed species, particularly as they relate to water quantity issues.

1.3 Conduct life history studies and other research necessary for the species' management and recovery, determine threats, and implement management actions where needed. Neves (1999a) stated that probably the greatest hindrance to the recovery of imperiled mussels was more an issue of the biological traits of disjunct subpopulations than it was of suitable habitat. Key biological factors (e.g., population isolation, low density, reproductive failure) are impeding any natural attempts of rare species to recover themselves. Garner (1999) presented an outline of research needs required for the conservation of southeastern unionids based on a national outline of mussel research needs (NNMCC 1998).

1.3.1 Conduct life history research on the species to include such factors as reproduction, host fish identification, food habits, age and growth, and demography. Some limited information is available with regard to the life history of these species (see "Life History"). However, much additional life history information will be needed in order to successfully implement the recovery tasks. With the exception of one experiment to determine the potential for striped bass (*Morone saxatilis*) to serve as a host for the shinyrayed pocketbook, anadromous and other imperiled fishes have not been examined as potential hosts for these seven mussels.

1.3.2 Characterize the species' habitats (e.g., relevant physical, biological, chemical components) for all life history stages. These species have been able to withstand some degree of habitat degradation. However, much of their habitat has been so severely altered that the species have been extirpated from numerous stream reaches. Knowledge of species-specific micro- and macrohabitat requirements and ecological associations is needed in order to focus management and recovery efforts on particular habitat problems.

1.3.3 Determine the mechanisms and impacts of present and foreseeable threats to the species at the micro- and macrohabitat level, and on a watershed basis. Impoundments, channelization, pollution, sedimentation, and other perturbations have contributed, and may continue to contribute, to substrate, water quality, and riparian zone degradation. The mechanisms by which the species and their habitats are affected by these perturbations are poorly understood (Brim Box and Mossa 1999), and the extent to which the species can withstand these impacts is unknown. In particular, the effects of these impacts upon juveniles, potentially the weakest link in their life cycle (see "Patterns of Imperilment"), should be investigated. Also the impact of low flow conditions as it relates to reproductive success (e.g., shinyrayed pocketbook example in "Past and Present Threats"), should be explored.

In Florida, permits are currently being issued to remove deadhead logs in the Chipola River from reaches known to support populations of some of these seven species. Although no research has documented the effects of deadhead log removal on mussels and their habitat, this activity has the potential to affect their habitat and populations.

1.3.4 **Determine contaminant sensitivity for each life history stage.** Sensitivity of mussel glochidia, juveniles, and adults to common contaminants may vary significantly (see "Past and Present Threats"). The technology and methodology to determine sublethal and lethal levels of contaminants (e.g., pesticides, herbicides, heavy metals, organic compounds, excessive nutrients, other pollutants) on these species or their surrogates should be developed. The effects of multiple-toxin "cocktails" should be investigated for those compounds commonly encountered in the ACF Basin and adjacent watersheds.

1.3.5 **Investigate the need for management, including habitat improvement, based on new data including life history information and information on the impacts of existing threats.** Additional management actions where needed should be implemented in order to secure viable subpopulations of these mussels. Specific components of the species' habitats may be lacking, limiting their potential expansion, or certain activities in the watersheds may be adversely affecting the species. Habitat improvement programs will probably be needed as a prerequisite for mussel reintroduction into historical habitat, and in order to increase host fish abundance, spawning success for both mussels and host fishes, and overall survivability. Cooperative projects with willing landowners and local and state governments for the purpose of providing alternative water sources may be needed to help minimize the impacts of water withdrawal and livestock access to the streams (see Task 1.2.3). Such efforts will be needed to overcome some of the impacts to these mussels listed in Task 1.3.3.

1.3.6 **Determine the number of specimens and sex ratio required to maintain long-term viable natural subpopulations.** Inbreeding depression can be a major obstacle to a species' recovery, especially if the remaining subpopulation size is small and/or has gone through some type of genetic bottleneck (Neil et al. 1975, Avise and Hambrick 1996). The actual number of specimens in a population is not necessarily a good indication of the population's genetic viability; rather, the effective population size (EPS) is critical (Neves 1997, Garner 1999). The EPS is the size of an "ideal" population in which genetic drift takes place at the same rate as in the actual population (Chambers 1983).

Franklin (1980) suggested that the inbreeding coefficient should be limited to no more than one percent per generation. This figure implies that maintenance EPS, in the short term, should be no fewer than 50 specimens (Franklin 1980, Soulé 1980, Frankel and Soulé 1981). Because the EPS is typical for only one-third to one-fourth the actual population size (being affected by sex ratio, overlapping generations, generally nonrandom distribution of offspring, and nonrandom mating) (Soulé 1980), a population of 150 to 200 specimens is needed for short-term population maintenance. Soulé (1980) further suggests that for long-term viability, an EPS of 500 specimens is necessary, translating into population size of 1,500 to 2,000 specimens. However, Allendorf et al. (1997) considered stocks of Pacific salmon to be at high risk of extinction if EPS was below 500 individuals (Total population below 2,500 individuals) and chronic population declines are present.

The EPS of these seven species is unknown and may vary among species depending on levels of genetic diversity within and among subpopulations, fecundity, and recruitment. Density within subpopulations, sex ratios, fecundity, survivorship, recruitment, and mortality rates need to be determined for these seven mussel species in order to calculate whether their remaining subpopulations are capable of long-term self-maintenance or whether propagation and augmentation programs should be initiated. Allozyme and/or mitochondrial DNA studies should also be considered in order to assess genetic variability and viability in the remaining subpopulations of these species.

1.3.7 Conduct detailed anatomical and molecular genetic analyses of these mussels throughout their ranges. Researchers in the Southeast United States recognize that the taxonomic identity for many mussel taxa has probably not been determined (Butler 1989, Mulvey et al. 1997, Brim Box and Williams 2000), and that this information is crucial to mussel conservation (Williams and Mulvey 1997, Lydeard and Roe 1998, Roe 2000). Genetic information (e.g., allozyme, mitochondrial DNA studies) on various subpopulations of these species would be useful in determining which genetic stocks should be used in particular translocation efforts (see Task 3). Otherwise, there is the risk of inadvertent genetic swamping of species via introgressive hybridization or loss of subpopulations from outbreeding depression (Avise and Hambrick 1996, Lydeard and Roe 1998). Additional research on soft and shell anatomy, and other applicable studies should be undertaken to determine if there are any cryptic species masquerading under these seven species that may warrant specific conservation and management consideration (see "Species Descriptions and Taxonomy," oval pigtoe account).

1.3.8 Determine if increase in the current extent of occurrence to 50 percent of the total historical extent of occurrence for each species is adequate for recovery. All of the species considered within this recovery plan have experienced a decline within their historical range which was one factor that led to receiving protection under the ESA. At this time, an increase in the current extent of occurrence to 50 percent of the total historical extent of occurrence for each species is believed to be an achievable goal that will provide protection from catastrophic events and protect subpopulations at the periphery of their ranges (Soulé and Terborgh, 1999). In conjunction with tasks 1.3.6 and 1.3.7, determine if additional range increases are necessary for recovery.

1.4 **Conduct research necessary to determine if populations of host fish species are stable and implement management actions where needed.** Many mussel species require specific species or genera of host fish. Unfortunately, many species of fish have experienced declines in population abundance similar to those of mussels. Host fish populations should be assessed to ensure that stable populations are maintained so that fish species do not become a limiting factor for mussel populations.

1.4.1 **Determine culture techniques for host fish.** Host fish can be cultured in the laboratory so that wild populations are not further reduced or wild populations can be augmented if necessary.

1.4.2 **Conduct biennial monitoring of host fish populations using standard quantitative techniques.** Monitoring of host fish populations are necessary in order to ensure that no declines are occurring. Biennial monitoring is suggested to adequately assess new year class recruitment. New recruitment is especially important since several host fish identified (e.g. shiners and darters) have short life-spans and many fishes have been demonstrated to develop immunity to glochidia after initial infection (See General Reproductive Biology).

2. **Search for additional subpopulations of the species and suitable habitat.** It is probable that some currently unknown subpopulations of these seven mussels may exist. An effort should be made to search unsurveyed river reaches and to resurvey river reaches from which the species are thought to have disappeared. This activity has recently resulted in new stream and site records for some of these species (see "Distributional History and Relative Abundance").

2.1 **Develop a prioritized list by species of streams and stream reaches that should be surveyed.** A prioritized list of streams in need of surveying would help determine where limited survey funds should be spent.

2.2 **Survey to locate additional subpopulations of the species.**

2.2.1 **Complete a standardized mussel survey protocol.** A standardized survey protocol will provide QA/QC measures for consistency among surveyors and surveys over time. A draft mussel survey protocol has been developed and is currently being tested.

2.2.2 Implement surveys to locate additional subpopulations. Using the list of streams developed from task 2.1 begin survey work, to locate additional subpopulations of the species. When the protocol in task 2.2.1 is finalized, ensure that is implemented in ongoing surveys.

___**3. Determine through research and propagation technology the feasibility of augmenting extant subpopulations and reintroducing the species into historical habitat.** Mussel propagation technology and subsequent translocation is fast becoming an important tool in the recovery of native populations (Garner 1999). See Neves (1997) for a summary of captive propagation and mussel translocations and Watters (1994) for an annotated bibliography of mussel propagation studies. Severe range restriction and overall population declines characterize the status of these 7 mussels. Their recovery is not possible without augmenting some existing subpopulations and/or reintroducing subpopulations into habitat within their historical ranges.

3.1 Develop or adopt a mussel propagation, augmentation, and reintroduction plan for these seven species. A strategy must be developed or adopted to ensure appropriate procedures are followed and precautions are taken to not harm the species (e.g., mixing of stocks, introducing diseased or otherwise unfit mussels). Any existing plans could be tailored to meet the requirements of these 7 mussels, or as a subset of an overall basin plan.

3.2 Refine techniques and methodologies for propagating and translocating specimens as a prelude to potential augmentation and reintroduction efforts. Sufficient specimens of most listed mussels are not presently available to allow for the translocation of enough adults to augment or reintroduce subpopulations. These methodologies will need to be tested on a variety of species in order to increase production levels and improve survival rates of captive-propagated and translocated animals.

3.3 Determine the need, appropriateness, and feasibility of augmenting and expanding certain existing subpopulations. Many extant subpopulations may be characterized by a size or demographic composition that is insufficient to maintain long-term genetic viability (see Task 1.3.6 and "Reasons for Decline"). These subpopulations may be able to expand naturally if environmental conditions are improved. However, some subpopulations may be too small and may need to be augmented to reach a sustainable level of viability.

3.3.1 In coordination with partners, survey efforts should be undertaken to identify and prioritize extant subpopulations as a prerequisite for augmentation activities based on biological, ecological, and habitat characterization criteria. A set of biological, ecological, and habitat parameters specific to recovery factor criteria will need to be developed to determine if an existing population will provide suitable numbers of individuals for species augmentation. Prioritized subpopulations for this task will be selected based on present population size, demographic composition, population trend data, potential site threats, habitat suitability, and any other limiting factors that might decrease the likelihood of long-term benefits from population augmentation efforts.

3.4 Determine the need, appropriateness, and feasibility of reintroducing the species into prioritized stream reaches within their historical ranges. Numerous subpopulations of these mussel species have been lost from streams and stream reaches within their historical ranges. Habitat and water quality improvements have recently been documented in some stream reaches where these species once occurred (see "Conservation Measures"). However, since many extant subpopulations are isolated by impoundment or otherwise long stretches of inappropriate habitat, natural repopulation of now suitable but unoccupied historical habitat is impossible. This task will explore the possibility of reintroducing subpopulations into unoccupied historical habitat.

3.4.1 In coordination with partners, survey efforts should be undertaken to identify and prioritize sites within the species' historical ranges as a prerequisite for reintroduction activities based on biological, ecological, and habitat characterization criteria. A set of biological, ecological, and habitat characterization parameters specific to recovery factor criteria will need to be developed to determine if a site will be suitable for species reintroduction. These will include habitat suitability, substrate stability, presence of host fishes, potential site threats, and any other limiting factors that might decrease the likelihood of long-term benefits from population reintroduction efforts.

3.5 Identify and prioritize those streams, stream reaches, and watersheds most in need of protection and habitat recovery from further threats to these species and their host fishes. Streams, stream reaches, and watersheds should be prioritized for protection and habitat recovery based on a variety of factors, with emphasis on conserving the best existing habitats and stream reaches over restoring habitats. These factors include high endemicity; high diversity of imperiled species; biogeographic history of rare species; high longitudinal connectivity; presence of host fish populations; highly fragmented habitats based on host dispersal abilities; past, present, and future aquatic habitat integrity; cost effectiveness and ease of preservation, management, recovery, and restoration; landowner complexity; watershed size; existing land use patterns; public accessibility; likelihood for project success; and those systems exhibiting low resilience to disturbance (Angermeier et al. 1993, Carroll and Meffee 1994, Shute et al. 1997). Furthermore, augmentation and reintroduction activities should not be conducted at totally unprotected sites or at sites with significant uncontrollable threats.

3.6 Augment existing subpopulations where needed and establish new subpopulations within the species' historical range. Using techniques developed under Task 3.1 and 3.2, activities to augment and/or reintroduce subpopulations of these species should be undertaken.

4. Evaluate efforts and monitor subpopulation levels and habitat conditions of existing subpopulations, as well as newly discovered, introduced, or expanding subpopulations. During and after the implementation of recovery actions, the program should be evaluated, and the status of the species and their habitats must be monitored to assess progress towards recovery. Information gathered from this action and Task 3.2 will aid in refining techniques and methodologies that are critical aspects of the recovery program for these species.

4.1 Develop a comprehensive Geographic Information System (GIS) database to incorporate information on the species' entire distribution, population demographics, and various threats identified during monitoring activities. A GIS database will act as a tool to do the bookkeeping for the population criteria, and to the extent practicable, for the listing/recovery factor criteria as well. This tool will to the extent practicable, track the listing/recovery factor criteria as well (especially the channel/riparian zone condition criterion, which can be assessed during status surveys).

4.2 Conduct biennial monitoring of the seven species of listed mussels and their habitats. A standardized mussel monitoring protocol should be developed and implemented to evaluate existing, augmented, and reintroduced subpopulations for viability and long-term stability. Additionally monitoring will indicate whether recovery efforts have been successful or are in need of adaptive management practices. Biennial monitoring is suggested in order to alert resource managers to problems if recruitment is not detected or habitat quality or quantity is declining. Stream reaches with augmented and/or reintroduced subpopulations should be monitored biannually for at least 10 years to evaluate the success of these activities.

5. Develop and implement cryogenic techniques to preserve genetic material until such time as conditions are suitable for reintroduction. Cryogenic preservation of the mussel species and host fish could maintain genetic material (much like seed banks for endangered plants) from all extant subpopulations. If a population were lost to a catastrophic event, such as toxic chemical spill, cryogenic preservation could allow for the eventual reestablishment of the population using the genetic material preserved from that population.

5.1 Develop and implement cryogenic techniques for mussel species. The Ochlockonee moccasinshell is a candidate for cryogenic preservation, since only one individual specimen has been detected since 1975 (Williams and Butler, 1994).

5.2 **Evaluate the need for implementing cryogenic techniques for host fish populations.** If host fish populations are imperiled, cryogenic preservation may be necessary to prevent extinction of the host.

6. **Develop and utilize a public outreach and environmental education program.** A comprehensive outreach and environmental education program is an important part of the recovery process.

6.1 **Develop a public outreach and environmental educational program to promote an aquatic ecosystem management, community-based watershed restoration approach to manage water and aquatic habitat quality, and prevent the introduction of nonindigenous species in Apalachicolan Region streams.** The use of tools and activities (e.g., slide/video presentations, workshops, volunteer workdays, mobile displays, brochures) to achieve this task should be championed among conservation organizations; government agencies; schools; agricultural, silvicultural, and developmental groups; civic and youth groups; churches; and other watershed stakeholders. Educational materials and activities that further recovery goals, with emphasis on the ecological and human benefits to be derived from maintaining and upgrading water and aquatic habitat quality, is essential for gaining public support for this recovery program and fostering pride in and the wise stewardship of these natural resources.

6.2 **Educate law enforcement officers, natural resource managers, and the general public in identification of these species and their habitat by preparing brochures.** A guide for the identification and distribution of Florida unionids is in preparation (J.D. Williams, USGS, pers. comm., 2000). All seven species covered in this plan will be included in the guide.

7. **Assess the overall success of the recovery program and recommend actions (e.g., changes in recovery objectives, delist, implement new measures, conduct additional studies).** The recovery plan must be evaluated periodically to determine if it is on track and to recommend future actions. As more is learned about these species, the recovery objectives may need to be modified. (See also task 4.2).

7.1 **Regularly meet with all stakeholders to listen to concerns, discuss achievements, and implementation of future actions.** Stakeholder involvement will successfully allow for collaborative conservation efforts and will increase the likelihood of recovering the seven species.

7.2 **Conduct annual oversight of the recovery plan.** Review the recovery program, recommend actions, and consider adaptive management of the recovery plan implementation for these seven mussels.

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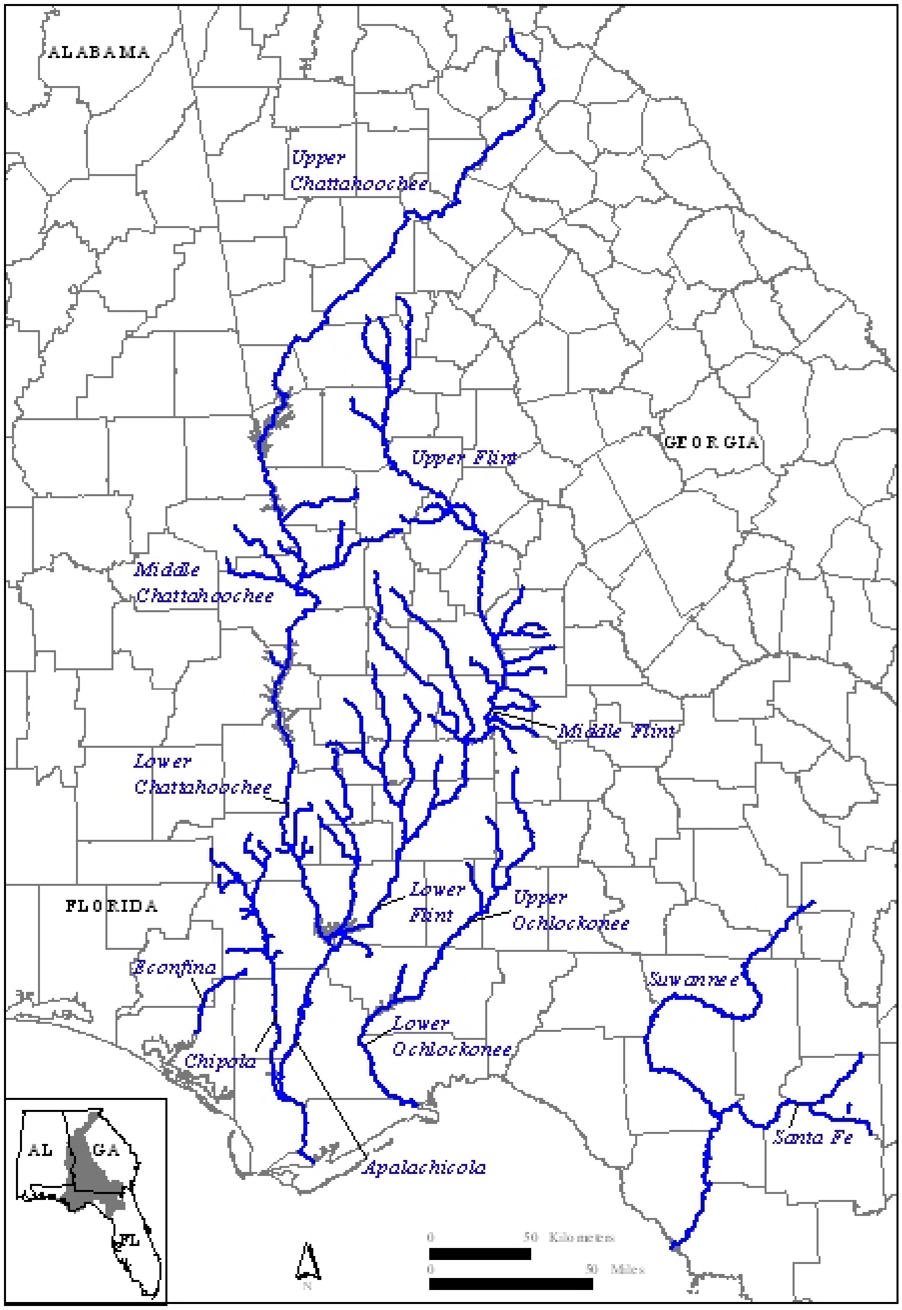

Figure 1. Apalachicolan Region drainages that support(ed) one or more mussel communities with the fat threeridge, shinyrayed pocketbook, Gulf moccasinshell, Ochlockonee moccasinshell, oval pigtoe, Chipola slabshell, and purple bankclimber.

Table 1. Fat threeridge (*Amblema neislerii*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
ACF Basin, Flint River System		
Flint River, Macon County, GA [Type Locality]	Brim Box and Williams (2000) Lea (1858a)	1981, 1976 <1858
Flint River, Dougherty County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1929 ?
Flint River, Baker and Mitchell Counties, GA	R.S. Butler (Service, unpub. data)	1988 R
Flint River, Decatur County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1991 R, 1954 ?
ACF Basin, Apalachicola River System		
Apalachicola River, Gadsden and Jackson Counties, FL	Brim Box and Williams (2000) Heard (1975) Heard (1964) Clench and Turner (1956) Williams and Fradkin (1999)	1992 R, 1987-88 R, 1986, 1981, 1977-78, 1970, 1954 1974-75 R 1963 ? A
Apalachicola River, Calhoun and Liberty Counties, FL	Brim Box and Williams (2000) Williams and Fradkin (1999)	1996, 1975, 1970 A
Swift Slough, Liberty County, FL	J.D. Williams (USGS, unpub. data)	2000
Apalachicola River, Franklin and Gulf Counties, FL	Brim Box and Williams (2000) Richardson and Yokley (1996)	1996, 1991 1995
ACF Basin, Chipola River System		
Chipola River, Calhoun County, FL [1]	Brim Box and Williams (2000) Heard (1975) van der Schalie (1940) Clench and Turner (1956)	1991 R, 1986-88, 1974-75, 1954, 1924, 1915-18 1974-75 1915-18 ?
Chipola River, Gulf County, FL	Brim Box and Williams (2000) van der Schalie (1940)	1990-91, 1988, 1984, 1967, 1930, 1918 1915-18

CODES: < = collected prior to (date), and R = relic shells only.

[1] Van Hyning (1925) reported finding this species without giving a specific date of collection. Brim Box and Williams (2000) reported three separate museum lots of 17 specimens each dated August 24, 1924, that probably correspond to Van Hyning's (1925) collection.

Table 2. Shinyrayed pocketbook (*Lampsilis subangulata*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
ACF Basin, Chattahoochee River System		
Chattahoochee River, Fulton County, GA	Brim Box and Williams (2000)	?
Chattahoochee River, Muscogee County, GA; and Russell County, AL [Type Locality]	J.D. Williams (USGS, pers. comm., 2000) Lea (1840) Brim Box and Williams (2000)	1999 R <1840 ?
Mill Creek, Russell County, AL [2]	Brim Box and Williams (2000)	?
Uchee Creek, Russell County, AL	Brim Box and Williams (2000) Jenkinson (1973) Clench and Turner (1956)	1992, 1982-84, 1972, 1955, 1915 1972 ?
Little Uchee Creek, Russell County, AL	Jenkinson (1973), Brim Box and Williams (2000)	1972
Cowikee Creek, Barbour County, AL	Brim Box and Williams (2000) Clench and Turner (1956)	1955 ?
Sawhatchee Creek, Early County, GA	Brim Box and Williams (2000)	1994, ?
Kirkland Creek, Early County, GA [3]	Brim Box and Williams (2000)	1992 R, ?
ACF Basin, Flint River System		
Line Creek; Coweta, Fayette, and Spalding Counties; GA	G.R. Dinkins (Dinkins Biological, pers. comm., 1999) Butler and Brim Box (1995) Brim Box and Williams (2000)	1997 1995 1992, 1981, 1964-66
Whitewater Creek, Fayette County, GA	Roe (2000) Butler and Brim Box (1995)	1997 1995
Flint River, Fayette and Spalding Counties, GA	G.R. Dinkins (pers. comm., 1999) Brim Box and Williams (2000)	1997 1992, 1966

2 Brim Box and Williams (2000) note this uncatalogued, undated museum record as simply "Mill Branch near Columbus" under their heading for Muscogee County, Georgia, records. There is no Mill Branch (nor Mill Creek) in the vicinity of Columbus in Georgia, at least according to modern maps. However, there is a Mill Creek in Phenix City, Russell County, Alabama, which Brim Box and Williams (2000) thought was the correct locality for this record. Located directly across the Chattahoochee River from Columbus, Muscogee County, this now heavily urbanized locality probably represents the more appropriate locality for a single specimen that may have been collected in the 19th century.

3 Brim Box and Williams (2000) report a historical record of unknown collection date (mid-1900s?) as "Dry Creek 2 mi NE of Jakin" in Early County, Georgia, under their heading for Flint River System records. The stream at this locality is actually Kirkland Creek, a tributary of the Chattahoochee River, from which Brim Box and Williams (2000) found a relic shell in 1992.

Table 2. Shinyrayed pocketbook (*Lampsilis subangulata*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Flint River, Meriwether and Pike Counties, GA	Brim Box and Williams (2000)	1992 R, 1981, 1965-68
Patsiliga Creek, Taylor County, GA	Clench and Turner (1956) Brim Box and Williams (2000)	<1956 ?
Flint River, Macon County, GA	Brim Box and Williams (2000)	1981
Gum Creek, Crisp County, GA	Brim Box and Williams (2000)	1961
Swift Creek, Crisp and Worth Counties, GA	L. Andrews (Service, pers. comm., 2000) H.N. Blalock-Herod (USGS, pers. comm., 1999)	2000 1997
Jones Creek, Worth County, GA	P. Johnson (JERC, unpub. data) Brim Box and Williams (2000) Clench and Turner (1956)	1999 1933 ?
Abrams Creek, Worth County, GA [4]	P. Johnson (unpub. data) Brim Box and Williams (2000)	1999 ?
Mill Creek, Worth County, GA	P. Johnson (unpub. data) Brim Box and Williams (2000) Clench and Turner (1956)	1999 1933 ?
Muckalee Creek, Lee County, GA	P. Johnson (unpub. data) H.N. Blalock-Herod (pers. comm., 1999) G.R. Dinkins (pers. comm., 1999) Brim Box and Williams (2000)	1999 1997 1995 1992
Kinchafoonee Creek, Webster County, GA	P. Johnson (unpub. data) G.R. Dinkins (pers. comm., 1999) Brim Box and Williams (2000)	1999 1995 1992, ?
Kinchafoonee Creek; Lee, Sumter, and Terrell Counties; GA	P. Johnson (unpub. data) G.R. Dinkins (pers. comm., 1999) Brim Box and Williams (2000)	1999 1995 1992
Fowlton Creek, Lee County, GA	P. Johnson (unpub. data)	1999 R
Flint River, Dougherty County, GA	Clench and Turner (1956) Brim Box and Williams (2000)	<1956 ?
Cooleewahee Creek, Baker County, GA	P. Johnson (unpub. data)` Brim Box and Williams (2000) Clench and Turner (1956)	1999 1992-95, 1958, 1929 ?

[4] Brim Box and Williams (2000) report several other records with similar museum accession numbers with localities identical to that reported for other species by Clench and Turner (1956). This record probably represents either a museum record that was overlooked at the time Clench and Turner (1956) conducted their study, or was collected by them but inadvertently omitted from their publication.

Table 2. Shinyrayed pocketbook (*Lampsilis subangulata*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Ichawaynochaway Creek, Calhoun County, GA	P. Johnson (unpub. data)	1999
Ichawaynochaway Creek, Baker County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1992, 1958, 1929 ?
Chickasawhatchee Creek, Terrell County, GA	H.N. Blalock-Herod (pers. comm., 1999) Brim Box and Williams (2000)	1997 1992
Chickasawhatchee Creek, Baker County, GA	Gerry Dinkins (Dinkins Biological Consulting, pers. comm., 2001) P. Johnson (unpub. data) Brim Box and Williams (2000)	2001 1999 1992
Aycocks Creek, Miller County, GA	P. Johnson (unpub. data) Brim Box and Williams (2000)	1999 R 1992 R
Spring Creek, Early County, GA	P. Johnson (unpub. data)	1999
Dry Creek, Early County, GA [5]	Brim Box and Williams (2000)	?
Spring Creek, Miller County, GA	L. Andrews (pers. comm., 2000) H.N. Blalock-Herod (pers. comm., 1999) Brim Box and Williams (2000)	2000 1997 1992 R
Spring Creek, Decatur and Seminole Counties, GA	P. Johnson (unpub. data) H.N. Blalock-Herod (pers. comm., 1999) R.S. Butler (unpub. data) Brim Box and Williams (2000) Clench and Turner (1956)	1999 1997 1993 1992, 1988, 1953 ?
Flint River, Decatur County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1954 ?
ACF Basin, Apalachicola River System		
Mosquito Creek, Gadsden County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1962, 1953 ?
ACF Basin, Chipola River System		
Marshall (Big) Creek, Jackson County, FL	R.S. Butler (unpub. data) Brim Box and Williams (2000) Clench and Turner (1956)	1987 R 1967, 1954 ?
Cowarts (Reedy) Creek, Houston County, AL	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916

5 The Dry Creek record reported by Brim Box and Williams (2000) is a tributary to Spring Creek in the Flint River system. Most of Early County drains into the Chattahoochee River system.

Table 2. Shinyrayed pocketbook (*Lampsilis subangulata*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Cowarts (Reedy) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1978, 1954 ?
Chipola River, Jackson County, FL	R.S. Butler (unpub. data) Brim Box and Williams (2000) R.S. Butler (unpub. data) van der Schalie (1940) Walker (1905a) Clench and Turner (1956)	2000 1991 R, 1981, 1953-54, 1918 1987 R 1915-18 1902 ?
Baker Creek, Jackson County, FL	R.S. Butler (unpub. data)	1994 R
Waddells Mill Creek, Jackson County, FL	R.S. Butler (unpub. data)	1999
Spring Creek, Jackson County, FL [6]	Brim Box and Williams (2000) van der Schalie (1940)	1991 R, 1932-33 1915-18
Dry Creek, Jackson County, FL	H.N. Blalock-Herod (unpub. data) R.S. Butler (unpub. data) Brim Box and Williams (2000)	2000 1993 1988
Rocky Creek, Jackson County, FL [7]	Brim Box and Williams (2000)	1953
Chipola River, Calhoun County, FL	Brim Box and Williams (2000) van der Schalie (1940) Clench and Turner (1956)	1990-91, 1986-88, 1980-83, 1974, 1964-67, 1954-55, 1918 1915-18 ?
Ochlockonee River System		
Ochlockonee River, Thomas County, GA	J.D. Williams (pers. comm.)	1993
Little Ochlockonee River, Thomas County, GA	J.D. Williams (unpub. data)	1993
Ochlockonee River, Grady County, GA	J.D. Williams (unpub. data) Clench and Turner (1956)	1993, 1974, 1964, 1954, 1930 ?
Barnetts Creek, Grady and Thomas Counties, GA	J.D. Williams (unpub. data)	1993

6 There are two Spring Creeks in Jackson County, Florida, both in the Chipola River system. The one recorded here is an eastern tributary to the Chipola River near Marianna.

7 Brim Box and Williams (2000) note a record from "Chipola River system (a creek) 2.4 mi. NNW of Sink Creek." This locality probably refers to Rocky Creek, Jackson County, Florida, as another record with the same locality, same date, and a similar catalog number is at the Museum of Comparative Zoology stating Rocky Creek as the stream name. This record was probably made by Clench and Turner (1956), who worked at this museum, but was inadvertently omitted from their publication.

Table 2. Shinyrayed pocketbook (*Lampsilis subangulata*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Ochlockonee River, Gadsden and Leon Counties, FL [8]	J.D. Williams (unpub. data) Wright (1897)	1993, 1988, 1963-64, 1957, 1954, 1947, 1930-34 <1897
Little River, Gadsden County, FL	J.D. Williams (unpub. data) Clench and Turner (1956)	1954 ?
Ochlockonee River, Liberty County, FL	J.D. Williams (unpub. data.) Clench and Turner (1956)	1967 ?

CODES: < = collected prior to (date), A = archeological record, and R = relic shells only.

[8] This is the type locality for *Unio kirklandianus*, which is considered a synonym of *Lampsilis subangulata* (see "Species Descriptions and Taxonomy").

Table 3. Gulf moccasinshell (*Medionidus penicillatus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
Econfina Creek System		
Econfina Creek, Bay County, FL	J.D. Williams (USGS, unpub. data) Johnson (1977)	1993, 1987, 1970, 1961 ?
ACF Basin, Chattahoochee River System		
Chattahoochee River, Fulton County, GA	Brim Box and Williams (2000)	1977
Chattahoochee River, DeKalb County, GA [9]	Lea (1857a)	<1857
Mulberry Creek, Harris County, GA [10]	Clench and Turner (1956) Johnson (1977) Brim Box and Williams (2000)	<1956 ? ?
Chattahoochee River, Muscogee County, GA; and Russell County, AL [9]	Lea (1857a) Brim Box and Williams (2000)	<1857 ?
Uchee Creek, Russell County, AL	Brim Box and Williams (2000) Jenkinson (1973)	1982, 1972 1972
Little Uchee Creek, Lee County, AL	Jenkinson (1973), Brim Box and Williams (2000)	1972
Little Uchee Creek, Russell County, AL	Jenkinson (1973), Brim Box and Williams (2000)	1972
Sawhatchee Creek, Early County, GA [11]	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1993-95, 1992 R, 1953 ? ?
Kirkland Creek, Early County, GA	Brim Box and Williams (2000)	1995
ACF Basin, Flint River System		
Line Creek, Coweta and Fayette Counties, GA	Brim Box and Williams (2000)	1981, 1964

9 According to Johnson (1977), Clench and Turner (1956) erroneously restricted the type locality of *Unio penicillatus* to the first of three localities mentioned in the original description ("Chattahoochee River, near Columbus [Muscogee County"]), when actually the figured holotype was from the "Flint River, near Albany [Dougherty County"] locality. The third locality was "Atlanta, DeKalb County, Georgia." Clench and Turner (1956) thought this latter locality was in error, mistaking the locality for the Altamaha River system, and not realizing that the Chattahoochee River flowed from northeast to southwest of Atlanta.

10 Brim Box and Williams (2000) list a record as "Chattahoochee River drainage near Columbus [Muscogee County]." This may represent a tributary other than Mulberry Creek, but is included here because of the Clench and Turner (1956) and Johnson (1977) records.

11 Clench and Turner (1956) record a Sawhatchee Creek site ("about 14 mi. NW Donalsonville, Early Co."), which Johnson (1977) erroneously recorded as being in Seminole County.

Table 3. Gulf moccasinshell (*Medionidus penicillatus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Whitewater Creek, Fayette County, GA	H.N. Blalock-Herod (USGS, pers. comm., 1999) Butler and Brim Box (1995), Brim Box and Williams (2000)	1997 1995
Flint River, Meriwether and Pike Counties, GA	Brim Box and Williams (2000)	1967, 1965
Patsiliga Creek, Taylor County, GA [12]	Brim Box and Williams (2000)	<1956
Sandy Mount Creek, Dooly County, GA [13]	Clench and Turner (1956) Johnson (1977) Brim Box and Williams (2000)	<1956 ? ?
Turkey Creek, Dooly County, GA [14]	Brim Box and Williams (2000)	<1956
Flint River, Crisp and Sumter Counties, GA	Brim Box and Williams (2000)	1976
Gum Creek, Crisp County, GA	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1929 ? ?
Cedar Creek, Crisp County, GA	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1992 R, 1929 ? ?
Swift Creek, Crisp County, GA	L. Andrews (Service, pers. comm., 2000) Brim Box and Williams (2000)	2000 1992
Jones Creek, Worth County, GA	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1933 ? ?
Abrams Creek, Worth County, GA	Johnson (1977) Brim Box and Williams (2000)	<1977 ?
Mill Creek, Worth County, GA	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1978, ? ? ?
Muckalee Creek, Lee County, GA	Brim Box and Williams (2000)	1992

12 Since Brim Box and Williams (2000) report several other records with similar museum accession numbers with localities identical to that reported for other species by Clench and Turner (1956), this record probably represents either a museum record that was overlooked at the time Clench and Turner (1956) conducted their study, or was collected by them but inadvertently omitted from their publication.

13 Clench and Turner (1956) list a locality simply as "[s]tream, 6 mi. N Vienna, Dooly Co.," which Johnson (1977) apparently interpreted as being from Sandy Mount Creek, in the Pennahatchee Creek system. This is probably correct (Brim Box and Williams 2000), although Sandy Mount Creek is closer to 3 miles (mi) N of Vienna (see footnote 14).

14 Brim Box and Williams (2000) note a museum record from "Flint River drainage (a stream) 6 mi NW of Vienna." This locality probably refers to Turkey Creek, also in the Pennahatchee Creek system (see footnotes 12 and 13).

Table 3. Gulf moccasinshell (*Medionidus penicillatus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Kinchafoonee Creek, Webster County, GA	P. Johnson (JERC, unpub. data) Brim Box and Williams (2000)	1999 1995, 1992
Kinchafoonee Creek; Lee, Sumter, and Terrell Counties; GA	P. Johnson (unpub. data) Brim Box and Williams (2000)	1999 1992
Flint River, Dougherty County, GA [9] [Type Locality]	Brim Box and Williams (2000) Lea (1857a)	1991 <1857
Flint River, Baker and Mitchell Counties, GA	Brim Box and Williams (2000) Johnson (1977)	1958 ?
Chickasawhatchee Creek, Terrell County, GA	R.S. Butler (Service, unpub. data) H.N. Blalock-Herod (pers. comm., 1999) Brim Box and Williams (2000)	1998 1997 1992
Chickasawhatchee Creek, Calhoun and Dougherty Counties, GA	P. Johnson (unpub. data) H.N. Blalock-Herod (pers. comm., 1999)	1999 1997
Chickasawhatchee Creek, Baker County, GA	Brim Box and Williams (2000)	1992
Ichawaynochaway Creek, Calhoun County, GA	Johnson (1977)	?
Ichawaynochaway Creek, Baker County, GA [15]	Wright (1900) Clench and Turner (1956) Johnson (1977) Brim Box and Williams (2000)	<1900 ? ? ?
Flint River, Decatur County, GA	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1954 ? ?
Spring Creek, Decatur County, GA	Brim Box and Williams (2000)	?
ACF Basin, Apalachicola River System		
Apalachicola River, Gadsden and Jackson Counties, FL	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977) Williams and Fradkin (1999)	1954 ? ? A
Apalachicola River, Liberty County, FL	Williams and Fradkin (1999)	A
ACF Basin, Chipola River System		

15 Clench and Turner's (1956) record for "Branch of Flint River, Baker Co." is most likely a reiteration of the identically stated locality for *Unio kingii*, and probably refers to Ichawaynochaway Creek, the largest tributary to the Flint River. A population of the Gulf moccasinshell still occurs in the upper portion of the system. The only other sizable direct tributary to the Flint River in Baker County is the much smaller Cooleewahee Creek, where no population of this species has ever been found. Brim Box and Williams' (2000) record for this locality is probably also based on the earlier record of Clench and Turner (1956).

Table 3. Gulf moccasinshell (*Medionidus penicillatus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Spring Creek, Jackson County, FL [16]	van der Schalie (1940) Brim Box and Williams (2000) Johnson (1977)	1915-18 1916 ?
Spring Creek, Houston County, AL [16]	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916
Big Creek, Houston County, AL [17]	van der Schalie (1940) Brim Box and Williams (2000) Johnson (1977)	1915-18 1916 ?
Marshall (Big) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1954, ? ? ?
Cowarts (Reedy) Creek, Houston County, AL	van der Schalie (1940) Brim Box and Williams (2000) Clench and Turner (1956) Johnson (1977)	1915-18 1916 ? ?
Cowarts (Reedy) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1957, 1954 ?
Chipola River, Jackson County, FL	Brim Box and Williams (2000) Heard (1975) van der Schalie (1940) Walker (1905a) Clench and Turner (1956)	1975, 1965, 1954, 1918 1974-75 1915-18 1902 ?
Waddells Mill Creek, Jackson County, FL	R.S. Butler (unpub. data) D.N. Shelton (Alabama Malacological Research Center [AMRC], pers. comm., 1998) Brim Box and Williams (2000)	1999 1994 1990, ?
Baker Creek, Jackson County, FL	Brim Box and Williams (2000)	1994

16 There are two Spring Creeks in Jackson County, Florida, both in the Chipola River system. One is a western tributary to Big Creek, which crosses the Alabama state line (the first one listed in the table), while the other is an eastern tributary to the Chipola River near Marianna.

17 Johnson (1977) includes a record as “Reedy Creek, nr. Madrid [Houston Co.]. Madrid is actually near Big Creek.

Table 3. Gulf moccasinshell (*Medionidus penicillatus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Spring Creek, Jackson County, FL [16, 18]	Brim Box and Williams (2000) van der Schalie (1940)	1932-33 1915-18
Dry Creek, Jackson County, FL [19]	R.S. Butler (unpub. data) Clench and Turner (1956)	1988 R ?
Rocky Creek, Jackson County, FL	Brim Box and Williams (2000)	1953
Chipola River, Calhoun County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1988, 1954, 1952 ?

CODES: < = collected prior to (date), A = archeological record, and R = relic shells only.

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18 van der Schalie (1940) notes a locality in his distributional table as "creek, 5 mi. NE of Marianna, Jackson Co., [Florida]." This locality approximately coincides with Blue Springs (Brim Box and Williams 2000), a first magnitude spring (discharge of at least 100 cubic feet per second) that serves as the source of Spring Creek (see footnote 16), which has been impounded at the U.S. 90 crossing as Merritts Mill Pond since 1868 (N. Young, Florida Fish and Wildlife Conservation Commission, pers. comm., 1998). The historical site was probably the outfall of the springs before dam improvements backed the water up to the main spring, as no other surface stream is located in this area. van der Schalie's Spring Creek historical site ("[2.5] - 3 mi. SE of Marianna") is located in the vicinity of the U.S. 90 crossing, approximately 4 mi downstream of Blue Springs.

19 Clench and Turner's (1956) locality is stated as "small creek, [7.5] mi. NW Altha [Jackson County, Florida]." This locality coincides with the vicinity of the lowermost portion of Dry Creek. However, Brim Box and Williams (2000) could not locate any museum collections from this locality.

Table 4. Ochlockonee moccasinshell (*Medionidus simpsonianus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
Ochlockonee River System		
Ochlockonee River, Grady County, GA [Type Locality] [20]	J.D. Williams (USGS, unpub. data) Walker (1905b) Clench and Turner (1956) Johnson (1977)	1993 R, 1988 R <1905 ? ?
Ochlockonee River, Gadsden and Leon Counties, FL [20]	J.D. Williams (unpub. data) Williams and Butler (1994) Heard (1975) W.H. Heard (Florida State University [FSU], pers. comm, 1994) Clench and Turner (1956) Johnson (1977)	1993, 1987 R, 1974, 1968-71, 1931-33, 1920, ? 1990 1974-75 1965 ? ?
Little River, Gadsden County, FL [20]	Clench and Turner (1956) Johnson (1977)	<1956 ?
Ochlockonee River, Liberty and Wakulla Counties, FL [20]	Clench and Turner (1956) Johnson (1977)	<1956 ?

CODES: < = collected prior to (date), and R = relic shells only.

20 Johnson (1977) remarked that this species "...was collected in some numbers from a single locality in 1934 and again from several localities in 1954," but without giving specific locality data. The latter date may refer to a collection made by Clench and Turner (1956), although no specimens with either date were located in major museums in a thorough search by J.D. Williams (USGS, unpub. data).

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
Econfina Creek System		
Econfina Creek, Bay County, FL	J.D. Williams (USGS, unpub. data)	1993, 1970
ACF Basin, Chattahoochee River System		
Chattahoochee River, Muscogee County, GA; and Russell County, AL [Type Locality]	Lea (1857b) Brim Box and Williams (2000)	<1857 ?
Randall Creek, Muscogee County, GA [21]	Brim Box and Williams (2000)	?
Uchee Creek, Russell County, AL	Brim Box and Williams (2000) Jenkinson (1973)	1984, 1982, 1972, 1955 1972
Little Uchee Creek, Lee County, AL	Jenkinson (1973), Brim Box and Williams (2000)	1972
Chattahoochee River, Early County, GA; and Houston County, AL	Williams and Fradkin (1999)	A
Sawhatchee Creek, Early County, GA [22]	Brim Box and Williams (2000) Clench and Turner (1956)	1994, 1992 R, ? ?
ACF Basin, Flint River System		
Line Creek, Coweta and Fayette Counties, GA	Brim Box and Williams (2000)	1992
Flint River, Decatur County, GA	Sandy Abbott (Service, pers. comm., 2001)	2000
Flint River, Fayette and Spalding Counties, GA	Brim Box and Williams (2000)	1992
Flint River, Meriwether and Pike Counties, GA	R. C. Stringfellow (Columbus University, pers. comm., 2000) L. Andrews (Service, pers. comm., 2000) Brim Box and Williams (2000)	2000 2000 1973, 1965
Red Oak Creek, Meriwether County, GA	H.N. Blalock-Herod (USGS, pers. comm., 1999)	1997

21 Brim Box and Williams (2000) list several records as "Chattahoochee River drainage near Columbus [Muscogee Co.]." These probably represent tributary streams in addition to Randall Creek.

22 There are two published records for Sawhatchee Creek. Clench and Turner (1956) record one as "4 mi. NW Donalsonville, Seminole Co. [Georgia]," while Brim Box and Williams (2000) record the other as "14 mi NW of Donaldsonville [sic] [Early County]." As Sawhatchee Creek does not occur in Seminole County but does lie northwest of Donalsonville, we will assume that both records refer to the same Sawhatchee Creek, Early County, site.

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Patsiliga Creek, Taylor County, GA [23]	Lea (1865) Clench and Turner (1956) Brim Box and Williams (2000)	<1865 ? ?
Little Patsiliga Creek, Taylor County, GA [23]	Clench and Turner (1956) Brim Box and Williams (2000)	<1956 ?
Flint River, Macon County, GA [24]	Brim Box and Williams (2000) Lea (1857a)	1981, 1976, 1958 <1857
Sandy Mount Creek, Dooly County, GA [25]	Brim Box and Williams (2000) Clench and Turner (1956)	1929, ? ?
Turkey Creek, Dooly County, GA	L. Andrews (pers. comm., 2000)	2000
Gum Creek, Crisp County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1961, ? ?
Cedar Creek, Crisp County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1954, 1929 ?
Swift Creek, Crisp County, GA	L. Andrews (pers. comm., 2000) Clench and Turner (1956) Brim Box and Williams (2000)	2000 ? ?
Chokee Creek, Lee County, GA [26]	Clench and Turner (1956) Brim Box and Williams (2000)	<1956 ?
Jones Creek, Worth County, GA	P. Johnson (JERC, unpub. data) Brim Box and Williams (2000) Clench and Turner (1956)	1999 1933 ?

23 This is the type locality for *Unio amabilis*, which is considered a synonym of *Pleurobema pyriforme* (see "Species Descriptions and Taxonomy"). Brim Box and Williams (2000) state the type locality as being "Butler, Taylor County, [Flint River drainage], Georgia." In their historical records for Taylor County, Brim Box and Williams (2000) list Patsiliga Creek, Little Patsiliga Creek, and Flint River drainage. The type locality is probably Patsiliga Creek, which lies closer to Butler than does Little Patsiliga Creek.

24 The type locality for *Unio bulbosus*, which is considered a synonym of *Pleurobema pyriforme* (see "Species Descriptions and Taxonomy"), is the "Flint River, near Macon, Georgia." Clench and Turner (1956) stated that the actual type locality was "very probably the Flint River, Macon Co., Georgia" as the city of Macon is on the Ocmulgee River (Altamaha River system) approximately 30 mi from the Flint River.

25 Clench and Turner (1956) list a locality simply as "stream, 6 mi. N Vienna, Dooly Co.," which Johnson (1977) apparently interpreted as representing Sandy Mount Creek, although this stream is only about 3 mi N of Vienna.

26 Brim Box and Williams (2000) list two museum records with the identical locality of "Flint River drainage (a creek) near Chokee and DeSoto [Lee County, Georgia]," while Clench and Turner list a site as "Lee Creek, Chokee, Lee Co." The Chokee Creek system occupies this area. We will assume that Clench and Turner (1956) confused the county name with the stream name, and that these references represent possibly a single collection from Chokee Creek.

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Abrams Creek, Worth County, GA	J. Brim Box (USGS, pers. comm., 2000) Brim Box and Williams (2000) Clench and Turner (1956)	1994 R 1933 ?
Mill Creek, Worth County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1933 ?
Muckalee Creek, Schley County, GA	P. Johnson (unpub. data)	1999
Muckalee Creek, Lee County, GA	P. Johnson (unpub. data) H.N. Blalock-Herod (pers. comm., 1999) Brim Box and Williams (2000)	1999 1997 1992
Kinchafoonee Creek, Webster County, GA	P. Johnson (unpub. data) Brim Box and Williams (2000)	1999 1992, 1961
Kinchafoonee Creek; Lee, Sumter, and Terrell Counties; GA	P. Johnson (unpub. data) Brim Box and Williams (2000)	1999 1992
Flint River, Dougherty County, GA	Clench and Turner (1956) Brim Box and Williams (2000)	<1956 ?
Flint River, Baker and Mitchell Counties, GA	Brim Box and Williams (2000)	?
Cooleewahee Creek, Baker County, GA	Brim Box and Williams (2000)	1992, 1958
Little Pachitla Creek, Calhoun County, GA	P. Johnson (unpub. data)	1999 R
Chickasawhatchee Creek, Baker County, GA	Gerry Dinkins (Dinkins Biological Consulting, pers. comm., 2001)	2001
Chickasawhatchee Creek, Terrell County, GA	R.S. Butler (Service, unpub. data) Brim Box and Williams (2000)	1998 1992
Chickasawhatchee Creek, Doughtery County, GA	H.N. Blalock-Herod (pers. comm., 1999)	1997
Chickasawhatchee Creek, Meriwether County, GA	H.N. Blalock-Herod (pers. comm., 1999)	1997
Dry Creek, Early County, GA	Brim Box and Williams (2000)	?
Spring Creek, Miller County, GA	L. Andrews (pers. comm., 2000) H.N. Blalock-Herod (pers. comm., 1999) Brim Box and Williams (2000)	2000 1997 1992 R
Spring Creek, Decatur County, GA [27]	Wright (1899), Johnson (1967b), Brim Box and Williams (2000)	<1899

[27] The type locality for *Unio harperi*, which is considered a synonym of *Pleurobema pyriforme* (see "Species Descriptions and Taxonomy"), was stated as the Altamaha, Suwannee, and Flint Rivers. In the original description, Wright (1899) stated "[t]wo adults were first received from the Altamaha River, Liberty County, [Georgia]. Later three others came from the Suwannee River, Madison County, [Florida], and still later twenty others from Spring Creek, a branch of the Flint River, in Decatur County, [Georgia]." Both Clench and Turner (1956) and Johnson (1967b) stated that Wright was in error in naming the Altamaha River the type locality due to the fact that this genus is not known from this southern Atlantic Slope system. Johnson (1967b) restricted the type locality to Spring Creek, Decatur County, Georgia, because this is "where the majority of the [type] specimens were found."

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
ACF Basin, Apalachicola River System		
Apalachicola River, Gadsden and Jackson Counties, FL	Percy (1976), Williams and Fradkin (1999), Brim Box and Williams (2000)	A
Apalachicola River, Liberty County, FL	Williams and Fradkin (1999)	A
ACF Basin, Chipola River System		
Spring Creek, Jackson County, FL [28]	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916
Spring Creek, Houston County, AL [28]	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916
Big Creek, Houston County, AL	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916
Marshall (Big) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1954, 1916 ?
Rocky Creek, Houston County, AL	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 1916
Cowarts (Reedy) Creek, Houston County, AL	van der Schalie (1940) Brim Box and Williams (2000) Clench and Turner (1956)	1915-18 1916 ?
Cowarts (Reedy) Creek, Jackson County, FL	Brim Box and Williams (2000)	1978, 1954
Chipola River, Jackson County, FL	Brim Box and Williams (2000) Walker (1905a)	1991, 1987, 1954 1902
Waddells Mill Creek, Jackson County, FL	R.S. Butler (unpub. data)	1999
Baker Creek, Jackson County, FL	Brim Box and Williams (2000)	1994, 1990
Spring Creek, Jackson County, FL [28, 29]	Brim Box and Williams (2000)	?
Dry Creek, Jackson County, FL	J.D. Williams (USGS, unpub. data) R.S. Butler (unpub. data) Brim Box and Williams (2000)	2000 1993 1987-88
Rocky Creek, Jackson County, FL	R.S. Butler (unpub. data) Brim Box and Williams (2000)	1999 1953

28 There are two Spring Creeks in Jackson County, both in the Chipola River system. One is a western tributary to Big Creek, which crosses the Alabama state line (the first one listed in the table), while the other is an eastern tributary to the Chipola River near Marianna.

29 Brim Box and Williams (2000) note a museum record as "Chipola River system near Marianna [Jackson County]." This record probably refers to Spring Creek (see footnote 28), where they have placed a dot on the historical distribution map for this species.

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Chipola River, Calhoun County, FL	Brim Box and Williams (2000) Heard (1975) Clench and Turner (1956)	1993, 1990-91, 1986-88, 1983, 1980, 1975, 1954 1974-75 ?
Chipola River, Gulf County, FL	Brim Box and Williams (2000)	1988
Ochlockonee River System		
Little Ochlockonee River, Thomas County, GA	J.D. Williams (unpub. data)	1993
Ochlockonee River, Thomas County, GA	J.D. Williams (unpub. data)	1993, 1980
Ochlockonee River, Grady County, GA	J.D. Williams (unpub. data) Clench and Turner (1956)	1993, 1983, 1974, 1966, 1954, 1939 ?
Barnetts Creek, Grady and Thomas Counties, GA	J.D. Williams (unpub. data)	1993
Ochlockonee River, Gadsden and Leon Counties, FL [30]	J.D. Williams (unpub. data) Heard (1975) Wright (1898) Clench and Turner (1956)	1993, 1988, 1986, 1980, 1976-77, 1974, 1969, 1957, 1949, 1931-34 1974-75 <1898 ?
Suwannee River System		
Suwannee River, Madison and Suwannee Counties, FL [27]	Wright (1899)	<1899
Santa Fe River; Alachua, Bradford, Columbia, and Union Counties; FL	Blalock-Herod and Williams (2001) Williams (unpub. data) Clench and Turner (1956)	2001 1996-98, 1993, 1987, 1980, 1974, 1953, 1949, 1932-34, 1926, 1916 ?
Sampson River, Bradford County, FL	J.D. Williams (unpub. data)	1974
New River, Bradford and Union Counties, FL	Blalock-Herod and Williams (2001) Blalock-Herod (2000) J.D. Williams (unpub. data)	2001 1997-98 1996-98, 1993, 1987, 1983, 1974, 1931-34

30 This is the type locality for *Unio reclusus*, which is considered a synonym of *Pleurobema pyriforme* (see "Species Descriptions and Taxonomy").

Table 5. Oval pigtoe (*Pleurobema pyriforme*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Suwannee River; Dixie, Gilchrist, and Levy Counties; FL	J.D. Williams (unpub. data)	1916

CODES: < = collected prior to (date), A = archeological record, and R = relic shells only.

Table 6. Chipola slabshell (*Elliptio chipolaensis*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
ACF Basin, Chattahoochee River System		
Howards Mill Creek, Houston County, AL	Brim Box and Williams (2000)	1968
ACF Basin, Chipola River System		
Marshall (Big) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1987, 1954 ?
Cowarts (Reedy) Creek, Houston County, AL	Brim Box and Williams (2000)	1916
Cowarts (Reedy) Creek, Jackson County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1978, 1954 ?
Chipola River, Jackson County, FL [Type Locality]	R.S. Butler (Service, unpub. data) Brim Box and Williams (2000) Heard (1975) van der Schalie (1940) Walker (1905a) Clench and Turner (1956)	2000 1991, 1987, 1981, 1965, 1954, 1918 1965 1915-18 1902 ?
Spring Creek, Jackson County, FL [31]	van der Schalie (1940) Brim Box and Williams (2000)	1915-18 ?
Dry Creek, Jackson County, FL	R.S. Butler (unpub. data) Brim Box and Williams (2000)	1993 1988
Chipola River, Calhoun County, FL	Brim Box and Williams (2000) Heard (1975) van der Schalie (1940) Clench and Turner (1956)	1990-91, 1986-88, 1980, 1975, 1954, 1918 1975 1915-18 ?
Chipola River, Gulf County, FL	Brim Box and Williams (2000)	1991, 1988

CODES: < = collected prior to (date).

31 There are two Spring Creeks in Jackson County, Florida, both in the Chipola River system. The one recorded here is an eastern tributary to the Chipola River near Marianna.

Table 7. Purple bankclimber (*Elliptoideus sloatianus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records.

Stream, County, State	Authority	Date
ACF Basin, Chattahoochee River System		
Chattahoochee River, Muscogee County, GA; and Russell County, AL [Type Locality]	L. Andrews (Service, pers. comm., 2000) Lea (1840) Brim Box and Williams (2000)	2000 <1840 ?
Chattahoochee River, Early County, GA; and Houston County, AL	Williams and Fradkin (1999)	A
ACF Basin, Flint River System		
Line Creek, Coweta and Fayette Counties, GA	Brim Box and Williams (2000)	1981
Flint River, Crawford and Taylor Counties, GA [32]	Brim Box and Williams (2000) Conrad (1849)	1992, 1962 1833
Flint River, Macon County, GA	E.Van De Genachte (Georgia Natural Heritage Program, pers. comm., 1999) Brim Box and Williams (2000)	1999 1992, 1981, 1976, 1958
Flint River, Dooly and Sumter Counties, GA	Brim Box and Williams (2000)	1992
Flint River, Crisp and Sumter Counties, GA	Brim Box and Williams (2000)	1992, 1950
Flint River, Lee and Worth Counties, GA	Brim Box and Williams (2000) Heard (1975)	1991, 1975 1974-75 R
unnamed tributary of Mill Creek, Worth County, GA	Brim Box and Williams (2000)	1992
Flint River, Dougherty County, GA	Brim Box and Williams (2000)	1991, ?
Flint River, Baker and Mitchell Counties, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1991, 1958, ? ?
Ichawaynochaway Creek, Baker County, GA [33]	Brim Box and Williams (2000)	?
Flint River, Decatur County, GA	Brim Box and Williams (2000) Clench and Turner (1956)	1992, 1975, 1954 ?
ACF Basin, Apalachicola River System		

32 According to Wheeler (1935), T.A. Conrad crossed the Flint River in Crawford and Taylor Counties, Georgia, during an 1833 trip to Alabama. The material upon which he based descriptions of the nominal species *Unio plectophorus* and *Unio aratus*, which are considered synonyms of *Elliptoideus sloatianus* (see "Species Descriptions and Taxonomy"), were probably from this vicinity and date.

33 Undated museum records exist that simply state "Branch of Flint River," Baker County, Georgia (Brim Box and Williams 2000). Although not specifically stated in their writeup in the historical distribution section, Figure 59 in Brim Box and Williams (2000) depicts a dot on Ichawaynochaway Creek signifying its historical occurrence in this stream, the largest tributary to the Flint River.

Table 7. Purple bankclimber (*Elliptoideus sloatianus*) occurrences by stream (working downstream), county, and state; authority; and chronology of occurrence for primary literature and other records (continued).

Stream, County, State	Authority	Date
Apalachicola River, Gadsden and Jackson Counties, FL	Richardson and Yokley (1996) R.S. Butler (Service, unpub. data) Brim Box and Williams (2000) Heard (1975) Clench and Turner (1956) Williams and Fradkin (1999)	1995 1993 1991, 1986-88, 1981-82, 1975-77, 1965, 1953-54 1974-75 R ? A
Apalachicola River, Calhoun and Liberty Counties, FL	Brim Box and Williams (2000) Williams and Fradkin (1999)	1991, 1970 A
Apalachicola River, Franklin and Gulf Counties, FL	Brim Box and Williams (2000)	1991
ACF Basin, Chipola River System		
Chipola River, Calhoun County, FL	Brim Box and Williams (2000) Clench and Turner (1956)	1988 ?
Chipola River, Gulf County, FL	Brim Box and Williams (2000)	1988, 1930, 1915
Ochlockonee River System		
Ochlockonee River, Thomas County, GA	J.D. Williams (USGS, unpub. data)	1993
Ochlockonee River, Grady County, GA	J.D. Williams (unpub. data) Clench and Turner (1956)	1993, 1954 R ?
Ochlockonee River, Gadsden and Leon Counties, FL	J.D. Williams (unpub. data) Clench and Turner (1956)	1993, 1986-88, 1980, 1974-76, 1969, 1964, 1961, 1957, 1954, 1951, 1930-34 ?
Ochlockonee River, Liberty and Wakulla Counties, FL	J.D. Williams (unpub. data)	1993, 1958
Suwannee River System		
Suwannee River, a spring on main stem	Brim Box and Williams (2000)	A
Hillsborough Bay System		
Leisey Shell Pit, early Pleistocene deposits, near Tampa	Bogan and Portell (1995)	A

CODES: < = collected prior to (date), A = archeological record, and R = relic shells only.

Table 8. Drainage sub-basins with historical and current extent of occurrence and number of extant sites of occurrence for the seven mussel species.

Species **Sub-Basin, State**	Historical Extent of Occurrence in RM	Current Extent of Occurrence in RM	No. Extant Viable and Non-Viable Sub-Populations or Sites
fat threeridge			
upper Flint River, GA	46	0	0
middle Flint River, GA	31	0	0
lower Flint River, GA	103	0	0
Apalachicola River, FL	93	93	~5
Chipola River, FL	35	35	~3
Total	308	128	8
shinyrayed pocketbook			
upper Chattahoochee River, GA	119	0	0
middle Chattahoochee River, AL and GA	169	21	~1
lower Chattahoochee River, AL and GA	58	9	~2
upper Flint River, GA	240	47	~2
middle Flint River, GA	144	108	~10
lower Flint River, GA	259	127	~10
Apalachicola River, FL	4	0	0
Chipola River, FL	137	69	~6
upper Ochlockonee River, GA and FL	118	82	~6
Total	1248	463	36
Gulf moccasinshell			
Econfina Creek, FL	25	25	~2
upper Chattahoochee River, GA	102	0	0
middle Chattahoochee River, AL and GA	176	0	0
lower Chattahoochee River, AL and GA	84	9	~2
upper Flint River, GA	257	30	~1
middle Flint River, GA	127	49	~8

Table 8. Drainage sub-basins with historical and current extent of occurrence and number of extant sites of occurrence for the seven mussel species (continued).

Species **Sub-Basin, State**	Historical Extent of Occurrence in RM	Current Extent of Occurrence in RM	No. Extant Viable and Non-Viable Sub-Populations or Sites
lower Flint River, GA	207	42	~4
Apalachicola River, FL	27	0	0
Chipola River, FL	137	79	~4
Total	1142	234	21
Ochlockonee moccasinshell			
upper Ochlockonee River, GA and FL	94	34	~1
Lower Ochlockonee River, FL	16	0	0
Total	110	34	1
oval pigtoe			
Econfina Creek, FL	25	25	~2
middle Chattahoochee River, AL and GA	156	0	0
lower Chattahoochee River, AL and GA	84	9	~1
upper Flint River, GA	288	69	~2
middle Flint River, GA	184	100	~10
lower Flint River, GA	261	45	~7
Apalachicola River, FL	27	0	0
Chipola River, FL	162	90	~8
upper Ochlockonee River, GA and FL	88	32	~4
Santa Fe River, FL	102	16	~2
Suwannee River, FL	35	—	—
Total	1412	386	36
Chipola slabshell			
lower Chattahoochee River, AL and GA	6	0	0
Chipola River, FL	107	83	~6
Total	113	83	6

Table 8. Drainage sub-basins with historical and current extent of occurrence and number of extant sites of occurrence for the seven mussel species (continued).

Species **Sub-Basin, State**	Historical Extent of Occurrence in RM	Current Extent of Occurrence in RM	No. Extant Viable and Non-Viable Sub-Populations or Sites
purple bankclimber			
middle Chattahoochee River, AL and GA	93	2	~1
lower Chattahoochee River, AL and GA	75	0	0
upper Flint River, GA	167	105	~2
middle Flint River, GA	33	25	~6
lower Flint River, GA	119	87	~8
Apalachicola River, FL	86	86	~5
Chipola River, FL	50	50	~2
upper Ochlockonee River, GA and FL	67	51	~3
lower Ochlockonee River, FL	47	47	~2
Total	737	453	30

NOTES: **Column 1:** For the purposes of this table, the Apalachicolan Region range of these seven species is divided into river systems and sub-basins within the ACF Basin, Ochlockonee, and Suwannee rivers. The sub-basins are defined as follows: 1) Econfina Creek; 2) upper Chattahoochee River from headwaters to West Point Dam; 3) middle Chattahoochee River from West Point Dam to W.F. George Dam; 4) lower Chattahoochee River from W.F. George Dam to Jim Woodruff Lock and Dam; 4) upper Flint River, including the headwaters downstream to Warwick Dam which forms Lake Blackshear; 5) middle Flint River from Warwick Dam at Lake Blackshear to the dam at Albany that forms Lake Chehaw, including the Muckafoonee (Muckalee-Kinchafoonee) Creek system; 6) lower Flint River, from the dam at Albany downstream to Jim Woodruff Lock and Dam; 7) Apalachicola River; 8) Chipola River; 9) upper Ochlockonee River above Talquin Reservoir; 10) lower Ochlockonee River below Talquin Reservoir; 11) Suwannee River main channel and tributaries excluding the Santa Fe watershed; and 12) Santa Fe River. **Column 2:** Extent of historical occurrence was determined for each species by plotting historical distribution data outlined from each species occurrence by stream (Tables 1 through 7) using ArcView 3.2 software. Historical occurrences were considered connected to the upstream- and downstream-most sites within a basin most even if specific records were lacking in between. This determination was made based on a likelihood of distribution between occupied sites in the absence of habitat fragmentation.
Column 3: Current extent of occurrence was plotted similarly, except that sites were not considered connected to the upstream- and downstream-most sites if records were lacking in between since recent status surveys have been completed surrounding locations through out the historic ranges of these species. **Column 4:** This column represents approximately (~) how many sites still harbor the species. Sites are loosely defined as stream reaches that would typically yield multiple live specimens with approximately 4-6 person hours sampling effort. Sites are generally separated by reaches of unsuitable habitat and adjacent sites are generally not susceptible to single minor stochastic events. The viability of “Extant Sites” is not generally known, but status surveys suggest that many may not be recruiting, are in decline, or are otherwise non-viable. A viable population is defined as a wild, naturally reproducing population that is large enough to maintain sufficient genetic variation to enable the species to evolve and respond to natural habitat changes without further intervention. Viable subpopulations will therefore have multiple age classes, including newly recruited juveniles, gravid females during the appropriate season, and sufficient genetic variability to evolve in response to natural habitat changes without further human intervention .

GLOSSARY

Allopatric: Pertaining to populations of two or more species whose ranges do not occupy the same geographical area.
Biangulate: Having two angles or double angular in shape.
Bioreserve: A discreet geographic region, such as a watershed, that has been established by a conservation organization as a focus area for habitat restoration and other concerted conservation efforts.
Byssus: A protein thread secreted by juvenile mussels as a means of attachment to hard surfaces; byssal thread.
Cohort: All the organisms produced in a single breeding season; year class.
Contra: Latin for against. Herein used in reference to a published finding that is contradictory to that previously published (e.g., *contra* Lydeard et al. 1999).
Crenulate: Having margins that are minutely scalloped.
Distinct Viable Population: A population that satisfies the criteria specified in the February 7, 1996, *Federal Register*, pages 4722-4725. The criteria require it to be readily separable from the rest of its populations and to be biologically and ecologically significant. Such a population responds to natural habitat changes without any intervention. Also see "viable population."
Effective Population Size: The size of an "ideal" population where genetic drift takes place at the same rate as in the actual population.
Endemism: Native or confined to a certain region and having a relatively restricted distribution; endemic.
Genetic Bottleneck: When the number of breeding specimens in a population is reduced to a level that results in the loss of genetic variation as a consequence of decreased random genetic drift.
Geomorphic: Relating to earth, its shape, or surface configuration. Herein used in reference to stream channel morphology.
Glochidia, Glochidium: The bivalve larvae of freshwater mussels in the superfamily Unionoidea which are generally parasitic upon vertebrates, typically fish.
Holotype: The single specimen chosen for designation of a new species and housed in a museum.
Lanceolate: Pointed or lance-shaped
Lateral Teeth: The elongated, raised, and interlocking structures located dorsally along the hinge line of the inside of the valves of mussels.
Malacologist: A biologist who studies mollusks.
Marsupia: The portion of the gills of a female mussel that are used to incubate glochidia.
Metapopulation: Several populations that have the potential for natural genetic interchange.
Monotypic: In taxonomy, having only one subordinate unit, such as a genus represented by a single species.
Museum Lot: All the specimens of a single species in a museum collection representing a specific locality and date.
Nacre: The interior iridescent, thin layer of a mussel shell; mother of pearl.
Nonindigenous: Organisms that are intentionally imported or accidentally introduced from another or foreign area; exotic or non-native.
Periostracum: Exterior or outside protein-comprised layer of the shell.

Phagotrophic: The act of an organism ingesting or engulfing solid particles of food.
Phytoplankton: The plant organisms comprising plankton.
Piscivorous: Organisms that habitually feed on fish.
Plication: Parallel ridges on the surface of the shell; plicate.
Pseudocardinal Teeth: Triangular-shaped hinge teeth near the anterior-dorsal margin of the inside of the valves.
Quadrate, Subquadrate: Square or nearly square in outline.
Riverine: Found in or characteristic of rivers.
Silviculture: Care and cultivation of forest trees; forestry.
Sympatric: Pertaining to populations of two or more species which occupy identical or broadly overlapping geographical areas.
Taxonomy: The science of classifying plants and animals and their evolutionary relationship to one another.
Translocation: A management tool that involves the movement of organisms from one location to another.
Type Locality: The locality from where the holotype for a newly described species was collected.
Umbo, Umbonal: The raised, inflated area of the bivalve shell, centrally or anteriorly placed along the dorsal margin of the valve. The oldest portion of the shell.
Unionid: Freshwater bivalve mollusks that belong to the superfamily Unionoidea, family Unionidae.
Valve: The left or right half of a bivalve shell, such as a mussel.
Viable Population: A wild, naturally reproducing population that is large enough to maintain sufficient genetic variation to enable the species to evolve and respond to natural habitat changes without further intervention. Viable populations will therefore have multiple age classes, including newly recruited juveniles.

PART III

IMPLEMENTATION SCHEDULE

Recovery plans are intended to assist the U.S. Fish and Wildlife Service and potential Federal, State, and private partners in planning and implementing actions to recover and/or protect endangered and threatened species. The following Implementation Schedule indicates task priorities, task numbers, task descriptions, duration of tasks, potential partners and responsible agencies, and lastly, estimated costs. It is a guide for planning and meeting the objectives discussed in Part II of this plan. The Implementation Schedule outlines recovery actions and their estimated costs for the first 3 years of this recovery program. Downlisting and delisting dates cannot be estimated at this time. A time period of at least 10 years or three generations, which ever is longer, is needed to document the long-term viability of mussel populations. Task 4.2 addresses the monitoring component of the recovery plan to ensure that these data will be collected and evaluated in order to estimate downlisting and delisting dates. The cost estimates provided are based on the Implementation Schedule and identify foreseeable expenditures that could be made to implement the specific recovery tasks during a 5-year period. **Actual expenditures by identified agencies/partners will be contingent upon appropriations and other budgetary constraints.**

Recovery tasks are assigned numerical priorities to highlight the relative contribution they may make to species recovery. Priorities in column 1 of the Implementation Schedule are assigned as follows:

1. An action that must be taken to prevent extinction or to prevent the species from declining irreversibly in the foreseeable future.

2. An action that must be taken to prevent a significant decline in species population/habitat quality or some other significant negative impact short of extinction.

3. All other actions necessary to provide for full recovery of the species.

While the Endangered Species Act assigns a strong leadership role for the U.S. Fish and Wildlife Service in recovery of listed species, it also recognizes the importance of other Federal agencies, States, and private citizens in the recovery process. The Responsible Agency column of the Implementation Schedule identifies partners who can make significant contributions to specific recovery tasks. **The identification of agencies within the Schedule does not constitute any additional legal responsibilities beyond existing authorities**; i.e., Endangered Species Act, Federal Land Policy and Management Act, Clean Water Act, etc. **Recovery plans do not obligate other parties to undertake specific tasks and may not represent the views nor the official positions or approval of any individuals or agencies involved in developing the plan**, other than the U.S. Fish and Wildlife Service.

Key to acronyms used in Implementation Schedule:

USFWS	U.S. Fish and Wildlife Service
ES	Ecological Services Division within USFWS
LE	Law Enforcement Division within USFWS
FR	Fisheries Resources Division within USFWS
USDA	U.S. Department of Agriculture, including Forest Service and Natural Resources Conservation Service
EPA	U.S. Environmental Protection Agency
CORPS	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey, including Biological Resources Division

Other State and Federal agencies which may participate in the implementation:

ADNR	Alabama Department of Conservation and Natural Resources
AFC	Alabama Forestry Commission
ADIR	Alabama Department of Industrial Relations
ADEM	Alabama Department of Environmental Management
FDEP	Florida Department of Environmental Protection
FDOT	Florida Department of Transportation
FDACS	Florida Department of Agriculture and Consumer Services, including Forestry Division
FWC	Florida Fish and Wildlife Conservation Commission
NWFWMD	Northwest Florida Water Management District
SRWMD	Suwannee River Water Management District
GDNR	Georgia Department of Natural Resources

Other partners and stakeholders may include concerned businesses and industries, research and university institutions, counties and city governments, private landowners, conservation organizations, etc.

FIVE ENDANGERED AND TWO THREATENED MUSSEL SPECIES IMPLEMENTATION SCHEDULE

Priority	Task #	Task Description	Task Duration	Responsible Agency USFWS	Responsible Agency Other	Cost Estimates ($K) FY04	FY05	FY06	FY07	FY08	Comments
1	1.2.1	Provide information and request support of state and local governments for recovery efforts	continuous	ES	Local governments of Albany, Atlanta, Columbus and Tallahassee	5	5	5	5	5	
1	1.2.2	Get support from private landowners, agriculture, silviculture and development groups to implement voluntary protection and conservation actions	continuous	ES	Landowners, developers, Federal, State agencies, county and local governments	100	100	100	100	100	
1	1.3.3	Determine mechanisms and impacts of present and future threats to the species	continuous	ES	appropriate State and Federal agencies	150	150	150	150	150	
1[34]	3.2	Refine techniques and methodologies for propagating and translocating specimens	8 years	ES	USFWS, appropriate State and Federal agencies, universities	60	40	40	40	40	
1	3.5	Identify and prioritize streams and watersheds in need of protection from further threats	continuous	ES	USFWS, appropriate State and Federal agencies, other organizations	30	30	5	5	5	

[34] This task is a priority 1 for the Ochlockonee moccasinshell, oval pigtoe (in the Suwannee River basin), and possibly the fat threeridge. For the remainder of the species, this task is a priority 2.

Implementation Schedule continued on next page

Priority	Task #	Task Description	Task Duration	Responsible Agency USFWS	Other	Cost Estimates ($K) FY04	FY05	FY06	FY07	FY08	Comments
2	1.1	Use existing laws, regulations, programs to protect species and habitat	continuous	ES/LE	Federal, State agencies, County and local governments	5	5	5	5	5	
2	1.2.3	Develop cooperative ventures to restore riparian habitat	continuous	ES	AFC, FDACS, GDNR, USDA, USFWS	60	60	60	60	60	
2	1.2.4	Encourage incorporation of conservation approaches into the ACF water allocation formula	continuous	ES	Appropriate State and Federal agencies	10	10	10	10	10	
2	1.3.1	Conduct studies on life history characteristics	6 years	ES	USFWS, appropriate State and Federal agencies, universities	100	100	100	100	100	
2	1.3.2	Characterize species' habitats for all life history stages	6 years	ES	USFWS, universities	50	50	50	50	50	
2	1.3.4	Determine contaminant sensitivity for life stages	3 years	ES	USGS, USFWS, universities	0	0	75	75	75	
2	1.3.5	Investigate need for habitat management and improvement	3 years	ES	USFWS, universities	5	5	5	0	0	
2	1.3.6	Determine numbers and sex ratio for long-term natural viable subpopulations	6 years	ES	USFWS, USGS universities	200	200	150	150	150	
2	1.3.7	Conduct anatomical and molecular genetic analyses throughout their range	3 years	ES	Appropriate State and Federal agencies, universities	75	75	50	0	0	

Implementation Schedule continued on next page

Priority	Task #	Task Description	Task Duration	Responsible Agency USFWS	Responsible Agency Other	Cost Estimates ($K) FY04	FY05	FY06	FY07	FY08	Comments
2	1.3.8	Determine if increase in the extent of occurrence for each species is adequate for recovery.	5 years	ES	Appropriate State and Federal agencies, universities, private companies	0	0	20	0	20	
2	1.4.1	Determine culture techniques for host fish	3 years	NFH	Appropriate State and Federal agencies, universities, private companies	60	40	40	0	0	
2	1.4.2	Conduct biennial monitoring of host fish subpopulations	Continuous	FR	Appropriate State and Federal agencies, universities	10	10	10	10	10	
2	2.1	Develop a prioritized list by species of streams and stream reaches that should be surveyed.	6 years	ES	USFWS, appropriate State and Federal agencies, universities	5	5	5	5	5	
2	2.2.1	Complete a standardized mussel survey protocol	2 years	USFWS	Appropriate State and Federal agencies, universities	15	5	0	0	0	
2	2.2.2	Implement surveys in streams identified in 2.1 to locate additional subpopulations of species	Continuous	FR	USFWS, Appropriate State and Federal agencies, universities	50	50	50	50	50	

Implementation Schedule continued on next page

Priority	Task #	Task Description	Task Duration	Responsible Agency USFWS	Other	Cost Estimates ($K) FY04	FY05	FY06	FY07	FY08	Comments
2	3.1	Develop or adopt a mussel propagation, augmentation, and reintroduction plan for these seven species	2 years	ES/FR	USFWS, appropriate State and Federal agencies, universities	0	10	10	0	0	
2	3.3.1	Identify and prioritize as a prerequisite for augmentation extant subpopulations based on biological, ecological, and habitat characterization	3 years	ES	USFWS, appropriate State and Federal agencies, universities	5	5	5	0	0	
2	3.4.1	Identify and prioritize suitable sites for reintroduction in historic range	3 years	ES	USFWS, appropriate State and Federal agencies, universities	3	3	3	0	0	
2	3.6	Augmentation at existing population sites and establish new subpopulations at historic range	10 years	ES	USFWS, appropriate State and Federal agencies, universities	0	5	5	0	0	
2	4.1	Develop a comprehensive Geographic Information System (GIS) database and update regularly	Continuous	ES	USFWS	8	5	5	5	5	
2	4.2	Conduct biennial monitoring of the seven mussels and their habitats.	Continuous	ES	USFWS, Appropriate State and Federal agencies, universities	40	175	40	175	40	

Implementation Schedule continued on next page

Priority	Task #	Task Description	Task Duration	Responsible Agency USFWS	Responsible Agency Other	Cost Estimates ($K) FY04	FY05	FY06	FY07	FY08	Comments
3	5.1	Develop and implement cryogenic techniques for mussels	3 years	ES	USFWS, appropriate State and Federal agencies, universities	0	60	42	42	0	
3	5.2	Evaluate need for cryogenic preservation of host fish	3 years	ES	USFWS, appropriate State and Federal agencies, universities	0	0	60	60	60	
3	6.1	Develop an education/ outreach program	6 years	ES	Appropriate State and Federal agencies	5	10	10	10	10	
3	6.2	Educational Training for LE, natural resource managers, and the general public	Continuous	ES	Appropriate State and Federal agencies	20	10	10	10	10	
3	7.1	Meet with stakeholders	Continuous	ES	All stakeholders	2	2	2	2	2	
3	7.2	Assess recovery program	Continuous	ES	USFWS Appropriate State and Federal agencies, universities	2	2	2	2	2	

Implementation Schedule continued on next page

PART IV

LIST OF REVIEWERS

Notice of availability of the technical/agency draft recovery plan was made available to the public for comments as required by the 1988 amendments to the Endangered Species Act of 1973. The public comment period was announced in the *Federal Register* on September 16, 1999 and closed on November 15, 1999. Copies of the draft plan were provided to qualified members of the academic and scientific community for peer review. The U.S. Fish and Wildlife Service (Service) solicited and/or received comments on the document from the academic and scientific community, private individuals, industry representatives, and Federal, State, and local agencies listed below. This does not imply that they provided comments or endorsed the contents of this plan. All comments received have been addressed in this final plan. (Reviewers' comments and letters are maintained in the administrative record).

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