BEFORE THE SECRETARY OF THE INTERIOR

Photo credit: Thomas Tarpley

PETITION TO LIST THE OBLONG ROCKSNAIL (*LEPTOXIS COMPACTA*) AS A THREATENED OR ENDANGERED SPECIES UNDER THE ENDANGERED SPECIES ACT

JUNE 21, 2016

CENTER FOR BIOLOGICAL DIVERSITY
CAHABA RIVERKEEPER

NOTICE OF PETITION

Sally Jewell, Secretary
U.S. Department of the Interior
1849 C Street NW
Washington, D.C. 20240
exsec@ios.doi.gov

Dan Ashe, Director
U.S. Fish and Wildlife Service
1849 C Street NW
Washington, D.C. 20240
Dan_Ashe@fws.gov

Douglas Krofta, Chief
Branch of Listing, Endangered Species Program
U.S. Fish and Wildlife Service
4401 North Fairfax Drive, Room 420
Arlington, VA 22203
Douglas_Krofta@fws.gov

PETITIONERS

The Center for Biological Diversity (Center) is a non-profit, public interest environmental organization dedicated to the protection of native species and their habitats through science, policy, and environmental law. The Center is supported by more than 990,000 members and activists throughout the United States. The Center and its members are concerned with the conservation of endangered species and the effective implementation of the Endangered Species Act.

The Cahaba Riverkeeper defends the ecological integrity of the Cahaba River, its tributaries and watershed, to ensure clean water, a healthy aquatic, and the recreational and aesthetic values of the water. A nonprofit community-based environmental organization, Cahaba Riverkeeper is also dedicated to the scientific study of the Cahaba and ensuring that current data are available to the public. The watershed is monitored to identify violations of clean water legislation. If notification to violators and appropriate authorities fails to produce appropriate action, remedial and legal action will be pursued to protect Alabama's natural resources and drinking water supply.

Submitted this 21st of June, 2016

Pursuant to Section 4(b) of the Endangered Species Act (ESA), 16 U.S.C. § 1533(b); section 553(e) of the Administrative Procedure Act (APA), 5 U.S.C. § 553(e); and 50 C.F.R. § 424.14(a), the Center for Biological Diversity, Tara Easter, Tierra Curry, and the Cahaba Riverkeeper, Myra Crawford, David Butler, Peggy Gargis, Shaun Crawford, Paula Fancher and Stephen L. Sexton hereby petition the Secretary of the Interior, through the U.S. Fish and Wildlife Service (FWS or Service), to protect the oblong rocksnail (*Leptoxis compacta*) as a threatened or endangered species.

FWS has jurisdiction over this petition. This petition sets in motion a specific process, placing definite response requirements on FWS. Specifically, the Service must issue an initial finding as to whether the petition "presents substantial scientific or commercial information indicating that the petitioned action may be warranted." 16 U.S.C. § 1533(b)(3)(A). FWS must make this initial finding "[t]o the maximum extent practicable, within 90 days after receiving the petition." *Id*.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The oblong rocksnail (*Leptoxis compacta*) is small aquatic snail found only in the Cahaba River in the Mobile River Basin of Alabama. This freshwater gastropod was declared extinct in 2000 and had not been seen since 1933, but in 2011, Dr. Nathan Whelan rediscovered the species. This snail occurs only in a single population in the Cahaba River and is threatened by point-source and nonpoint-source pollution from urban and agricultural runoff, human population growth, climate change, and invasive species. Its vulnerability to these threats is further compounded by its small population size, limited range, and inability to disperse.

The oblong rocksnail warrants listing as a threatened or endangered species. The Endangered Species Act states that a species shall be determined to be endangered or threatened based on any one of five factors (16 U.S.C. § 1533 (a)(1)). The snail is threatened by three of these factors – the modification or curtailment of habitat or range, the inadequacy of existing regulatory mechanisms to ensure its survival, and other factors including invasive species, climate change, and its limited range.

I. INTRODUCTION

The oblong rocksnail (*Leptoxis compacta*) is a small, gill-breathing, freshwater snail. It was considered extinct but was rediscovered in 2011 (Whelan et al. 2012) after having not been seen for at least 70 years. The oblong rocksnail lives only in the Cahaba River and currently occurs only in a single population. Its historic decline is assumed to be due to habitat degradation, pollution from urban and agricultural runoff, sedimentation, and eutrophication (Ibid.). Its single remaining population is threatened by restricted range, habitat degradation, invasive species, and climate change. Without Endangered Species Act protection, extinction looms for this endemic gastropod.

Freshwater snails are diverse and critical components of aquatic ecosystems worldwide (Johnson et al. 2013, p. 248). In many areas, gastropods dominate benthic stream communities in abundance and often make up more than half of the invertebrate biomass (Hawkins and Furnish 1987, Johnson and Brown 1997, Brown et al. 2008, Brown and Lydeard 2010, cited in Johnson et al. 2013, p. 248). Gastropods are important aquatic grazers, and they regulate primary productivity, playing a crucial role in aquatic food webs and nutrient cycling (Huryn et al. 1995, Covich et al. 1999, cited in Johnson et al. 2013, p. 248; Stewart and Garcia 2002, p. 177). That snails, and more specifically, pleurocerid snails such as *L. compacta*, can be the dominant invertebrate taxa suggests that they significantly contribute to the overall structure and function of the stream environment (Tolley-Jordan et al. 2015, p. 236).

North America, and the southeastern United States especially, holds the highest diversity of freshwater mollusks in the world, including a rich array of gastropod species (Neves et al. 1997, Bouchet and Rocroi 2005, cited in Johnson et al. 2013, p. 248). There are 703 freshwater gastropod species in North America (Johnson et al. 2013, p. 258) – 342 of which are gill-breathers (USFWS 2010, p. 14). Of these species, an assessment by the American Fisheries Society concluded that 73 are vulnerable, 102 are threatened, 278 are endangered, 67 are extinct or possibly extinct, and the status of 26 species is unknown (Johnson et al. 2013, p. 258). Almost half of all known Pleurocidea species in the United States are considered at risk (NatureServe 2007, cited in Brown et al. 2008, p. 484). While the high diversity and 74 percent imperilment rate of North American snails is astonishing, the Mobile River Basin of Alabama is the epicenter of molluscan diversity – and extinction events (Williams et al. 2008, Lydeard and Mayden 1995, Neves et al. 1997, Johnson et al. 2012, cited in Whelan et al. 2012, p. 1).

The Mobile River Basin has the highest levels of freshwater molluscan diversity with a total of 118 gastropod species, including many endemic species (Lévêque et al. 2005, Strong et al. 2008, cited in Tolley-Jordan et al. 2015, p. 236). Unfortunately, a striking number of these unique species have been lost due to anthropogenic activities (Whelan et al. 2012, p. 1). At least 47 mollusk species have gone extinct, including 37 gastropods, and many other species have been locally extirpated (Lydeard and Mayden 1995, Neves et al. 1997, Johnson et al. 2012, Ó Foighil et al. 2011, cited in Whelan et al. 2012, p. 1). These extinctions make the Mobile River Basin a hotspot of the global extinction crisis, the site of one third of all known molluscan extinctions globally (Regnier et al. 2009, cited in Whelan et al. 2012, p. 1). In fact, the inundation of the Coosa River alone drove 34 species in at least three genera to extinction and is considered the single largest modern extinction event in North America (Bogan et al. 1995, Neves et al. 1997, Lydeard et al. 2004, Ó Foighil et al. 2011, cited in Johnson et al. 2013, p. 249).

Of the 37 gastropod extinctions, the Pleurocidae family suffered the most, accounting for 29 of the 37 (Johnson et al. 2012, cited in Whelan et al. 2012, p. 1). Pleurocerids throughout North America are highly endangered and under-studied (*See* Table 1; Johnson et al. 2013, p. 253; Brown et al. 2008, p. 484), but the Cahaba River serves as a globally significant refuge for these snails (Stein 1976, cited in Tolley-Jordan et al. 2015, p. 236). This basin supports 20 pleurocerid species, nine of which are endemic (Mirarchi et al. 2004, cited in Tolley-Jordan et al. 2015, p. 236). Of these remaining snails, three are federally listed, seven are considered highest conservation concern (with the addition of *L. compacta*), and four others are considered critically imperiled, imperiled, or vulnerable (USFWS 2010, p. 14).

Table 1: Taxonomic distribution, percent imperiled, and number of extinct Canadian and United States freshwater gastropods assessed by the American Fisheries Society (Johnson et al. 2013, p. 253, Table 1).

Family	Genera	Species	Percent Imperiled	Number Extinct	Officially Listed
Ampullariidae	1	1	0	0	0
Amnicolidae	4	18	61	1	0
Assimineidae	1	2	100	0	1
Cochliopidae	14	48	91	0	6
Hydrobiidae	16	185	92	4	14
Lithoglyphidae	11	73	64	4	2
Pleuroceridae	**7**	**162**	**79**	**33**	**8**
Pomatiopsidae	1	6	66	1	0
Semisulcospiridae	1	11	91	1	0
Viviparidae	4	21	24	0	3
Neritidae	1	5	60	0	0
Acroloxidae	1	1	100	0	0
Lymnaeidae	9	61	60	10	3
Physidae	5	47	55	1	3
Planorbidae	16	52	44	10	1
Valvatidae	1	10	50	1	0
Total	93	703		67	23

Despite the critical role that snails play in freshwater ecosystems and their extraordinarily high rates of extinction, little attention has been given to their habitat requirements, life histories, and conservation statuses (Johnson et al. 2013, p. 249, 260; Brown et al. 2008, p. 489-490, 484; Stewart and Garcia 2002, p. 178-179). Species in the Mobile River Basin continue to be threatened by impoundments, channelization for navigation, pollution from agriculture, mines, and urban centers, invasive species, and a growing human population destined to compete with native fauna over water use as watersheds become depleted as a result of climate change (Whelan et al. 2012, p. 4; Brown et al. 2008, p. 484; USFWS 2009, p. 31121). The oblong rocksnail has been given a second chance and needs immediate protection under the Endangered Species Act to prevent its extinction.

II. NATURAL HISTORY

A. Taxonomy and Description

The oblong rocksnail, *Leptoxis compacta*, is a gastropod in the Pleuroceridae family, which includes gill-breathing, operculate snails found in North America, Asia, and Africa (Lydeard et al. 1997, p. 117). This family reaches its greatest diversity, however, in the southeastern United States (Ibid.). Pleurocerids are the second most diverse group of North American freshwater snails (Johnson et al. 2013, p. 253), comprised of seven genera and approximately 153 species (Lydeard et al. 1997, p. 117). Pleurocerids are also one of the most imperiled families; almost 80 percent of known species are threatened with extinction (Johnson et al. 2013, p. 253). There are 23 species in the genus *Leptoxis*, 15 of which occur or occurred in the Mobile River Basin (Ibid.), where *L. compacta* is also found (Whelan et al. 2012, p. 1).

Table 2: Oblong rocksnail taxonomy (NatureServe 2015)

Kingdom	Phylum	Class	Order	Family	Genus	Species
Animalia	Mollusca	Gastropoda	Neotaenioglossa	Pleuroceridae	Leptoxis	compacta

Leptoxis compacta was first described by Anthony (1854, cited in Whelan et al. 2012, p. 3). Its shells are easily distinguishable from other sympatric species, described below:

> Juvenile *L. compacta* shells possess one distinct carina on the main body whorl, which is eventually lost as adults (Fig. 1). Individuals with shell pigmentation lines are always present in three wide bands. Most wild-caught individuals had purple pigmentation on the columella indentation, but this trait was not observed in juveniles propagated in captivity. The external tissue pigmentation of *L. compacta* is yellow, mottled with black and includes prominent black bands in the middle of the proboscis and on both eyes (Fig. 3). This pigmentation banding pattern is identical to sympatric *L. ampla* (not figured). Pigmentation patterns and the presence of an ocular peduncle are features that distinguish *L. compacta* from sympatric *Elimia* spp. including *E. clara* (Anthony 1854) (Fig. 3), which is conchologically most similar to *L. compacta* (Figs. 1, 2) (Whelan et al. 2012, p. 3).

Figure 1: Growth series of *L. compacta* (Whelan et al. 2012, p. 3, Fig. 2)

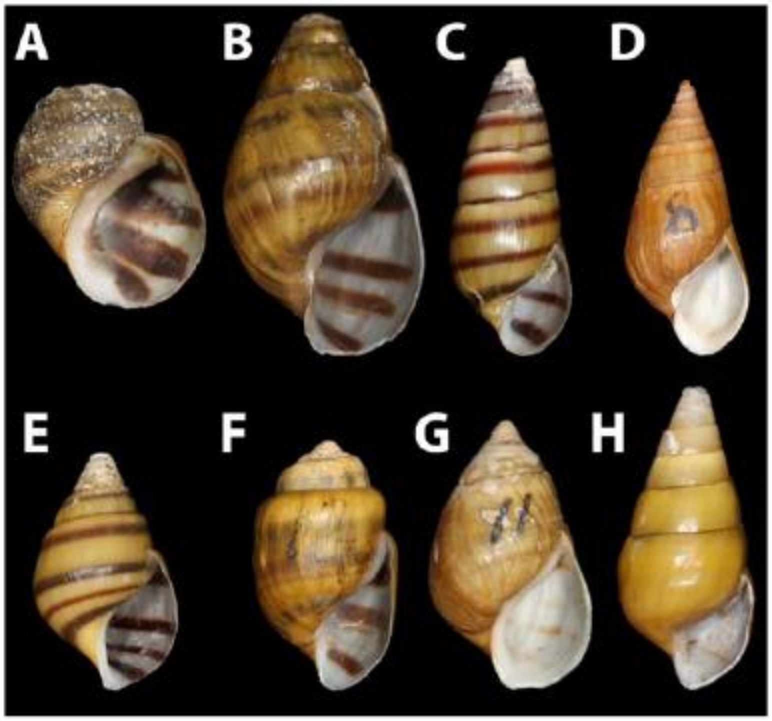

Figure 2: Lectotypes of pleurocerids sympatric with *L. compacta*. A) *L. ampla* (MCZ 161803). B) *E. ampla* (MCZ 161735). C) *E. annetae* (UMMZ 128908). D) *E. cahawbensis* (USNM 119055). E) *E. clara* (MCZ 072329) F) *E. showalteri* (ANSP 26881) G) *E. variata* (USNM 118756). F) *P. prasinatum* (USNM 122206) (Whelan et al. 2012, p. 4, Fig. 3)

Figure 3: Photograph of live *L. compacta* from the Cahaba River, Shelby County, Alabama (left) (Whelan et al. 2012, p. 4, Fig. 4), Photograph of live E. clara from the Cahaba River, Shelby County, Alabama (right) (*Id.*, Fig. 5).

The basal margin of the rachidian tooth is widely convex. The central cusp is blunt and flanked by 4–5 denticles, with the outermost being weakly developed in most cases (Fig. 4 A, B). The lateral tooth contains one larger rectangular central cusp that is flanked by 4–5 outer denticles and 3–4 inner denticles (Fig. 4 B, C). The inner marginal teeth contain 10–12 denticles (Fig. 5 D, E). The number of denticles on the outer marginal teeth varies from 12–16, within and among individuals, and the outer denticles are often weakly developed (Fig. 4 D, E) (Whelan et al. 2012, p. 3)

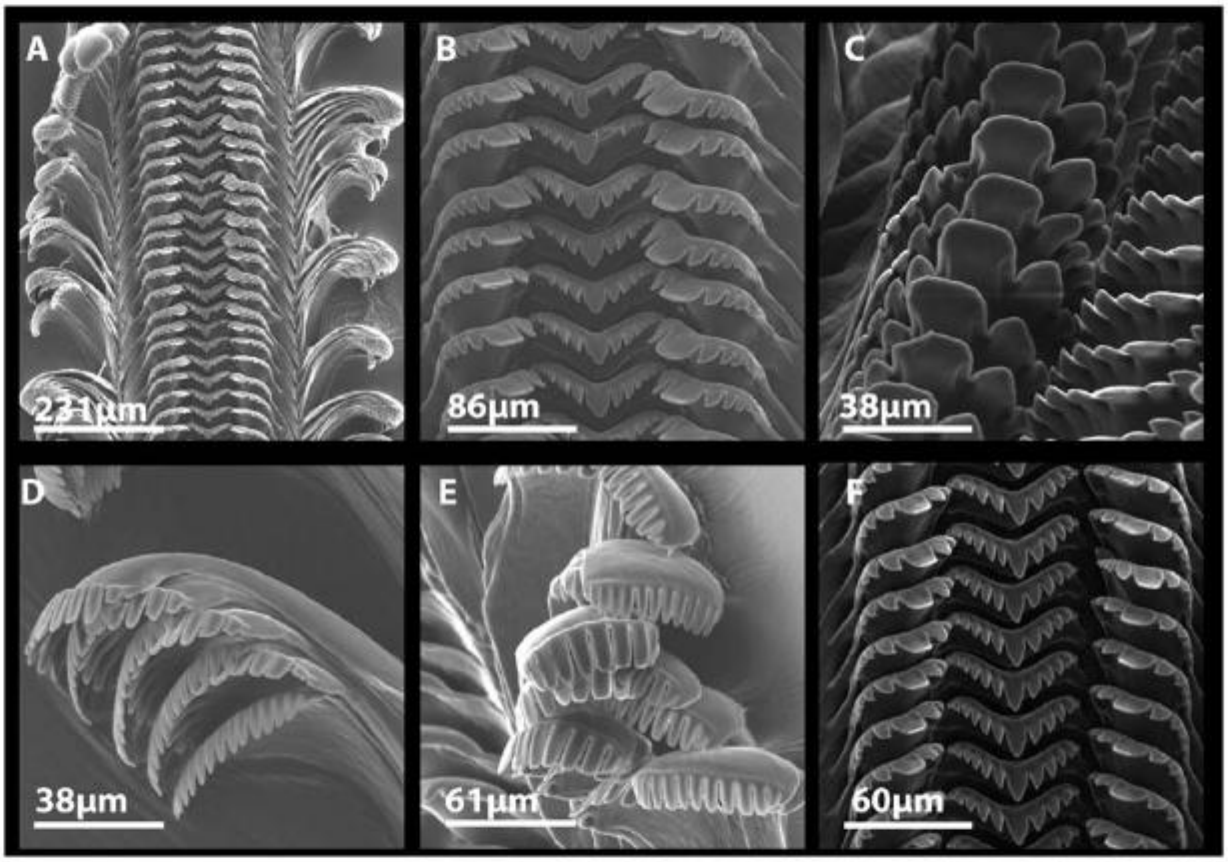

Figure 4: Scanning electron micrographs of *L. compacta* radulae collected in May 2011 (A–E) and the radula of historically collected individual (F). A) Section of anterior radular ribbon. B) Detailed view of rachidian and lateral teeth. C) View of lateral teeth at 45 degree angle, and slightly rotated counter-clockwise. D–E) Views of marginal teeth showing variation between individuals. F) Rachidian and lateral teeth removed from individual collected in 1881 (USNM 509539) (Whelan et al. 2012, p. 5, Fig. 6).

B. Life History

Life histories vary widely among species in the Pleuroceridae family (Whelan et al. 2015, p. 1). Life span varies from two years (for example, *Leptoxis carinata*) to six years (*Elimia* species), semelparity and iteroparity have both been documented, and eggs are laid in different patterns (Ibid.). Life history variations may have important implications for conservation strategies (Whelan et al. 2015, p. 1). For example, egg-laying behaviors are important to consider when making critical habitat designations (Ibid. at 9). Single-egg laying species, such as *L. compacta*, seem to reproduce better in faster flowing environments (Ibid.). More generally, their slow growth and prolonged maturation makes this family of snails exceptionally vulnerable to extinction (Brown and Johnson 2004, cited in Johnson et al. 2013, p. 253).

All pleurocerids are dioecious. Sexual maturity is reached around one or two years of age. Females fertilize eggs internally, but males lack a penis. Researchers have not yet observed the exact mechanism of sperm transfer (Dazo 1965, Strong 2005, cited in Whelan et al. 2015, p. 1). Leptoxis species lay eggs in one of three observed patterns: circular clutches, single eggs laid in a random pattern, and linear arrangements of single eggs, and egg-laying patterns do not vary within species (Whelan et al. 2015, p. 4). Leptoxis compacta lays eggs in a non-random linear pattern and are not cohesively bound together by mucus or other organic matter (Whelan et al. 2015, p. 6). Eggs are c. 0.3 mm in diameter, and the hatch about 14 days after oviposition (Ibid., p. 4). In lab studies, all Leptoxis species laid eggs below the water line (all but L. foremanni) on the walls of the tanks or on the underside of terracotta tiles, and sometimes on the shells of other snails (Ibid.). These observations match what one would expect to see in a natural environment; qualitative studies in the wild have observed eggs on the undersides or vertical sides of clean, hard substrates (Ibid.).

Oviposition occurs during species-specific time periods in the spring and/or summer (Stimpson 1864, Jones and Branson 1964, Aldridge 1982, Miller-Way and Way 1989, Brown and Johnson 2004, Johnson 2010a, b, cited in Whelan et al. 2015, p. 1). Following the rediscovery and collection of *L. compacta* in May 2011, eggs were laid by female *L. compacta* within three days of being transferred to captivity, which suggests that these rocksnails were breeding in the wild when collected (Whelan et al. 2012, p. 3). Oviposition appears to be spurred by temperature for *Leptoxis* species, and different temperature cues are correlated with egg-laying patterns (Whelan et al. 2015, p. 4). *L. compacta*, along with most other *Leptoxis* species, only laid eggs in a lab study when temperatures reached 22° Celsius or greater (Ibid.). Once oviposition began, it typically continued for 60 to 90 days (Ibid.).

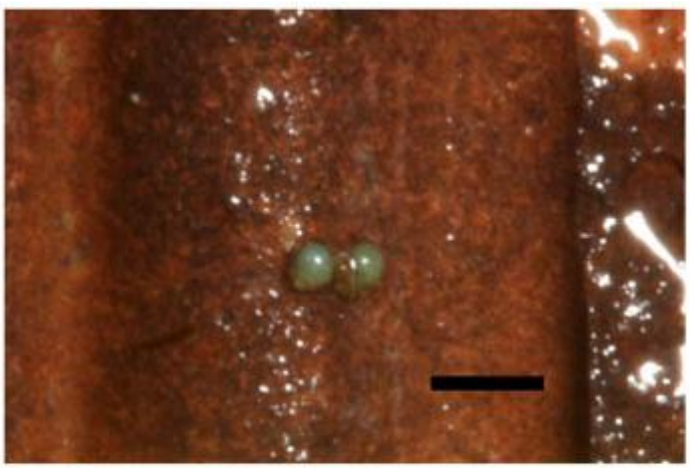

Figure 5: Photograph of two eggs that were laid by captive *L. compacta* (Whelan et al. 2012, p. 5, Fig. 7).

More detailed studies are needed to understand *Leptoxis* diversity, life-history evolution, and population densities and distributions (Brown et al. 2008, p. 489-490; Whelan et al. 2015, p. 8).

C. Feeding and Ecology

Little is known about the current feeding and ecological characteristics of *L. compacta* since it was not seen for over 70 years, and regardless, little is known about pleurocerid life history overall (USFWS 2009, p. 31116; USFWS 1997, p. 54021-54022). Generally, pleurocerids are considered to be important aquatic grazers which are adapted for scraping algae and other microorganisms from hard substrates (Hill et al. 1995, Johnson and Brown 1997, Rosemond et al. 2000, cited in Stewart and Garcia 2002, p. 177). They use their radulas (a horny band with minute teeth) to pull periphyton and biofilm detritus off of hard surfaces into their mouths (Johnson 2004, p. 116, cited in USFWS 2009, p. 31116). These snails structure communities and regulate energy/nutrient flow pathways by reducing and shifting periphyton biomass and composition and altering production (Stewart and Garcia 2002, p. 173; Gregory 1983, Lamberti et al. 1987, 1989, 1995, Hill and Harvey 1990, Hill 1992, Rosemond et al. 1993, Feminella and Hawkins 1995, Steinman et al. 1987, Tuchman and Stevenson 1991, Feminella and Hawkins 1995, reviewed in Brown 2001, cited in Brown et al. 2008, p. 487).

Indeed, gastropods tend to be the most abundant invertebrate grazers in the southeastern United States, but more research is needed on pleurocerid genera other than *Elimia* to understand species specific preferences, interspecific competition, and periphyton production and regulation (Brown et al. 2008, p. 487, 491). Studies on *Elimia* show that they consume algae, bacteria, periphyton and detritus, similar to most other gastropods (Morales and Ward 2000b, Mulholland et al. 2000, Brown 2001, cited in Brown et al. 2008, p. 487). Food availability seems to be an important driver of pleurocerid growth across genera (Brown et al. 2008, p. 486, 488).

D. Habitat Requirements

Freshwater Pleuroceridae, including *L. compacta*, are fluvial specialists that require clean, flowing water (Dazo 1965, Harman 1968, cited in Tolley-Jordan et al. 2015, p. 236). Rocksnails live in shoals, riffles and reefs of rivers and attach themselves to bedrocks, boulders, cobbles, and gravel where they feed on periphyton and detritus and lay eggs (USFWS 2009, p. 31116; USFWS 1997, p. 54021-54022). Despite the high diversity of pleurocerids in North America and their critical roles in the ecosystem, little is known about more specific factors influencing their distribution and abundance (Stewart and Garcia 2002, p. 178-179). Overall, if food availability, substrate composition, water velocity and snail size are important components in determining habitat suitability and influence the movement patterns of snails (USFWS 2009, p. 31116; Stewart and Garcia 2002, entire; Huryn and Denny 1997, p. 482).

Leptoxis spp. typically select for large substratum particles such as boulders and cobble, and they are rarely found in fine particles and sediment (Houp 1970, Krieger and Burbanck 1976, Ross and Ultsch 1980, cited in Stewart and Garcia 2002, p. 177). Stewart and Garcia (2002) found *Leptoxis carinata* density and total biomass increased with topographic complexity created by boulders and cobble (p. 177). Similarly, Harman (1972) collected *L. carinata* only in cobble substrata and never found this snail in silty habitats (cited in Stewart and Garcia 2002, p. 177). Boulders and cobble provide sites for attachment and egg deposition (Krieger and Burbanck 1976, Stiven and Kreisler 1994, cited in Stewart and Garcia 2002, p. 177), provide a refuge from hydrologic disturbances (Johnson and Brown 1997, cited in Stewart and Garcia 2002, p. 177), and harbor algae and bacteria for feeding (Hill et al. 1995, Johnson and Brown 1997, Rosemond et al. 2000, cited in Stewart and Garcia 2002, p. 177).

Depth and flow velocity also impact pleurocerid distribution and abundance. Ross and Ulstch (1980) found that two pleurocerid taxa in Alabama preferred waters with depths and velocities less that 30 cm and 0.25 m/s, respectively (cited in Stewart and Garcia 2002, p. 178). Similarly, Johnson and Brown (1997) found that pleurocerids (*Elimia semicarinata*) aggregated in flow refuges created by rocks when current velocities were high (0.35 m/s, cited in Stewart and Garcia 2002, p. 177). Snails are at risk of being dislodged and washed downstream in periods of high flow rates such as floods and are limited by slow adult dispersal rates (Brown et al. 2008, p. 484), so they select for shallow, rocky substrate where they can maintain their position on the downstream side of a rock and reduce bioenergetic costs of foraging and moving (Hill 1992, Johnson and Brown 1997, cited in Stewart and Garcia 2002, p. 177).

III. RANGE AND STATUS

The oblong rocksnail historically ranged from Centreville in Bibb County, Alabama upriver into lower Buck Creek in the Valley and Ridge physiographic province of the southern Appalachian Mountains (Whelan et al. 2012, p. 2). It was most abundant in the central section of the Cahaba River – a 180-mile long river flowing from Birmingham to the Alabama River west of Selma – at Lily Shoals in Bibb County, Alabama (Goodrich 1941, Goodrich 1922, cited in Whelan et al. 2012, p. 1).

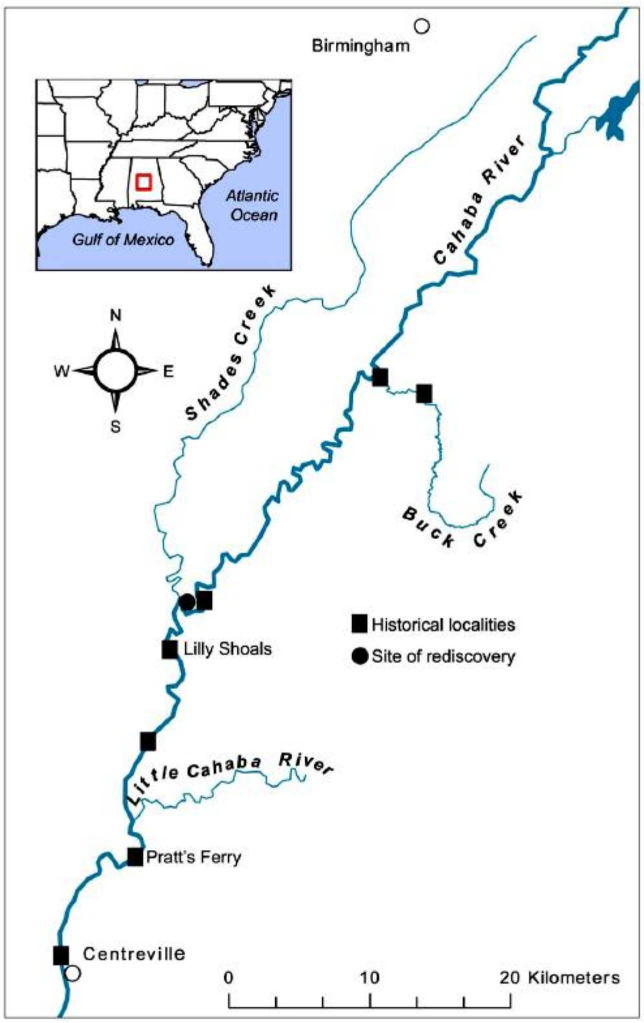

Figure 6: Map of the Cahaba River and select tributaries. Historical collections sites were sampled in August 2011, but *L. compacta* was found only at the site of re-discovery (Whelan et al. 2012, p. 2, Fig. 1).

By 1935, the species was already declining in abundance and range (Goodrich 1941, cited in Whelan et al. 2012, p. 1). The oblong rocksnail was declared extinct in 2000 (Neves et al. 1997, cited in Whelan et al. 2012, p. 1) after surveys for the species in 1992 (Bogan and Pierson 1993, cited in Whelan et al. 2012, p. 1), 2005 (Johnson et al. 2006, cited in Whelan et al. 2012, p. 1), and 2008 (Tolley-Jordan 2008, cited in Whelan et al. 2012, p. 1) failed to locate a single individual, though it had not been collected for at least 70 years prior (Whelan et al. 2012, p. 1). It was the only pleurocerid endemic to the Cahaba River declared extinct (Ibid.).

The oblong rocksnail was rediscovered in May 2011 on an unnamed shoal upstream of the Cahaba River and Shades Creek confluence in Shelby County, Alabama (33.1786°N, 87.0174°W; Whelan et al. 2012, p. 2), but was not found at other historical sites that were sampled (Ibid.).

The oblong rocksnail is now classified as Critically Imperiled by NatureServe (2015), but is still listed as extinct by the International Union for Conservation of Nature (Bogan 2000).

IV. THREATS

There can be no reasonable doubt that the oblong rocksnail (*Leptoxis compacta*) warrants protection as an endangered species. The Endangered Species Act states that a species shall be determined to be endangered or threatened based on any one of five factors (16 U.S.C. § 1533 (a)(1)):

(A) The present or threatened destruction, modification, or curtailment of its habitat or range
(B) Overutilization for commercial, recreational, scientific, or educational purposes;
(C) Disease or predation;
(D) The inadequacy of existing regulatory mechanisms;
(E) Other natural or manmade factors affecting its continued existence.

The oblong rocksnail was thought to be extinct until its recent rediscovery in 2011 (Whelan et al. 2012, entire). Exact reasons for its decline are unknown, but scientists agree that it was likely the result of its naturally small range, pollution from mines in the area, effluent from the Birmingham metropolitan area, impoundments, nonpoint source agricultural pollution, and introduced species (Shepard et al. 1994, cited in Whelan et al. 2012, p. 1; Neves et al. 1997, Bogan 1998, cited in Brown et al. 2008, p. 484; Tolley-Jordan et al. 2015, p. 236). The continued existence of *L. compacta* continues to be threatened by these factors, and it is at risk of extinction due to factors A, D, and E.

A. Modification or Curtailment of Habitat or Range

Freshwater habitats are among the most threatened ecosystems on the continent, plagued with impoundments, siltation, eutrophication, pollution, and over-use (Master et al. 2000, Heinz Center Report 2002, Burkhead 2012b, cited in Johnson et al. 2013, p. 260). The Mobile River Basin (MRB) harbors extraordinary molluscan diversity (Williams et al. 2008, Lydeard and Mayden 1995, Neves et al. 1997, Johnson et al. 2012, cited in Whelan et al. 2012, p. 1; Tolley-Jordan et al. 2015, p. 236), but it is also the site of the most extreme extinction events in modern history (Lydeard and Mayden 1995, Neves et al. 1997, Johnson et al. 2012, Ó Foighil et al. 2011, Régnier et al. 2009, cited in Whelan et al. 2012, p. 1). Urbanization, pollution, and impoundments were all factors in these extinctions, and they continue to threaten *L. compacta*'s only remaining population (USFWS 2005, p. 15-16; Whelan et al. 2012, p. 4).

Land Use and Population Growth

Alterations in the landscape as a result of human population growth and land use have a range of negative impacts on stream morphology, water chemistry, siltation, nutrient dynamics, and hydrology (Paul and Meyer 2001, cited in Tolley-Jordan et al. 2015, p. 236; Johnson et al. 2002, p. 32). In the southeastern United States, forest cover was lost to agricultural lands before the 1940s, and to urban development since the 1950s (Alig et al. 2000, Brown et al. 2005, cited in Tolley-Jordan et al. 2015, p. 236). Land-use maps are not available from the late 1800s to early 1900s, but historical accounts from the Cahaba River Basin of pollution caused by mining, sewage, agriculture, or other industrial developments are correlated with the historical decline of snail species' richness, including the decline of *L. compacta* populations (Goodrich 1941, Baldwin 1973, cited in Tolley-Jordan et al. 2015, p. 245-246; ADCNR 2005, cited in Thom et al. 2013, p. 2). This indicates that pleurocerids are sensitive to habitat alteration from human land use (Tolley-Jordan et al. 2015, p. 246-247).

While much of the lower Cahaba Basin was being converted for agricultural use and timber harvest (Goodrich 1941, cited in Tolley-Jordan et al. 2015, p. 237), Birmingham served as an industrial hub for ore mining and steel production (Ibid.). As a result, the Cahaba River's water quality was severely degraded by point-source inputs, releases of wastewater treatment plants, and diffuse fertilizer inputs from agricultural practices (El-Kaddah and Carey 2004, Shepard et al. 1994, O'Neil and Shepard 1999, cited in Tolley-Jordan et al. 2015, p. 237). Unfortunately, many polluting practices continue today, alongside rapidly expanding urban and sub-urban sprawl (Alig et al. 2000, cited in Tolley-Jordan et al. 2015, p. 242). Urban areas in the southeast United State are expected to double or triple in size, leading to greater amounts of urban run-off, increased urban warming, and habitat fragmentation (Terando et al. 2014, p. 6). This expansion will also create a greater need for rural and urban infrastructure, such as hydroelectric dams, irrigation systems, and wastewater treatment plants, to support a larger human population (Ibid.).

While silviculture threatens future degradation of instream habitat in the lower Cahaba basin (Murray et al. 2001, cited in Tolley-Jordan et al. 2015, p. 246), the expansion of development around the city of Birmingham is of particular concern for rare snails such as *L. compacta* in the upper basin (Buckner et al. 2002, cited in Tolley-Jordan et al. 2015, p. 243). In the upper Cahaba basin, land conversion was historically minimal, but the area has been one of the most rapidly developed areas in Alabama and currently has about 12 percent urban cover (Tolley-Jordan et al. 2015, p. 243; ADEM, undated p. 11). The local extirpations of closely related snail species such as: *Elimia cahawbensis*, *Elimia carinifera*, *Elimia carinocostata*, *Leptoxis ampla*, and *Pleurocera vestita* have been directly correlated with an increase in developed land cover in the upper zone of the Cahaba from 1992 to 2006, likely as a result of altered hydrology, geomorphology, and water quality (Tolley-Jordan et al. 2015, p. 243). The removal of riparian zones, increased impervious surfaces, pollution runoff – both point source such as sewage-treatment effluent and nonpoint-source such as sediment and chemicals from paved surfaces and golf courses – and increased likelihood of local flooding are likely to prevent the persistence of *L. compacta* and other snail species (Ibid.; Johnson et al. 2002, p. 32).

Habitat degradation resulting from dramatic land use changes, both historically and currently, as seen in the Mobile River Basin and Cahaba River, specifically, threaten the survival of the basin's many imperiled snails, including *L. compacta* (Tolley-Jordan et al. 2015, p. 247).

Pollution and Sedimentation

Water pollution was likely a significant factor in the extinction of numerous freshwater species in the Mobile River Basin prior to the passage of the Clean Water Act and the adoption of state water quality criteria (USFWS 2005, p. 15). Still, pollution and water quality degradation remain significant threats to oblong rocksnails, compounded by their isolation and small population size (Ibid.; Johnson et al. 2002, p. 32; ADEM 2006, p. 8; Whelan et al. 2012, p. 4).

As described earlier, pollution and urban runoff from the expanding Birmingham metropolitan area threatens the water quality of the Cahaba River and the survival of *L. compacta* (Whelan et al. 2012, p. 4). The Cahaba River Basin is considered highly impaired, and this impairment is comparable to the Mobile River Basin in general (Johnson et al. 2002, p. 42, 46). The causes of this impairment are point source discharges and nonpoint source runoff that lead to nitrification, decreased dissolved oxygen levels, increased acidity and conductivity, and other changes in water chemistry that have detrimental impacts on freshwater snails (USFWS 2005, p. 15-16; Johnson et al. 2002, p. 32, 42, 46).

The primary sources of this impairment are urban (Johnson et al. 2002, p. 46; O'Neil 2002, EPA 2003, cited in ADEM 2006, p. 8). Indeed, downstream of Birmingham, snails are chronically impacted by low dissolved oxygen levels, excessive ammonia, chlorine, phosphorous, and nitrogen as a result of runoff from more than 30 wastewater treatment plants and more than 100 industrial discharge permits in the upper basin (Thom et al. 2013, p. 2; Shepard et al. 1996, cited in USFWS 2005, p. 16-17). A single historical locality of *L. compacta* has three wastewater discharge points (ADEM 2009, Howard et al. 2002, cited in Whelan et al. 2012, p. 4).

Nonpoint-source pollution of pesticides and fertilizers also originates from urban areas, often in higher concentrations than from agricultural lands because lawns, golf courses, parks, and gardens are less regulated and subject to intense pesticide application (USGS 1999, cited in Johnson et al. 2002, p. 34). Pesticides are frequently detected in urban areas at toxic levels for aquatic life (Ibid.) in addition to agricultural areas where they remain a concern for the Cahaba River (USGS 1999, cited in Johnson et al. 2002, p. 34).

Sedimentation and eutrophication are more widespread and possibly the most concerning forms of pollution in the Cahaba system and occur throughout the upper, middle, and lower portions from a variety of rural and urban sources (Tolley-Jordan et al. 2015, p. 237; USFWS 2005, p. 16-17; ADEM 2006, p. 8; Thom et al. 2013, p. 61). Sediment is likely the most abundant pollutant produced in the Mobile River Basin and comes from many forms of land use or alteration (ADEM 1989, cited in USFWS 2005, p. 16; Johnson et al. 2002, p. 42, 46). Snails which require hard, clean surfaces for attaching, feeding, and reproducing, such as *L. compacta*, are harmed by sedimentation (See Habitat Requirements; USFWS 2005, p. 16). Excessive nutrients from urban runoff as well as agricultural sources – which are more widespread in lower reaches of the Cahaba Basin (Tolley-Jordan et al. 2015, p. 237; Thom et al. 2013, p. 61) – cause periodically low dissolved oxygen levels detrimental to aquatic snails and also promote heavy algal growth that may cover and eliminate rock surfaces snails utilize for feeding and reproducing (Atkins et al. 2004, Hynes 1970, cited in USFWS 2005, p. 16). Further exacerbating this issue is the synergistic effects of eutrophication and sedimentation acting together to threaten freshwater snails and their habitats (Waters 1995, cited in USFWS 2005, p. 16).

Dams

More than 30 dams regulate flow in the Mobile River Basin impounding more than 1,100 miles of river channels (Johnson et al. 2002, p. 814; USFWS 2005, p. 15), which has resulted in changing this system from a continuum of free-flowing riverine habitats into a series of impoundments connected only by short, free-flowing reaches (USFWS 2005, p. 15). By eliminating or reducing currents, allowing sediment to accumulate, altering water chemistry and lowering dissolved oxygen levels, dams and impoundments negatively impact river snails' ability to feed, respire, and reproduce (ADEM 1994, 1996, cited in USFWS 2005, p. 15; Brown et al. 2008, p. 486). As a result, numerous freshwater species have gone extinct or have been locally extirpated, including 38 gastropod species, and at least 71 more are on the brink of extinction (Neves et al. 1997, cited in Pringle et al. 2000, p. 814). In fact, the construction of a series of dams on the Coosa River resulted in the loss of 26 endemic gastropod species and is referred to as "one of the greatest known extinction episodes in the first half of the twentieth century" (Folkerts 1997, cited in Pringle et al. 2000, p. 814).

The Cahaba River – where the only population of *L. compacta* occurs – is somewhat unique, however, in that it is currently the only free-flowing river in the basin (Benke and Cushing 2005, cited in Tolley-Jordan et al. 2015, p. 237). Its discharge is mostly unregulated by dams and impoundments except for one impoundment, the Lake Purdy dam (Tolley-Jordan et al. 2015, p. 237; Johnson et al. 2002, p. 26). The Cahaba River was not always free-flowing, though. A small dam called the Marvel Slab was constructed on the Cahaba in the 1960s and disrupted the river's hydrology and obstructed the migration of aquatic fauna until it was removed in 2004 (Bennet and Howell, undated, p. 34).

Given the increasing human population and demand for freshwater in the Southeast, and especially in conjunction with increased drought, a higher demand for water and power may lead to the construction of new impoundments, such as the proposed dams on tributaries to the Pascagoula in Mississippi.[1] As the region moves away from coal and other fossil fuels, the demand for hydropower will also likely increase Though not currently a threat, it is important to acknowledge the role dams have played in the extinction of the region's species and the potential they have to become a threat again in the face of climate change. Maintaining the Cahaba as a free-flowing river is essential to the oblong rocksnail's survival.

[1] *See* http://www.sam.usace.army.mil/Portals/46/docs/OC/Environmental%20Assessment.pdf

B. Overutilization

This species of rocksnail is not known to be threatened by overutilization.

C. Disease and Predation

Leptoxis compacta is not known to be threatened by disease, though the subject is poorly researched for freshwater mollusks (USFWS 2009, p. 31120).

Oblong rocksnails are not currently known to be threatened by predation, but given their single population and restricted range, the species is highly vulnerable to natural or introduced predators (USFWS 2009, p. 31120). Freshwater mollusks are naturally consumed by a variety of fish, mammals and birds (Ibid.). Darters were observed switching to prey on *Elimia* spp. when abundance was high in spring and summer, while other fish such as species in the families Centrarchidae, Catostomidae, and Ictaluridae (Haag and Warren 2006, cited in Brown et al. 2008, p. 488) may prey on pleurocerids as well. These fish as well as crayfish may impact the survival rates of juvenile pleurocerids, but more work is needed to understand the potential role of predators in regulating pleurocerid populations (Brown et al. 2008, p. 488, 491).

Additionally, the potential invasion of non-native black carp (*Mylopharyngodon piceus*), a mussel-eating fish widespread in other U.S. river basins, threatens oblong rocksnails and other snail species in the Cahaba River (*See* Other Factors: Invasive Species; USFWS 2009, p. 31120). Invasive mollusks also potentially threaten *L.compacta* via competition for resources.

D. Inadequacy of Existing Regulatory Mechanisms

Oblong rocksnails are listed by Alabama's Department of Conservation and Natural Resources as a "Priority 1 - Highest Conservation Concern" species (Alabama Department of Conservation and Natural Resources, undated website). This listing describes the status of *L. compacta* as "critically imperiled and at risk of extinction/extirpation because of extreme rarity, restricted distribution, decreasing population trend/viability problems, and specialized habitat needs due to natural or human-caused factors and immediate research and conservation action is required" (Rainer 2012, PDF p. 1). While this listing identifies the status of the oblong rocksnail and highlights its need for conservation efforts, it affords the species no legal protection at the state or federal level (USFWS 2009, p. 31120). Propagation efforts are already underway at the Alabama Aquatic Biodiversity Center for the oblong rocksnail, but it is unknown whether or not those efforts have yet been successful (University of Alabama, undated fact sheet).

The oblong rocksnail declined to near extinction in the last century due to habitat degradation and pollution (Shepard et al. 1994, cited in Whelan et al. 2012, p. 1; Neves et al. 1997, Bogan 1998, cited in Brown et al. 2008, p. 484; Tolley-Jordan et al. 2015, p. 236). State and federal pollution regulations are assumed to provide protection for freshwater mollusks, but some species may be more sensitive to toxins and sediment than species commonly used in bioassays (USFWS 2009, p. 31120). Existing regulatory laws such as the Clean Water Act and its requirements under §303(d) are not adequately protective to safeguard sensitive freshwater organisms.

The Alabama Department of Environmental Management (ADEM) has designated the water use classification of most of the Cahaba River as an "Outstanding Alabama Water;" however, 185 miles of streams in the Cahaba River watershed do not support their designated uses (Thom et al. 2013, p. 64). As such, the EPA has placed 106 miles of the Cahaba River on the §303(d) list, meaning that these waters do not meet state water quality standards (Ibid. at 63). These waters are impaired due to nutrient over-enrichment, compounded by concurrent effects of excess sedimentation and extremes in prevailing hydrologic patterns, as well as elevated levels of pathogens, turbidity, and siltation (ADEM 2006, cited in Thom et al. 2013, p. 64).

Global climate change will exacerbate water quality problems for the oblong rocksnail, and there are no existing regulatory mechanisms at the state or federal level that address the urgent need to curb greenhouse gas emissions and curtail the worst projected impacts of climate change. Adverse effects of rising water temperatures on aquatic invertebrates are already being documented, and freshwater ecosystems are projected to be particularly sensitive to climate change as they are increasingly stressed by other factors (Ganser et al. 2013, p. 1168).

Despite the progress made in improving the water quality in the Cahaba Basin and efforts to reintroduce *L. compacta* populations, water quality degradation and lack of state and federal species protection continues to threaten the survival of oblong rocksnails.

E. Other Factors

Small Population Size and Restricted Range

Sensitive species with small population sizes are naturally more vulnerable to extinction (Pimm et al. 2006, cited in Johnson et al. 2013, p. 249). Freshwater gastropods exhibit exceptional endemism, which has come at a cost. More than 92 percent of aquatic snail extinctions have been of narrow endemic species with highly restricted ranges, often occurring in a single river, spring, or lake (Johnson et al. 2013, p. 249). This pattern is not restricted to snail species; the loss of rare and localized endemic species appears to be a common factor in most modern extinctions (Pimm et al. 1995, Burkhead 2012b, cited in Johnson et al. 2013, p. 249).

Leptoxis compacta is a recently rediscovered species that only occurs in one location in the Cahaba River. Given its small body size and range, freshwater snails, including *L. compacta,* are exceptionally susceptible to extirpation from a single pollution or siltation event (Whelan et al. 2012, p. 4; Brown et al. 2008, p. 484), progressive habitat degradation, floods, or drought (USFWS 2009, p. 31121). Its vulnerability is exacerbated by limited gene flow, reduced genetic diversity, and likelihood of inbreeding depression (Lynch 1996, p. 493-494, cited in USFWS 2009, p. 31121). Should a catastrophic event occur, the last remaining population of *L. compacta* would likely be eradicated. If it managed to survive, human assistance would be necessary to protect the population and ensure its successful introduction to other areas of suitable habitat given the limited ability for adult snails to disperse on their own (USFWS 2009, p. 31121; Brown et al. 2008, p. 484; Whelan et al. 2012, p. 4).

Climate Change

Ecological processes essential to the survival of *L. compacta* are critically threatened by changes in temperature and water availability expected as the result of climate change (Poff et al. 2002, p. 4, 7). Scientists have already observed unequivocal warming as a result of human-induced climate change since the 1950s, and many of the changes are unprecedented over decades to millennia (IPCC 2014, p. 2). Rising water temperatures and changes in geographic ranges or phenology of freshwater animals (*See* Strayer and Dudgeon 2010, p. 350) already provide evidence for human-induced climate change in freshwater ecosystems.

Climate models project continued warming across the southeast (Carter et al. 2014, p. 399). Warmer water temperatures may alter egg-laying behaviors and timing in Pleurocerids and research is needed to determine their upper thermal limits (Whelan et al. 2015, p. 9). *Leptoxis* species may be particularly vulnerable to thermal stress, as many of them initiate egg-laying at higher temperatures (Ibid.). Climate models also project increase in the frequency and severity of floods and droughts (Carter et al. 2014, p. 405; Strayer and Dudgeon 2010, p. 350; Hoerling and Kumar 2003, cited in Golladay et al. 2004, p. 504). This will produce large hydrological changes for riverine ecosystems, including increased water stress, with consequent impacts to freshwater fauna (Ibid.). The increased likelihood of severe droughts and floods combined with increased human population growth and demand for freshwater threaten the survival of limited range freshwater species like the oblong rocksnail. (Vörösmarty et al. 2000, cited in Dudgeon et al. 2006, p. 166). Climate change will exacerbate flow modifications during periods of drought, leaving freshwater fauna stranded – particularly mollusks which have limited ability to disperse (USFWS 2009, p. 31121).

The effects of climate change are already being observed in the southeast. During an extreme drought in 2007 and 2008, stream flow for the Conasauga River in the Coosa River watershed in Alabama in September 2007 was the lowest recorded for any month in almost 70 years (USGS 2007, cited in USFWS 2009, p. 31121). Nearly all of the flow of the Cahaba River is removed during periods of drought to supply water to Birmingham (Howard et al. 2002, cited in Thom et al. 2013, p. 2). Only a small portion is returned to the basin as treated wastewater (*Id.*). Declines of mollusks as a direct result of drought have already been documented (*See* Golladay et al. 2004, p. 504; Haag and Warren 2008, p. 1174), and the threat to freshwater snails posed by drought is magnified both by climate change and by human population growth (Terando et al. 2014, p. 7). Human response strategies to decreased water availability will likely include the construction of more dams and greater water withdrawals to sustain agriculture and urban facilities (Strayer and Dudgeon 2010, p. 351; Golladay et al. 2004, p. 504; USFWS 2009, p. 31121).

Sudden flooding will also negatively impact oblong rocksnails (Brown et al. 2008, p. 486). Physical disturbance from floods can be a major determinant of benthic communities in rivers (Bunn and Arthington 2002, p. 495). This is well documented through research on the impacts of dams where sudden increases in flow have caused catastrophic downstream drift resulting in the loss of up to 14 percent of the benthic biota in a single event (Ibid.). Snails are especially at risk of being dislodged and washed downstream in periods of high flow rates and are limited by slow adult dispersal rates (Brown et al. 2008, p. 484). Indeed, large numbers of pleurocerids have been stranded and killed during winter floods (Diamond 1982, Huryn et al. 1995, cited in Stewart and Garcia 2002, p. 178).

Many species of freshwater invertebrates are likely to go extinct due to climate change (Strayer 2006, p. 280). Freshwater mussels and snails are capable of moving only short distances and are unlikely to be able to adjust their ranges in response to climactic shifts (USFWS 2009, p. 31121). For these reasons, *L. compacta* is threatened by climate change.

Invasive Species

Introduced species have the potential to threaten *L. compacta*'s only population and prevent successful reintroductions. Many other pleurocerids have suffered dramatic reductions as a result of introduced species (Neves et al. 1997, Bogan 1998, cited in Brown et al. 2008, p. 484), and snails in the Mobile River Basin are not impervious to this threat (USFWS 2005, p. 17).

Introduced species negatively impact native fauna through predation and competition for resources. At least 16 exotic fishes have been introduced to the MRB, and very little attention has been given to other exotic species (Pringle et al. 2000, p. 815; Brown et al. 2008, p. 491). It is possible for the black carp (*Mylopharyngodon piceus*) to establish itself in Alabama through aquaculture facilities in Mississippi (USFWS 2005, p. 17). Black carp are nonselective snail eating fish that have wreaked havoc on native fauna in the rest of the United States, and it would surely cause the further decline of freshwater snails in the MRB (Ibid.). The establishment of zebra mussels represents another looming threat; if that were to occur, most native mollusks would be outcompeted for space and food, including *L. compacta* (Neves et al. 1997, Bogan 1998, Strayer 1999, cited in Stewart and Garcia 2002, p. 172; Pringle et al. 2000, p. 815; Brown et al. 2008, p. 489). Exotic snails, such as apple snails (*Pomacea* spp.) have also been detrimental to native snail communities in the United States, but they have received much less attention, despite the documentation of 37 nonnative freshwater gastropod species in North America (NatureServe 2007, cited in Brown et al. 2008, p. 489, 491). The extremely limited range of the oblong rocksnail makes it exceedingly vulnerable to impacts from invasive species.

V. REQUEST FOR CRITICAL HABITAT DESIGNATION

Petitioners request that the Service designate critical habitat for *Leptoxis compacta* concurrently with listing.

VI. CONCLUSION

Until its rediscovery in 2011, the oblong rocksnail had not been detected since 1933 and was thought to be extinct. The fortunate redetection of a species that was thought to be lost for all time provides the opportunity to ensure that this unique piece of our national freshwater heritage does survive for future generations. The rocksnail only persists in a quarter mile section of the Cahaba River and is exceedingly vulnerable to extinction. This small mollusk is threatened by pollution, habitat alteration, invasive species, climate change, small population size, limited range, and extreme vulnerability to catastrophic events. It is not adequately protected by any state or federal laws. Based on the best available scientific information, oblong rocksnails are in danger of extinction and qualify for protection under the Endangered Species Act.

On behalf of all parties,

Tara Easter
Scientist
Center for Biological Diversity
PO Box 11374
Portland, OR 97211

REFERENCES

Alabama Department of Conservation and Natural Resources. Undated. "Oblong Rocksnail". Available at: http://www.outdooralabama.com/oblong-rocksnail

[ADEM] Alabama Department of Environmental Management. 1989. Alabama nonpoint source management program. Montgomery, Alabama. 135 pp.

[ADEM] Alabama Department of Environmental Management. 1994. Water quality report to Congress for calender years 1992 and 1993. Montgomery, Alabama. 111 pp.

[ADEM] Alabama Department of Environmental Management. 1996. Water quality report to Congress for calender years 1994 and 1995. Montgomery, Alabama. 144 pp.

[ADEM] Alabama Department of Environmental Management. 2006. FINAL Nutrient Total Maximum Daily Loads (TMDLs) for the Cahaba River Watershed. Alabama Department of Environmental Management Water Quality Branch Water Division. September 2006.

[ADEM] Alabama Department of Environmental Management. 2009. Final Total maximum daily load (TMDL) for Buck Creek assessment Unit ID # AL03150201-0202-101 pathogens (fecal coliform). Submitted to the Alabama Deparment of Environmental Management. 45 p.

[ADEM] Alabama Department of Environmental Management. Undated. Cahaba River Basin Management Plan. www.cahabariver.com.

[ADCNR] Alabama Department of Conservation and Natural Resources. 2005. Conserving Alabama's Wildlife: A Comprehensive Strategy. ADCNR, Division of Wildlife and Freshwater Fisheries. Montgomery, AL. 322 pp. Available from: http://outdooralabama.com/research-mgmt/cwcs/outline.cfm

Alig R.J., Plantinga A.J., Ahn S., Kline J.D. 2000. Land use changes involving forestery in the United States: 1952 to 1997, with projections to 2050. USDA Forest Service, Washington, DC.

Anthony J.G. 1854. Descriptions of new fluviatile shells of the genus Melania Lam., from western states of North America. Annals of the Lyceum of Natural History of New York 6: 122.

Atkins, J. B., H. Zappia, J.L. Robinson, A.K. McPherson, R.S. Moreland, D.A. Harned, B.F. Johnston, and J.S. Harvill. 2004. Water quality in the Mobile River Basin, Alabama, Georgia, Mississippi, and Tennessee, 1999-2001:U.S. Geological Survey, Circular 1231, 40 p.

Baldwin C.S. 1973. Changes in the freshwater mussel fauna in the Cahaba River over the past 40 years. MS thesis, University of Alabama, Tuscaloosa.

Benke A.E., Cushing C.E. 2005. Rivers of North America. Academic/Elsevier: San Diego.

Bennett, M. G., Howell, J. H., & Kuhajda, B. R. Undated. Fish Diversity and Conservation in the Mobile Basin in Alabama: An Overview with Case Studies. JOSHUA, 31.

Bogan, A. E. 1998. Freshwater molluscan conservation in North America: problems and practices. Journal of Conchology, Special Publication 2:223–230.

Bogan, A.E. (Mollusc Specialist Group). 2000. *Leptoxis compacta*. The IUCN Red List of Threatened Species 2000: e.T11774A3304833. http://dx.doi.org/10.2305/IUCN.UK.2000.RLTS.T11774A3304833.en. Downloaded on 20 April 2016.

Bogan A.E., Pierson J.M. 1993. Survey of the aquatic gastropods of the Cahaba River Basin. Alabama: 1992. Final Report Submitted to the Alabama Department of Cosnervation and Natural Resources 20 p.

Bogan, A. E., J. M. Pierson, and P. Hartfield. 1995. Decline in the freshwater gastropod fauna in the Mobile Bay Basin. Pages 249–252 in E. T. LaRoe, G. S. Farris, C. E. Puckett, P. D. Doran, and M. J. Mac, editors. Our living resources, a report to the Nation on the distribution, abundance and health of U.S. plants, animals, and ecosystems. U.S. Department of Interior, National Biological Survey, Washington, D.C.

Bouchet, P., and J. P. Rocroi. 2005. Classification and nomenclator of gastropod families. With classification by J. Frýda, B. Hausdorf, W. Ponder, A. Valdés, and A. Warén. Malacologia 47:1–397.

Brown, K. M. 2001. Mollusca: Gastropoda. Pages 297–325 in J. H. Thorp and A. P. Covich (editors). Ecology and classification of North American freshwater invertebrates. 2nd edition. Academic Press, Orlando, Florida.

Brown, K. M., and P. D. Johnson. 2004. Comparative conservation ecology and pleurocerid and pulmonate gastropods of the United States. American Malacological Bulletin 19:57–62.

Brown D.G., Johnson K.M., Loveland T.R., Theobald D.M. 2005. Rural land-use trends in the conterminous United States, 1950–2000. Ecological Applications 15: 1851–1863.

Brown, K. M., B. Lang, and K. E. Perez. 2008. The conservation ecology of North American pleurocerid and hydrobiid gastropods. Journal of the North American Benthological Society 27:484–495.

Brown, K. M., and C. E. Lydeard. 2010. Mollusca: Gastropoda. Pages 277–307 in J. H. Thorpe and A. P. Covich, editors. Ecology and classification of freshwater invertebrates of North America. Elsevier.

Buckner MM, Smith W, Takats JA. 2002. Tennessee, Cumberland and Mobile River Basins at risk: A biological assessment and vision for the World Wildlife Fund's Southeast Rivers and Stream Project. World Wildlife Fund: Nashville, TN.

Bunn, S. E., & Arthington, A. H. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental management, 30(4), 492-507.

Burkhead, N. M. 2012b. Extinction rates in North American freshwater fishes, 1900 to 2010. BioScience 62:798–808.

Carter, L. M., J. W. Jones, L. Berry, V. Burkett, J. F. Murley, J. Obeysekera, P. J. Schramm, and D. Wear, 2014: Ch. 17: Southeast and the Caribbean. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 396-417. doi:10.7930/J0NP22CB.

Covich, A. P., M. A. Palmer, and T. A. Crowl. 1999. The role of benthic invertebrate species in freshwater ecosystems. BioScience 49:119–127.

Dazo, B.C. 1965. The morphology and natural history of *Pleurocera acuta* and *Goniobasis livescens* (Gastropoda: Cerithiacea: Pleuroceridae). Malacologia 2:1–80.

Diamond, J. M. 1982. Stream geomorphology and benthic habitat predictability as determinants of the population dynamics and life history of the snail Juga plicifera. J. Freshwater Ecol., 1:577–588.

Dudgeon, D., Arthington, A. H., Gessner, M. O., Kawabata, Z. I., Knowler, D. J., Lévêque, C., ... & Sullivan, C. A. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological reviews, 81(02), 163-182.

El-Kaddah D.N., Carey A.E. 2004. Water quality modeling of the Cahaba River, Alabama. Environmental Geology 45: 323–338.

Feminella, J. W., and C. P. Hawkins. 1995. Interactions between stream herbivores and periphyton: a quantitative analysis of past experiments. Journal of the North American Benthological Society 14:465–509.

Folkerts G.W. 1997. State and fate of the world's aquatic fauna. Pages 1–16 in Benz GW, Collins DE, eds. Aquatic Fauna in Peril: The Southeastern Perspective. Decatur (GA): Lenz Design and Communication, Southeast Aquatic Research Institute Special Publication 1.

Ganser, A.M., T.J. Newton, and R. J. Haro. 2013. The effects of elevated water temperature on native juvenile mussels: implications for climate change. Freshwater Science 32(4):1168-1177.

Golladay, S. W., Gagnon, P., Kearns, M., Battle, J. M., & Hicks, D. W. 2004. Response of freshwater mussel assemblages (Bivalvia: Unionidae) to a record drought in the Gulf Coastal Plain of southwestern Georgia. Journal of the North American Benthological Society, 23(3), 494-506.

Goodrich, C. 1922. The Anculosae of the Alabama River Drainage. University of Michigan Museum of Zoology Miscellaneous Publications 7: 63.

Goodrich, C. 1941. Distribution of the gastropods of the Cahaba River, Alabama. Occasional papers of the museum of zoology 428: 1–30.

Gregory, S. V. 1983. Plant–herbivore interactions in stream systems. Pages 157–189 in J. R. Barnes and G. W. Minshall (editors). Stream ecology. Plenum Press, New York

Haag, W. R., and M. L. Warren. 2006. Seasonal feeding specialization on snails by river darters (*Percina shumardi*) with a review of snail feeding by other darter species. Copeia 2006:604–612.

Haag, W. R., & Warren Jr, M. L. 2008. Effects of severe drought on freshwater mussel assemblages. Transactions of the American Fisheries Society, 137(4), 1165-1178.

Harman WN. 1968. Replacement of pleurocerids by Bithynia in polluted waters of central New York. Nautilus 81: 77–83.

Harman, W. N. 1972. Benthic substrates: their effect on fresh-water Mollusca. Ecology, 53:271–277.

Hartfield P. 1993. Headcuts and their effect on freshwater mussels. In Conservation and Management of Freshwater Mussels, Cummings KS, Buchanan AC, Koch LM (eds). Proceedings of a UMRCC Symposium, St. Louis, MO. Upper Mississippi River Conservation Committee: Rock Island; 131–141.

Hawkins, C. P., and J. K. Furnish. 1987. Are snails important competitors in stream ecosystems? Oikos 49:209–220.

Heinz Center Report. 2002. The state of the Nation's ecosystems: measuring the lands, waters, and living resources of the United States. Cambridge University Press, Cambridge, UK.

Hill, W. R. 1992. Food limitation and interspecific competition in snail-dominated streams. Canadian Journal of Fisheries and Aquatic Sciences 49:1257–1267.

Hill, W. R., and B. C. Harvey. 1990. Periphyton responses to higher trophic levels and light in a shaded stream. Canadian Journal of Fisheries and Aquatic Sciences 47: 2307–2314.

Hill, W.R., M.G. Ryon and E.M. Sschilling. 1995. Light limitation in a stream ecosystem: responses by primary producers and consumers. Ecology, 76:1297–1309.

Hoerling, M., and A. Kumar. 2003. The perfect ocean for drought. Science 299:691–694.

Houp, K. H. 1970. Population dynamics of Pleurocera acuta in a central Kentucky limestone stream. Am. Midl. Nat., 83:81–88.

Howard H.S., Quinn B., Flexner M.C., Raschke R.L. 2002. Cahaba River: biological and water quality studies, Birmingham, Alabama. March/April, September and July, 2002. Athens, GA: US EPA Region 4 Science and Ecosystems Support Division. Available: http://www.epa.gov/region4/sesd/reports/2002-0809.html. Accessed 2012 Jul 14.

Huryn, A.D. and M.W. Denny. 1997. A biomechanical hypothesis explaining upstream movements by the freshwater snail *Elimia*. Functional Ecology, 11: 472-483.

Huryn, A. D., J. Koebel, and A. C. Benke. 1994. Life history and longevity of the pleurocerid snail *Elimia*: a comparative study of eight populations. Journal of the North American Benthological Society 13:540–556.

Huryn, A. E., A. C. Benke, and G. M. Ward. 1995. Direct and indirect effect of geology on the distribution, biomass, and production of the freshwater snail *Elimia*. Journal of the North American Benthological Society 14:519–534.

Hynes, H.B.N. 1970. The Ecology of Running Waters. University of Toronto Press, Toronto.

IPCC, 2014: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp. Available at: http://www.ipcc.ch/report/ar5/syr/

Johnson, P. D., and K. M. Brown. 1997. The role of current and light in explaining the habitat distribution of the lotic snail *Elimia semicarinata* (Say). Journal of the North American Benthological Society 16:545–561.

Johnson, G. C., Kidd, R. E., Journey, C. A., Zappia, H., & Atkins, J. B. 2002. Environmental setting and water-quality issues of the Mobile River basin, Alabama, Georgia, Mississippi, and Tennessee (No. 2002-4162).

Johnson P.D., Sides J.D., McGregor S.W., Ahlstedt S.A., Garner J.T., et al. 2006. Inventory of Freshwater Mollusks in the Cahaba River Basin, Alabama. Report Submitted to the Alabama Department of Conservation and Natural Resources. 153 p.

Johnson P.D., Bogan A.E., Brown K.M., Burkhead N.M., Cordeiro J.R., et al. 2012. Conservation status of freshwater gastropods of Canada and the United States. Fisheries. In Press.

Johnson, P. D., Bogan, A. E., Brown, K. M., Burkhead, N. M., Cordeiro, J. R., Garner, J. T., ... & Tarpley, T. A. 2013. Conservation status of freshwater gastropods of Canada and the United States. Fisheries, 38(6), 247-282.

Krieger, K. A. and W. D. Burbanck. 1976. Distribution and dispersal mechanisms of *Oxytrema* (-*Goniobasis*) *saturalis* Haldeman (Gastropoda: Pleuroceridae) in the Yellow River, Georgia, U.S.A. Am. Midl. Nat., 95:49–63.

Lamberti, G. H., L. R. Ashkenas, S. V. Gregory, and A. D. Steinman. 1987. Effects of three herbivores on periphyton communities in laboratory streams. Journal of the North American Benthological Society 6:92–104.

Lamberti, G. H., S. V. Gregory, L. R. Ashkenas, J. L. LI, A. D. Steinman, and C. D. McIntire. 1995. Influence of grazer type and abundance on plant–herbivore interactions in streams. Hydrobiologia 306:179–186.

Lamberti, G. H., S. V. Gregory, L. R. Ashkenas, A.D. Steinman, and C. D. McIntire. 1989. Productive capacity of periphyton as a determinant of plant–herbivore interactions in streams. Ecology 70:1840–1856.

Lévêque C.E., Balian V., Martens K. 2005. An assessment of animal species diversity in continental waters. Hydrobiologia 542: 39–67.

Lydeard C., Mayden R.L. 1995. A Diverse and Endangered Aquatic Ecosystem of the Southeast United States. Conservation Biology 9: 800–805.

Lydeard, C., Holznagel, W. E., Garner, J., Hartfield, P., & Pierson, J. M. 1997. A molecular phylogeny of Mobile River drainage basin pleurocerid snails (Caenogastropoda: Cerithioidea). Molecular Phylogenetics and Evolution, 7(1), 117-128.

Lydeard, C. E., R. H. Cowie, W. F. Ponder, A. E. Bogan, P. Bouchet, S. A. Clark, K. S. Cummings, T. J. Frest, O. Gargominy, D. G. Herbert, R. Hershler, K. E. Perez, B. Roth, M. Seddon, E. E. Strong, and F. G. Thompson. 2004. The global decline of nonmarine mollusks. BioScience 54:321–330.

Master, L. L., B. A. Stein, L. S. Kutner, and G. A. Hammererson. 2000. Vanishing assets: Conservation status of U.S. species. Pages 93– 118 in B. A. Stein, L. S. Kutner, and J. S. Adams, editors. Precious heritage, the status of biodiversity in the United States. Oxford University Press, New York.

Mirarchi RE, Garner JT, Mette MF, O'Neil PE. 2004. Alabama Wildlife, Volume One. The University of Alabama Press: Tuscaloosa, USA.

Morales, J. B. T., and A. K. Ward. 2000b. Differential incorporation of algae and bacteria by *Elimia clara* (Prosobranchia: Pleuroceridae)—a study using duallabeled periphyton. Journal of the North American Benthological Society 19:289–297.

Mulholland, P. J., J. L. Tank, D. M. Sanzone, W. M. Wollheim, B. J. Peterson, J. R. Webster, and J. L. Meyer. 2000. Food resources of stream macroinvertebrates determined by natural-abundance stable C and N isotopes and a 15N tracer addition. Journal of the North American Benthological Society 19:145–157

Murray GE. 1961. Geology of the Atlantic and Gulf Coastal Province of North America. Harper: New York.

Murray B.C., Abt R.C., Wear D.N., Parks P.J., Hardie I.W. 2001. Land allocation in the southeastern US in response to climate change impacts on forestry and agriculture. World Resource Review 13: 239–251.

NatureServe. 2007. NatureServe explorer: an online encyclopedia of life [web application]. Version 6.1. NatureServe, Arlington, Virginia. (Available from: http://www.natureserve.org/explorer)

NatureServe. 2015. NatureServe Explorer: An online encyclopedia of life [web application]. Version 7.1. NatureServe, Arlington, Virginia. Available http://explorer.natureserve.org. (Accessed: April 20, 2016).

Neves, R. J., A. E. Bogan, J. D. Williams, S. A. Ahlstedt, and P. D. Hartfield. 1997. Status of aquatic mollusks in the southeastern United States: a downward spiral of diversity. Pages 43–85 in G. W. Benz and D. E. Collins, editors. Aquatic fauna in peril: the southeastern perspective. Southeast Aquatic Research Institute, Special Publication 1, Chattanooga, Tennessee.

Ó Foighil D., Li J., Lee T., Johnson P.D., Evans R.R., et al. 2011. Conservation genetics of a critically endangered limpet genus and rediscovery of an extinct species. PLoS ONE 6: e20496.

O'Neil P.E., Shepard T.E. 1999. Water quality assessment of the lower Cahaba River watershed, Alabama: A summary report. Geological Survey of Alabama, Tuscaloosa, AL.

Paul MJ, Meyer JL. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32: 333–365.

Pimm, S., G. J. Russell, J. L. Gittleman, and T. M. Brooks. 1995. The future of biodiversity. Science 269:347–350.

Pimm, S., P. Raven, A. Peterson, C. H. Şekercioğlu, and P. R. Ehrlich. 2006. Human impacts on the rates of recent, present, and future bird extinctions. Proceedings of the National Academy Sciences 103:10941–10946.

Poff, N.L., M.M. Brinson, J.W. Day, Jr. 2002. Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Prepared for the Pew Center on Global Climate Change, January 2002.

Pringle, C. M., Freeman, M. C., & Freeman, B. J. 2000. Regional Effects of Hydrologic Alterations on Riverine Macrobiota in the New World: Tropical-Temperate Comparisons. BioScience, 50(9), 807-823.

Rainer, D. 2012. "Conservation Plan for Nongame Species Updated". August 23, 2012. Available at: http://www.outdooralabama.com/conservation-plan-nongame-species-updated

Régnier C, Fontaine B, Bouchet P (2009) Not knowing, not recording, not listing: numerous unnoticed mollusk extinctions. Conservation Biology 23: 1214–1221.

Rosemond, A. D., P. J. Mulholland, and J. W. Elwood. 1993. Top-down and bottom-up control of stream periphyton: effects of nutrients and herbivores. Ecology 74:1264–1280.

Rosemond, A. D., P. J. Mulholland, and S. H. Brawley. 2000. Seasonally shifting limitation of stream periphyton: response of algal populations and assemblage biomass and productivity to variation in light, nutrients, and herbivores. Can. J. Fish. Aquat. Sci., 57:66–75.

Ross, M. J. and G. R. Ultsch. 1980. Temperature and substrate influences on habitat selection in two pleurocerid snails (*Goniobasis*). Am. Midl. Nat., 103:209–217.

Shepard T.E., O'Neil P.E., McGregor S.W., Harris S.C. 1994. Water-quality and biomonitoring studies in the upper Cahaba River drainage of Alabama. Geological Survey of Alabama Bulletin 160: 1–118.

Shepard, T.E., P.E. O'Neil, S.W. McGregor, and S.C. Harris. 1996. Water-quality and biomonitoring studies in the upper Cahaba River drainage of Alabama. Geological Survey of Alabama. Bulletin 165. 161 pp.

Stein, C.B. 1976. Gastropods. In Endangered and threatened species of Alabama. Bulletin of the Alabama Museum of Natural History 2: 21–41.

Steinman, A. D., C. D. McIntire, S. V. Gregory, G. H. Lamberti, and L. R. Ashkenas. 1987. Effects of herbivore type and density on taxonomic structure and physiognomy of algal assemblages in laboratory streams. Journal of the North American Benthological Society 6:175–186.

Stewart, T. W., & Garcia, J. E. 2002. Environmental factors causing local variation density and biomass of the snail *Leptoxis carinata*, in Fishpond Creek, Virginia. The American midland naturalist, 148(1), 172-180.

Stiven, A. E. and B. R. Kreisler. 1994. Ecological and genetic differentiation among populations of the gastropod *Goniobasis proxima* (Say) in streams separated by a reservoir in the piedmont of North Carolina. J. Elisha Mitchell Sci. Soc., 110:53–67.

Strayer, D. L. 1999. Effects of alien species on freshwater mollusks in North America J. N. Am. Benthol. Soc., 18:74–98.

Strayer, D. L. 2006. Challenges for freshwater invertebrate conservation. Journal of the North American Benthological Society, 25(2), 271-287.

Strayer, D. L., & Dudgeon, D. 2010. Freshwater biodiversity conservation: recent progress and future challenges. Journal of the North American Benthological Society, 29(1), 344-358.

Strong, E. E. 2005. A morphological reanalysis of *Pleurocera acuta* Rafinesque, 1831, and *Elimia livescens* (Menke, 1830) (Gastropoda: Cerithioidea: Pleuroceridae). The Nautilus 119:119–132.

Strong EE, Gargominy O, Ponder WF, Bouchet P. 2008. Global diversity of gastropods (Gastropoda; Mollusca) in fresh water. Hydrobiologia 595: 149–166.

Terando, A. J., Costanza, J., Belyea, C., Dunn, R. R., McKerrow, A., & Collazo, J. A. 2014. The southern megalopolis: using the past to predict the future of urban sprawl in the Southeast US. PloS one, 9(7), e102261.

Thom, T.A., R.E. Burns, J. Faustini and K.J. Hunt. 2013. Water Resource Inventory and Assessment (WRIA): Cahaba River National Wildlife Refuge, Bibb County, Alabama, U.S. Fish and Wildlife Service, Southeast Region. Atlanta, Georgia. 102 pp. + appendices.

Tolley-Jordan L.R. 2008. The biology of Pleuroceridae (Gatropoda: Caenogastropoda) in the Cahaba River Basin, Alabama. Tuscaloosa: Univeristy of Alabama Press. 239 p.

Tolley-Jordan, L., Huryn, A. D., & Bogan, A. E. 2015. Effects of land-use change on a diverse pleurocerid snail assemblage. Aquatic Conservation: Marine and Freshwater Ecosystems, 25(2), 235-249.

Tuchman, N. C., and R. J. Stevenson. 1991. Effects of selective grazing by snails on benthic algal succession. Journal of the North American Benthological Society 10:430–443.

University of Alabama. Undated. The Oblong Rocksnail (*Leptoxis compacta*) Rediscovery Fact Sheet.

[USFWS] U.S. Fish and Wildlife Service. 1997. Endangered and Threatened Wildlife and Plants; Proposed Rule to List Three Aquatic Snails as Endangered, and Three Aquatic Snails as Threatened in the Mobile River Basin of Alabama. October 17, 1997. 62 FR 54020.

[USFWS] U.S. Fish and Wildlife Service. 2005. Recovery Plan for 6 Mobile River Basin Aquatic Snails. U.S. Fish and Wildlife Service, Jackson, Mississippi. pp.

[USFWS] U.S. Fish and Wildlife Service. 2009. Endangered and Threatened Wildlife and Plants; Proposed Endangered Status for the Georgia Pigtoe Mussel, Interrupted Rocksnail, and Rough Hornsnail with Critical Habitat. June 29, 2009. 74 FR 31114.

[USFWS] U.S. Fish and Wildlife Service. 2010. Draft Environmental Assessment and Land Protection Plan For The Proposed Expansion of Cahaba River National Wildlife Refuge and the Proposed Establishment of Cahaba River Conservation Area. Bibb, Chilton, Jefferson, Perry and Shelby Counties, Alabama. Southeast Region, Atlanta, Georgia. June 2010.

[USGS] United States Geological Survey. 1999. The quality of our Nation's waters—nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Vörösmarty, C. J., Green, P., Salisbury, J. & Lammers, R.B. 2000. Global water resources : vulnerability from climate change and population growth. Science 289, 284–288.

Waters, Thomas F. 1995. Sediment in streams: sources, biological effects and control. American Fisheries Society Monograph 7.

Whelan, N.V., Johnson, P.D., and Harris, P.M. 2015. Life-history traits and shell morphology in the genus *Leptoxis* Rafinesque, 1819 (Gastropoda: Cerithioidea: Pleuroceridae). Journal of Molluscan Studies, 1-11. Doi:10.1093/mollus/eyu058

Whelan, N. V., Johnson, P. D., & Harris, P. M. 2012. Rediscovery of *Leptoxis compacta* (Anthony, 1854) (Gastropoda: Cerithioidea: Pleuroceridae). PloS one, 7(8), e42499.

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