Dwarf Wedgemussel

Alasmidonta heterodon

5-Year Review:
Summary and Evaluation

U.S. Fish and Wildlife Service
New England Field Office
Concord, New Hampshire

April 2013

5-YEAR REVIEW

Species reviewed: Dwarf wedgemussel (*Alasmidonta heterodon*)

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1.0 GENERAL INFORMATION

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1.2 Methodology used to complete the review

The dwarf wedgemussel (DWM) 5-year review was conducted by Brett Hillman and Susi von Oettingen, biologists at the New England Field Office of the U.S. Fish and Wildlife Service (USFWS), the lead field office for the species. It summarizes information about the species' status, biology, and threats that has become available since the 2007 review. All USFWS and State natural resource agency personnel responsible for the recovery of this species were contacted for up-to-date information on occurrences, threats and recovery activities. U.S. Geological Survey (USGS) biologists and other academics conducting research on the DWM were also contacted. Since the current recovery plan

(USFWS 1993) is 19 years out of date, the information that was provided by State, USFWS and USGS biologists, academic researchers, and private consultants, primarily as reports and other gray literature, is the principal basis for this status review.

1.3 Background

1.3.1 FR Notice citation announcing initiation of this review:

76 FR 33334 (June 8, 2011): Notice of Endangered and Threatened Wildlife and Plants; Initiation of a 5-Year Review of Nine Listed Species: the Purple Bean (*Villosa perpurpurea*), Clubshell (*Pleurobema clava*), Roanoke Logperch (*Percina rex*), Swamp Pink (*Helonias bullata*), Northern Riffleshell (*Epioblasma torulosa rangiana*), Flat-spired Threetoothed Land Snail (*Triodopsis platysayoides*), Puritan Tiger Beetle (*Cicindela puritana*), Dwarf Wedgemussel (*Alasmidonta heterodon*), and Bog Turtle (*Glyptemys muhlenbergii*).

1.3.2 Listing history

FR notice: Determination of Endangered Status for the Dwarf Wedge Mussel; 55 FR 9447 9451
Date listed: March 14, 1990
Entity listed: Species
Classification: Endangered

1.3.3 Associated rulemakings: None

1.3.4 Review History:

This review constitutes the second 5-year status review of the DWM since its listing. Information that has become available since the last review (USFWS 2007) has been used to evaluate and assess the current status of the DWM.

1.3.5 Species' Recovery Priority Number at start of 5-year review:

The Recovery Priority Number for the DWM is 5, indicative of a species with a high degree of threat and low recovery potential.

1.3.6 Recovery Plan or Outline

Name of plan: Dwarf Wedgemussel (*Alasmidonta heterodon*) Recovery Plan
Date issued: February 8, 1993

2.0 REVIEW ANALYSIS

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

2.1.1 Is the species under review a vertebrate? No, the species is an invertebrate; therefore, the DPS policy is not applicable.

2.2 Recovery Criteria

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

2.2.2 Adequacy of recovery criteria

2.2.2.1 Do the recovery criteria reflect the best available and most up-to-date information on the biology of the species and its habitat? No.

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria? No.

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

1993 Recovery Plan Criteria

In order to reclassify the DWM as threatened from endangered, the following criterion (Criterion 1) must be met (Table 1 summarizes the viability of the Recovery Plan populations):

1. The following populations of the DWM must be shown to be viable (a viable population is defined in the Recovery Plan as one that "contains a sufficient number of reproducing adults to maintain genetic variability and in which annual recruitment is adequate to maintain a stable population"): mainstem Connecticut River (NH/VT), Ashuelot River (NH), Neversink River (NY), Upper Tar River (NC), three sites in the Neuse River system (NC), and six other rivers/creeks representative of the species' range.

   This criterion has been partially met.

   Populations remain viable in the mainstem Connecticut River and Ashuelot River. Three additional sites are also considered by experts to support viable populations based on survey data. These sites are as follows:

   Big/Little Flat Brook, NJ – A population of the DWM was discovered in the Flat Brook system, a tributary of the Delaware River, in 2001. Subsequent surveys led researchers to estimate the population at around 8,000 individuals (Lellis and Cole 2011). It is worth noting that the DWM occurs in great numbers in both Big Flat Brook and Little Flat Brook, and this branched range can act as a safeguard should a natural or anthropogenic disaster affect only one of the branches. One researcher familiar with the Flat Brook system considers the population to be viable, although it may exhibit natural fluctuations (W. Lellis, USGS, e-mail dated 5/3/2012).

Upper Tar River, NC – Although this population is not nearly as large or as dense as populations farther north, it is believed to be viable as evidenced by recent recruitment, ability to find individuals (albeit in low numbers) upon repeat surveys, and connected tributaries being occupied (S. McRae, USFWS, e-mail dated 10/23/2012).

Upper Fishing Creek, NC – Like the Upper Tar population, recruitment is evident in the Upper Fishing Creek system, and a healthy population has persisted for years, even though it is relatively small when compared to populations in the north. The population also benefits from having a branched range, with Shocco Creek, Rocky Swamp, and the Maple Branch all harboring the species in relatively high numbers (S. McRae, USFWS, e-mail dated 10/23/2012).

A number of additional sites may hold viable populations, but further surveys are required before this determination can be made. These sites are as follows:

Farmington River, CT – Nedeau (2006) estimated the DWM population to be in the thousands to perhaps the tens of thousands. However, the methods used to survey the population were qualitative and are inadequate for determining population viability. Moreover, encounter rates are lower than those of both the Ashuelot River and Connecticut River sites, habitat is at risk from development, and the effects of recent high flow events are unknown (E. Nedeau, Biodrawversity, e-mail dated 5/3/2012).

Neversink River, NY - Strayer *et al.* (1996) believed this population consisted of over 10,000 individuals. After some intense flood events, Campbell *et al.* (2006) found only 34 individuals along a 12.4-mile stretch of the river. A survey of an additional 13.8 river miles by Campbell *et al.* (2007) yielded no individuals. Together, these surveys covered nearly half of the 55-mile river. It should be noted that due to the qualitative nature of these surveys, it is difficult to draw conclusions about the population based on this data. However, these surveys do suggest that the post-flood population is currently not as robust as Strayer *et al.* (1996) thought nearly two decades ago. It is very possible that the Neversink population is viable and is simply experiencing a natural fluctuation due to the flooding (W. Lellis, USGS, e-mail dated 5/3/2012), and it remains to be seen whether or not the population will rebound.

Paulins Kill, NJ – A qualitative population study was performed in 2007 (Cole and Lellis 2007). Researchers concluded that not only was there recruitment in this population, but, in terms of absolute numbers, the population was greater than that of the Flat Brook system (W. Lellis, USGS, e-mail dated 5/3/2012). A total of 497 individuals were found over 36 river miles, 492 of which were concentrated in a 5-mile reach. In certain locations, researchers found more than 20 individuals per hour of searching, suggesting a relatively dense population. A quantitative survey has not yet been performed, making it difficult to draw solid conclusions about the viability of this population.

Table 1: Viability of Recovery Plan Populations

Recovery Plan Population	**Is it viable?**
Those Listed in Recovery Plan	
Mainstem Connecticut River (NH/VT)	Yes
Ashuelot River (NH)	Yes
Neversink River (NY)	Perhaps - more survey work needed
Upper Tar River (NC)	Yes
Little River (NC; Neuse basin)	No
Swift Creek (NC; Neuse basin)	Not likely – currently being assessed
Turkey Creek (NC; Neuse basin)	No
Other Populations (Six Required)	
1. Big/Little Flat Brook (NJ)	Yes
2. Upper Fishing Creek (NC)	Yes
3. Farmington River (CT)	Perhaps - more survey work needed
4. Paulins Kill (NJ)	Likely - more survey work needed

In order to then delist the species, the following additional criteria must be met:

2. At least 10 of the rivers/creeks in Criterion 1 must support a widely dispersed viable population so that a single catastrophic event in a given river will be unlikely to result in the total loss of that river's population.

   This criterion has not been met since there are fewer than 10 river systems harboring viable populations (see discussion of viable populations above).

3. The rivers in Criterion 2 should be distributed throughout the species' current range with at least two in New England (NH, VT, MA, CT), one in New York, and four south of Pennsylvania (including New Jersey).

   While there are a sufficient number of viable populations in New England, there are not enough in the southern portion of the species' range to meet this criterion.

4. All populations referred to in the criteria for downlisting and delisting (Recovery Plan populations) must be protected from present and foreseeable anthropogenic and natural threats that could interfere with their survival.

   This criterion has not been met. A number of Recovery Plan populations continue to face anthropogenic and natural threats. For example, in a recent survey of the upper Connecticut River populations, Nedeau (2012a) noted severe bank erosion, sedimentation, and an overall high degree of active geomorphic processes in areas where the DWM was found. This can be attributed primarily to the location of agricultural lands right at the river's edge with no forested buffer in place.

   Development continues to threaten southern populations as well. In North Carolina, a highway project, a proposed water supply reservoir, and a proposed wastewater discharge are examples of anthropogenic threats to DWM populations (S. McRae, USFWS, e-mail dated 5/31/2012). As far as natural threats are concerned, both droughts and floods have negatively impacted DWM populations in recent years, and it remains to be seen whether or not they can recover. These extreme events may not be entirely natural, as both development along rivers and in floodplains and anthropogenic climate change may be playing a part. The implications of climate change are discussed in greater detail in section 2.3.2.5.

   However, it should be mentioned that some measures have been taken to help conserve various DWM populations across the species' range. For example, two different conservation easements were put in place in 2006 along Shelton Creek, a stream in the Upper Tar River basin that harbors a population that suffered major declines following a recent drought (R. Nichols, North Carolina Wildlife Resources Commission, e-mail dated 9/30/2011). Together, these easements protect over 22 acres of uplands and nearly 2,000 feet of stream reaches ("Granville County," not dated). In the Nanjemoy Creek watershed, which supports perhaps the largest and most viable DWM population in Maryland (J. McCann, Maryland Department of Natural Resources, e-mail dated 5/24/2012), the Nature Conservancy has been acquiring land for decades. This includes the recent acquisition of a tract of land that is just upstream of a river reach that is known to support the DWM ("About Nanjemoy Creek," not dated).

Issues with 1993 Recovery Plan

In the 2007 5-Year Review (USFWS 2007), a few issues with the Recovery Plan were raised:

1) *Issue*: The definition of "site" or "occurrence" is no longer clear. For example, under the Recovery Plan, the upper Connecticut River is

considered one population. However, surveys have shown that there are three large, viable, and geographically distinct populations on the river. It is unclear as to how these populations should be treated.

Discussion: It is worth noting that even if these were considered as three distinct, viable populations representative of the species' range, there would still not be enough evidence to downlist the species. The DWM is considered to be stable in the northern part of its range, based on both population numbers and the extent of occupied habitat (USFWS 2007; Nedeau 2009b), so the issue of whether or not to consider these as one or three populations for the purposes of meeting Recovery Plan criteria may be purely academic. Regardless of how many viable populations exist in the Northeast, there are simply not enough in the south to warrant delisting. According to Criterion 3 of the Recovery Plan, the ten recovery populations must be distributed throughout the species' current range.

2) *Issue*: The criteria are vague in quantifying how large or inclusive, as well as how geographically separate, the viable populations must be.

   Discussion: These issues are currently being addressed in North Carolina through the use of the Strategic Habitat Conservation (SHC) framework (see http://www.fws.gov/science/shc/ [Accessed March 2013]). This involves setting specific biological goals—in the case of the DWM, these could be target population sizes or densities—and taking the steps necessary to meet these goals.

3) *Issue*: Specific sites or stretches of river identified in the Recovery Plan as critical to recovery and essential for maintaining viable populations no longer coincide with new population information.

   Discussion: Some populations listed in the Recovery Plan—such as that of the Turkey Creek in the Neuse River basin—may not be feasible sites for recovery (S. McRae, USFWS, e-mail dated 6/27/2012). However, in order for the DWM to be downlisted according to the Recovery Plan, the population at this site must be viable. Therefore, the criteria as they are written will never be met. It may be necessary to remove Turkey Creek as a recovery population and replace it with one that shows more promise for recovery. Or, instead of the three specific Neuse River populations listed on the Recovery Plan, the criteria can be amended to allow for any three populations in the southernmost portion of the species' range to be viable.

4) *Issue*: It is not clear what constitutes protection of the habitat and populations from present and foreseeable threats. For example, the criterion identifying the Upper Tar River as a site that must be protected does not specify if this includes the entire Upper Tar River watershed or merely the single site documented in the Upper Tar River.

Discussion: Nedeau (2009b) outlined a variety of conservation strategies for the DWM on the upper Connecticut River that fell under the following broad categories:

- identify and address point source pollution;
- minimize threats from nonpoint source pollution and invasive species;
- protect land;
- protect or restore ecosystem processes and connectivity;
- minimize direct mortality;
- raise awareness and support for freshwater mussel conservation; and
- conduct research and monitoring.

These strategies make it clear that protection of habitats and populations involve protecting an area that extends well beyond a site, both upriver and into the surrounding uplands. Many of the strategies listed are specific to the threats faced by the DWM in the upper Connecticut River, while others apply to all populations throughout the species' range. Experts with intimate knowledge of other populations and the threats they face should use these strategies as a framework for developing and implementing population-specific conservation strategies.

2.3 Updated Information and Current Species Status

2.3.1 Biology and Habitat

2.3.1.1 New information on the species' biology and life history:

Fish host species

White (2007) confirmed that the slimy sculpin (*Cottus cognatus*), mottled sculpin (*Cottus bairdi*), Atlantic salmon (*Salmo salar*), and tessellated darter (*Etheostoma olmstedi*) serve as host species for the DWM. In addition, four new potential hosts were identified: the shield darter (*Percina peltata*), striped bass (*Morone saxitilis*), banded killifish (*Fundulus diaphanus*), and brown trout (*Salmo trutta*). Levine *et al.* (2009) determined that the fantail darter (*Etheostoma flabellare)* may also act as an efficient host for the DWM in North Carolina. The researchers determined the efficiency (measured as juvenile mussels produced per fish) of a number of other host fish as well.

Propagation

Based on the fish host efficiency experiments discussed above, Levine *et al.* (2009) concluded that propagating the DWM in a laboratory environment is more difficult than it is for other mussel species in North Carolina for the following reasons:

- individual specimens are difficult to find in the wild;
- females are gravid during the winter months when collection is difficult;
- their small size makes for a small brood. In addition, extracting a sizable number of glochidia in a manner that will not harm the mussel is difficult;
- the fantail darter, the species that seemed to be the most efficient fish host, fared poorly in captivity; and
- juveniles require a long period of time for transformation.

Sexual dimorphism

Baginski *et al.* (2012) found significant differences between the length-to-width ratios of male and female DWM. Four linear measurements—length, width, height, and umbo-to-anterior distance—were used to accurately predict the sex of an individual 95.2 percent of the time. Further, a relative warps analysis of shell shape, performed on photos taken of individuals, showed clear sexual dimorphism as well. These results suggest that taking simple measurements is an accurate and noninvasive method for determining the sex of individuals in the field.

2.3.1.2 Abundance, population trends, demographic features, or demographic trends:

Recent information regarding population viability was discussed in section 2.2.3. Table 2 below summarizes recent information (post-2006) on the populations discussed in that section as well as other DWM populations across the species' range. This information was also used to update Appendix 1, which is a comprehensive list of all DWM occurrences.

Table 2: DWM population information post-2007 (since initial status review).

River	State	DWM Notes
Fort River	MA	Thirteen found in watershed (five in Fort River, eight in Hop Brook) in 2007 survey (Nedeau 2008a). Ten found in followup survey on different section of Hop Brook two years later (Nedeau 2009a).
Farmington River	CT	Population estimated in the thousands to perhaps the tens of thousands (Nedeau 2006).
Ten Mile River	NY	Only one individual found in large scale study (Strayer 2010). First known occurrence of the DWM in the Housatonic basin.
Neversink River	NY	Qualitative studies yielded a total of 34 individuals over 26 miles of this 55-mile river (Campbell *et al.* 2006; Campbell *et al.* 2007).
Delaware River	NY	Qualitative surveys were performed on two river reaches in 2006 and 2008. Combined with surveys performed in 2000 and 2002, 30 individuals were found in the area of Callicoon, NY. Population size was estimated to be 894 individuals at this site (90 percent confidence interval: 311 to 3,081) from the 2002 quantitative survey (Lellis and Cole 2009).
Flat Brook	NJ	The combined population of both branches of Flat Brook (Big and Little) was estimated at 8,000 (Lellis and Cole 2011).
Paulins Kill	NJ	Nearly 500 individuals found in a 5-mile reach in a qualitative study (Cole and Lellis 2007). Lellis (2010) collected 52 individuals for laboratory experiments.
Pequest River	NJ	Survey in 2012 turned up only one relict valve (Jeanette Bowers, NJ Division of Fish and Wildlife, e-mail dated 2/6/2013).
Nanjemoy Creek	MD	Thirteen individuals found in 2008 monitoring (20.2 person-hours). This population, which spans greater than 1.5 river km, may be the largest in Maryland (J. McCann, Maryland Department of Natural Resources, e-mail dated 5/24/2012).
McIntosh Run	MD	Four live specimens found in 2008 monitoring (10.3 person-hours) (J. McCann, Maryland Department of Natural Resources, e-mail dated 5/24/2012).
Three Bridges Branch	MD	One dead shell found in 2009 represents the most upstream record of this river system (J. McCann, Maryland Department of Natural Resources, e-mail dated 5/24/2012).

River	State	DWM Notes
Herring Run	MD	One live and one dead individual found in survey consisting of 26.9 person-hours. This was a previously unknown occurrence (J. McCann, Maryland Department of Natural Resources, e-mail dated 5/24/2012).
Po River	VA	DWM were found in the upper reaches of the Po, but they were not found in areas where they were formerly known to occur (B. Watson, VA Dept. of Game and Inland Fisheries, e-mail dated 2/6/2013). Two additional surveys, both covering 1,000 m of the river, turned up one dead and one live specimen each (Ostby 2007; Ostby and Neves 2008).
Neuse River	NC	Since 2007, 11 stream reaches that once harbored the DWM in the Neuse River basin have been surveyed. Presence was only confirmed at one of the sites (Swift Creek) (S. McRae, USFWS, e-mail dated 5/31/2012).
Upper Tar River	NC	The 2007 drought likely caused a massive die off. In Shelton Creek, 22 DWM were found in 2007, 5 in 2010, and then just 3 shells in 2011. There may have been other local extirpations as well (R. Nichols, North Carolina Wildlife Resources Commission, e-mail dated 9/30/2011).
Upper Fishing Creek	NC	The presence of DWM has been confirmed in three out of the four locations where it has been known to occur in the past (S. McRae, USFWS, e-mail dated 5/31/2012). One new occurrence was also found (R. Nichols, North Carolina Wildlife Resources Commission, e-mail dated 12/5/2011).

2.3.1.3 Genetics, genetic variation, or trends in genetic variation:

Dr. Timothy King (USGS) and associates have been investigating the rangewide phylogeographic structure of DWM with a focus on determining the genetic relatedness of disjunct populations within the Delaware River watershed (Delaware mainstem, Neversink, and Flat Brook), and between the Delaware and the Connecticut River watershed (upper Connecticut and Ashuelot). Results thus far suggest the following (T. King, personal communication, 6/26/2012):

- sequence variation at the mitochondrial DNA cytochrome oxidase I region identified shallow yet diagnostic differentiation among the major river drainages from North Carolina to New Hampshire;
- nuclear DNA allele size (microsatellite DNA) and frequency differ significantly at multiple loci between Connecticut River and Delaware River populations;
- significant genetic differences are also apparent among Delaware River populations, including disjunct populations along the mainstem (at Callicoon, Hankins, and Frisbie Island);

- a maximum likelihood assignment test correctly assigned 100 percent of individuals to the drainage of origin (either the Delaware or Connecticut) and 98.6 percent of individuals to the collection of origin (either the Delaware mainstem, Neversink, Flat Brook, Connecticut mainstem, or Ashuelot); and
- the low degree (or absence) of gene flow between drainages (and within drainages, for the most part) suggests that individual host fish do not move between drainages, nor do they exhibit effective movement (resulting in gene flow) within drainages.

2.3.1.4 Taxonomic classification or changes in nomenclature:

Bogan *et al.* (2008) analyzed tissue samples from all taxa of living *Alasmidonta* species using mitochondrial DNA sequences from cytochrome oxidase c subunit 1 (COI) and NADH dehydrogenase subunit (ND1). Their analyses indicated that *A. heterodon* is significantly different from other species in the genus, and recommended that its subgenus, *Prolasmidonta*, be elevated to the generic level.

2.3.1.5 Spatial distribution and trends:

In 2010, a single individual was found in the Ten Mile River basin, a tributary of the Housatonic River. This marked the first time the species was found in this drainage and brings the total number of major drainages in which the DWM occurs to 16.

The mainstem of the Connecticut River in New Hampshire and Vermont is still considered to have the largest remaining DWM population, consisting of three distinct stretches of sporadically occupied habitat segmented by hydroelectric dams. It is estimated that there are hundreds of thousands of DWM scattered within an approximate 75-mile stretch of the Connecticut River. The Ashuelot River in New Hampshire, the Flat Brook in New Jersey, Paulins Kill in New Jersey, and the Neversink River in New York harbor large populations, but these likely number in the thousands only. Relatively large populations may also occur in the Farmington River in Connecticut, but additional survey work is needed. The remaining populations from New Jersey south to North Carolina are estimated at a few individuals to a few hundred individuals.

Table 3. Dwarf wedgemussel major drainages.[1]

State	Major Drainage	County
NH	Upper Connecticut River	Coos, Grafton, Sullivan, Cheshire
VT	Upper Connecticut River	Essex, Orange, Windsor, Windham
MA	Middle Connecticut River	Hampshire, Hampden
CT	Lower Connecticut River	Hartford
NY	Housatonic River*	Dutchess
NY	Middle Delaware	Orange, Sullivan, Delaware
NJ	Middle Delaware	Warren, Sussex
PA	Upper Delaware River	Wayne
MD	Choptank River	Queen Anne's, Caroline
MD	Lower Potomac River	St. Mary's, Charles
MD	Upper Chesapeake Bay	Queen Anne's
VA	Middle Potomac River	Stafford
VA	York River	Louisa, Spotsylvania
VA	Chowan River	Sussex, Nottoway, Lunenburg
NC	Upper Tar River	Granville, Vance, Franklin, Nash
NC	Upper Fishing Creek	Warren, Franklin, Nash, Halifax
NC	Upper Contentnea Creek	Wilson, Nash, Johnston
NC	Upper Neuse River	Johnston, Wake, Orange

* New addition

In summary, it appears that populations in New Hampshire, Massachusetts, and Connecticut appear to be stable, while the status of populations in the Delaware River watershed affected by the floods of 2005 are still being studied. The populations in North Carolina, Virginia, and Maryland are declining as evidenced by low densities, lack of reproduction, and/or inability to relocate any DWM in followup surveys. Although a few new sites have been discovered in Maryland, New York, and New Jersey, the prognosis for DWM recovery in the southern portion of its range is not as positive as in the northern portion. One mussel surveyor in Virginia has not found a single individual since 1993 (Kimberly Smith, USFWS, e-mail dated 5/30/2012). Results from surveys in North Carolina make it clear that populations are on the decline. All populations in the Neuse River basin appear to be declining, as are most in the Upper Tar River drainage (Table 2) (S. McRae, USFWS, e-mail dated 5/31/2012).

It is also worth noting that the species is officially listed as extirpated in Canada (COSEWIC 2009).

[1] The 16 major drainages identified in Table 3 do not necessarily correspond to the original drainages identified in the 1993 Recovery Plan, although there is considerable overlap. Watersheds are based on USGS and EPA Cataloguing Units.

2.3.1.6 Habitat or ecosystem conditions:

Descriptions of DWM Habitat

The DWM is a wide-ranging species that may be found in a variety of habitats and water depths. Nedeau provides habitat descriptions for recent surveys conducted on the upper Connecticut River (2009b; 2012a), Fort River (2008a) and Hop Brook (2009a). In the Flat Brook basin, 94 percent of individuals were observed in shallow pools within open sand/gravel substrate. They were also located in stream reaches that had an average gradient of 5 ft/mile; the DWM was not found in areas with gradients above 20 ft/mile (Lellis and Cole 2011).

Baldigo *et al.* (2003) found that DWM abundance in the Neversink River was significantly and positively correlated with three physical characteristics of streams (mean annual flow, channel width, and drainage area), along with concentrations of hardness, calcium, and silica and acid neutralizing capacity. Abundance was negatively correlated with elevation, percent open canopy, and concentrations of all nutrients. Together, the physical, chemical, and spatial variables measured by the researchers explained 100 percent of the variability in DWM abundance.

In more recent studies, Pandolfo *et al.* (2011) determined that the DWM has more restrictive microhabitat requirements (in terms of water depth, bottom velocity, dominant substrate, and sediment compaction) than a more common, generalist species, the eastern elliptio (*Elliptio complanata*). Maloney *et al.* (2012) performed a comprehensive study of the microhabitat requirements of the DWM in the Delaware River. The researchers estimated the available DWM habitat over a range of modeled flows. In addition, they determined that mussel beds were present in areas that served as refuges during periods of high flows; beds were found in areas exhibiting lower shear stress and velocity, and with stable streambeds over a five-year period. The DWM was present in depths ranging from 0.0 to 7.9 m and velocities ranging from less than 0.001 to 3.3 m/s.

Flow requirements

The DWM, like all aquatic species, requires a certain streamflow regime to persist. One of the biggest threats mussel species face is the alteration of their river or stream's natural flow regime by inundation due to impoundments, flow diversion and withdrawals, and other human activities. In the upper Delaware River, drought and an ever-increasing demand for water in New York City result in decreased streamflow which threatens the DWM. Cole *et al.* (2008) developed models to predict the minimum streamflow required to maintain the habitat conditions required by the DWM.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

Although water quality in the Ten Mile River has improved markedly since the mid-1900s, most mussel species, including the DWM, have not repopulated the river system. Strayer (2010) speculated that legacy pollution trapped in the sediments may be limiting repopulation.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes:

Not applicable.

2.3.2.3 Disease or predation:

No updates since 2007 review.

2.3.2.4 Inadequacy of existing regulatory mechanisms:

No updates since 2007 review.

2.3.2.5 Other natural or manmade factors affecting its continued existence:

Invasive Species

Four aquatic invasive species—Asian clam (*Corbicula fluminea*), "rock snot" or didymo (*Didymosphenia geminata*), zebra mussel (*Dreissena polymorpha*), and quagga mussel (*Dreissena rostriformis bugensis*)—are potential threats to native mussel species, including the DWM (Nedeau 2008b).

The Asian clam, which is slowly expanding its range north up the Connecticut River (Nedeau 2008b), may outcompete native mussels for food or space, predate on juveniles, and/or alter the nutrient cycling of streams in which they are abundant. It is present in all streams where the DWM occurs in North Carolina and it is also established in most river systems in Virginia. The decline of DWM populations in Virginia was observed concurrently with, or shortly after, the colonization of the state's rivers by the Asian clam. Anecdotal observations indicate that the Asian clam has negative effects on the abundance of native bivalves that are of similar size (Philip Stevenson, Creeklab, e-mail dated 6/7/2012). In recent years, this species has been documented in a few new locations in the Northeast. It was first discovered in Lake George in New York in 2010 (Nearing 2010), and in 2011, it was found in Cobbetts Pond and the Merrimack River in New Hampshire (Toole 2012).

Rock snot is a coldwater diatom that is expanding its range south along the upper reaches of the Connecticut River, and it has also been found in the East Branch Delaware River in New York (Nedeau 2008b). It forms dense mats that can cover the entire substrate within a stream, smothering aquatic invertebrates (Spaulding and Elwell 2007).

Two species of *Dreissenids*, the zebra and quagga mussels, are well established in the Saint Lawrence River and the Great Lakes and have been expanding their ranges closer to existing populations of the DWM. Both of these species are extremely prolific and can completely dominate entire ecosystems once established. Zebra mussels tend to establish themselves in larger rivers (greater than 30 meters wide) (Wicklow 2005; Strayer 1991), therefore DWM populations in the mainstem Connecticut and Delaware rivers may be at the greatest risk. Both species have the potential to thrive in lakes, impoundments, and large rivers within the range of the DWM if introduced (Nedeau 2008b).

These four species are known to hitchhike on boats, fishing gear, or both, which is aiding and quickening the expansion of their ranges.

Flood and Drought

Surveys in 2006 indicated that the DWM population in the Neversink River was adversely affected by flood events, although some live mussels were detected (Campbell *et al.* 2006; Campbell *et al.* 2007). However, it is possible that these declines represent natural fluctuations and populations will rebound over time (W. Lellis, USGS, e-mail dated 5/3/2012).

Drought also appears to have adverse effects on DWM populations. This is evident in the Upper Tar River watershed in North Carolina, where severe population declines have been witnessed following a substantial drought in 2007 (R. Nichols, North Carolina Wildlife Resources Commission, e-mail dated 9/30/2011). It remains to be seen whether or not this population will rebound.

Climate Change

Nedeau (2008b) provides an overview of how predicted effects of climate change may impact the DWM. Increasing water temperatures are likely to alter or restrict the ranges of coldwater fish species (Eaton and Scheller 1996), many of which serve as hosts for larval mussels. It is likely that changes in precipitation patterns will bring about more extreme and more frequent flood and drought events (Karl *et al.* 2009). Milly *et al.* (2005) predict that runoff will increase from 10 to 40 percent in rivers of eastern North America, and Najjar *et al.* (2000) also predict increases in streamflow in mid-Atlantic coastal streams. Droughts will be more common in the southern portion of the DWM's range, particularly in North Carolina (Karl *et al.* 2009). The DWM requires stable river systems (Nedeau 2008b), and the deleterious effects of floods and droughts have already been witnessed in the Neversink River and Upper Tar River populations, respectively. Given this, it is reasonable to conclude that climate change will have a negative impact on the DWM.

2.4 Synthesis

DWM populations should still be considered stable in the northern extent of its range in New Hampshire, Massachusetts, and Connecticut, based on population numbers and extent of occupied habitat. Populations in the Delaware River drainage, which were decimated by flooding in 2005, may be rebounding (W. Lellis, USGS, e-mail dated 5/3/2012). Southern populations are faring poorly overall and many may be at risk of extirpation, especially in the most southern extent of the range in the Neuse River basin.

Little riverine habitat adjacent to extant populations is protected other than by state shoreline and/or buffer protection regulations or local land use regulations. Development of adjacent uplands continues to be a significant and pervasive threat, especially to southern populations.

The DWM should continue to remain listed as *endangered*. The criteria to warrant delisting the species entirely or downlisting it to *threatened* have not been met. The extensive, but geographically limited populations found in New England do not compensate for the declining populations and loss of viable habitat in the southern portion of its range. Without significant recovery activities targeted at southern populations, such as those outlined by Nedeau (2009b) for the upper Connecticut River, it is unlikely the species can be downlisted in the near future, since there is a real possibility of range contraction.

3.0 RESULTS

3.1 **Recommended Classification:** No change is needed. Retain as endangered.

3.2 New Recovery Priority Number:

The RPN of 5 should be retained. The DWM still faces a high degree of threat throughout its range, and its recovery potential is low given its status in the southern portion of its range.

3.3 **Listing or Reclassification Priority Number:** Not applicable.

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

Recommendation: Revise recovery plan.

Much new information has become available since the Recovery Plan was written in 1993, both in terms of the species' biology and the status of individual populations. A revised Recovery Plan should take this new information into account. Specific revisions may include the following:

- define protective measures in order to meet recovery criterion 4, i.e. "protecting [DWM populations] from present and foreseeable anthropogenic and natural threats that could interfere with their survival." Nedeau (2009b) could be used as a framework;
- review the recovery populations outlined in the Recovery Plan and determine if these populations and/or habitats are relevant for recovery. For example, is a viable population in Turkey Creek, NC realistic? If not, remove it from the criteria for downlisting; and
- determine objective metrics for evaluating the viability of populations. This approach is being implemented in North Carolina through the use of the Strategic Habitat Conservation (SHC) framework. Quantitative, measurable goals have been built into the Recovery Plan for the listed Higgins eye pearlymussel *(Lampsilis higginsii)* (USFWS 2004). A number of "Essential Habitat Areas" must meet quantitative density, overall mussel diversity, and relative abundance (in terms of *L. higginsii*) targets in order to delist the species. Similar targets can be determined for the DWM through the use of the SHC framework.

Recommendations for specific recovery actions:

1. Develop persistence probability models (i.e., Population Viability Analysis) to help determine when a population is viable and when it may need intervention. To create these models and to ensure that they are realistic and reliable, more data is required. Additional studies that address age structure, sex ratio, age-specific growth rate and death rate, and age-specific reproduction and survival rates of DWM populations are needed to fill data gaps.

2. Complete population genetic analyses and determine whether taxonomic nomenclature needs revision.

3. Resolve the question of whether or not northern and southern populations are genetically distinct.

4. Complete ongoing statewide population surveys in North Carolina and Virginia, and assess population status in these states.

5. Develop criteria for determining high priority populations needed for the recovery of the species.

6. Develop habitat protection strategies for high priority populations.

7. Encourage and support publication of scientific research in peer-reviewed journals.

8. Resurvey the Neversink and Delaware rivers to assess impacts from severe flooding in 2005 and 2006 and establish new baselines for future comparison.

9. Implement management strategies identified during the North Carolina SHC workshops.

10. Revisit established survey sites on the Connecticut River that have not been resurveyed within the last ten years to verify that the sub-populations still persist, as well as to determine the long-term viability of the macrosites.

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U.S. FISH AND WILDLIFE SERVICE FIVE-YEAR REVIEW
Species: Dwarf wedgemussel *(Alasmidonta heterodon)*

Current Classification: Endangered

Recommendation Resulting from the Five-Year Review: No change

Review Conducted by: Brett Hillman, New England Field Office

FIELD OFFICE APPROVAL:

Thomas R. Chapman
New England Field Office Supervisor
U.S. Fish and Wildlife Service

Approve ______________________ Date 17 Apr 2013

Appendix: Dwarf Wedgemussel Site Information

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
NH/VT	Sullivan/Windsor-Windham,VT	Connecticut River	Connecticut River	18± miles	2002 - 2004 (select sites)	Charlestown surveyed in 2004	50+ observed during bank stabilization project in Charlestown (about 400 m of riverbank), 2 live at Rockingham site	incremental loss due to bank stabilization
NH/VT	Grafton/Windsor and Orange	Connecticut River	Connecticut River	14 mile +/-	2006	2005 - 2006	2005 - 1 live at site 9, 5 live and 2 shells at site 10; short duration snorkel surveys, 2006 - 12 additional sites found. Most sites with >1 ind found	incremental loss due to bank stabilization
NH/VT	Coos/Essex	Connecticut River	Connecticut River	16-18 miles	2001- 2005 (select sites)	1.Lunenburg 2002 and 2004; 2.Northumberland 2004	1. Relocation Project, over 6000 live DWM estimated at site near Lunenberg; 2. a quantitative survey well upstream of stabilization project estimated population size of over 6000 in a small area and extrapolation to large area yielded estimates of 100,000.	incremental loss due to bank stabilization
NH	Coos	Johns River	Connecticut River	4 sites	2006	2006	50+ over 4 sites	
VT	Windsor	Black River	Connecticut River	1 mile	1998		3 live, 6 shells	STP and mills impact water quality. Near confluence with Ct. R., part of Ct. R. south population

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
NH	Cheshire	Ashuelot River	Connecticut River	2 ± miles	2005	Quantitative survey in 2004; qualitative survey in 2005 to find gravid females for research on reproduction, Quantitative survey in 2006	~100, though primary survey was quantitative (systematic random sampling with multiple random starts & double sampling, using 0.25m2 quadrats). Population estimate of 989 and 464 for 2 50-m reaches	Impacts from golf course and urban run-off, development, water quality degradation; flood control dam operations; severe flooding in October 2005
NH	Cheshire	Ashuelot River	Connecticut River	8 ± miles	2001-2004	2004	2001: 13 live at 5 different sites; 2004: 2 live upstream of West Swanzey Dam (none observed prior), and approximately 45 live toward upper end of the impoundment in a ~1 mile reach using adaptive cluster sampling	Keene STP copper loading?, water quality degradation, erosion, upriver contamination (near 101 bridge in Keene), road/development run-off; possible dam removal
NH	Cheshire	S. Branch Ashuelot River	Connecticut River	0.5 ± miles	2005	1995	6 live DWM, material taken for genetic analysis	Road run-off, agricultural run-off, sedimentation, development
MA	Hampshire	Mill River (Whately and Hatfield)	Connecticut River	18 ± miles	199? - 2001-2005	2006, 2001, 2 live DWM downstream of dam in portion of Mill River that is essentially the Connecticut River floodplain (Brook Hollow Road Crossing, Hatfield)	2005: first specimen (1) located below Hatfield Dam, 2001: 476 upriver of dam in Hatfield and Whately	Agricultural run-off, localized die-off in 2001 due to ammonia from cattle run-off, bank erosion, water withdrawal from upstream water supply reservoirs, beaver activity, livestock access to river
MA	Hampshire	Running Gutter/Broad Brook (tributaries to Mill R.)	Connecticut River	0.2 miles occurrence; 2.5 miles habitat	1999	1999	13+ individuals	Agricultural run-off upstream
MA	Hampshire	Mill River	Connecticut River	0.2 miles occurrence; 1.2 miles habitat	1998	1998	1998: 1 adult female, 1 old adult shell; 1996 & 1994: shells observed, one ~4 yrs. old; 1973: 4 gravid females, 1adult male.	Upstream dredging of Paradise Pond

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
MA	Hampden	Fort River	Connecticut River	2.8 miles occurrence; ~8 miles habitat	2007	2007	2007: 5 live found; 2002: 1 live; 2001: 2 live; 1988: none found; 1984: 2 live; 1980: 2 males; 1976, '74, & '52: total of 8 found.	
MA	Hampden	Hop Brook	Connecticut River	< 1 mile	2007	2009	10 found in 2009; 8 live found in different stretch of river in 2007.	sedimentation, change in hydrology
CT	Hartford	Muddy Brook	Connecticut River	1 ± miles	1991		1 live	
CT	Hartford	Podunk River	Connecticut River	Unknown	2008	2008	Live individuals and shells found in 2008. 7 shells, 2 live (1997), 0 DWM in 2000	Development, water quality degradation,
CT	Hartford	Philo Brook	Connecticut River	Unknown	1991		2 shells	
CT	Hartford	Stony Brook	Connecticut River	Unknown	2005	2005	1 live in 3-hour survey near a bridge slated for replacement. 1st record in Stony Brook in 24 years.	bridge replacement; urbanization
CT	Hartford	Farmington	Connecticut River	Unknown	2002, 2005	2005	1 live + 2 shells in 2000; 12 live + 1 shell in 2005, including 11 live in 45 minutes at a site in Avon. 4 sites altogether, separated by several miles	water quality degradation, riparian development; WWTP, bank erosion, rapid urbanization
NY	Dutchess	Tenmile River	Housatonic River	Unknown	2010	2010	1 Live found in Webatuck Creek	Legacy pollution
NY	Orange	Neversink River	Delaware River	5 miles - Cuddebackville Dam to confluence	2006	2006	Surveys done in 2005 and 2006 at selected sites following flooding in 2005 indicate that at least one to two locations have very few individuals remaining. 2006 - 25 DWM found in 5 locations between confluence of Basher Kill to 5 mi downriver, but population has been severely damaged.	Dam removal, sedimentation, severe flood events, bridge replacements, dredging, debris removal, bank stabilization.

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
PA / NY	Wayne (PA), Sullivan (NY), Delaware (NY)	Delaware River	Delaware River	21 miles	2006	2000 - snorkel survey of entire stretch; 2002 - quadrat survey of individual sites	2000 - 13 live and 4 shells found at 3 sites during snorkel survey; 2002 - 16 live found at 2 sites during quadrat surveys. 2006 – 3 live found at 2 sites. 2008 – 5 live found at 4 sites.	Altered hydrology, siltation, nutrient enrichment
NJ	Warren	Pequest River	Delaware River	< 1 mile	2000		2012: one relict valve found in survey. Pre-2012: 2 live, some spent shells.	
NJ	Sussex	Paulins Kill	Delaware River	approx. 6 miles	2010	2007	2007 – Nearly 500 found within 5 mile reach of river. 2010 – 52 collected for lab studies. 2000 - 159 live observed.	
NJ	Sussex	Delaware River	Delaware River	Point location	2001	2006	1 live in 2001, may have been a washout from the Neversink River, may not have a population in this location.	Sewage treatment plant, urbanization
NJ	Sussex	Flat Brook	Delaware River	11 miles	2009	2009 quantitative survey– river km 4.7 to 17.4 of Big Flat Brook and river km 0.0 to 1.7 of Little Flat Brook.	2009 - pop. estimated to be 8,000+ individuals. 2006 - surveyed 13 miles of Big Flat Brook, found 227 over a 7 mi stretch;135 live individuals found in 2001, mostly from upper portion of 11 mile stretch around Wallpack Center. 200 live found in 2006 surveys post-flooding	Recreational fishing, agriculture in lower system.

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
MD	Queen Anne's/Talbot	Norwich Creek	Tuckahoe River	~0.8 km	2002	2007	Just one valve of dead specimen found in 2007 quadrat survey (spanning 70 m). Severe decline. Possibly extirpated. First reported in 1979 at densities of 0.5-1/m2. During 1984-1999, at least 1 live and/or dead A.h. were found during 11 of 14 surveys; surveys varied greatly in intensity, techniques and extent. Max #live found = 74	Chronic agricultural-related sediment and nutrient problems; suburban sprawl; upper part of watershed ditched and channelized.
MD	Queen Anne's/ Caroline	Long Marsh Ditch (Mason Branch)	Tuckahoe River	~5 km	1992	2006	Severe decline. Possibly extirpated. First reported in 1985 when "several" were found. From 1-8 live and/or dead were found during 7 surveys in 1989-97; surveys varied greatly in intensity, extent and technique. Last live obs = 1992, 5 found. No dead or live.	Stream channel ditched and channelized; chronic agricultural-related sediment and nutrient problems; suburban sprawl.
MD	Caroline	Herring Run	Choptank River	< 0.1 km	2008	2008	One shell found in 2007. 2008 survey spanning 1.6 km and consisting of 26.9 person-hrs. turned up 1 live/1dead.	Little to no surface flow due to dry conditions

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
MD	Charles	Nanjemoy Creek	Potomac River	~ 3 km	2008	2008	Among top 3 heterodon streams in MD. First reported in 1991 when 2 live and "several" dead were found. From 2-5 live found during 4 surveys in 1992-97; surveys varied greatly in intensity, extent and technique. Intensive surveys during 2001 detected 127 live specimens. 13 live found (20.2 person-hrs) in 2008 survey spanning 100 m. Numbers plummeted after a drought followed by flooding in 2003. They have bounced back, but not to 2001 levels.	Suburban sprawl, illegal trash dumping, drought, flooding
MD	St. Mary's	McIntosh Run	Potomac River	~4 km	2008	2008	Among top 3 heterodon streams in Md. First reported in 1970 when 1 dead indiv was found. From 0-13 live found during 10 surveys in 1983-97; surveys varied greatly in intensity, extent and technique. Population size estimated at 900 in 1994. 4 live found in 2008 survey in 10.3 person-hrs. Detection rates fairly stable during 2001-2008 monitoring period.	Suburban sprawl, livestock grazing in floodplain, sand/gravel mining in watershed.
MD	Queen Anne's	Browns Branch	Southeast Creek	> 4 km	2002	2004	Among top 3 heterodon streams in Md. Best known population on Delmarva Peninsula. Mean of 1.2 live/1.7 dead per 100 m of stream length; mean stream width = 3.8 m.	Suburban sprawl, agricultural runoff, groundwater withdrawal for agric and residential use, lack of watershed forest cover and riparian buffers - 30-35% forest cover.

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
MD	Queen Anne's	Granny Finley Branch	Southeast Creek	n/a (single specimen)	2002	2003	1 old live specimen found.	Suburban sprawl, agricultural runoff, groundwater withdrawal for agric and residential use, lack of watershed forest cover and riparian buffers - 30-35% forest cover.
MD	Queen Anne's	Unnamed 2nd order trib of Southeast Cr	Southeast Creek	> 0.5 km	2003	2003	1 live/1 dead found.	Suburban sprawl, agricultural runoff, groundwater withdrawal for agric and residential use, lack of watershed forest cover and riparian buffers - 30-35% forest cover.
MD	Queen Anne's	Three Bridges Branch & Unnamed 2nd order trib	Southeast Creek	> 1 km	2009	2009	Total 16 live/10 dead found in two 100-m long sections. Intensive inventory in summer of 2006 yielded 24 live/25 dead found (160.6 person/hrs). Population spans at least 5.3 river km. 1 dead individual found during routine benthic sampling in 2009; represents most upstream record.	Suburban sprawl, agricultural runoff, groundwater withdrawal for agric and residential use, lack of watershed forest cover and riparian buffers - 30-35% forest cover.
VA	Stafford	Aquia Creek	Potomac River	3 miles	2003	2003	2 live/2 shells(1998); 1 dead shell collected, no live spec. obs.(2003)	Development. Spill?
VA	Stafford	Aquia Creek	Potomac River	~0.5 mi NE of Skidmore Corner; Between confluence of Cannon Creek with Aquia Creek	8/27/1992		69	

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
VA	Stafford	Aquia Creek	Potomac River	2 mi W of Garrisonville, downstream 400m	10/4/1990		2 live	
VA	Stafford	Aquia Creek	Potomac River	2 mi W of Garrisonville, upstream to Cannon Creek confluence	10/3/1990	2003	1990 - 4 live, 12 shells; 2003 - no mussels found	
VA	Stafford	Rappahannock River	Rappahannock	0.20 km	1994		1 fresh dead	
VA	Culpepper/Fauquier	Mountain Run	Rappahannock	37.6 km	1919	1919	Unknown - questionable record.	
VA	Orange	Blue Run	Rappahannock	14.5 km	ND			
VA	Spotsylvania	Ni River	York	6.25 km	1925		Unkn.	
VA	Spotsylvania	Po River	York	0.25 km	2000	2000	3 live/1shell obs. In 36.5 survey hours	
VA	Spotsylvania	Po River	York	1000 m (at Singing Wood Lane)	2007	2007	1 live/1 dead found in 2008 survey (6 person-hrs.)	
VA	Spotsylvania	Po River	York	1000 m (at Route 648 bridge)	2008	2008	1 live/1 dead found in 2008 survey (33.5 person-hrs.)	
VA	Spotsylvania	Po River	York	1.03 km	2003	2003	7 live observed (1999); 9 live/3 shells obs. In 15 survey hours	
VA	Spotsylvania	Po River	York	1 km	1995	1995	1 live spec. collected	
VA	Louisa	South Anna River	York	0.22	1972	1972	Riddick South Anna sites (1972) were surveyed in 2005 by Bill Lees and no evidence of DWM was found; given old records, species is likely extirpated	
VA	Louisa	South Anna River	York	0.23	1991	1991	0 live, 1 relict	

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
VA	Louisa	South Anna River	York	0.14	1972	1972	midden shell	
VA	Sussex	Nottoway River	Chowan	0.11 km	1996	1996	1 live	
VA	Nottoway/Lunenburg	Nottoway River	Chowan	0.21	1996	1996	1996 = 3 and 1 live; approx. 5 ind. collected/obs during a construction project survey, 1 collected in 1994; 1993 = 5 live (all at VA 40)	
VA		Nottoway River			1999		2 collected below The Falls @ VA 49	
VA	Orange	Tomahawk Creek		2.5 mi S of the city of Orange	ND		6 live collected @ SR 647	
NC	Granville	Tar River (headwaters)	Tar	Point location	1997	2010	3 live in 1997; none since	beaver activity, silviculture, residential development
NC	Granville	Cub Creek	Tar	3 reach surveys, plus (1) 400m reach	2011	2011	4 shells found in 2011 and 7 live in 2010 (combined with Shelton Creek). 10 live and 2 shells total (3 sites in 2004, 8 live, 1 shell); (400m reach in 2005 , 2 live, 1 shell)	small stream, livestock, beaver activity, silviculture, drought
NC	Granville	Shelton Creek	Tar	7 reaches surveyed since 1999	2011	2011	4 shells found in 2011 and 7 live in 2010 (combined with Cub Creek); 22 live in 2007; 54 live were observed at 2 sites in 2004 ; 44 live observed In 2005 in same reach	beaver activity, silviculture, residential development, low water, low D.O.(0.38), thick algae due to possible nutrient enrichment, drought
NC	Granville	Fox Creek (Trib to Shelton Creek)	Tar	4 reaches	2005 at new sites (Last observed at previously surveyed sites was 1995)	2010	3 (DWM found at 2 sites not previously surveyed) but no DWM found at site where they have historically been found (in 2005 survey). Nothing found in 2010.	

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
NC	Vance	Ruin Creek (Trib to Tabbs Creek)	Tar	5km stretch (7 sites), 2 other reach surveys	2005 (Point surveys along 5 km stretch)	2008	1 live, 2 shells in 2005. None in 2008.	Degraded habitat, beaver activity, headwaters are urbanizing, 2005 and 2002 extremely low water, Pool where DWM found in 2005 had D.O. of 3.25, drought
NC	Vance	Tabbs Creek	Tar	Reach surveys	2002	2004	2 live	
NC	Warren/Franklin	Shocco Creek	Tar	Reach surveys, 500m	2012	2012	8 in 2005. 13+ live, 3 shells observed in 2010-2012 (inc. tribs).	beaver activity, silviculture, drought
NC	Warren/Franklin	Little Shocco Creek	Tar	Reach surveys, 800 m	2005	2005	7 live	beaver activity, silviculture?
NC	Warren/Franklin	Isinglass Creek (Formerly Unnamed Trib to Shocco Creek)	Tar	Reach survey	2005	2005	3 live (1 live/2 shells in 1999, 3 live in 2005)	beaver activity, silviculture
NC	Warren	Maple Branch	Tar	Reach survey	2012	2012	6 in 2003. 14+ live individuals observed in 2011-2012.	small stream, beaver activity, silviculture, emergency bridge replacement, gravel road to be paved, drought
NC	Warren	Long Branch	Tar	Reach Survey	2005	2011	1 in 2005, none in 2011.	Low water and D.O. Stream was dry upstream of bridge access point and extremely low downstream of bridge. D.O. in pools was 4.0, beaver activity, drought
NC	Franklin	Red Bud Creek	Tar	Reach Survey	2004	2010	1 live in 2004. None in 2010.	Drought 2007; Silviculture; Excessive woody debris; Sedimentation
NC	Franklin	Cedar Creek	Tar	N/A	1993	2005. Also surveyed in 2003 at point sites, four additional sites surveyed	0- Note the 401 site is the only place where a live DWM has been recovered (in 1993).	potential bridge replacement/repair impacts, beaver activity, drought

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
NC	Franklin	Crooked Creek	Tar		2004	2004	I live in 2004. 1 live in 2000 - Survey in 2000 was not a mussel survey but a habitat assessment of bridge 3 years after constructions Assessment yielded 1 live DWM	Sign. declines, much beaver activity, heavy sediment load, Hurricane Fran damage, much of creek surveyed on foot in 1996, drought
NC	Franklin	Fox Creek (Franklin Co.)	Tar	N/A	2005	2005	3 live found at sites not surveyed before. No DWM found at sites where DWM previously observed.	Much beaver activity, urbanization of stream corridor
NC	Nash	Stony Creek	Tar	N/A	1992	1995	1 shell; New sites surveyed in 2004 and 0 were observed. Note-sites where shell observed in 1992 have not been resurveyed since 1995.	Timber harvest in subbasin; new threats unknown
NC	Halifax	Rocky Swamp Creek	Tar	N/A	1993	3 survey stations, last surveyed 1997	1 live	Beaver activity, drought
NC	Halifax	Rocky Swamp Creek	Tar		2011	2011	100+ in 2004. 17 live, 2 shells observed in 2010-2011.	Beaver activity, drought
NC	Halifax	Little Fishing	Tar	N/A	2011	2011	1 live found in 2011.	Drought 2007
NC	Wilson/Nash	Neuse River mainstem	Neuse	N/A	1951	2010	Historical occurrence below Falls Lake	
NC	Wilson/Nash	Turkey Creek	Neuse		1996	2009 & 2005, not all sites where DWM previously found were surveyed	0 since 3 live found in 1996.	Drought 2007, habitat fragmentation
NC	Nash/Wilson/Johnson	Moccasin Creek	Neuse	few miles	2004	2009. Shells found in 2004 at a site not previously surveyed. Other sites need to be resurveyed.	4 shells in 2004; nothing in 2009	Drought 2007
NC	Johnson/Wake	Upper Little River	Neuse	1 site	1998	2011	1 live in 1998	Proposed water supply reservoir; Proposed wastewater discharge; Development; Beaver activity

State	County	River	Watershed	Est. River Length	Last Obs.	Last Survey	Number shells at site (live or dead)	Threats
NC	Johnson/Wake	Lower Little River	Neuse	1 site	2005	2010	1 live in 2005	Proposed water supply reservoir; Proposed wastewater discharge; Development; Beaver activity
NC	Johnson	Buffalo Creek	Neuse	5 sites	1998	2010 (1998 sites have not been resurveyed), 5 new sites surveyed between 2001-2005)	1 live/2 shells in 1998 (none since)	Proposed water supply reservoir; Proposed wastewater discharge; Development; Beaver activity
NC	Johnson	Swift Creek	Neuse	5 miles	2012	2012	6 live/2shells observed in 2012 survey. 3 live observed in 2002 in a point survey (not surveyed historically)	Major highway project, urban growth in subbasin, regular raw wastewater spills, beaver activity, heavy sediment load, Hurricane Fran damage to riparian habitat, heavy sed. load;
NC	Johnson	Little Creek	Neuse	N/A	2003	2011	2 live observed in 2003	Major highway project; Development; Sedimentation; Wastewater spills
NC	Johnson	White Oak Creek	Neuse	N/A	1992	2010. Also, 2003; two point samples in 2001, ~ 2km surveyed in 2003 in reach where DWM found in 92'	1 live found in 1992; none since	Development pressure was just beginning in 2003, beaver dams present
NC	Johnson	Middle Creek	Neuse	N/A	1992	42 sites surveyed in 2003 in Middle Creek Basin; 10 other sites surveyed between 2001-2005	0	Development from Carey, Apex, Holy Springs, and Morrisville; Cumulative and secondary impacts from municipalities to Middle Creek basin
NC	Orange	Eno River	Neuse	Point location	1995	Point surveys, In 2004, 2005, 2006. 2007; historic sites resurveyed where shell was found in 1995	Nothing since one shell was found in 1995 - A dam was removed within Eno River State Park. Invasion of hydrilla observed in Eno River State Park.	Development; Invasive Species