APPENDIX C

U.S. FISH AND WILDLIFE SERVICES LETTERS TO NORTH CAROLINA

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Raleigh Field Office
Post Office Box 33726
Raleigh, North Carolina 27636-3726

August 22, 2014

Ms. Connie Brower
DENR/ Division of Water Resources/Water Planning Section
1611 Mail Service Center
Raleigh, NC 27699-1611

Dear Ms. Brower:

This letter conveys the U.S. Fish and Wildlife Service's (Service) comments on proposed amendments to the North Carolina rules for surface water quality standards stemming from the 2008-2010 Triennial Review of Surface Water Quality Standards. Proposed changes are to 15A NCAC 02B .0206, .0211, .0212, .0214, .0215, .0216, .0218, and .0220. The Division of Water Resources (DWR), on behalf of the Environmental Management Commission, seeks comments on the proposed changes which were detailed in a July 1, 2014 Notice of Rule-making Action.

The Service is the principal Federal agency responsible for conserving, protecting and enhancing fish, wildlife and plants and their habitats for the continuing benefit of the American people. In North Carolina, we manage 11 National Wildlife Refuges, comprising over 400,000 acres. We also operate a national fish hatchery, two ecological services field stations and additional offices offering technical assistance on fisheries and migratory bird management. We enforce federal wildlife laws, administer the Endangered Species Act with a local focus on recovery of imperiled species, restore nationally significant fisheries, and conserve and restore wildlife habitat.

We have reviewed all proposed changes and are pleased to see the proposed adoption of water quality standards for metals (other than mercury and selenium) based on the dissolved metal fraction. We were supportive of this approach in comments provided on September 7, 2010, and January 3, 2014, and we appreciate the hard work of DWR to complete this rulemaking.

In those same letters, incorporated here by reference, the Service expressed concerns with several aspects of the current proposal and offered suggestions for addressing our concerns. We also made suggestions for additional rule changes which have not yet been acted upon. Briefly, those remaining concerns are as follows:

- We disagree with the proposal that aquatic life biological integrity criteria take precedence over ambient numerical water quality standards for water quality assessment. We note that important taxa of conservation concern, like mussels (50 species in NC), clams (15 species in NC), snails (66 species in NC), and reptiles and amphibians (98 species in NC) are not adequately covered through biocriteria.

- We disagree with the retention of action levels in lieu of standards for copper and zinc associated with permitted releases. Numeric standards should be enforceable instream targets.

- We note that waters with hardness less than 25 mg/L may continue to be under-protected unless site-specific hardness data are permitted to be used to tailor standards to local conditions.

- We continue to encourage development of guidance or procedures for addressing the fraction of metals bound to solids to manage metals accumulation in sediments or pore water – sources of exposure to sediment dwelling organisms like mussels which are of conservation concern.

- We encourage prompt adoption of USEPA's 2013 Ammonia Water Quality Criteria into State standards.

- We continue to encourage better use of antidegradation and use restoration tools aimed at ecologically significant species and their habitat, particularly 15A NCAC 02B .0110 *Considerations for Federally-Listed Threatened or Endangered Aquatic Species* and 15A NCAC 02B .0101 (e) (7) *Unique Wetlands.*

- We continue to encourage the establishment of flow criteria that protect the ecological integrity of streams and rivers in North Carolina.

- We continue to encourage revision to the dissolved oxygen standard to provide for higher concentrations in important fish spawning areas.

We reiterate the offer to participate in collaborative ventures with DWR and others to resolve these issues and explore future changes to the State's rules implementing maintenance and restoration of water quality for the benefit of fish, wildlife and people. If you would like additional detail on any of our recommendations or comments, please contact Tom Augspurger at tom_augspurger@fws.gov or 919-856-4520 x.21.

Sincerely,

Tom Augspurger

For Pete Benjamin
Field Supervisor

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Raleigh Field Office
Post Office Box 33726
Raleigh, North Carolina 27636-3726

January 3, 2014

Connie Brower
North Carolina Department of Environment and Natural Resources
Division of Water Resources/Water Planning Section
1611 Mail Service Center
Raleigh, NC 27699-1611

Dear Ms. Brower:

This letter conveys the U.S. Fish and Wildlife Service's (Service) comments on potential revisions to North Carolina water quality regulations in Title 15A NCAC 02B .0100-.0110, .0201-.0228, .0230-.0231 and .0300-.0317, *Surface Water and Wetland Standards*. The Division of Water Resources (DWR), on behalf of the Environmental Management Commission (EMC), is seeking comments on water quality standards to protect human health and the aquatic environment. While no changes are proposed by the EMC at this time, DWR is seeking input required by the Clean Water Act's triennial review provisions.

The Service is the principal Federal agency responsible for conserving, protecting and enhancing fish, wildlife and plants and their habitats for the continuing benefit of the American people. In North Carolina, we manage 11 National Wildlife Refuges, comprising over 400,000 acres. We also operate a national fish hatchery, two ecological services field stations and additional offices offering technical assistance on fisheries and migratory bird management. We enforce federal wildlife laws, administer the Endangered Species Act with a local focus on recovery of imperiled species, manage migratory bird populations, restore nationally significant fisheries, and conserve and restore wildlife habitat.

We offer the following comments for DWR consideration in revising water quality standards. Our recommendations are focused on adoption of up-to-date water quality criteria (particularly for ammonia and metals) as State standards to reflect the latest science, adoption of final or interim nutrient standards for all fresh and estuarine waters, development of site-specific water quality standards in habitats important for endangered species recovery, and more explicit definition of instream flow requirements. We also procedurally encourage a more interactive approach to crafting revisions to take advantage of the expertise available in the State.

1) Adopt U.S. Environmental Protection Agency's (US EPA) 2013 Ammonia Water Quality Criteria

On August 22, 2013, the US EPA published new national recommended ambient water quality criteria for the protection of aquatic life from effects of ammonia in freshwater. Those criteria should now be adopted in North Carolina water quality standards as the state-wide foundation, and more protective standards should be pursued on a case by case basis in waters essential for recovery of endangered mollusks.

The 2013 criteria are current and have undergone extensive peer review

The US EPA revised ammonia criteria between 2004 and 2013; the new document is 242 pages, with three technical support documents and two responses to public and expert panel review comments totaling more than 1,000 pages. The 2013 ammonia criteria recommendations take into account freshwater toxicity information for ammonia available through 2012, and they include toxicity data for over 100 species in 69 genera (acute data) and 16 genera (chronic data). The US EPA provides a rationale for their recommendations drawn from these data in a transparent fashion.

The Service has previously provided DWR with published results of freshwater mussel toxicity data indicating the sensitivity of mussels to ammonia. We suggested development of State standards for ammonia during the 2001-2003 and 2004-2006 triennial reviews. The feedback at those times was that no changes would be made until US EPA completed re-evaluation of the ammonia criteria; those criteria are now ready for State implementation.

The 2013 criteria include data for species known to occur in North Carolina

The most sensitive species in the revised ammonia criteria are freshwater mussels (Family: Unionidae). Freshwater mussels are suspension-feeding bivalves. As biofiltering animals which historically occurred in high abundance in the State's waters, mussels provide important ecosystem services such as removing phytoplankton and suspended particulate matter from the water. Mussels also are long lived and on a population basis may store large amounts of nutrients that otherwise would be transferred downstream. Mussels play other important roles in the aquatic ecosystem: they provide food for other animals and help stabilize stream sediments.

There are about 300 species of freshwater mussels known from North America, and the revised criteria document has ammonia toxicity data for 17 of those species (Table 1). Among those 17 species are eight which are known from North Carolina, including three species federally-listed or petitioned to be listed as threatened or endangered. Water quality criteria typically have data for a very small fraction of the nation's aquatic life, as indicators of the sensitivity of the vast majority of taxa which remain untested. In the case of ammonia however, the criteria includes data for sensitive species known to occur in North Carolina which clearly indicates the need for the more protective limits to be applied here.

Adopting the criteria into standards is an important foundation for freshwater mussel conservation

Ammonia is a constituent of nitrogen pollution, and it is considered one of the most important pollutants in the aquatic environment because of its highly toxic nature and common occurrence, entering the environment directly in municipal and industrial wastewater discharges and runoff. The 2013 criteria recommend lower ammonia concentrations in the nation's waters – from 1.5 to 2.5 times less than those in effect previously under certain conditions. With the sensitivity of mollusks to ammonia and the many sources of ammonia, it is important that North Carolina adopt the new water quality criteria as State standards to better manage this potential limiting factor for freshwater mussels.

The laboratory studies upon which the criteria are based are supported by field observations. Ammonia has been a concern for freshwater mussel survival and recovery for over 30 years (e.g.,

Horne and McIntosh 1979, Wade et al. 1992, Goudreau et al. 1993). Recently, Strayer and Malcolm (2012) rule-out some potential factors limiting mussel recruitment but report a strong correlation between interstitial ammonia concentrations and recruitment failure. Haag's (2012) recent mussel conservation synthesis discusses ammonia as the type of factor that may have the temporal and geographic pervasiveness and trends to explain mussel declines nationwide.

In waters important for freshwater mussel recovery, more protective ammonia concentrations should be considered on a case by case basis

The US EPA 2013 ammonia criteria document indicates that where sensitive species occur at a site and sufficient data indicate that a criterion may not be sufficiently protective at that site, it is appropriate to consider deriving a site-specific criterion. US EPA's (2013) assessment endpoint (page 9) and conceptual model (page 18) indicate the national criteria are to protect populations and community structure:

> Criteria are designed to be protective of the vast majority of aquatic animal species in an aquatic community (i.e., approximately 95th percentile of tested aquatic animals representing the aquatic community). As a result, health of the aquatic ecosystem may be considered as an assessment endpoint indicated by survival, growth, and reproduction.

That perspective is a different goal than recovery of aquatic threatened and endangered mollusks. We recently presented results of a site-specific ammonia instream water quality target derivation (Augspurger 2013) which demonstrates a sound approach for deriving standards in waters important for mussel recovery. We also recently completed ammonia toxicity tests for four additional species of mussels that occur in North Carolina: the endangered Tar River spinymussel (*Elliptio steinstansana*), notched rainbow (*Villosa constricta*), yellow lampmussel (*Lampsilis cariosa*) and yellow lance (*Elliptio lanceolata*). We encourage that the 2013 USEPA ammonia criteria be adopted state-wide now. In certain areas, the 15A NCAC 02B .0110 *Considerations for Federally-Listed Threatened or Endangered Aquatic Species* provisions could then be used to provide standards focused on mussel recovery which would be lower than those recommended by US EPA in areas important for delisting, or preventing the need to list, imperiled mussels.

In summary, ammonia is a common pollutant for which a robust, expert-reviewed water quality criteria derivation has just been completed. Those criteria should be adopted in North Carolina water quality standards so that pollutant discharge permit limits, water quality use support ratings, total maximum daily load allocations, and nonpoint source pollution reduction targets are properly guided. Adoption should improve conditions for freshwater mollusks and other aquatic life; that's important in North Carolina's rivers and streams which include about 50 species of freshwater mussels, 66 species of freshwater snails, and 15 species of clams.

2) Adopt up-to-date metals criteria as State standards, but modified from those proposed in the unfinished 2008 - 2010 Triennial Review

Between January and March 2010, the DWR presented proposed amendments to the Water Quality Committee of the EMC then the full EMC. The EMC approved proceeding to hearings with the proposed rules, but they have been delayed for more than three years in economic

analyses. We reference our September 7, 2010 comments to you on those proposed changes which should move to public hearing. Some additional context on those changes is offered here.

North Carolina should adopt the dissolved metals criteria

The DWR proposed adoption of new standards for metals in 2010. The proposed changes will provide more protective standards in freshwater for chromium, copper, lead, nickel, and zinc; and in the saltwater environment for arsenic and lead. It is known that freshwater mussels are at the sensitive end of the range with regard to metal toxicity (March et al. 2007, Wang et al. 2007a, 2007b, 2009, 2010), so more stringent standards will provide a greater level of protection for them.

The Service is supportive of DWRs proposed regulation of metals on a dissolved rather than total recoverable basis. While there are concerns, the dissolved fraction is a better predictor of toxicity to aquatic life and therefore an advance in water quality management (one that many other states have already adopted). Our only concern with this approach is that in regulating based on dissolved metals, the fraction of metal bound to solids may go unregulated. From an aquatic toxicity perspective the dissolved fraction is the most appropriate form to regulate, therefore we support DWR's actions. But, from a more holistic environmental protection perspective, metals enriched on sediment particles could accumulate in sediments at concentrations of concern. Because there are no national sediment quality criteria or State sediment quality standards, we encourage the DWR to consider how regulation of metals in water will not create an unregulated burden in sediments. Some components of addressing this concern could include 1) continuing to measure total and dissolved metals in ambient and effluent samples (because there are metals for which particulate forms are important); 2) ensuring the new dissolved metals standards will be used / applicable to evaluating metals in sediment pore water too; and 3) establishing or adopting existing sediment quality benchmarks used elsewhere and a framework for incorporating them into the overall water quality management program in North Carolina.

Hardness Dependent Metals

Because the DWR's analyses indicate that a significant portion of the State periodically has hardness values equal to or less than 25 mg/L, the Service believes the proposed recommendation that numerical standards for hardness-dependent metals use a default hardness of 25 mg/L is a positive change. We note that waters with hardness less than 25 mg/L may continue to be under-protected by this approach, but we envision that site-specific use of hardness data allows a means to compensate for this when needed.

Other considerations

We encourage the DWR to more thoroughly consider revising two aspects of the 2010 proposed rule changes: the retention of action levels, in lieu of standards, for copper and zinc; and, the codification of biological diversity scores trumping numeric water quality standards in determining use attainment.

The rationale for retaining action levels versus more enforceable standards for copper and zinc is unclear to us. It appears that the analytical chemistry and toxicological considerations for interpretation of ambient copper data are no longer an issue. If there are implementation issues

that are limiting the development of standards, these should be made explicit along with a plan for how to address those issues in the future.

Our concern regarding biological monitoring and use of it to trump numeric ambient water quality standards for metals is that the biological monitoring is limited in terms of spatial, temporal and even ecosystem coverage. The State's well-recognized expertise in biological monitoring should not be a substitute for numerical water chemistry standards, especially in view of the spatial and temporal limitations of sampling. Further, the USEPA water quality criteria (upon which State standards are based) are often derived with databases that include taxa which are not part of biological monitoring in North Carolina. We know mussels, snails and cladocerans are at the sensitive end of the range for copper toxicity, as reflected in the criteria document and current literature on mussels. As noted above, it is also known that mussels are sensitive to zinc and lead relative to other tested freshwater organisms. However, mussels, snails, and cladocerans are not among the organisms with good metrics in our State's biological monitoring program (these species, known to be sensitive to metals, are not adequately covered by the biomonitoring program). As such, the numeric and biological portions of water quality standards are essential and complimentary, but one should not trump the other.

3) Adopt final or interim nutrient standards for all fresh and estuarine waters

U.S. EPA (2012) lists nutrient pollution as the leading causes of water quality impairment nationwide. Effects of elevated nutrients in lakes, rivers, and estuaries are well known and include severe impacts on fish and invertebrates from nuisance algal blooms resulting in oxygen depletion (with associated fish kills and reduced recruitment) as well as increased bacterial, harmful algal bloom-related biotoxin, aesthetic, and odor problems in both fresh and estuarine waters. These concerns are documented in lakes and estuaries of North Carolina (e.g., Paerl et al. 2004 and references therein, Isaacs et al. 2014). Strayer (2013) notes the concern with excessive nutrients for freshwater mussel conservation which, as noted above, is a focus for our office. While well-known and pervasive water quality concerns, it is troublesome that there are no State standards for nitrogen or phosphorous.

Because there are no aquatic life nitrogen or phosphorus standards for North Carolina's surface waters, damaging effects of nutrient over-enrichment have occurred at which time water quality impairment leads to time- and fiscal-intensive derivations of nutrient reduction targets which only apply to the impaired waterbody. This reactive approach is undesirable for a common water quality concern like nutrient enrichment (i.e., a widespread concern, likely to continue, with important ecological consequences). The US EPA and others have synthesized the science and recommended ecoregionally-appropriate standards for nitrogen and phosphorous that should be adopted now while more geographically-refined approaches are pursued later.

Adopting nitrogen and phosphorous standards should help in ameliorating nuisance algal blooms in lakes, estuaries and sounds in the future. New standards on these causal parameters of eutrophication would complement the State's eutrophication response standard, chlorophyll, and provide triggers for use support rating and for focusing actions to restore water quality and reduce nutrient loading. The monitoring system necessary for using nitrogen and phosphorous standards as a management tool is already in place in North Carolina (DWR Ambient Monitoring System, as well as data from discharge monitoring consortiums, university researchers, and U.S. Geological Survey) and should not add to costs required for monitoring.

4) Better use should be made of antidegradation and use restoration tools aimed at ecologically significant species and their habitat

The 15A NCAC 02B .0110 *Considerations for Federally-Listed Threatened or Endangered Aquatic Species* and 15A NCAC 02B .0101 (e) (7) *Unique Wetlands* rules are important provisions of State standards that have not been used to their full potential. Each includes mechanisms to provide locally-tailored water quality conservation actions to habitat important for survival and recovery of federally-listed threatened or endangered species. We have previously shared ideas for streamlining the development of these site-specific standards and continue to encourage that they be used to their fullest extent.

5) Establish flows that protect the ecological integrity of streams and rivers in North Carolina

The Service was a participant in the Ecological Flows Scientific Advisory Board (EFSAB), and we encourage adoption of a statewide approach to establishing ecological flows based on the simultaneous use of two strategies (EFSAB 2013):

1) The percentage of flow strategy using 80-90% flow-by combined with a critical low flow component as the ecological flow threshold. If the basinwide hydrologic models indicate that there is insufficient water available to meet all needs, essential water uses and ecological flows at a given location, then further review by North Carolina Department of Environment and Natural Resources (DENR) is recommended. [Flow-by is defined as "the percentage of ambient modeled flow that remains in the stream"]

2) The biological response strategy should be used to determine the current and future modeled biological condition of locations in the basinwide hydrologic models. DENR should evaluate the change in current and future biological condition as a decision criterion. A 5-10% reduction in biological condition is suggested as a threshold for further review by DENR.

As indicated in the final report, the flow requirements of listed species are not often fully understood. In order to conserve state and federally listed species, we support the EFSAB recommendations that the flow needs of these species should be considered by DENR in addition to the standard recommendations offered. For planning purposes, portions of basins that include listed species should be treated by DENR as needing additional analysis in consultation with WRC, NMFS, and USFWS. When a decision moves beyond planning, then applicable environmental review documents will be sought from appropriate agencies. We also encourage DENR and other appropriate agencies to support further research on the flow requirements of listed species.

6) Consider revision to the dissolved oxygen standard in important fish spawning areas

North Carolina's freshwater dissolved oxygen (DO) standard is not less than 6.0 mg/l for trout waters. For non-trout waters, the standard is not less than a daily average of 5.0 mg/l with a minimum instantaneous value of not less than 4.0 mg/l (NCDWQ 2007). The standards also contain a provision for swamp waters, lake coves or backwaters, and lake bottom waters to have lower values if caused by natural conditions. Those are similar to part of USEPA's (1986a, b) DO recommended *minimum* values which they define as foreseeing as having the potential for

production impairment to fish. Accordingly, the national criteria document also includes DO concentration recommended for "no production impairment" of 8 to 11 mg/L in waters important for Salmonids and 6.5 to 8 mg/L in non-Salmonid waters (USEPA 1986a, b). The Service encourages those be considered the lower end of water quality standards for waters known to be critically important spawning and nursery areas. At concentrations below these, larval mortality, altered growth, and behavioral changes have been reported in both field and lab studies (McMahon et al. 1982; Stuber et al. 1982).

Experience in fish culture, where the objective is to ensure robust spawning and survival of young (rather than conditions below which stress and other adverse effects are readily apparent) is relevant to this issue. Fish culturists identify DO concentrations >6 mg/l as desirable with optimal development of embryos and fry at or near the point of oxygen saturation (Piper et al. 1989). For example, published information on optimal DO ranges for larvae and juvenile striped bass are >6 to 12 mg/l (Hill et al. 1989; Nicholson et al. 1990). Higher DO standards in important fish nursery areas, based on conditions for robust fish production, would be helpful because ambient conditions in excess of standards are frequently allocated to assimilative capacity for oxygen consuming wastes.

7) Once existing criteria are established as State standards, reform the Triennial Review Advisory Committee to guide future revisions

The Service has interacted with the State on triennial reviews for more than 30 years. Over that time, the most productive and efficient exchanges were during the 1997-2000 triennial when a Triennial Review Advisory Committee was used throughout the process of scoping, modification, public hearing, and final revisions. That group included diverse stakeholders and got to consensus on the scope and content of revisions; the subsequent changes were adopted and on time. The State has an exemplary university system with extensive local expertise in water quality science and management which could better be used through a collaborative approach to rules review similar to the Triennial Review Advisory Committee.

Thank you for your consideration of these comments on potential revisions to North Carolina *Surface Water and Wetland Standards*. Several of the revisions we suggest should be done without delay based on the availability of technically-sound criteria to adopt as standards and the demonstrated need for revisions. Moving forward from those revisions, we would be pleased to participate in a collaborative venture to explore further changes to the State's rules for maintenance and restoration of water quality for the benefit of fish, wildlife and people. If you would like additional detail on any of our recommendations, please contact Tom Augspurger at tom_augspurger@fws.gov or 919-856-4520 x.21.

Sincerely,

Tom Augspurger

For Pete Benjamin
Field Supervisor

References:

Augspurger T. 2013. Site-specific ammonia recommendation for the South Toe River's (NC) endangered freshwater mussels. Poster RP099, Society of Environmental Toxicology and Chemistry annual meeting, November 21, Nashville, TN.

Goudreau SE, Neves RJ, Sheehan RJ. 1993. Effects of wastewater treatment plant effluents on freshwater mollusks in the upper Clinch River, Virginia, USA. *Hydrobiologia* 252: 211-230.

Haag WR. 2012. *North American Freshwater Mussels: Natural History, Ecology, and Conservation.* Cambridge University Press, New York, NY.

Hill J, Evans JW, Van Den Avyle MJ. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic) -- striped bass. U.S. Fish and Wildlife Service Biological Report 82(11.118). U.S. Army Corps of Engineers TR EL-82-4. Vicksburg, MS.

Horne FR, McIntosh S. 1979. Factors influencing distribution of mussels in the Blanco River of central Texas. *Nautilus* 94: 119-133.

Isaacs JD, Strangman WK, Barbera AE, Mallin MA, McIver MR, Wright JLC. 2014. Microcystins and two new micropeptin cyanopeptides produced by unprecedented *Microcystis aeruginosa* blooms in North Carolina's Cape Fear River *Harmful Algae* 31: 82-86.

March FA, Dwyer FJ, Augspurger T, Ingersoll CG, Wang N, Mebane CA. 2007. An evaluation of freshwater mussel toxicity data in the derivation of water quality guidance and standards for copper. *Environ Toxicol Chem* 26: 2066-2074.

McMahon TE, Terrell JW. 1982. Habitat suitability index models: channel catfish. US Fish and Wildlife Service. FWS/OBS-82/10.2.

NCDWQ. 2007. NC DENR - Division of Water Quality "Redbook" Surface Waters and Wetlands Standards NC Administrative Code Title 15A NCAC 2B .0100, .0200 and .0300). Environmental Management Commission, Raleigh NC.

Nicholson LC, Woods LC III, Woiwode JG. 1990. Intensive culture techniques for the striped bass and its hybrids. Pages 141-157 In: R.M. Harrell, J.H. Kerby and R.V. Minton (eds.), *Culture and Propagation of Striped Bass and its Hybrids*. American Fisheries Society, Bethesda, MD.

North Carolina Ecological Flows Science Advisory Board. 2013. Recommendations for Estimating Flows to Maintain Ecological Integrity in Streams and Rivers in North Carolina. Submitted to the North Carolina Department of Environment and Natural Resources. Raleigh, NC. http://www.ncwater.org/files/eflows/sab/EFSAB_Final_Report_to_NCDENR.pdf

Paerl HW, Valdes LM, Piehler MF, Lebo ME. 2004. Solving problems resulting from solutions: The evolution of a dual nutrient management strategy for the eutrophying Neuse River Estuary, North Carolina, USA. *Environ Sci Technol* 38: 3068-3073.

Piper RG, McElwain IB, Orme LE, McCraren JP, Fowler LG, Leonard JR. 1989. *Fish Hatchery Management.* U.S. Fish and Wildlife Service and American Fisheries Society, Bethesda, MD.

Strayer DL. 2013. Understanding how nutrient cycles and freshwater mussels (Unionoida) affect one another. *Hydrobiologia* doi: 10.1007/s107050-013-1461-5

Strayer DL, Malcom HM. 2012. Causes of recruitment failure in freshwater mussel populations in southeastern New York. *Ecological Applications* 22: 1780-1790.

Stuber RJ, Gebhart G, Maughan OE. 1982. Habitat suitability index models: largemouth bass. US Fish and Wildlife Service. FWS/OBS-82/10.16.

US EPA. 1986a. Ambient water quality criteria for dissolved oxygen. EPA 440/5-86-003. Office of Water Regulations and Standards, Washington, DC.

US EPA. 1986b. Quality Criteria for Water 1986 (The Gold Book). EPA 440/5-86-001 Office of Water Regulations and Standards, Washington, DC.

US EPA. 2012. Preventing eutrophication: Scientific support for dual nutrient criteria. EPA - 820-S-12-002. Office of Water, Washington, DC.

US EPA. 2013. Aquatic life ambient water quality criteria for ammonia – freshwater. EPA 822–R–13–001. Office of Water, Office of Science and Technology, Washington, DC.

Wade DC. 1992. Definitive evaluation of Wheeler Reservoir sediment toxicity using juvenile freshwater mussels (*Anodonta imbecillis* Say). TVA/WR-92/25. Tennessee Valley Authority, Water Resources Division, Muscle Shoals, AL.

Wang N, Ingersoll CG, Hardesty DK, Ivey CD, Kunz JL, May TW, Dwyer FJ, Roberts AD, Augspurger T, Kane CM, Neves RJ, Barnhart MC. 2007a. Acute toxicity of copper, ammonia, and chlorine to glochidia and juveniles of freshwater mussels (Unionidae). *Environ Toxicol Chem* 26: 2036-2047.

Wang N, Ingersoll CG, Greer IE, Hardesty DK, Ivey CD, Kunz JL, Dwyer FJ, Roberts AD, Augspurger T, Kane CM, Neves RJ, Barnhart MC. 2007b. Chronic toxicity of copper and ammonia to juvenile freshwater mussels (Unionidae). *Environ Toxicol Chem* 26:2048-2056.

Wang N, Ingersoll CG, Ivey CD, Hardesty DK, May TW, Augspurger T, Roberts AD, van Genderen E, Barnhart MC. 2010. Sensitivity of early life stages of freshwater mussels (Unionidea) to acute and chronic toxicity of lead, cadmium and zinc in water. *Environ Toxicol Chem* 29: 2053-2063.

Wang N, Mebane CA, Kunz JL, Ingersoll CG, May TW, Arnold WR, Santore RC, Augspurger T, Dwyer FJ, Barnhart MC. 2009. Evaluation of acute copper toxicity to juvenile freshwater mussels (Fatmucket, *Lampsilis siliquoidea*) in natural and reconstituted waters. *Environ Toxicol Chem* 28: 2367–2377.

Table 1. Freshwater mussel species represented in the database used to calculate the ambient water quality criteria for the protection of aquatic life from effects of ammonia in freshwater (USEPA 2013).

Species	Status in North Carolina
Mucket, *Actinonaias ligamentina*	
Pheasantshell, *Actinonaias pectorosa*	
Dwarf wedgemussel, *Alasmidonta heterodon*	Occurs in NC, federally-listed as Endangered
Oyster mussel, *Epioblasma capsaeformis*	Occurred historically in NC - federally-listed as Endangered
Atlantic pigtoe, *Fusconaia masoni*	Occurs in NC
Pink mucket, *Lampsilis abrupta*	
Plain pocketbook, *Lampsilis cardium*	
Wavy-rayed lampmussel, *Lampsilis fasciola*	Occurs in NC
Higgin's eye, *Lampsilis higginsii*	
Neosho mucket, *Lampsilis rafinesqueana*	
Fatmucket, *Lampsilis siliquoidea*	
Green floater, *Lasmigona subviridus*	Occurs in NC, petitioned to be listed
Pink papershell, *Potamilus ohiensis*	
Giant floater, *Pyganodon grandis*	Occurs in NC
Paper pondshell, *Utterbackia imbecillis*	Occurs in NC
Ellipse, *Venustaconcha ellipsiformis*	
Rainbow, *Villosa iris*	Occurs in NC

USEPA. 2013. Aquatic life ambient water quality criteria for ammonia – freshwater. EPA 822–R–13–001. Office of Water, Office of Science and Technology, Washington, DC.