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A NEW DATABASE FOR FACILITATING EVALUATION OF WETLAND AND AQUATIC AMPHIBIAN COMMUNITIES IN NORTH CAROLINA

KRISTIE D. GIANOPULOS[1,*], JEFFREY C. BEANE[2], ALVIN L. BRASWELL[3], JEFFREY G. HALL[4], W. JEFFREY HUMPHRIES[5], and NATHAN A. SHEPARD[6]

[1]*North Carolina Department of Environmental Quality, Division of Water Resources, MSC #1621, Raleigh, 27699-1621, kristie.gianopulos@ncdenr.gov, 919-743-8479*

[2]*North Carolina State Museum of Natural Sciences, Research Laboratory, Raleigh, NC 27699*

[3]*(retired) North Carolina State Museum of Natural Sciences, Raleigh, NC 27601*

[4]*North Carolina Wildlife Resources Commission, Greenville, NC 27858*

[5]*North Carolina Wildlife Resources Commission, Chapel Hill, NC 27516*

[6]*North Carolina Natural Heritage Program, Raleigh, NC, 27699*

**Corresponding author*

Abstract: Wetland condition assessment is often performed by land managers, federal and local governments, and conservation organizations to document current condition and potentially take action to protect or restore valuable wetland resources. These condition assessments often include data collection or surveys of biotic communities such as vegetation, macroinvertebrate, and amphibian communities. Assessment tools for gauging quality of these communities are needed to allow scientists to understand overall condition. To facilitate a better understanding of amphibian communities found in wetlands and associated habitat quality, we created ratings of anthropogenic disturbance sensitivity for wetland and aquatic amphibian species in North Carolina. With adequate surveys of amphibian communities, these ratings can be input into an index of amphibian wetland habitat quality for North Carolina wetlands, the Amphibian Quality Assessment Index (AQAI). Comparison of the AQAI against amphibian species richness in a 3-yr study in 16 wetlands showed the two indices to be correlated but not strongly so. The AQAI has the advantage of providing additional habitat quality information beyond indices based solely on species richness and abundance.

Key Words: amphibian; wetland; aquatic; habitat; assessment; coefficient of conservatism; C-value; North Carolina.

Because wetlands and aquatic habitats are protected under the federal Clean Water Act and state/local rules, they frequently must be evaluated or monitored for quality, to ensure adequate protection of the resource, via management or mitigation. Evaluating biotic communities in wetland and aquatic habitats can yield important insights into habitat function and condition. Amphibians have been used as indicators of water quality (Veselka 2008), restoration success (Walls et al. 2014a; Walls et al. 2014b; Gianopulos et al. 2016), and wetland hydrology (Waddle 2006). One method of using amphibians as indicators is the Amphibian Quality Assessment Index (AQAI), which is based on ratings of each amphibian species' sensitivity to anthropogenic disturbance and the broadness of its niche (Gianopulos et al. 2016). The Ohio Environmental Protection Agency currently uses an AQAI as part of its wetland assessment program and mitigation success assessment (Micacchion 2004, 2011). In this paper, we present newly developed ratings for North Carolina's (NC) wetland-dependent and aquatic amphibian species, to facilitate calculation of the AQAI in NC and possibly serve as a model for other states.

The AQAI uses the formula for the Floristic Quality Assessment Index (FQAI), which was first developed in the 1960s and employs the use of Coefficients of Conservatism (C-values) as estimates of sensitivity to anthropogenically driven perturbations (Swink and Wilhelm 1979; Wilhelm and Ladd 1988; Andreas and Lichvar 1995; Taft et al. 1997). C-values are developed by experts, usually by consensus, on a scale from 0 to 10 for each species. High C-values are associated with species restricted to high quality, undegraded habitats; low C-values represent species found in a broad range of habitats, usually with a strong tolerance for anthropogenic disturbance (Table 1). The FQAI, which incorporates C-values along with number of species in an area, has been

Table 1. Criteria for assignment of Coefficients of Conservatism (C values) to amphibian species.

C value	Criterion
0–1	Species adapted to severe anthropogenic habitat alteration. These species can colonize areas with high degrees of anthropogenic alteration. (Experts would have no confidence that a specimen brought into a collection was collected from a remnant or high-quality natural area. Zero reserved for non-native species.)
2–3	Species associated with somewhat more stable, though degraded, environments.
4–6	Species with a high consistency of occurrence within given community types. They may persist with light/moderate alteration but may decline with increase in intensity/duration/frequency of this alteration.
7–8	Species associated mostly with well-established natural areas, but that can be found persisting where the habitat has been somewhat degraded.
9–10	Species considered to be restricted to high-quality natural areas, including those which show high frequencies of natural disturbance, such as flooding or fire. These species exhibit a high degree of fidelity to a narrow range of habitat requirements. (Experts would have nearly 100% confidence that a sample brought into a collection was collected from a remnant or high-quality natural area.)

found to be a robust indicator of wetland condition in natural systems (Bourdaghs et al. 2006; Matthews et al. 2015).

The AQAI is derived using the following formula:

$$\text{AQAI} = \overline{C}\sqrt{N}$$

where $\overline{C}$ = mean C-value for all amphibian species and N = total number of amphibian species.

The authors include a panel of five expert herpetologists who assigned amphibian C-values to NC's wetland and aquatic amphibian species. This panel has decades of experience surveying for amphibians in NC and included two co-authors of *Amphibians and Reptiles of the Carolinas and Virginia, Second Edition* (Beane et al. 2010): Jeff Beane (Collections Manager for Herpetology, NC State Museum of Natural Sciences) and Alvin Braswell; Jeff Hall (Partners in Amphibian & Reptile Conservation Biologist); Jeff Humphries (Wildlife Diversity Biologist/Herpetologist); and Nathan Shepard (Eastern Region Field Biologist). To assign C-values, the panel referred to NC Natural Heritage Program records and lack of recent records, NC State Museum of Natural Sciences records/lack of records resulting from program surveys, the NC Wildlife Action Plan (NC Wildlife Resources Commission 2015), the latest Scientific Council Report from the Nongame Wildlife Advisory Committee of the NC Wildlife Resources Commission (Dorcas et al. 2009), and our collective field observations (or lack of observations in areas where species historically were found) dating back to the 1960s in NC.

The panel evaluated each species in the context of what that species indicated about the quality of wetland or aquatic habitat. Criteria for amphibian C-value assignments were similar to those used for FQAI plant species assignments (Table 1). Low C-values were assigned to amphibian species that can tolerate a broad range of environmental conditions, including impacted habitats such as suburban lawns and stormwater retention ponds. These species are habitat generalists and not significantly affected by anthropogenic habitat alterations. Higher C-values were assigned to species with narrow habitat requirements and those not found in areas altered by human activities. While there is a loose correlation between rarity and high C-value, we did not consider rarity alone to be an indicator of a species' tolerance of alteration and therefore rarity was not used as the sole determinant of C-values.

We assigned mean C-values by consensus (Table 2). To do so, we first discussed each species and then individually assigned C-values, from which means were calculated. Any disagreement in mean assignment was met by further discussion until consensus was reached. For 67 of 71 species considered, our individual C-values were within one point of each other. We agreed completely on C-values for 34 species. The greatest ranges in individual C-value assignments were 2.0–2.5 points, as given for four species: Mabee's salamander (*Ambystoma mabeei*), common mudpuppy (*Necturus maculosus*), southern chorus frog (*Pseudacris nigrita*), and carpenter frog (*Rana* [*Lithobates*] *virgatipes*). No non-native amphibian species have been detected reproducing in the wild in North Carolina, so no species received a C-value of zero.

The C-value database and AQAI can be useful for identifying wetland and aquatic habitats of high conservation value, following sites through time, and gauging ecological condition. Wetlands with particularly sensitive species can be assumed to be of higher quality or in better condition than those with only the more tolerant species. However, the absence of a particular species requires cautious interpretation, because absence has many potential causes (e.g., wetland degradation, migration barriers, population dynamics, species rarity). Because wetland amphibian assemblages can be highly dynamic from year to year (Hecnar and M'Closkey 1996), especially within ephemeral wetlands, studies should combine results over multiple years after the manner of Pechmann et al. (2001) and Gonzalez (2004). The impacts of natural variations in species detection can be lessened through long-term sampling efforts at multiple locations and with a combination of visual and auditory data collection.

The NC Division of Water Resources and the NC Wildlife Resources Commission utilized this AQAI in a recent 3-yr project to better understand amphibian communities in natural and restored wetlands, to improve

Table 2. *Coefficient of conservatism values for wetland and aquatic amphibians of North Carolina.* (Ecoregions are from the US Environmental Protection Agency's Level III Ecoregions of the Continental United States [US EPA 2013]. Mtns = Mountains ecoregion, Pdmnt = Piedmont ecoregion, CP = Coastal Plain ecoregion. Species in the genera *Plethodon* and *Aneides* were excluded as they are not aquatic taxa.)

Ecoregion			Scientific Name	Common Name	Assigned C Value	General Notes
Mtns	Pdmnt	CP				
x	x		*Acris crepitans*	Eastern/ Northern Cricket Frog	2.0	This species is a generalist, breeding in open grassy pond margins, ditches, marshy areas with shallow water, and sometimes closed canopy wetlands.
	x	x	*Acris gryllus*	Southern Cricket Frog	2.6	This species is a generalist, breeding in grassy margins of ponds, streams or ditches, and ephemeral ponds.
		x	*Ambystoma mabeei*	Mabee's Salamander	7.9	This species is a fish-free specialist, restricted in range to North and South Carolina and extreme southeastern Virginia.
x	x	x	*Ambystoma maculatum*	Spotted Salamander	5.8	Spotted salamanders tend to use isolated or deeper headwater sites with semi-permanent pools but will sometimes use other areas. They generally breed in natural fish-free wetland areas but will breed in manmade areas. They can survive in habitats with fish if sufficient leaf cover is present. *A unique population in the Coastal Plain (Hyde and Beaufort counties) is assigned a higher C value of 7.
x	x	x	*Ambystoma opacum*	Marbled Salamander	5.6*	*Marbled salamander populations in the Mountains and on the Outer Banks are assigned a C value of 7.
x	x		*Ambystoma talpoideum*	Mole Salamander	7.1	Mole salamanders need semi-permanent, fish-free places to breed. At many sites, they require 2 or 3 yr to metamorphose.
	x	x	*Ambystoma tigrinum*	Eastern Tiger Salamander	8.8	Tiger salamanders breed in ephemeral ponds in the longleaf pine ecosystem.
	x	x	*Amphiuma means*	Two-toed Amphiuma	4.1	This species is an inhabitant of permanently flooded wetlands and adjacent seasonally flooded wetlands.
x	x	x	*Bufo* (*Anaxyrus*) *americanus*	American Toad	2.0	The American toad mostly breeds in the same wide variety of ponds, swales, streams, and shallow waters as the Fowler's toad.
x	x	x	*Bufo* (*Anaxyrus*) *fowleri*	Fowler's Toad	2.0	The Fowler's toad is a generalist with fast-developing eggs that can tolerate disturbed environments [ponds, swales, shallow water].
		x	*Bufo* (*Anaxyrus*) *quercicus*	Oak Toad	7.5	This ephemeral pond breeder was historically common in North Carolina but is now uncommon to rare.
		x	*Bufo* (*Anaxyrus*) *terrestris*	Southern Toad	2.0	The southern toad is a generalist with fast-developing eggs, and it can tolerate disturbances. It can breed in areas such as temporary pools, shallow water, sandy areas, and flooded meadows.
x			*Cryptobranchus alleganiensis*	Eastern Hellbender	10.0	Eastern hellbenders are a long-lived species (30 to 50 yr), so using this species to categorize a site as high-quality requires identification of successful reproduction. High-quality wetlands and watersheds are important to promote the high-quality stream habitat this species depends on.
x			*Desmognathus aeneus*	Seepage Salamander	7.0	This species uses moderate to high quality forested habitats with seepage wetlands for breeding. It has a restricted range in the southwest Mountains of North Carolina.
		x	*Desmognathus cf. auriculatus*	Southern Dusky Salamander	7.0	This species is mainly associated with high quality seepage areas, where it prefers warmer water, lower oxygen content, and muddy substrate. The southern dusky salamander cannot tolerate poor water quality or contaminated water.

Table 2. Continued

Ecoregion			Scientific Name	Common Name	Assigned C Value	General Notes
Mtns	Pdmnt	CP				
x			*Desmognathus carolinensis*	Carolina Mountain Dusky Salamander	5.6	This salamander needs seeps and streams for breeding, but adults are frequently terrestrial. This species differs from the Ocoee salamander and Blue Ridge dusky salamander primarily in range.
x	x		*Desmognathus conanti*	Spotted Dusky Salamander	5.6	This species' range extends from Kentucky south into Louisiana, but in North Carolina, is only found in the southwestern Mountains, where it occupies seeps, and stream and swamp margins.
x			*Desmognathus folkertsi*	Dwarf Black-bellied Salamander	7.0	Little is known about the life history of this recently described species, which barely enters North Carolina in the extreme southwestern corner of the state. Its habitat is presumed to be similar to that of the black-bellied salamander.
x	x	x	*Desmognathus fuscus*	Northern Dusky Salamander	4.3	This species requires seepage areas with reasonably clean water but can still be found in some more urbanized streams and floodplains.
x			*Desmognathus imitator*	Imitator Salamander	6.0	This species prefers intermittent streams and seeps in the Smoky Mountains, where females attach eggs to undersides of rocks.
x			*Desmognathus marmoratus*	Shovel-nosed Salamander	7.0	This species inhabits a small range in the Mountains from southwestern Virginia to northeastern Georgia, where it lives in high-quality streams.
x	x		*Desmognathus monticola*	Seal Salamander	5.4	Seal salamanders are abundant in seeps, springs, and stream edges in the Mountains and adjacent areas in the Piedmont.
x			*Desmognathus ocoee*	Ocoee Salamander	6.0	At lower elevations in the Mountains, these salamanders inhabit seepage areas and stream edges. At higher elevations, they will live away from these wetter areas, under rocks and logs in nearby forests. They differ from the Carolina mountain dusky salamander and Blue Ridge dusky salamander primarily in range.
x	x		*Desmognathus orestes*	Blue Ridge Dusky Salamander	6.0	In lower elevations of the Mountains, these salamanders inhabit seepage areas and stream edges. At higher elevations, they will live away from these wetter areas, under rocks and logs in nearby forests. They differ from the Carolina mountain dusky salamander and Ocoee salamander primarily in range.
x			*Desmognathus organi*	Northern Pygmy Salamander	9.0	The pygmy salamander is endemic to a small portion of the high Mountains in North Carolina, southwestern Virginia, and Tennessee. It inhabits seeps in winter, where females lay eggs, and lives in high-elevation spruce-fir forests during summer.
x	x		*Desmognathus quadramaculatus*	Black-bellied Salamander	6.8	This large salamander lives near seeps, springs, or waterfalls in the Mountains and portions of the adjacent Piedmont region. The larval period lasts 2 to 3 yr.
x			*Desmognathus santeetlah*	Santeetlah Dusky Salamander	7.0	This species is endemic to a small area of the Great Smoky Mountains, Balsam, and Unicoi mountains of North Carolina and Tennessee, where it lives in higher elevation seeps and headwater streams. Females lay eggs under moss clumps in seepage areas.
x			*Desmognathus wrighti*	Pygmy Salamander	9.0	The pygmy salamander is endemic to a small portion of the high Mountains in North Carolina and adjacent Tennessee. It inhabits seeps in winter, where females lay eggs, and lives in high-elevation spruce-fir forests during summer.
	x	x	*Eurycea chamberlaini*	Chamberlain's Dwarf Salamander	6.0	This species lives in high quality seepage areas.

Table 2. Continued

Ecoregion			Scientific Name	Common Name	Assigned C Value	General Notes
Mtns	Pdmnt	CP				
x	x	x	*Eurycea cirrigera*	Southern Two-lined Salamander	2.6	The southern two-lined salamander seems to tolerate lower water quality conditions. Groundwater infusions into perennial streams help this species remain in degraded areas.
x	x	x	*Eurycea guttolineata*	Three-lined Salamander	6.0	This species occurs in bottomland hardwood wetlands in the Piedmont and Coastal Plain, but in the Mountains is only found in larger valleys.
x			*Eurycea junaluska*	Junaluska Salamander	6.9	This species is endemic to a few streams in North Carolina and adjacent Tennessee. It has been found only in clean streams; not much is known about its environmental tolerance.
x			*Eurycea longicauda*	Long-tailed Salamander	7.0*	*Note: Isolated populations of the long-tailed salamander are assigned a C value of 7 and non-isolated populations near the Virginia border, a C value of 6.
		x	*Eurycea quadridigitata*	Dwarf Salamander	7.0	This salamander lives in the southeastern part of North Carolina, in clay-based Carolina bays, cypress savanna ponds, and similar habitats.
x			*Eurycea wilderae*	Blue Ridge Two-lined Salamander	4.0	This salamander occupies streams, seeps, and springs throughout most of North Carolina's mountains.
	x	x	*Gastrophryne carolinensis*	Eastern Narrow-mouthed Toad	2.9	This species can breed in stormwater retention ponds, and even puddles in dirt roads.
x	x		*Gyrinophilus porphyriticus*	Spring Salamander	6.3	Spring salamanders mostly live in mountain springs and other cold streams, as well as mountain caves. Females do not reproduce until about 5 yr of age.
x	x	x	*Hemidactylium scutatum*	Four-toed Salamander	8.2	Seepage areas and bogs are required habitat for this species, which needs mature wetland forests and developed moss cavities to lay eggs. Sedge tussocks may be a key habitat feature for this species.
		x	*Hyla* (*Dryophytes*) *andersonii*	Pine Barrens Treefrog	8.7	The uncommon Pine Barrens treefrog is primarily found in the Sandhills and south-central Coastal Plain of North Carolina. It can be found in high quality bayhead wetlands, pocosins, seeps, and seasonal freshwater marshes.
x	x	x	*Hyla* (*Dryophytes*) *chrysoscelis*	Cope's Gray Treefrog	2.1	This species breeds in a variety of wet habitats, natural and manmade, including ditches, puddles, shallow ponds, and other temporary wetlands.
	x	x	*Hyla* (*Dryophytes*) *cinereus*	Green Treefrog	1.6	The green treefrog has a higher tolerance for fish in breeding areas than other treefrogs, using permanent water more frequently than other species.
	x	x	*Hyla* (*Dryophytes*) *femoralis*	Pine Woods Treefrog	4.8	The pine woods treefrog relies on a wide variety of temporary wetlands in Coastal Plain pine flatwoods and savannas. It sometimes can be found in bottomland hardwood swamps and pine plantations. This species can tolerate very acidic waters.
	x	x	*Hyla* (*Dryophytes*) *gratiosus*	Barking Treefrog	7.9	The barking treefrog does not tolerate disturbance as well as the pine woods treefrog and generally requires quality fish-free wetlands to breed but will occasionally breed in retention ponds and fish-free farm ponds. This species cannot tolerate very acidic waters.
	x	x	*Hyla* (*Dryophytes*) *squirellus*	Squirrel Treefrog	2.6	The squirrel treefrog can be found in urban settings and will use ditches and other areas to breed. It will also use ephemeral wetlands and deeper water headwater wetlands.

Table 2. Continued

Ecoregion			Scientific Name	Common Name	Assigned C Value	General Notes
Mtns	Pdmnt	CP				
	x		*Hyla versicolor* (*Dryophytes versicolor*)	Gray Treefrog	2.1	Little is known about this species in North Carolina, but in other parts of its range, this treefrog breeds in a wide variety of wet habitats and seems tolerant of disturbance.
	x	x	*Necturus lewisi*	Neuse River Waterdog	7.8	This species is endemic to North Carolina, where it lives in large brownwater tributaries and the main stems of the Neuse and Tar rivers between tidewater and the lower Piedmont. It occupies leaf beds in quiet waters during winters.
x			*Necturus maculosus*	Common Mudpuppy	6.6	The common mudpuppy can tolerate poor water quality resulting from point-source effluent, runoff, and sedimentation in other states, but this has not been observed in North Carolina.
	x	x	*Necturus punctatus*	Dwarf Waterdog	7.0	This species occupies smaller streams than the Neuse River waterdog and occurs more widely in blackwater streams across the Coastal Plain. It uses leaf beds in winter.
x	x	x	*Notophthalmus viridescens*	Eastern Newt	2.0	The eastern newt is a common species found in ponds, lakes, and pools near rivers and streams; juveniles (red efts) occupy moist forests nearby.
x			*Pseudacris brachyphona*	Mountain Chorus Frog	3.3	The mountain chorus frog is found only in the extreme southwest corner of North Carolina, where it breeds in temporary wetlands, including roadside ditches.
		x	*Pseudacris brimleyi*	Brimley's Chorus Frog	4.6	This secretive frog inhabits low areas in hardwood forests and swamps near rivers and streams and breeds in shallow ponds, ditches, and other temporary wetlands in the Coastal Plain.
x	x	x	*Pseudacris crucifer*	Spring Peeper	1.7	The spring peeper is highly tolerant of disturbance and can breed in a wide range of habitats, including ephemeral wetlands, deeper water, headwater wetlands, swamps, and in vegetation at the edges of ponds and ditches.
x	x	x	*Pseudacris feriarum*	Upland Chorus Frog	4.0	The upland chorus frog relies on ephemeral ponds and deeper water headwater wetlands, using semi-permanent pools. This species is most common in the Piedmont, with some populations in the Mountains and Coastal Plain ecoregions.
		x	*Pseudacris nigrita*	Southern Chorus Frog	7.0	The southern chorus frog seems to be very susceptible to fire ants and drought. This species is found in pine flatwoods, wet meadows, roadside ditches in natural areas, and moist woodlands.
		x	*Pseudacris ocularis*	Little Grass Frog	4.8	The little grass frog prefers grassy margins of ponds or wetlands in pine areas, or pools and streams in hardwood forests and swamps.
		x	*Pseudacris ornata*	Ornate Chorus Frog	10.0	The ornate chorus frog breeds in Carolina bays and ephemeral wetlands in the Coastal Plain. It has become increasingly rare in recent years, like many ephemeral wetland breeders associated with the longleaf pine ecosystem.
x	x	x	*Pseudotriton montanus*	Mud Salamander	5.0	The mud salamander needs mature forest seepage areas. It can be found in muck soil beneath logs and stones on banks of seepages, springs, brooks, or swamps.
x	x	x	*Pseudotriton ruber*	Red Salamander	5.0	Red salamanders need seepage areas or small perennial streams with quality habitat to reproduce, including leaf litter accumulation, nearby crevices and burrows, logs, stones, and debris.

Table 2. Continued

Ecoregion			Scientific Name	Common Name	Assigned C Value	General Notes
Mtns	Pdmnt	CP				
		x	*Rana* (*Lithobates*) *capito*	Carolina Gopher Frog	10.0	The gopher frog breeds in ephemeral wetlands in pine savannas of the Coastal Plain but spends most of its time in associated high-quality uplands. This rare species is listed as an Endangered Species in South Carolina and a Threatened Species in North Carolina.
x	x	x	*Rana* (*Lithobates*) *catesbeianus*	American Bullfrog	1.0	The American bullfrog is a generalist species, tolerant of a wide range of aquatic conditions.
x	x	x	*Rana* (*Lithobates*) *clamitans*	Green Frog	1.0	The green frog is a generalist species that can persist in areas with fish.
		x	*Rana* (*Lithobates*) *kauffeldi*	Atlantic Coast Leopard Frog	3.0	This recently described leopard frog has not been well-studied but is presumed to be a generalist species.
		x	*Rana* (*Lithobates*) *heckscheri*	River Frog	8.0	This species inhabits oxbows, river swamps, and other permanent waters associated with blackwater rivers. It is presumed extirpated in North Carolina.
x	x	x	*Rana* (*Lithobates*) *palustris*	Pickerel Frog	3.0	The pickerel frog is a generalist species which is very tolerant of fish in breeding areas.
	x	x	*Rana* (*Lithobates*) *sphenocephalus*	Southern Leopard Frog	2.2	Southern leopard frogs breed in ephemeral ponds or other areas, permanent ponds, ditches and swamps, and lake and stream margins.
x	x	x	*Rana* (*Lithobates*) *sylvaticus*	Wood Frog	4.1	In the Carolinas, this frog occupies primarily the Mountains and upper Piedmont, where it spends most of its time far from water in wooded ravines under logs and leaves. It breeds in shallow pools or vegetated ponds. Disjunct populations live in Hyde and Tyrrell counties in the Coastal Plain, and are assigned a C value of 8.
		x	*Rana* (*Lithobates*) *virgatipes*	Carpenter Frog	5.4	Carpenter frog tadpoles take about a year to metamorphose, so they require more permanent wetlands. They live throughout the Coastal Plain. Adults are highly aquatic.
x	x	x	*Scaphiopus holbrookii*	Eastern Spadefoot	5.0	Eastern spadefoots can be found in sandy lowlands in burrows, and breed in ephemeral wetlands. They will also breed in man-made pools in ditches, tire ruts, flooded agricultural fields, etc., but they require temporary fish-free water.
		x	*Siren intermedia*	Lesser Siren	5.6	The lesser siren lives in slow-moving waters of swamps, ditches, and ponds throughout the Coastal Plain.
	x	x	*Siren lacertina*	Greater Siren	4.3	The greater siren is found in muddy, heavily vegetated ditches, swamps, and ponds, along with lakes, rivers, and streams. It burrows in the mud at the bottom, where it can survive a long time during droughts.
		x	*Stereochilus marginatus*	Many-lined Salamander	7.0	This mostly aquatic salamander lives in swamps, ditches, slow streams, and shallow cypress or gum ponds in pine savannas.

* Asterisks indicate location dependent C value assignment; see General Notes for the given species for information.

Table 3. Mean amphibian quality assessment index (AQAI) values and species richness for each study wetland over three sampling years; sites were ranked from one to 16, from highest AQAI to lowest. Ref = reference.

Site Type	Site Name	Mean AQAI	Mean Species Richness
Open Canopy Ref	17 Frog Pond	13.5	9.7
Open Canopy Ref	Brandon's Pond	13.3	8.0
Enhanced	Block T Pond	11.7	11.7
Enhanced	Little Little Dismal Pond	11.1	8.7
Closed Canopy Ref	Pulpwood Pond	11.0	8.7
Open Canopy Ref	Tiger Pond	9.8	5.7
Enhanced	Slate Circle	9.6	8.5
Open Canopy Ref	Swain Pond	9.5	6.3
Re-established	Juniper Bay	7.8	10.0
Enhanced	Braswell Ponds	7.7	6.7
Closed Canopy Ref	Gum Pond	6.6	8.3
Re-established	Stone Farm	6.4	5.7
Closed Canopy Ref	Cypress Pond	6.1	3.7
Re-established	Dover Bay	5.9	5.5
Re-established	Parker Farms	5.5	8.0
Closed Canopy Ref	Block O Pond	2.5	1.3

mitigation design and restoration practices to benefit these animal communities (Gianopulos et al. 2016). Sixteen (16) wetlands were selected for study in the Coastal Plain and Sandhills regions of NC, representing four types: re-established wetlands, closed-canopy reference wetlands, enhanced wetlands, and open-canopy reference wetlands. Re-established wetlands had been historically drained for silviculture or agriculture and were restored by plugging ditches and planting wetland tree species. Enhancement wetlands were historically open-canopy systems, but fire suppression allowed trees to invade, so trees were removed in an effort to improve aquatic animal habitat. After re-establishment and enhancement, amphibian sampling was performed consistently across all sites and years with dipnetting, visual surveys, and call recordings. The amphibian communities found in

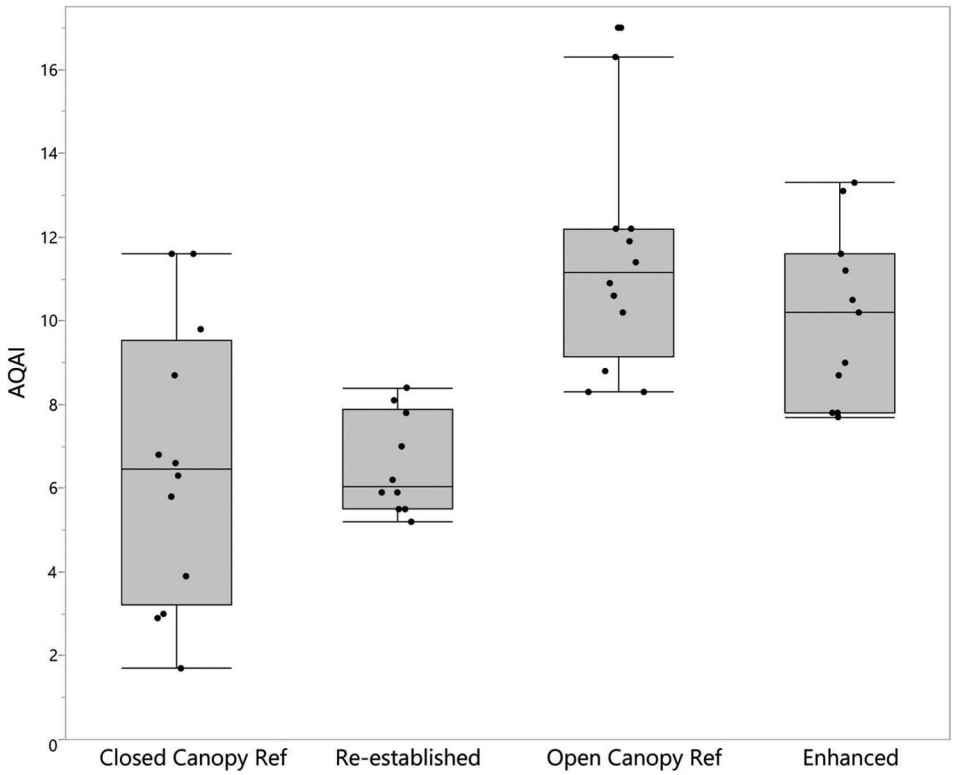

FIG. 1. Amphibian quality assessment index (AQAI) values for amphibian communities in four types of wetland. Ref = reference. Data from Gianopulos et al. (2016).

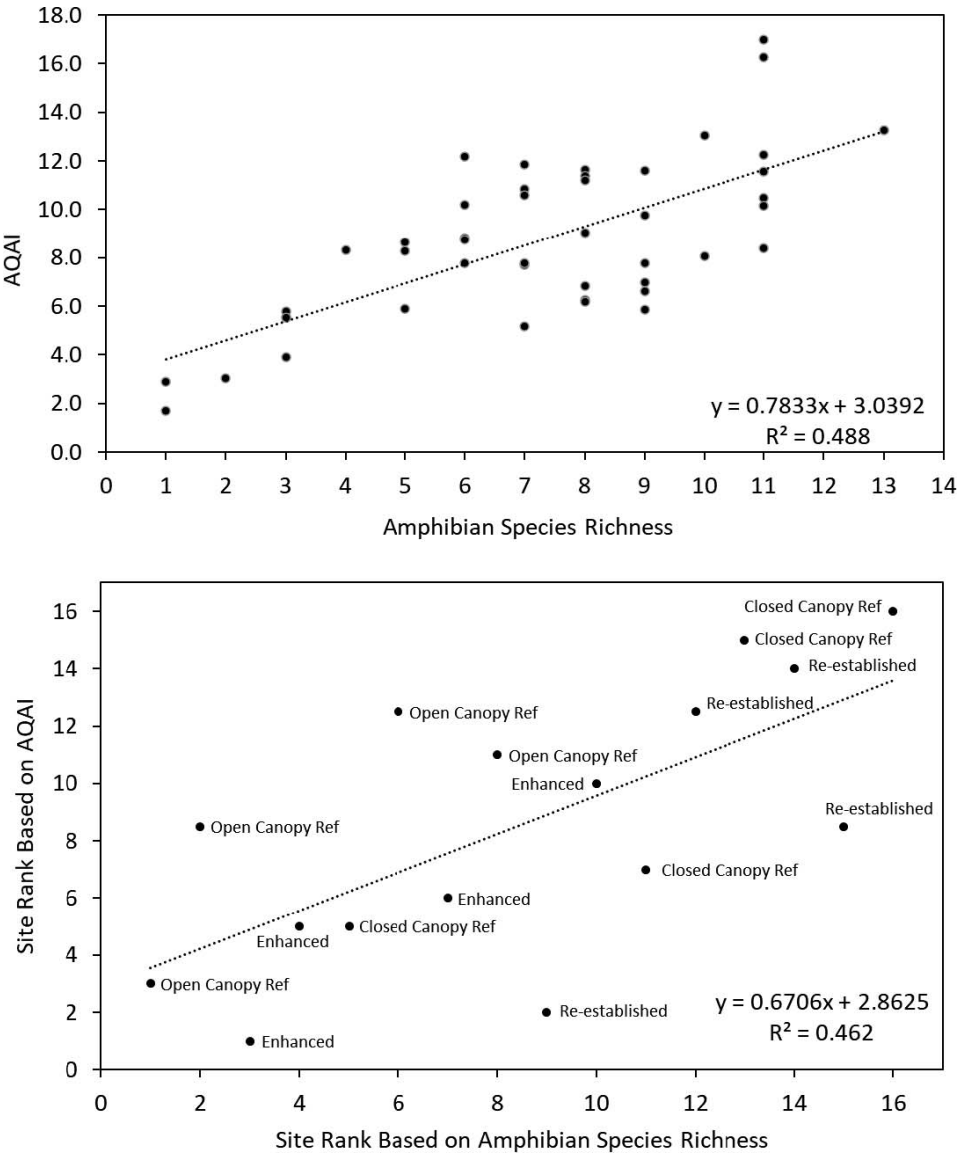

FIG. 2. Values and site ranks on 16 wetland sites over a 3-yr study for amphibian quality assessment index (AQAI) versus species richness; dots in top graph represent index values in a given year at a given site. Sites were ranked from one to 16, from highest AQAI to lowest. Data from Gianopulos et al. (2016).

open canopy wetlands (reference and enhanced) were of higher quality than those in closed canopy wetlands (Fig. 1). High C-value species such as the tiger salamander (*Ambystoma tigrinum*), gopher frog (*Rana* [*Lithobates*] *capito*), Pine Barrens treefrog (*Hyla* [*Dryophytes*] *andersonii*), and barking treefrog (*Hyla gratiosa* [*Dryophytes gratiosus*]) were only detected in the open canopy wetlands, indicating that restoring overgrown wetlands can be advantageous for these specialized species, which are of conservation interest.

Species richness and diversity indices are often used to evaluate biotic communities, but these indices rely solely on total numbers of species and abundances. A major benefit to using an AQAI for amphibian community evaluation is that it incorporates species level information about habitat quality. While species richness was positively related to AQAI in Gianopulos et al. (2016), the sites with moderate to higher levels of amphibian species richness showed a wide range of AQAI values (Fig. 2). Site rankings based on AQAI did not always agree with site rankings based on species richness, though generally the two indices grouped open canopy wetlands (enhanced and reference) together, with less consistency among closed canopy wetlands (re-established and reference) (Fig. 2).

Incorporation of habitat quality information into the AQAI makes the index potentially more useful or actionable than richness or diversity indices. Management

actions are sometimes targeted toward benefiting higher C-value species, which are often rare as a function of their sensitivity to anthropogenic disturbance and particular habitat requirements. Certain management activities such as removing permanent water and eliminating fish could make habitat less suitable for some low C-value species like the American bullfrog (*Rana catesbeiana* [*Lithobates catesbeianus*]) or pickerel frog (*Rana* [*Lithobates*] *palustris*), but also result in an increased AQAI by making habitat more suitable for high C-value species who need fish-free environments to successfully breed.

One disadvantage to distilling amphibian community data into a single number, no matter what the index, is that important information can be hidden, such as patterns in the occurrence of unusual or protected species. However, indices can be particularly useful when assessing large numbers of sites or when needing to succinctly describe certain aspects of sites. The AQAI offers the benefit of indicating extra information about the quality of aquatic habitat and surrounding uplands utilized by amphibians, beyond simple species presence and abundance.

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