North American Journal of Fisheries Management 39:778–787, 2019
© 2019 American Fisheries Society
ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10317

ARTICLE

Evaluation of Artificial Cover Units as a Sampling Technique and Habitat Enhancement for Madtoms in Rivers

W. Robert Cope[1]
North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, North Carolina 27695, USA

Thomas J. Kwak*
U.S. Geological Survey, North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, North Carolina 27695, USA

Tyler R. Black
RK&K, 900 Ridgefield Drive, Suite 350, Raleigh, North Carolina 27609, USA

Krishna Pacifici
Department of Forestry and Environmental Resources, North Carolina State University, 3120 Jordan Hall, Raleigh, North Carolina 27607, USA

Abstract
Instream habitat degradation and loss are major threats to freshwater fishes and critical conservation issues among nongame species due to a lack of research and knowledge concerning their habitat requirements. Instream physical cover is an important component of fish habitat, especially for benthic species that require cover for reproduction and shelter from predators. One such species is the Carolina Madtom *Noturus furiosus*, a small, imperiled, nongame catfish that is endemic to the Neuse and Tar River basins of North Carolina. To enhance understanding of instream cover dynamics, we constructed artificial cover units from terra cotta materials and deployed them in rivers to (1) evaluate whether they could be an effective passive-sampling technique to estimate detection and occupancy of the Carolina Madtom and (2) determine their potential to enhance habitat in systems where instream cover has been lost. Artificial cover units were deployed at eight sites in the Neuse and Tar River basins, and the units collected 30 Carolina Madtoms at two sites in the Tar River basin. Occupancy modeling estimated a Carolina Madtom detection probability of 0.92 using artificial cover units. Compared to other standardized sampling methods, artificial cover units were an efficient passive-sampling technique for detecting Carolina Madtoms. Observations also revealed that artificial cover units were occupied by Carolina Madtoms for reproduction. These findings provide an additional means by which natural resource managers can assess the status of this imperiled species via an inexpensive passive-sampling device that can provide spawning habitat and protection from predators as well as helping to mitigate the effects of instream habitat degradation.

*Corresponding author: tkwak@ncsu.edu
[1]Present address: Department of Natural Resource Ecology and Management, Iowa State University, 2310 Pammel Drive, 339 Science Hall II, Ames, Iowa 50011, USA.
Received December 20, 2018; accepted May 23, 2019

Instream habitat occurrence and quality are essential for biodiversity and aquatic organism survival in lotic ecosystems (Gorman and Karr 1978; Schlosser 1982). Degradation and loss of stream habitat have become common stressors affecting biota in regions with high freshwater diversity, such as the southeastern United States (Angermeier 1995; Warren et al. 2000; Jelks et al. 2008). Habitat loss directly leads to declines in freshwater fish populations and community diversity (Ricciardi and Rasmussen 1999; Reynolds et al. 2002). Instream habitat relations and population declines due to habitat degradation are well documented, yet many river systems lack habitat-based management plans. In systems where stream habitat is managed, conservation efforts are typically allocated to more economically or recreationally important species, leaving nongame species' habitat requirements understudied and poorly understood (Hubert and Rahel 1989; Reynolds et al. 2002; Cooke et al. 2005). Furthermore, nongame and sport fish species often have different habitat affinities and requirements, potentially harming nongame stream fish when habitat is strictly managed for sport fish species (Aadland 1993; Kwak and Freeman 2010). Therefore, habitat management for nongame species remains a vital conservation objective to help maintain stream system biodiversity.

Instream habitat may be defined as the place where fish can find the physical and chemical features required for life (Maddock 1999; Orth and White 1999). An important feature of stream habitat is available instream cover, which is any physical object or formation that offers concealment or visual isolation (Orth and White 1999). Cover is a critically important element of stream habitat for many species, as instream cover provides a location for fish to spawn and rear eggs and to seek shelter from predators (Mann 1996; MacKenzie and Greenberg 1998). Benthic species in particular rely on instream cover, as their association with the substrate and related cover gives them an ecological niche distinct from that of midwater species (Rahel and Stein 1988; Magoulick 2004).

Benthic and endemic species are among the most impacted by habitat degradation (Angermeier 1995). For example, over 25% of fishes in the benthic-dwelling families Percidae and Ictaluridae are classified as jeopardized (Piller et al. 2004). Especially threatened members of Ictaluridae are the madtoms—small, nongame fishes belonging to the genus *Noturus*. Most madtoms are benthic and endemic to restricted distributions, leaving them especially vulnerable to habitat degradation and imperilment. Robison and Harp (1985) found that anthropogenic habitat degradation had negatively affected populations of the Ouachita Madtom *Noturus lachneri*, while Etnier and Starnes (1991) concluded that benthic species, such as madtoms and darters (*Ammocrypta*, *Crystallaria*, *Etheostoma*, and *Percina*), were the most jeopardized fishes due to loss of available instream cover for nesting and reproduction. One approach to mitigating instream habitat loss is through the introduction of artificial cover or the augmentation of existing instream cover of natural materials. Introduction of artificial cover has been documented as beneficial to salmonids and other sport fishes (Heggenes and Traaen 1988; Moring and Nicholson 1994; Eklöv and Greenberg 1998), and studies of benthic-dwelling nongame darters have demonstrated that artificial cavities were suitable structures for nesting and spawning activities (Lindquist et al. 1984; Piller and Burr 1999).

The Carolina Madtom *Noturus furiosus* is a small, nongame, cover-associated catfish that is endemic to two river basins in North Carolina. Due to recent population declines and a shrinking distribution, the Carolina Madtom is currently listed as threatened in the state of North Carolina (LeGrand et al. 2008; NCNHP 2016). Suitable cover is required for Carolina Madtom spawning and parental care activities, and cobble, leaf packs, woody debris, and native unionid mussel shells are used as cover items (Burr et al. 1989; Midway et al. 2010b). Carolina Madtoms may also occupy artificial structures for nesting. Burr et al. (1989) found that the species inhabited 355-mL aluminum cans, and Wood and Nichols (2008) collected individuals from aluminum cans and glass beverage containers. Midway et al. (2010b) conducted an intensive before–after–control–impact study using constructed artificial cover units to determine whether they increased the abundance of Carolina Madtoms in river reaches; those authors found that abundance was significantly higher in experimental reaches augmented with artificial cover units than in control reaches. Midway et al. (2010a) also conducted laboratory cover preference trials during which Carolina Madtoms were placed in aquaria and were presented with three natural cover objects and one artificial cover unit. Carolina Madtoms selected the artificial cover unit in 63% of the experimental trials, indicating a clear preference for artificial cover over natural cobble, leaf pack, and mussel shell cover.

Carolina Madtoms preferentially occupy artificial cover units in the laboratory, and the units provide suitable cover habitat in streams (Midway et al. 2010a, 2010b); thus, they have the potential to serve as a sampling technique for the species in stream and river habitats. The objective of this research was to assess artificial cover units as an effective passive-sampling technique for Carolina Madtom detection with a minimal amount of field sampling effort relative to typical active-sampling techniques (e.g., snorkeling or electrofishing). The Neuse and Tar River basins have both experienced effects of urbanization and sedimentation (NCDEQ 2009; NCDWR 2010), and Carolina Madtoms have undergone drastic population declines (Cope 2018). This evaluation may also serve as a comparison with findings by Midway et al.

(2010b), who deployed these same cover units during a period (2007–2008) when the Carolina Madtom was more widespread and abundant in the Neuse and Tar River basins. If Carolina Madtom occupancy of artificial cover units remains high at current reduced population levels, the units may provide a simple and affordable method for managers to use in sampling, monitoring, habitat enhancement, and broodstock collection for captive propagation to help conserve the species.

STUDY AREA

This research was conducted in the Neuse and Tar River basins of the Piedmont and Coastal Plain physiographic provinces of North Carolina. The Neuse River flows approximately 325 km through North Carolina from its headwaters originating in the Piedmont at the confluence of the Eno and Flat rivers to its mouth at Pamlico Sound near the city of New Bern (NCDWR 2010). The basin covers an area of 10,034 km^2 and spans 18 counties. Approximately 1.7 million people currently live in the Neuse River basin, with the population expected to reach 3 million by the year 2050 (NCDWR 2010). The associated human activities in the river and over its watershed impact the habitat and water quality of the Neuse River. Currently, 13% of the basin is considered urban, 45% is classified as forested, and 29% is designated as crop and pasture land (NCWRC 2005). In 2007, the American Rivers Foundation listed the Neuse River as one of the 10 most endangered rivers in the United States (American Rivers Foundation 2007). Non-point-source pollution from agriculture and forestry has degraded water quality and habitats throughout the basin. Commercial farming inputs, such as animal waste and fertilizers, contribute 60% of the nitrates and phosphates in the system (NCWRC 2005). Due to the dense human population in the basin, many municipalities have constructed dams and withdraw water from the created impoundments for human use, affecting river flow and connectivity. Habitat loss is also an issue in the Neuse River basin, as the increasing human population results in the loss of natural areas and leads to increases in impervious surfaces (NCDWR 2010).

The Tar River runs through North Carolina from its origin in Person County to the town of Washington, where it becomes the Pamlico River and flows an additional 65 km to its mouth at Pamlico Sound (NCDWR 2001). The basin covers 8,755 km^2 and spans 16 counties. With a human population of only 415,000, the Tar–Pamlico River basin is more rural and less impacted by human activities than the Neuse River basin. Currently, 55% of the basin is classified as forest and wetland, 28% is categorized as crop and pasture, and 7% is designated as urban (NCDEQ 2010). The primary habitat problems affecting the basin are erosion and sedimentation, which are due mainly to channel dredging for crop and livestock irrigation and drainage purposes (NCWRC 2005). Urbanization is a concern but is not considered a serious cause of water degradation.

We selected eight sites based on the surveying results of Midway et al. (2010b), Wood and Nichols (2011), and Cope (2018). Six sites were located in the Tar River basin, and two were situated in the Neuse River basin (Figure 1). All eight sites had Carolina Madtom occurrences in 2007, which were confirmed through snorkel surveying efforts (Wood and Nichols 2011). Sites in the Tar River basin covered most of the extant range of the species, with multiple sites in Fishing, Swift, and Little Fishing creeks. Sites in the Neuse River basin covered the remaining recent range of the Carolina Madtom in the basin: Contentnea Creek and Little River.

METHODS

We constructed artificial cover units by following the design of Midway et al. (2010a, 2010b; Figure 2). We deployed the units via a standardized protocol at eight stream sites in the range of the Carolina Madtom and then monitored their occupancy by the Carolina Madtom and other aquatic species.

Construction.— Artificial cover units were built to the specifications reported by Midway et al. (2010a, 2010b). Due to a lack of availability of the exact original building materials, artificial cover units were constructed using materials similar to those used in the original design. The enclosure cover was formed by the bottom 133 mm of a 150-mm-diameter, terra cotta clay pot that was removed using a Dremel Model 4000 rotary cutting tool with a diamond grit cutting wheel. An approximately 19- × 32-mm, inverted-U-shaped "mouse hole" entryway and three 10-mm vent slots were cut out of the enclosure. The cover was then glued to an inverted, 133-mm-diameter planter saucer to form the enclosure, and landscaping river rocks (~20–30-cm diameter) were glued into the concave portion of the planter saucer to serve as a weight and provide stability for the unit (Figure 2). To complete the unit, a rubber stopper was inserted into the drain hole of the terra cotta enclosure and was cut off flush with the top of the unit. The stopper was then glued into place from the outside so as not to introduce any unnecessary chemicals from gluing on the inside of the cover unit. All materials were sourced from local hardware stores, and materials for unit construction were inexpensive (<$5 per unit).

Deployment.— At each site, 150-m reaches were delineated for snorkel surveying efforts. Twelve artificial cover units were deployed along each 150-m reach in areas deemed "quality habitat." Quality habitat was determined visually based on known microhabitat characteristics related to Carolina Madtom occurrence from previous

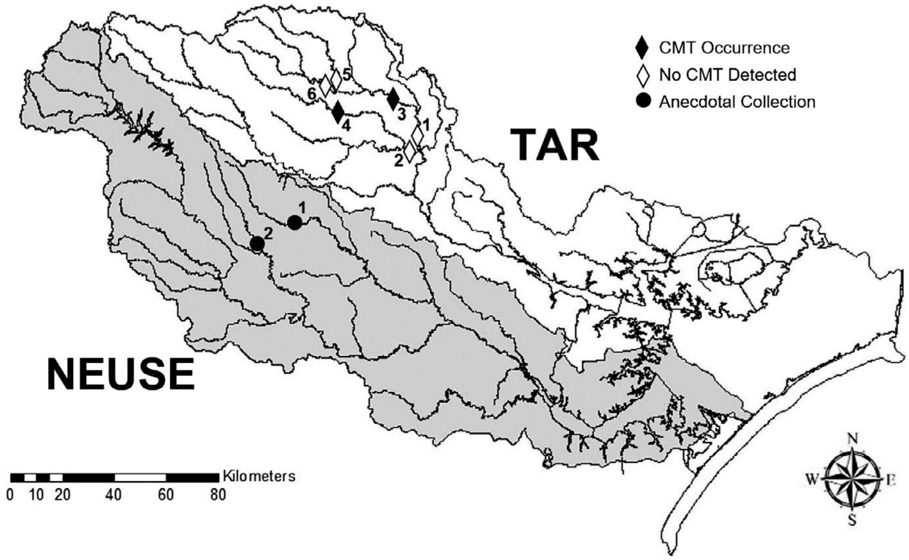

FIGURE 1. Map of artificial cover unit sampling sites in the Neuse and Tar River basins of North Carolina. Anecdotal collections of the Carolina Madtom (CMT) came from Contentnea Creek (site 1) and Little River (site 2) in the Neuse River basin by using nonstandardized snorkeling (Little River) or artificial cover unit sampling methods (Contentnea Creek).

research findings (Burr et al. 1989; Midway et al. 2010b). Our intent was to avoid deploying cover units in areas where occupancy would be unlikely, such as deep pools or areas that were prone to dewatering. Cover units were placed in a cross-sectional grid pattern near the left bank, central channel, and right bank to account for any microhabitat changes across the stream. Cover units were deployed with the vent slots facing upstream and the entryway facing downstream to avoid accumulation of debris or sediment washing downstream in the unit. The units were deployed during July–September 2016 and June–November 2017. Sampling period was dependent upon completed construction and weather conditions each year. In 2016, construction and deployment occurred in July and all units were retrieved from the rivers in September before the impacts of Hurricane Matthew. In 2017, deployment began in June and the sampling period extended into November until cold water and accumulated fallen leaf packs made visual assessment impractical.

Monitoring.— Artificial cover units were deployed for at least a 14-d soak period as weather conditions dictated; they were then were checked to determine occupancy by Carolina Madtoms and associated benthic, cover-oriented species. In 2016, cover units were initially deployed at two sites and were rotated to other sites after three soak periods. Additional construction of cover units in 2017 allowed for longer unit deployment duration, and some units were checked up to six times during the sampling period. All units in both 2016 and 2017 were deployed for at least three soak periods. During each observation event, artificial habitats were approached from downstream by a snorkeling observer with a dip net. The observer then gently grasped the cover unit with a finger over the entryway to confine any occupant, lifted the cover unit out of the water, and emptied the contents of the unit into the dip net. Area beneath the cover unit was also observed for any animals that occurred under the unit rather than inside it. Any other fish or amphibian species found in or under the habitat unit was also recorded. The cover unit was then re-deployed in the same location and was left for another 14-d soak period. Collected Carolina Madtoms were weighed to the nearest 0.1 g, and TL was measured in millimeters. A right-side pelvic fin clip was taken for genetic analysis. After data collection, each madtom was released alive near the cover unit it had occupied. Microhabitat characteristics were measured at all Carolina Madtom points of capture.

Depth (m), bottom velocity (m/s), mean column velocity (m/s), dominant substrate composition, and subdominant substrate composition were measured at the point directly beside the occupied cover unit. Depth, bottom velocity, and mean column velocity were measured using a top-set wading rod and a Marsh-McBirney Model 2000 flow meter. Bottom velocity was measured directly on the substrate surface, and mean column velocity was measured at 60% of the total depth from the surface. Dominant and subdominant substrate compositions were determined based on the greatest and second-greatest percentages of substrate type at the location according to a modified Wentworth particle scale (Bovee and Milhous 1978).

Instream microhabitat surveys were performed at all sites under base flow conditions by sampling cross-sectional

FIGURE 2. Artificial cover unit construction using terra cotta saucers (upper left panel); instream placement of a cover unit in the Little River (Neuse River basin), North Carolina (upper right panel); and biofilm-covered cover units, showing the opening created to allow fish access (lower left panel) and vents on the opposite side (lower right panel). Numbered units on the measuring stick are centimeters. [Color figure can be viewed at afsjournals.org.]

transects. At each 150-m reach, 10 cross-sectional transects were spaced 15 m apart, starting from a random point within the first 15 m moving upstream through the reach. Each transect was sampled at a minimum of 10 evenly spaced points, usually 1–3 m apart depending on stream width. At each transect point, we measured depth, bottom velocity, mean column velocity, dominant and subdominant substrate, distance to the nearest cover, and cover type according to the methods above.

Snorkel survey methods.— As part of a concurrent study (Cope 2018), snorkel surveys were completed at all eight reaches where artificial cover units were deployed. For this protocol, each snorkeler (2–5, depending on stream width) started at the downstream portion of the reach and slowly surveyed upstream, upturning any leaf litter, woody debris, cobble, or litter present in the river to maximize detection potential. This method was standardized by effort, with each snorkeler covering no more than a 5-m wetted width of the stream. Each snorkeler sampled more than one 5-m section of the stream if the river width was five times greater than the total number of snorkelers. This protocol was similar to that used by Wood and Nichols (2008), who conducted intensive snorkel surveying to sample Carolina Madtom populations.

Statistical analyses.— Means were calculated for Carolina Madtom length and weight and the depth, bottom velocity, and mean column velocity at capture locations. Modes were identified for dominant and subdominant substrates. To determine the efficiency of artificial cover units as a sampling technique, we fitted a single-season, single-species occupancy model (MacKenzie et al. 2002) to estimate the probabilities of occupancy (Ψ) and detection (p) and compare them to occupancy and detection estimates from previous Carolina Madtom studies. Detection histories were created using each successive artificial cover unit observation event as a repeat visit to the location. In total, artificial cover unit surveying occurred at eight sites, and the number of observation events ranged from three to six per site, resulting in eight occupancy locations with three to six visits serving as the detection history for each site. Occupancy modeling was completed using the program PRESENCE (U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland; https://www.mbr-pwrc.usgs.gov/software/presence.html).

Using the cross-sectional transect and point-of-capture microhabitat data collected from artificial cover unit surveys, we examined the available instream habitat relative to occupied artificial cover unit microhabitat to determine whether microhabitat characteristics influenced the selectivity of artificial cover units. Microhabitat variable distributions were assessed for normality by using a Shapiro–Wilk test. A majority of distributions did not conform to the normality assumption; thus, available instream microhabitat and occupied artificial cover unit microhabitat distributions were compared using a Kruskal–Wallis one-way ANOVA (on ranks) for all variables (depth, bottom velocity, mean column velocity, dominant substrate, and subdominant substrate), with $P < 0.05$ (α) revealing significant differences between available instream habitat and occupied artificial cover unit microhabitat.

RESULTS

In total, 30 Carolina Madtoms were collected from artificial cover units at two of the eight sites in which they were deployed. These 30 captures included 21 unique collections and 9 recaptures, as assessed by the presence or absence of fin clips. Collections came from sites 3 and 4 in the Tar River basin (Fishing and Swift creeks; Figure 1). No Carolina Madtoms were collected from cover units deployed at two sites in the Neuse River basin during the study period. However, concentrated artificial cover unit deployment (30 units per 150 m) by the North Carolina Wildlife Resources Commission (NCWRC) in 2018 detected a Carolina Madtom at Neuse River basin site 1 (Contentnea Creek) after both standardized and nonstandardized snorkeling methods failed to detect the species in either 2016 or 2017. In snorkel surveys during 2016, 2017, and 2018, Carolina Madtoms were captured at three of the eight sites in which artificial cover units were deployed. The species was detected at two sites (Tar River basin sites 3 and 4) via the standardized snorkel survey protocol. Carolina Madtoms were also detected at one additional site (Neuse River basin site 2) during nonstandardized intensive snorkel surveying with the NCWRC in 2017 and 2018. Comparison of Carolina Madtom detection between standardized snorkel surveying and artificial cover deployment showed complete agreement between the two methods (2 of 8 sites occupied). Our modeled $\hat{p}$ for sampling with artificial cover units was 0.92, which was similar to that obtained from snorkeling surveys ($\hat{p} =$ 0.81 and 0.94; Table 1). The $\hat{\Psi}$ associated with artificial cover unit sampling was 0.25, similar to that based on recent snorkel surveys ($\hat{\Psi} = 0.35$; Table 1). Considering all sampling (standardized and nonstandardized intensive sampling) at eight sites, Carolina Madtoms were detected at two sites by both snorkel surveys and artificial cover units, at a third site only by snorkel surveys, and at a fourth site only by artificial cover units.

TABLE 1. Comparison of occupancy modeling results using snorkel survey methods from Wood and Nichols (2008) and Cope (2018) and using artificial cover units in this study ($\hat{\Psi}$ = estimated occupancy probability; $\hat{p}$ = estimated detection probability).

Method (study)	$\hat{\Psi}$	$\hat{p}$
Snorkel (Wood and Nichols 2008)	0.75	0.94
Snorkel (Cope 2018)	0.35	0.81
Artificial cover units (present study)	0.25	0.92

TABLE 2. Length, weight, and microhabitat characteristics for Carolina Madtoms ($N = 21$) collected in artificial cover units deployed within the Tar River basin, North Carolina (modes are presented for substrates; means are presented for all other variables).

Variable	Mean or mode	SD	Range
TL (mm)	93.52	12.34	72.00–121.00
Weight (g)	9.69	3.92	4.21–20.54
Depth (m)	0.40	0.19	0.16–0.72
Bottom velocity (m/s)	0.20	0.14	0.02–0.54
Mean column velocity (m/s)	0.35	0.23	0.07–0.77
Dominant substrate	Sand		Sand–gravel
Subdominant substrate	Gravel		Sand–gravel

Carolina Madtoms occupying cover units ranged from 72 to 121 mm TL and weighed 4.2–20.5 g. They occupied cover units placed in microhabitats with a mean water depth of 0.40 m, bottom velocity of 0.20 m/s, mean column velocity of 0.35 m/s, and substrates composed of sand and gravel (Table 2). In addition to Carolina Madtoms, other species occupied the cover units. Ictalurids, including the Margined Madtom *Noturus insignis*, Tadpole Madtom *Noturus gyrinus*, Channel Catfish *Ictalurus punctatus*, and Flathead Catfish *Pylodictis olivaris*, were observed inside cover units (Table 3). Other benthic and cover-oriented fishes were also observed occupying cover units, including a darter, a sunfish, and an American Eel.

By comparing available instream microhabitat with occupied artificial cover unit microhabitat, we found that the locations of artificial cover units occupied by Carolina Madtoms were characterized by a specific nonrandom subset of microhabitat characteristics in the reaches where

TABLE 3. Observation of co-occurring ictalurid species and other fishes captured in artificial cover units deployed for use by Carolina Madtoms in the Tar and Neuse River basins during summer 2016 and 2017.

Species	Number
Channel Catfish *Ictalurus punctatus*	49
Margined Madtom *Noturus insignis*	4
Flathead Catfish *Pylodictis olivaris*	2
Tadpole Madtom *N. gyrinus*	1
Darter *Etheostoma* sp.	1
Sunfish *Lepomis* sp.	1
American Eel *Anguilla rostrata*	1

TABLE 4. Kruskal–Wallis test results (chi-square statistic [χ^2] and *P*-value) comparing microhabitat characteristics at the locations of artificial cover units occupied by Carolina Madtoms in the Tar River basin, North Carolina, and available instream habitat in the reach where cover units were deployed.

	Tar River basin site 3		Tar River basin site 4	
Variable	χ^2	*P*	χ^2	*P*
Depth	4.134	0.042	2.458	0.117
Bottom velocity	11.644	<0.001	17.352	<0.001
Mean column velocity	16.099	<0.001	12.751	<0.001
Dominant substrate	7.478	0.006	5.339	0.021
Subdominant substrate	9.185	0.002	6.822	0.009

cover units were deployed. Microhabitat characteristics were compared at two sites with occupied artificial cover units (Tar River basin sites 3 and 4). At Tar River basin site 3, all measured microhabitat characteristics of occupied artificial cover units were significantly different from those of the habitat available in the reach where cover units were deployed (Kruskal–Wallis test: $P < 0.05$; Table 4). At Tar River basin site 4, similar results were found, with significant differences between available instream microhabitat and occupied artificial cover unit microhabitat for all measured variables except depth ($P < 0.05$).

Descriptive observations regarding Carolina Madtom occupancy of artificial cover units provided additional insight. Artificial cover units that were originally deployed by Midway et al. (2010b) during 2007–2008 were discovered at site 4 in the Tar River basin (Figure 1). Four units were found, still functional and free of debris after 10 years. Carolina Madtoms were observed occupying these units during snorkel surveys and monitoring events. Carolina Madtoms were also observed guarding eggs inside these units, indicating nesting and successful spawning within artificial habitats. Another observation in the Tar River basin illustrated Carolina Madtoms using an entire unit as cover, hiding between saucer and substrate. Two individuals were captured from that component of the cover unit during different observation events.

DISCUSSION

Our findings indicated that artificial cover units can be an efficient passive-sampling device for detecting the presence or absence of Carolina Madtoms. Compared to our standardized snorkeling effort, cover units were as effective at detecting the occurrence of madtoms at the sites where both methods were employed. Modeling estimates for detection probability using cover units were also similar to estimates from snorkel surveying. The probability of detecting Carolina Madtoms by using artificial cover units was 0.92. Compared to $\hat{p}$ of 0.94 (Wood and Nichols 2011) and 0.81 (Cope 2018) estimated from snorkel surveying, artificial habitats are similarly efficient at detecting Carolina Madtoms. These findings may be in accord with those of Midway et al. (2010b), where similar cover units increased Carolina Madtom numbers in study reaches. Midway et al. (2010a) also found that Carolina Madtoms preferred artificial cover units over natural cover in laboratory experiments, while Burr et al. (1989) and Wood and Nichols (2008) observed Carolina Madtoms occupying beverage containers and other instream litter.

Intensive snorkeling surveys and deployment of artificial cover units may both be effective methods for detecting madtoms in areas of low abundance, as suggested by our anecdotal findings associated with supplemental sampling in the Neuse River basin. These results highlight the difficulty in detecting rare species. For madtom population surveys, where knowledge of sparse populations is critical, employing both intensive snorkel surveys and artificial cover unit deployment may be warranted.

Snorkel surveys and artificial habitat unit deployment were both effective for detecting madtoms but differed in associated properties. Snorkeling efforts are time consuming, require multiple trained personnel, and may not be cost effective for routine monitoring. Artificial cover units are inexpensive, are simple to construct, and can be deployed and observed with much less effort than snorkeling. Passive minnow trap sampling is currently the standard protocol for population status assessment of the Neuse River waterdog *Necturus lewisi*, another rare endemic of the Neuse and Tar River basins (Braswell and Ashton 1985); likewise, deployment of artificial cover units may be a time-efficient and cost-effective method for monitoring the population status of the Carolina Madtom. Furthermore, our collection of four Margined Madtoms and one Tadpole Madtom—the two other co-occurring madtom species in the sampled basins—and 51 other ictalurid individuals in artificial cover units suggests that this method may be applicable to other species.

Artificial cover units could also be used as long-term habitat enhancement tools. While snorkel surveying site 4 in the Tar River basin during 2016, we captured Carolina Madtoms inside four cover units that were originally deployed by Midway et al. (2010b) in 2007. Through 10 years of substrate alterations and flow fluctuations, the units remained operational and provided cover for madtoms. Even after the passing of Hurricane Matthew during fall 2016, which was one of the most intense rainfall events in eastern North Carolina and caused drastic flooding and massive current flow through Swift Creek (~200-m^3/s flooding versus ~1.2-m^3/s base flow), these units were found in 2017, validating their durability and effectiveness as long-term instream cover.

Physical instream habitat was likely an important factor in successful occupancy of artificial cover units. Our findings revealed that microhabitat characteristics of cover unit locations occupied by Carolina Madtoms were not a random subset of those characteristics available in the reach where cover units were deployed. Cover units were placed in a cross-sectional grid pattern throughout the reaches in varying depths, water velocities, and substrates. However, occupied units were deployed in areas with sand and gravel substrate, moderate depth, and low to medium velocity. These microhabitat characteristics were similar to those found most suitable for Carolina Madtoms by Midway et al. (2010b) and a concurrent microhabitat study associated with our deployments (Cope 2018). Cover units deployed in areas with silt substrate or low velocities were frequently found with sediment, and units deployed in shallow areas were prone to dewatering as stream levels receded. These observations suggest that random grid placement of artificial cover units would not be the most effective and that microhabitat analysis conducted prior to placing the units would maximize occupancy potential if that is the objective.

In addition to serving as an efficient sampling technique, artificial cover units can provide spawning habitat and protection from predators for Carolina Madtoms. Adequate cover is necessary for successful Carolina Madtom nesting and spawning (Burr et al. 1989). Both the Neuse and Tar River basins are degraded and have experienced habitat alteration and loss, and madtoms are especially at risk from habitat degradation, as substrate, flow, and instream cover are some of the first habitat components to become altered in impacted streams (Warren et al. 1997). Both the Neuse and Tar River basins contain limited instream cover. Cope (2018) found that 41% of the measured microhabitat in the basins contained no suitable cover within a 4-m^2 area around each sampling point during cross-sectional transect microhabitat analysis. One specific cover loss for madtom occupancy and reproduction is the reduction of available empty mussel shells, a result of the declines in freshwater mussel diversity and abundance and the imperilment of the fauna as whole—locally (in North Carolina waters) as well as globally (Keferl 1993; Williams et al. 1993; Lydeard et al. 2004).

Deployment of artificial cover units may compensate for lost habitat in the form of overhead cover that is essential for madtom viability. Male Carolina Madtoms were found guarding eggs inside artificial habitats, further validating their function as spawning habitat. Cover is also important in protecting prey species from predators (Savino and Stein 1982; Johnson et al. 1988). The Neuse and Tar River basins both contain nonnative Flathead Catfish populations. Flathead Catfish are known to consume native bullheads *Ameiurus* spp. as well as other *Noturus* spp. in North Carolina (Pine et al. 2007; Baumann and Kwak 2011), and cover to avoid predation may be vital for survival of the species. Unlike other cover types, which may be lifted or displaced during Flathead Catfish foraging, these artificial units provide a single small entryway that may prevent predators from gaining access to the fish inside.

Carolina Madtoms represent an important component of stream ecosystems: they not only provide important functions but also add to the high fish diversity found in the southeastern USA. Given recent declines of the Carolina Madtom, proper conservation and management will be vital to retain the species. Habitat loss is the greatest threat to madtom conservation (Etnier and Starnes 1991), and artificial cover units may enhance degraded habitat in impacted basins. In addition to providing critical spawning habitat and protection from predators, our findings demonstrate that artificial cover units can also serve as an efficient sampling device that may enhance scientists' ability to conserve this important but imperiled species.

ACKNOWLEDGMENTS

Funding for this research was provided by the NCWRC through the State Wildlife Grant Program. We thank William Wood, Joseph McIver, Spencer Gardner, Tom Fox, Zoe Nichols, and Mike Walter for field support. The North Carolina Cooperative Fish and Wildlife Research Unit is jointly supported by North Carolina State University, NCWRC, U.S. Geological Survey, U.S. Fish and Wildlife Service, and Wildlife Management Institute. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. There is no conflict of interest declared in this article.

ORCID

W. Robert Cope https://orcid.org/0000-0003-4838-8131
Thomas J. Kwak https://orcid.org/0000-0002-0616-137X

REFERENCES

Aadland, L. P. 1993. Stream habitat types: their fish assemblages and relationship to flow. North American Journal of Fisheries Management 13:790–806.

American Rivers Foundation. 2007. America's most endangered rivers of 2007. American Rivers Foundation, Washington, D.C.

Angermeier, P. L. 1995. Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conservation Biology 9:143–158.

Baumann, J. R., and T. J. Kwak. 2011. Trophic relations of introduced catfish in an Atlantic river. Transactions of the American Fisheries Society 140:1120–1134.

Bovee, K. D., and R. T. Milhous. 1978. Hydraulic simulation in instream flow studies: theory and technique. U.S. Fish and Wildlife Service FWS/OBS 78/33.

Braswell, A. L., and R. E. Ashton Jr. 1985. Distribution, ecology, and feeding habits of *Necturus lewisi* (Brimley). Brimleyana 10:13–36.

Burr, B. M., B. R. Kuhajda, W. W. Dimmick, and J. M. Grady. 1989. Distribution, biology, and conservation status of the Carolina Madtom, *Noturus furiosus*, an endemic North Carolina catfish. Brimleyana 15:57–86.

Cooke, S. J., C. M. Bunt, S. J. Hamilton, C. A. Jennings, M. P. Pearson, M. S. Cooperman, and D. F. Markle. 2005. Threats, conservation strategies, and prognosis for suckers (Catostomidae) in North America: insights from regional case studies of a diverse family of nongame fishes. Biological Conservation 121:317–331.

Cope, W. R. 2018. Status, trends, habitat, and genetics of the endemic Carolina Madtom. Master's thesis. North Carolina State University, Raleigh.

Eklöv, A. G., and L. A. Greenberg. 1998. Effects of artificial instream cover on the density of 0 + Brown Trout. Fisheries Management and Ecology 5:45–53.

Etnier, D. A., and W. C. Starnes. 1991. An analysis of Tennessee's jeopardized fish taxa. Journal of the Tennessee Academy of Science 66:129–134.

Gorman, O. T., and J. R. Karr. 1978. Habitat structure and stream fish communities. Ecology 59:507–515.

Heggenes, J., and T. Traaen. 1988. Daylight responses to overhead cover in stream channels for fry of four salmonid species. Ecography 11:194–201.

Hubert, W. A., and F. J. Rahel. 1989. Relations of physical habitat to abundance of four nongame fishes in high-plains streams: a test of habitat suitability index models. North American Journal of Fisheries Management 9:332–340.

Jelks, H. L., S. J. Walsh, N. M. Burkhead, S. Contreras-Balderas, E. Diaz-Pardo, D. A. Hendrickson, J. Lyons, N. E. Mandrak, F. McCormick, J. S. Nelson, S. P. Platania, B. A. Porter, C. B. Renaud, J. J. Schmitter-Soto, E. B. Taylor, and M. L. Warren. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. Fisheries 33:372–407.

Johnson, D. L., R. A. Beaumier, and W. E. Lynch Jr. 1988. Selection of habitat structure interstice size by Bluegill and Largemouth Bass in ponds. Transactions of the American Fisheries Society 117:171–179.

Keferl, E. P. 1993. The status of freshwater mussels in some Georgia, South Carolina, and North Carolina waters. Pages 298–302 *in* K. J. Hatcher, editor. Proceedings of the 1993 Georgia water resources conference. University of Georgia, Athens.

Kwak, T. J., and M. C. Freeman. 2010. Assessment and management of ecological integrity. Pages 353–394 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

LeGrand, H. E., S. E. McRae, S. P. Hall, and J. T. Finnegan. 2008. Natural Heritage Program list of the rare animal species of North Carolina. North Carolina Department of Environment and Natural Resources, Division of Natural Resource Planning and Conservation, North Carolina Natural Heritage Program, Raleigh.

Lindquist, D. G., J. R. Shute, P. W. Shute, and L. M. Jones. 1984. Selection of sites for egg deposition and spawning dynamics in the Waccamaw Darter. Environmental Biology of Fishes 11:107–112.

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

MacKenzie, A. R., and L. Greenberg. 1998. The influence of instream cover and predation risk on microhabitat selection of Stone Loach *Barbatula barbatula* (L.). Ecology of Freshwater Fish 7:87–94.

MacKenzie, D. I., J. D. Nichols, G. B. Lachman, S. Droege, J. A. Royle, and C. A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. Ecology 83:2248–2255.

Maddock, I. 1999. The importance of physical habitat assessment for evaluating river health. Freshwater Biology 41:373–391.

Magoulick, D. D. 2004. Effects of predation risk of habitat selection by water column fish, benthic fish, and crayfish in stream pools. Hydrobiologia 527:209–221.

Mann, R. H. K. 1996. Environmental requirements of European non-salmonid fish in rivers. Hydrobiologia 323:223–235.

Midway, S. R., D. D. Aday, T. J. Kwak, and K. Gross. 2010a. Cover preference of the Carolina Madtom (*Noturus furiosus*), an imperiled endemic southeastern stream fish. Journal of Freshwater Ecology 25:151–154.

Midway, S. R., T. J. Kwak, and D. D. Aday. 2010b. Habitat suitability of the Carolina Madtom, an imperiled, endemic stream fish. Transactions of the American Fisheries Society 139:325–338.

Moring, J. R., and P. H. Nicholson. 1994. Evaluation of three types of artificial habitats for fishes in a freshwater pond in Maine, USA. Bulletin of Marine Science 55:1149–1159.

NCDEQ (North Carolina Department of Environmental Quality). 2009. Neuse River basinwide water quality plan. NCDEQ, Raleigh.

NCDEQ (North Carolina Department of Environmental Quality). 2010. Tar–Pamlico River basin water quality plan. NCDEQ, Raleigh.

NCDWR (North Carolina Division of Water Resources). 2001. State water supply plan. North Carolina Department of Environment and Natural Resources, Raleigh.

NCDWR (North Carolina Division of Water Resources). 2010. Neuse River basin water resources plan. NCDWR, Raleigh.

NCNHP (North Carolina Natural Heritage Program). 2016. Natural Heritage Program list of rare animal species of North Carolina 2016. NCNHP, Raleigh.

NCWRC (North Carolina Wildlife Resources Commission). 2005. North Carolina wildlife action plan. NCWRC, Raleigh.

Orth, D. J., and R. J. White. 1999. Stream habitat management. Pages 249–283 *in* C. C. Kohler and W. A. Hubert, editors. Inland fisheries management in North America, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Piller, K. R., H. L. Bart Jr., and J. A. Tipton. 2004. Decline of the Frecklebelly Madtom in the Pearl River based on contemporary and historical surveys. Transactions of the American Fisheries Society 133:1004–1013.

Piller, K. R., and B. M. Burr. 1999. Reproductive biology and spawning habitat supplementation of the Relict Darter, *Etheostoma chienense*, a federally endangered species. Environmental Biology of Fishes 55:145–155.

Pine, W. E. III, T. J. Kwak, and J. A. Rice. 2007. Modeling management scenarios and the effects of an introduced apex predator on a coastal riverine fish community. Transactions of the American Fisheries Society 136:105–120.

Rahel, F. J., and R. A. Stein. 1988. Complex predator–prey interactions and predator intimidation among crayfish, piscivorous fish, and small benthic fish. Oecologia 75:94–98.

Reynolds, J. D., N. K. Dulvy, and C. R. Roberts. 2002. Exploitation and other threats to fish conservation. Pages 319–341 *in* P. J. Hart and J. D. Reynolds, editors. Handbook of fish biology and fisheries, volume 2. Blackwell Publishing, Oxford, UK.

Ricciardi, A., and J. B. Rasmussen. 1999. Extinction rates of North American freshwater fauna. Conservation Biology 13:1220–1222.

Robison, H. W., and G. L. Harp. 1985. Distribution, habitat and food of the Ouachita Madtom, *Noturus lachneri*, a Ouachita River drainage endemic. Copeia 1985:216–220.

Savino, J. F., and R. A. Stein. 1982. Predator–prey interactions between Largemouth Bass and Bluegills as influenced by simulated vegetation. Transactions of the American Fisheries Society 111:255–266.

Schlosser, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecological Monographs 52:395–414.

Warren, M. L., P. L. Angermeier, B. M. Burr, and W. R. Haag. 1997. Decline of a diverse fish fauna: patterns of imperilment and protection in the southeastern United States. Pages 105–164 *in* G. W. Benz and D. E. Collins, editors. Aquatic fauna in peril: the southeastern perspective. Lenz Design and Communications, Southeast Aquatic Research Institute Special Publication 1, Decatur, Georgia.

Warren, M. L., B. M. Burr, S. J. Walsh, H. L. Bart, R. C. Cashner, D. A. Etnier, B. J. Freeman, B. R. Kuhajda, R. L. Mayden, H. W. Robison, S. T. Ross, and W. C. Starnes. 2000. Diversity, distribution, and conservation status of the native freshwater fishes of the southern United States. Fisheries 25(10):7–31.

Williams, J. D., M. L. Warren Jr., K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of the freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

Wood, C. J., and R. B. Nichols. 2008. Status assessment of the Carolina Madtom, final report. North Carolina Wildlife Resources Commission, Raleigh.

Wood, C. J., and R. B. Nichols. 2011. Status assessment of the Carolina Madtom: a rare North Carolina endemic. Pages 295–303 *in* P. H. Michaletz and V. H. Travnichek, editors. Conservation, ecology, and management of catfish: the second international symposium. American Fisheries Society, Symposium 77, Bethesda, Maryland.