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ARTICLE

Response of Imperiled Okaloosa Darters to Stream Restoration

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Abstract
The Okaloosa Darter *Etheostoma okaloosae* is a small percid endemic to six stream drainages in northwestern Florida. The U.S. Fish and Wildlife Service listed Okaloosa Darters as endangered in 1973 and downlisted them to threatened in 2011 because of habitat improvements and increasing abundance across much of their geographic range. Delisting is possible if remaining recovery criteria are met, including restoration of degraded stream reaches. Impounded reaches of Anderson Branch, Mill Creek, and Toms Creek were restored by removing impediments to water flow, draining impoundments, and reconstructing stream reaches. Restorations of Anderson Branch and Mill Creek were designed to rehabilitate populations of Okaloosa Darters without significantly affecting popular recreational activities at these locations. Restorations were evaluated from 2007 to 2013 by comparing counts of Okaloosa Darters and the composition of microhabitats in restored and nearby undisturbed reference sites. Okaloosa Darters were absent from degraded stream reaches at the beginning of the study, but they rapidly colonized once restorations were completed. Counts of Okaloosa Darters in reference and restoration sites in Anderson Branch were similar by the end of the study, whereas counts in restoration sites were significantly lower than nearby reference sites in Mill and Toms creeks. Restoration sites tended to have lower coverage of sand and root and higher coverage of macrophytes. As riparian vegetation surrounding restoration sites matures to a closed canopy that reduces excessive growth of macrophytes, stream microhabitats and numbers of darters will probably become similar to reference sites. Restoration of degraded stream sites increased abundance and distribution of Okaloosa Darters and reconnected formerly isolated upstream and downstream populations. These projects demonstrated that restoration is a useful conservation tool for imperiled fishes such as Okaloosa Darters and can be undertaken without interfering with popular recreational activities.

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Approximately 39% of North America's freshwater fishes are imperiled, and the primary threats to these fishes are habitat loss and alteration (Jelks et al. 2008). Degradation of lotic habitats often results in the isolation of fish populations, which is associated with decreases in genetic variation (Brown 1986) and local extinction of some species (Winston et al. 1991; Angermeier 1995). Restoring degraded habitats and reconnecting isolated populations of imperiled fishes should therefore be a priority for natural resource managers (Roni et al. 2002).

Considerable emphasis is placed on restoring essential habitats and ecosystem functions, but managers are limited by uncertainty over the response of target organisms (Cooke et al. 2012). The United States spends about US$1 × 10^9 dollars annually on restoration of rivers and streams (Bernhardt et al. 2005). It is unclear if these financial resources are being invested optimally because postrestoration success is evaluated in only about half of all restoration projects (Bash and Ryan 2002), and those projects that are evaluated tend to have high failure rates (Kondolf 1995). Successful application of adaptive management to restoration of rivers and streams requires monitoring at both restoration and appropriate reference sites to ensure that essential habitat is restored (Kondolf 1995; Palmer et al. 2005; Jenkinson et al. 2006; Bernhardt et al. 2007). We used this approach to evaluate the response of an imperiled fish to restoration of habitat in three degraded stream reaches.

Okaloosa Darters *Etheostoma okaloosae* are small (up to 49 mm SL) percid fish endemic to six small stream drainages in northwest Florida (Figure 1). About 95% of the geographic range (447 km^2) of Okaloosa Darters is located within the boundaries of Eglin Air Force Base (AFB; USFWS 1998), which is one of the world's largest conventional weapons testing facilities. The surrounding landscape is actively managed to maintain a biologically diverse sandhill forest dominated by longleaf pine *Pinus palustris*, wiregrass *Aristida stricta*, red oak *Quercus falcata,* and turkey oak *Quercus laevis* (Blaustein 2008; Stein et al. 2008; USOFR 2011). Streams within the geographic range of Okaloosa Darters are 1–12 m in width, have minimal daily temperature fluctuations, and have persistent discharge (Burkhead et al. 1992). Okaloosa Darters are typically found along the margins of sandy streams in association with leaves, roots, woody debris, sparse aquatic plants, and other microhabitats that provide food resources and refuge from predation (Burkhead et al. 1992). These darters have small home ranges and a life expectancy of up to 8 years, making this the longest-lived species in the genus *Etheostoma* (Holt et al. 2013). Exchange of migrants among drainages is limited and the six stream drainages support genetically distinct subpopulations (Austin et al. 2011).

Okaloosa Darters were added to the U.S. endangered species list in 1973 because of limited geographic range, habitat degradation associated with road construction and uncontrolled erosion on Eglin AFB, and potential competition with Brown Darters *E. edwini* (USFWS 1998). Long-term monitoring initiated in the mid-1990s indicates that Okaloosa Darters have responded positively to an adaptive management plan implemented by the natural resource program at Eglin AFB (Jelks et al. 2011). These long-term data also indicate that Okaloosa Darters are not being competitively excluded from streams where they co-occur with Brown Darters (Jordan and Jelks 2012). Long-term increases in abundance of Okaloosa Darters are probably due to improved range management, reduced erosion and sedimentation, and restoration of upland habitat (Jelks et al. 2011). Okaloosa Darters were downlisted to threatened status in 2011 because of these long-term population increases associated with improvement of stream habitat (USOFR 2011).

Complete removal of Okaloosa Darters from the U.S. endangered species list (i.e., delisting) is an attainable goal if remaining recovery criteria are met, including restoration of degraded stream reaches that once supported viable populations (USFWS 1998; USOFR 2011). Many stream reaches were impounded either deliberately to create recreational ponds or unintentionally due to poorly designed road crossings that allowed North American beavers *Castor canadensis* to create and maintain permanent impoundments. Impounded stream reaches are deeper and have lower flow rates, more variable water temperatures, greater accumulation of flocculent organic substrates, and higher numbers of large-bodied predatory fishes than nonimpounded stream reaches (Nicholson 2009). Since Okaloosa Darters do not occupy impounded stream reaches (Mettee et al. 1976; Nicholson 2009), restoration should increase their distribution and abundance by reconnecting healthy upstream and downstream populations.

Restoration of two of the degraded stream reaches included in this study was undertaken with the additional goal of preserving popular recreational activities such as camping, hunting, fishing, and golfing. This secondary goal was considered critical because it provided an opportunity to demonstrate that conservation of natural resources and public recreation can coexist, as required on military lands by the Sikes Act of 1960. Overcoming the perception that ecological restoration and recreation are mutually exclusive activities should broaden public support for conservation of imperiled species on biologically diverse, multiuse public lands such as Eglin AFB (Jacobson and Marynowski 1997; Stein et al. 2008; Jenni et al. 2012).

In this paper, we present the results from more than 5 years of restoration monitoring undertaken to characterize the responses of Okaloosa Darters and microhabitats to restoration of Anderson Branch, Mill Creek, and Toms Creek. Restorations were designated as being successful when Okaloosa Darters were consistently present in restoration areas. Okaloosa Darters are good candidates for study because they are similar to many other imperiled stream fishes that similarly have limited geographic distribution and range of stream sizes (Etnier and Starnes 1991; Angermeier 1995; Jelks et al. 2008). The construction of entirely new channels and restoration of flow provide important contrasts to previous projects that focused on restoration of existing degraded channels. Additionally, there were healthy populations of Okaloosa Darters upstream and downstream of restoration areas that probably provided a source of recruits.

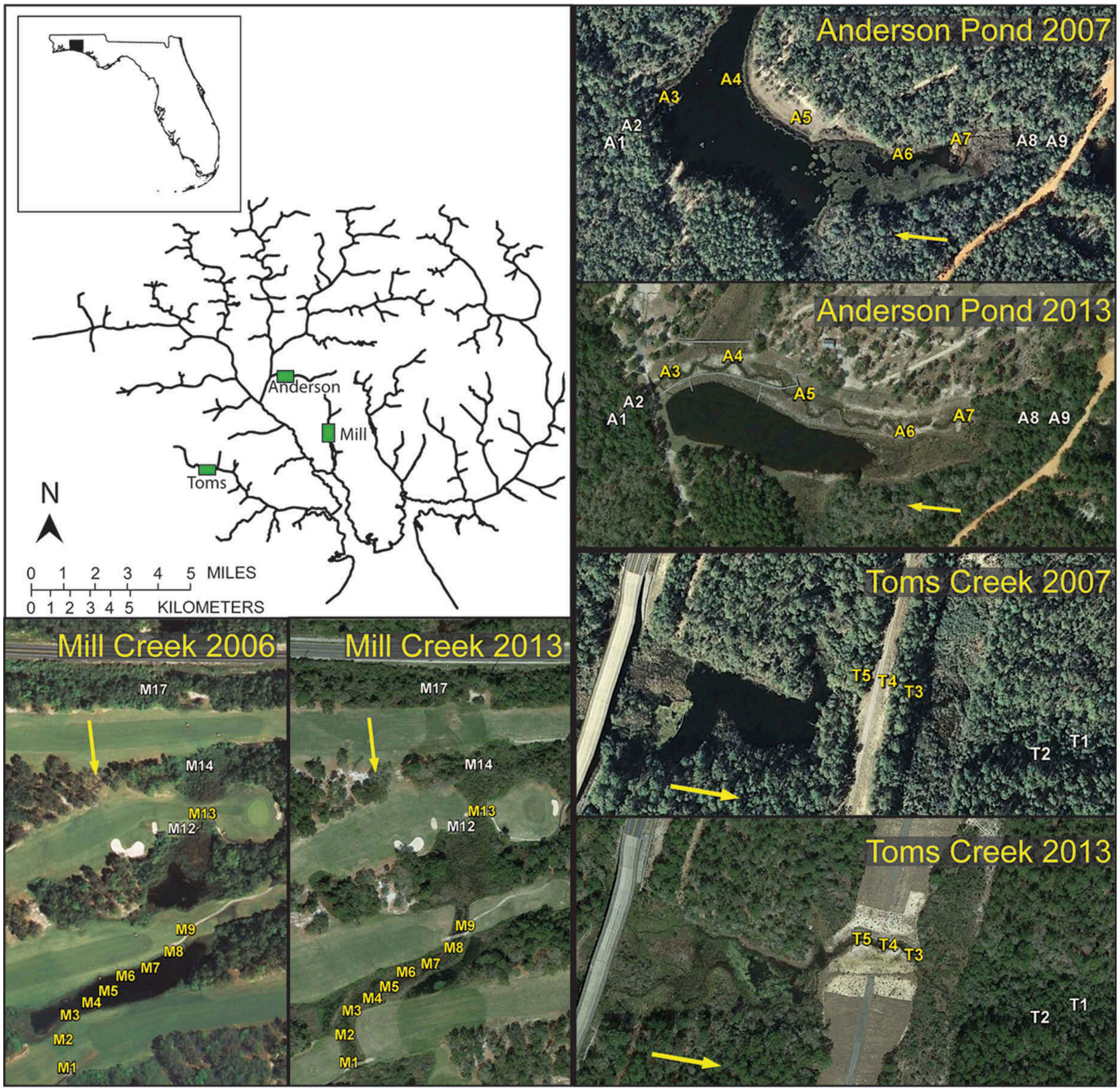

FIGURE 1. Location of six small drainages comprising geographic range of Okaloosa Darters in northwest Florida and maps of three restoration areas before and after construction. Green rectangles denote locations of restorations. Yellow text denotes restoration sites, and white text denotes reference sites. Mill Creek M1–M9 and M13 are restoration sites, and M12, M14, and M17 are reference sites. Anderson Branch A3–A7 are restoration sites, and A1, A2, A8, and A9 are reference sites. Toms Creek T3–T5 are restoration sites, and T1 and T2 are reference sites. Arrows indicate the direction of flow and 50 m of length.

METHODS

Study sites.—Mill Creek is one of the smallest drainages (4.6 km^2) occupied by Okaloosa Darters, and it has experienced considerable habitat loss and alteration, especially in lower reaches where it flows through a golf course and a highly urbanized area before emptying into Choctawhatchee Bay. Upstream portions of the golf course were designed and constructed in 1989 with wide riparian buffers and no stream impoundments in order to minimize negative effects on Okaloosa Darters. In contrast, downstream portions of the golf course were constructed between 1923 and 1960—before implementation of the U.S. Endangered Species Act in 1973 and the Clean Water Act in 1972—and were therefore designed with little or no regard to conservation of Okaloosa Darters or lotic habitat. Mill Creek was routed through a series of culverts buried underneath fairways or impounded to create water features on the golf course. Okaloosa Darters are present in Mill Creek where it runs through upstream portions of the golf course and in a few remnant reaches on the downstream golf course. The darters presumably occupied the remainder of the stream before construction of the golf course. Restoration of this degraded stream reach was undertaken in 2007, the primary goal being to increase suitable lotic habitat for Okaloosa Darters and the secondary goal of maintaining the size and layout of the existing golf course. This project required draining impoundments, constructing a new channel about 700 m long and averages about 3 m wide, and enhancing the adjacent floodplain (U.S. Fish and Wildlife Service, unpublished data). Banks were stabilized with coconut matting, riparian vegetation was planted in the new floodplain, and submerged aquatic plants (American burweed *Sparganium americanum* and slim spikerush *Eleocharis elongata*) and coarse woody debris were added to provide instream habitat. Water flow was established in the new channel during March of 2007. Open floodplain could not be constructed across one fairway, so the existing 40-m-long culvert was excavated and replaced with a wider culvert that included three 1-m-diameter Plexiglass windows to illuminate the buried channel and encourage fish passage.

Anderson Branch is located entirely on Eglin AFB and has not been directly affected by urbanization. A stretch of Anderson Branch was impounded, dredged, and stocked with Largemouth Bass *Micropterus salmoides* and other sport fishes in 1960 to provide a public fishing pond. Okaloosa Darters are present in Anderson Branch above and below Anderson Pond and presumably occupied the impounded reach prior to 1960. Restoration of this degraded stream reach was undertaken in 2010, the primary goal being to increase suitable lotic habitat for Okaloosa Darters and the secondary goal of preserving and enhancing fishing and other recreational activities in and around Anderson Pond. This project required modestly reducing the size of Anderson Pond, constructing a 900-m-long and approximately 3-m-wide channel in the reclaimed floodplain, installing a structure upstream to regularly divert about one-third of stream flow into Anderson Pond, and installing another structure downstream to divert runoff from Anderson Pond back into Anderson Branch (Metcalf and Morris 2015). Banks were stabilized with coconut matting, riparian vegetation was planted in the new floodplain, coarse woody debris was added to provide instream habitat, and water flow was established in the new channel during August of 2010. Rather than planting aquatic vegetation, it was allowed to naturally colonize the new channel. Recreational opportunities were enhanced in the surrounding area by adding picnic areas, campsites, and a boardwalk alongside the restored stream.

Toms Creek is the third largest drainage (20.7 km^2) occupied by Okaloosa Darters and largely lies within Eglin AFB. A reach of Toms Creek downstream of Florida State Road 123 was routed through a pipe culvert and then covered with an overburden of sand in the early 1950s to provide a stream crossing for a military supply railway. The culvert was undersized and enabled beavers to construct a permanent dam and series of impoundments that stretched about 2 km upstream. Okaloosa Darters are present in Toms Creek above and below the beaver impoundment and presumably occupied the impounded reach prior to the 1950s. Restoration of this degraded stream reach was undertaken in 2010 to increase suitable lotic habitat for Okaloosa Darters. Toms Creek and surrounding uplands were basically unused by the public, so no recreational improvements were made at this location. This project required the trapping and relocation of beavers and removal of the decommissioned railway, soil overburden, and culvert. A new channel was constructed that is about 100 m long and averages about 4 m wide. Banks were stabilized with coconut matting, riparian vegetation was planted in the new floodplain, coarse woody debris was added to provide instream habitat, and water flow was established in the new channel during May 2010. Aquatic vegetation was allowed to naturally colonize the new stream channel.

*Study design.—*Comparing restored to undisturbed reference reaches provides a rigorous method to evaluate restoration success (Miller et al. 2010). We therefore counted Okaloosa Darters and quantified microhabitat in 10-m stretches at a total of 9 reference sites and 18 restoration sites between 2007 and 2013 (Figure 1). The 10-m site length was chosen to optimize replication and spatial coverage of restorations. Reference sites were located at least 20 m away from restoration areas in order to minimize the influence of construction, and they were established in relatively undisturbed stream reaches. However, reference sites in Anderson Branch and Mill Creek seemed to be influenced by construction of restorations. Differences in the sizes of restorations precluded our having equal numbers of reference and restoration sites in the three study streams, and little nondegraded stream habitat precluded a balanced sampling design for Mill Creek (3 reference versus 10 restoration sites). There were 2 upstream reference sites, 2 downstream reference sites, and 5 restoration sites in Anderson Branch; 1 upstream reference site, 2 reference sites between restored reaches, and 10 restoration sites (5 of which were monitored for only the first two years) in Mill Creek; and 2 downstream reference sites and 3 restoration sites in Toms Creek. Restorations were sampled frequently in the year following restoration to determine the necessary temporal scale to document colonization. Thereafter, restorations were sampled at greater intervals that did not exceed 14 months. Specific sampling intervals (months after restoration) were 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 16, 19, 32, and 39 for Anderson Branch; 1, 3, 5, 13, 16, 25, 29, 42, 53, and 67 for Mill Creek; and 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 19, 22, 35, and 42 months for Toms Creek. Prerestoration surveys were conducted to verify that no Okaloosa Darters inhabited restoration areas before construction began.

*Field sampling.—*We used the visual survey method detailed in Jordan et al. (2007), where two snorkelers moved slowly side-by-side upstream to count Okaloosa Darters on their respective sides. Counts from the two snorkelers were combined and recorded as the number of Okaloosa Darters per

10 m of stream. Removal experiments indicate that this visual survey method is much more precise and accurate than seining and regularly detects about 60% of the Okaloosa Darters present in a given site (Jordan et al. 2007). Novice counters underwent extensive training and were tested until their counts were comparable with those of experienced counters.

We quantified changes in the composition of microhabitats on a yearly basis at two to five transects that stretched across each site perpendicular to stream flow. A 50 × 50-cm quadrat with 25 cells of equal size was used to visually estimate the relative abundance of substrate types at 50-cm intervals across each transect. Substrates were classified as flocculent organic material, leaves, twigs, sticks and branches (<50 mm diameter), logs, roots, sand, gravel (2–10 mm), and different species of submerged and emergent aquatic vegetation. Preliminary data analysis indicated that we could simplify comparison of restored and reference sites by focusing on changes in the relative abundance of four substrate types: sand, detritus (flocculent organic matter, leaves, twigs, and sticks combined), roots, and macrophytes (all species of aquatic vegetation combined). Data from multiple transects were averaged to provide a single estimate of the relative abundance of the four substrate types for each site during each sampling date.

Statistical analyses.—We used repeated measure ANOVAs (Proc Mixed, SAS 9.4) to test for temporal changes in the counts of Okaloosa Darters per 10-m site and the relative abundance of different types of substrates in response to stream restoration. Residual plots indicated that data were not normally distributed, so these data were $\log_{10}(x + 1)$-transformed to better approximate normality. Given the differences in the frequency and duration of monitoring among streams, we performed three separate analyses with time-scales specific to each stream. Models were constructed to test the effects of treatment, time (months), and the interaction between treatment and time. Since restorations appeared to affect nearby reference sites, distance (m) to restoration area (upstream = positive, downstream = negative) was used as a random effect in all analyses and modelled with a spatial power correlation structure. Sites were treated as repeated measures subjects in all models. Models were evaluated using Akaike information criterion (AIC) to choose between unstructured and compound symmetry correlation matrices, and denominator degrees of freedom were corrected with Kenwood–Rogers adjustments. When heteroscedasticity was detected, denominator degrees of freedom were estimated with a Satterthwaithe adjustment and heterogeneous correlation matrices were utilized (SAS Institute 2008). We used Tukey–Kramer adjustment for *P*-values when making post hoc comparisons for constant variance models and Dunnett's T3 method for models with heteroscedasticity (Dunnett 1980). Treatments were compared on final sample dates using single degree of freedom a priori contrasts.

RESULTS

Mill Creek

Okaloosa Darters were first observed in a Mill Creek restoration site after 3 months and counts increased in all study sites until there were about 3.5 times more Okaloosa Darters in reference sites than restoration sites ($F_{1, 88} = 11.4$, $P < 0.01$; Figure 2A; Table 1). A marginally significant treatment-by-months interaction ($F_{10, 95} = 1.8$, $P = 0.06$) reflected the faster rate of increase in reference site counts.

Relative abundances of microhabitats in Mill Creek varied throughout the study, and the make-up of reference and restoration sites were substantially different at the end of the study (Figures 2B–E, Table 1). The relative abundance of macrophytes in reference sites remained at about 31.5% (SD, 11.3) throughout the study, whereas relative abundance of macrophytes increased in restoration sites until it was significantly higher than reference sites ($F_{1, 5} = 8.23$, $P = 0.03$; Figure 2B). The relative abundance of sand increased in reference sites and decreased in restoration sites (Figure 2C), and relative abundances were significantly different at the end of the study ($F_{1, 5} = 10.2$, $P = 0.02$). A significant treatment effect ($F_{1, 12} = 10.0$, $P < 0.01$; Figure 2D) and no significant treatment-by-months interaction ($F_{8, 69} = 1.7$, $P = 0.12$) indicated the relative abundance of roots was higher in reference sites throughout the study. The relative abundance of detritus varied among months ($F_{8, 18} = 7.4$, $P < 0.01$; Figure 2E) but did not significantly differ between reference and restoration sites.

Anderson Branch

Okaloosa Darters were first observed in an Anderson Branch restoration site after 2 months and counts in restoration sites increased until they did not significantly differ from reference sites at the end of the study ($F_{1, 35} = 0.10$, $P = 0.75$; Figure 3A; Table 1). Counts of Okaloosa Darters in restoration and reference sites both varied considerably over time, but they did not follow similar patterns of change (treatment-by-month interaction: $F_{16, 112} = 4.2$, $P < 0.01$). Counts in reference sites declined considerably during the first 10 months but rebounded and reached prerestoration levels by the final survey.

With the exception of macrophytes, the relative abundances of microhabitats in Anderson Branch were similar across treatments and months (Figures 3B–E; Table 1). The relative abundance of macrophytes in reference sites remained low throughout the study, whereas macrophytes quickly colonized restoration sites and spread until they were much more abundant than in reference sites ($F_{1, 15} = 14.4$, $P = < 0.01$; Figure 3B). The relative abundances of sand, roots, and detritus in reference sites remained somewhat higher than in restoration sites throughout the study (Figures 3D, E).

Toms Creek

Okaloosa Darters were first observed in a Toms Creek restoration site after 2 months. Counts in restoration sites

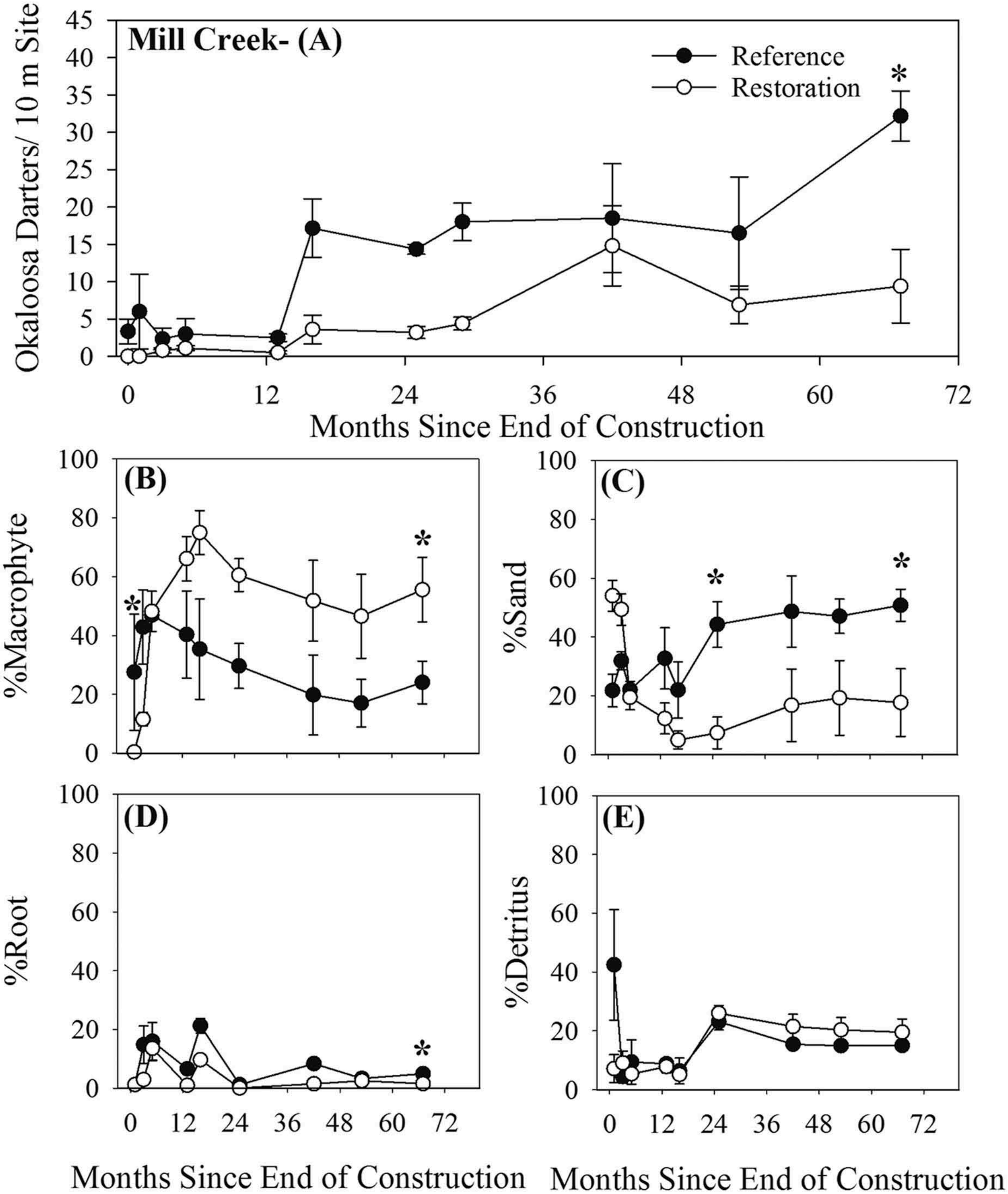

FIGURE 2. Temporal variation in mean (±SE) counts of Okaloosa Darters and relative abundance of select substrate types in restoration and reference sites in Mill Creek, Florida. Asterisks denote significant ($P < 0.05$) differences between restoration and reference sites at the given time interval. Means and standard errors are based on the raw data and are not model adjusted.

increased for 19 months until they were similar to counts in reference sites (t_{19} = 1.33, P = 0.99; Figure 4A; Table 1). Counts of Okaloosa Darters in restoration sites decreased thereafter and were significantly lower than reference counts at the end of the study ($F_{1,\ 19}$ = 10.7, $P < 0.01$).

Relative abundances of microhabitats of Toms Creek reference sites were consistent in reference sites throughout the study, but there were substantial changes in restoration sites as macrophytes spread until they overgrew all other substrates (Figures 4B–E, Table 1). Relative abundance of macrophytes increased in

TABLE 1. Statistical analysis (F-tests) and corresponding P-values for individual Florida streams (Anderson Branch, Mill Creek, Toms Creek) comparing the effects of treatment (T), months, stream, and interaction terms upon response variables.

	Treatment (T)	Months (M)	T × M
Response	(F, $P > F$)	(F, $P > F$)	(F, $P > F$)
Mill Creek			
Okaloosa Darters (count)	$13.7_{(1, 11)}$, <0.01	$16.0_{(10, 95)}$, <0.01	$1.8_{(10, 95)}$, 0.06
Macrophyte (%)	$4.5_{(1, 41)}$, 0.04	$40.6_{(8, 13)}$, <0.01	$32.6_{(8, 13)}$, <0.01
Sand (%)	$29.1_{(1, 11)}$, <0.01	$8.7_{(8, 7)}$, <0.01	$13.1_{(8, 7)}$, <0.01
Root (%)	$10.0_{(1, 12)}$, <0.01	$11.5_{(8, 69)}$, <0.01	$1.7_{(8, 69)}$, 0.12
Detritus (%)	$1.3_{(1, 13)}$, 0.28	$7.4_{(8, 18)}$, <0.01	$1.2_{(8, 18)}$, 0.36
Anderson Branch			
Okaloosa Darters (count)	$16.7_{(1, 6)}$, <0.01	$6.4_{(16, 112)}$, <0.01	$4.2_{(16, 112)}$, <0.01
Macrophyte (%)	$5.4_{(1, 6)}$, 0.06	$4.8_{(4, 28)}$, <0.01	$9.2_{(4, 29)}$, <0.01
Sand (%)	$2.0_{(1, 19)}$, 0.17	$2.3_{(4, 8)}$, 0.06	$2.6_{(4, 8)}$, 0.11
Root (%)	$2.3_{(1, 7)}$, 0.18	$25.1_{(4, 4)}$, <0.01	$22.2_{(4, 4)}$, <0.01
Detritus (%)	$4.5_{(1, 24)}$, 0.04	$0.7_{(4, 11)}$, 0.64	$0.8_{(4, 11)}$, 0.53
Toms Creek			
Okaloosa Darters (count)	$63.9_{(1, 5)}$, <0.01	$2.4_{(17, 32)}$, 0.02	$1.8_{(17, 32)}$, 0.08
Macrophyte (%)	$3.7_{(1, 3)}$, 0.15	$24.3_{(4, 12)}$, <0.01	$17.1_{(4, 12)}$, <0.01
Sand (%)	$7.2_{(1, 4)}$, 0.06	$190.2_{(4, 4)}$, <0.01	$124.4_{(4, 4)}$, <0.01
Root (%)	$49.0_{(1, 2)}$, 0.01	$5.2_{(4, 12)}$, 0.01	$8.7_{(4, 12)}$, <0.01
Detritus (%)	$8.0_{(1, 2)}$, 0.10	$2.9_{(4, 12)}$, 0.07	$1.7_{(4, 12)}$, 0.23

restoration sites until they were marginally higher than reference sites ($F_{1,13}$ = 14.0, P = 0.07; Figure 4B) and accounted for 94.5% (SD, 0.7%) of restoration substrate. Increases in the relative abundance of macrophytes resulted in significantly lower relative abundances of sand ($F_{1,\ 2}$ = 101.2, P < 0.01; Figure 4C) and roots ($F_{1,\ 5}$ = 42.3, P < 0.01; Figure 4D) in restored versus reference sites. The relative abundance of detritus did not vary significantly (Figure 4E).

DISCUSSION

Overview of Monitoring

Okaloosa Darters colonized all restoration sites following the construction of new stream habitat. Final counts within reference and restoration sites in Anderson Branch converged until they were nearly identical, whereas counts in restoration sites in Mill and Toms creeks were lower than in reference sites at the end of the study. The significant difference between final counts in reference and restoration sites in Mill Creek appears to be due to a 10-fold increase in reference sites rather than low colonization of restoration sites. In contrast, there was lower recruitment of Okaloosa Darters into restoration sites in Toms Creek.

Colonists arrived within 2–3 months, rapidly dispersed, and spread throughout restoration sites by the end of the study. Colonists were a mixture of young of year (10–20 mm SL; Holt et al. 2013) that probably drifted from areas upstream and adults that could have relocated from either upstream or downstream. Removal of impoundments at all three sites and removal of poorly designed culverts at Mill and Toms creeks reconnected upstream and downstream populations of Okaloosa Darters. Increased counts of Okaloosa Darters in Mill Creek reference sites suggest that removal of these barriers affected both restoration and reference sites. Prior to restoration, unmanipulated reaches in Mill Creek were severely fragmented by a series of culverts and impoundments. Culverts and impoundments may have affected unmanipulated stream reaches by altering nutrient loads, temperature variability, and flow and by promoting populations of large predatory fishes (e.g., Largemouth Bass, sunfishes) that may have grazed within unmanipulated stream reaches (e.g. Winston et al. 1991). Impoundments and culverts are a leading cause of habitat fragmentation in stream systems and contribute to reduced gene flow (Brown 1986), alterations to fish assemblages (Perkin and Gido 2012), and extirpation of some taxa (Winston et al. 1991; Angermeier 1995).

Differences in counts of Okaloosa Darters in restoration and reference sites probably reflect changes in abundance driven by differences in environmental conditions. Substrates in reference sites tended to be dominated by detritus, roots, and open sand throughout the study. In contrast, substrates at restoration sites were increasingly dominated by macrophytes. High abundances of macrophytes were probably related to the retention of nutrients within previously impounded areas, the use of fertilizers on the golf course, and a lack of canopy shading because restoration sites were in open meadows and

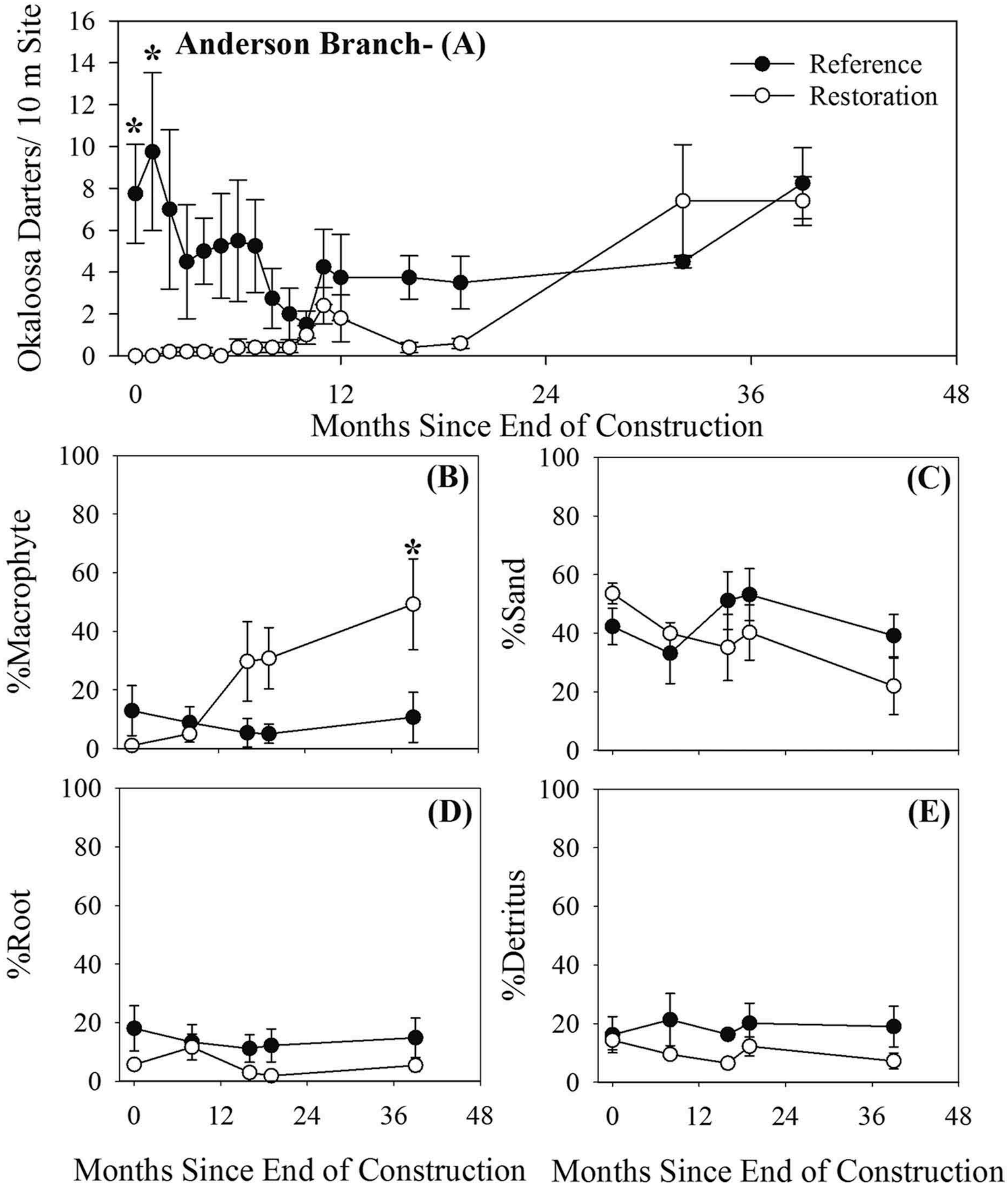

FIGURE 3. Temporal variation in mean (±SE) counts of Okaloosa Darters and relative abundance of select substrate types in restoration and reference sites in Anderson Branch, Florida. Asterisks denote significant ($P < 0.05$) differences between restoration and reference sites at the given time interval. Means and standard errors are based on the raw data and are not model adjusted.

reference sites were in forests. The visual survey method we used is effective across habitat conditions similar to those encountered in our study (Jordan et al. 2007), indicating that reduced counts in areas with dense macrophytes reflected real differences in abundance rather than underestimation.

Okaloosa Darters commonly feed and spawn in and around beds of macrophytes that retain moderate stream flow and limited amounts of flocculent detritus (Burkhead et al. 1992). However, beds of macrophytes in restoration sites covered large expanses of stream bottom, impeded stream flow, and trapped significant

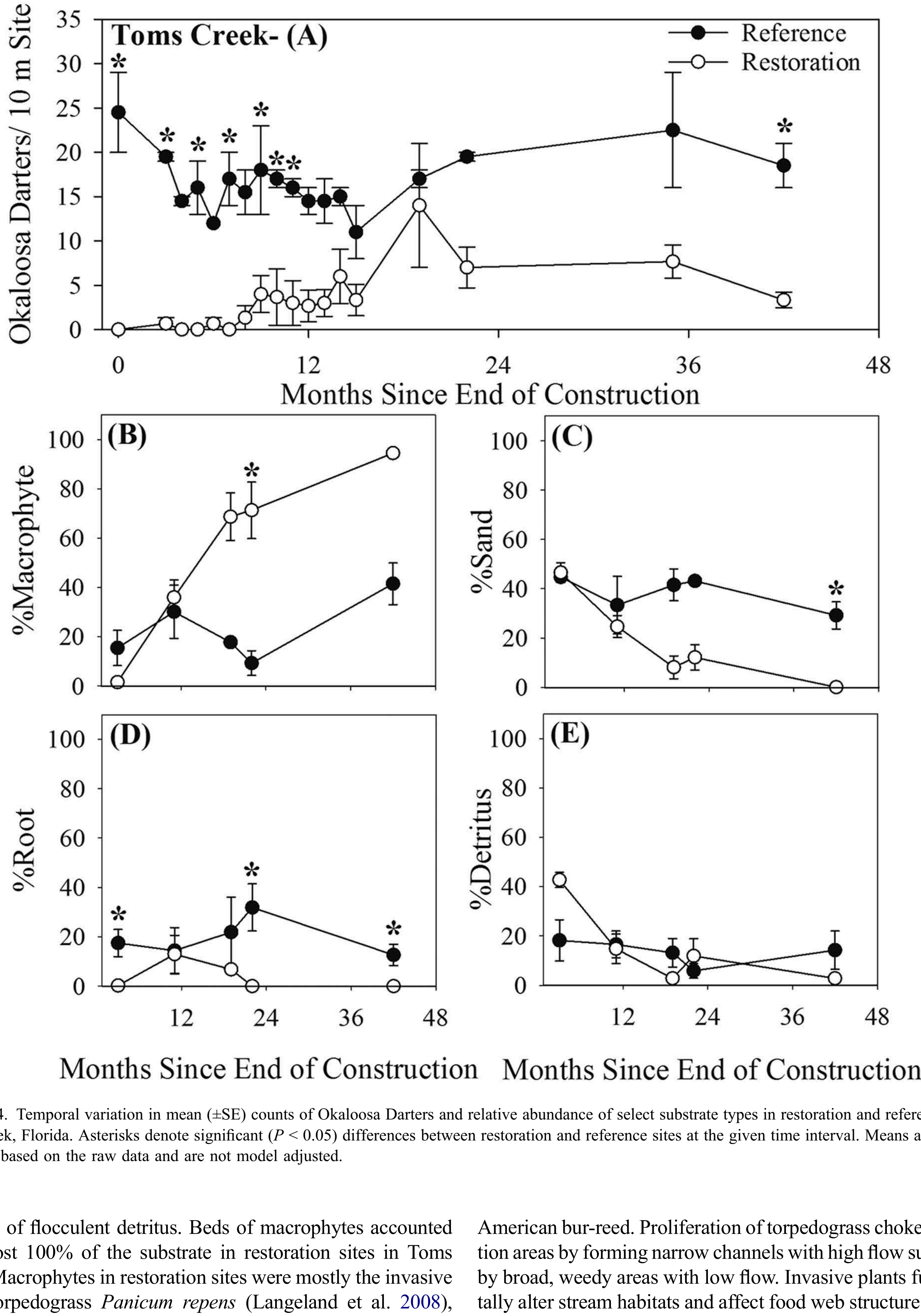

FIGURE 4. Temporal variation in mean (±SE) counts of Okaloosa Darters and relative abundance of select substrate types in restoration and reference sites in Toms Creek, Florida. Asterisks denote significant ($P < 0.05$) differences between restoration and reference sites at the given time interval. Means and standard errors are based on the raw data and are not model adjusted.

amounts of flocculent detritus. Beds of macrophytes accounted for almost 100% of the substrate in restoration sites in Toms Creek. Macrophytes in restoration sites were mostly the invasive weed, torpedograss *Panicum repens* (Langeland et al. 2008), whereas macrophytes in reference sites were mostly native American bur-reed. Proliferation of torpedograss choked restoration areas by forming narrow channels with high flow surrounded by broad, weedy areas with low flow. Invasive plants fundamentally alter stream habitats and affect food web structure in stream ecosystems (e.g., Clarke et al. 2004).

Fluctuations in Habitat Variables

There were notable similarities in the pattern of fluctuations of habitat variables in both reference and restoration sites throughout the study period. This correspondence was especially pronounced for Anderson Branch and Mill Creek and probably reflected natural variation in those systems. Interannual variability in flow affects the biomass of aquatic macrophytes (Chambers et al. 1991). Seasonal changes in vegetation cover can also influence the accumulation of fine sediments (Cotton et al. 2006). Parallel shifts in habitat variables between reference and restoration sites suggest that some natural processes (likely climatic) affected sites similarly across treatment types.

CONCLUSIONS

The primary goal of this study was to determine if restoration of degraded stream habitat would lead to increased distribution and abundance of imperiled Okaloosa Darters and reconnect populations upstream and downstream of impoundments. Removal of impoundments, construction of new channels, enhancement of instream and riparian habitat, and restoration of flow provided about 700 m of additional suitable habitat for Okaloosa Darters in Mill Creek, 900 m in Anderson Branch, and 100 m in Toms Creek. Restoration of degraded stream reaches has therefore increased the distribution of Okaloosa Darters by about 1.7 km. Because the reestablishment of an extirpated fish population is a sign of ecological recovery (Palmer et al. 2005) and Okaloosa Darters were present in restorations for the last 2–4 years of monitoring, we consider all three restorations to be successful.

Full ecological recovery of Anderson Branch, Mill Creek, and Toms Creek is a long-term goal that is tied to the recovery of riparian vegetation. Riparian restoration is key for rehabilitating degraded rivers and streams (Pusey and Arthington 2003) and is probably important for controlling macrophyte densities because sunlight is the most limiting factor for macrophyte growth in Florida streams (Canfield and Hoyer 1988). Restoration of riparian vegetation can take 50–100 years (Bash and Ryan 2002), so full ecological recovery will not happen in the short term. Because Okaloosa Darter counts in Toms Creek decreased after macrophyte densities exceeded about 66% of total substrate, high macrophyte densities may continue to inhibit their abundances until riparian shading reduces macrophyte growth. Removal of weeds and grasses that discourage growth of more mature vegetation may accelerate development of the targeted riparian community (Connell and Slayter 1977) and increase riparian shading. However, the best solution may be to simply wait for natural maturation of uplands surrounding restored stream reaches.

Lessons learned from these three successful restoration projects could be used to guide restoration of remaining degraded stream reaches, including reaches that were impounded to support recreational activities (e.g., Florida's Roberts Lake on Swift Creek and Brandt Pond on Fox Head Branch), and to move Okaloosa Darters towards recovery and delisting. A key factor in the success of these three restorations was the presence of suitable Okaloosa Darter habitat and healthy populations of Okaloosa Darters upstream and downstream of restored stream reaches. The presence of nearby populations that can serve as a source of recruits should be considered when planning future restorations.

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