EFFECTS OF ARTIFICIAL LIGHTING AND PRESENCE OF *MENIDIA BERYLLINA* ON GROWTH AND DIET OF *LABIDESTHES SICCULUS*

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ABSTRACT—Two atherinid species, *Labidesthes sicculus* (brook silverside) and *Menidia beryllina* (inland silverside), often co-occur in North American reservoirs. *Menidia beryllina* is a superior competitor for zooplankton and has displaced *Labidesthes* in a number of reservoir habitats. In Lake Texoma (Oklahoma-Texas), *Labidesthes* was thought extirpated from the reservoir after introduction of *Menidia* in the 1950s, but several recent populations were discovered in down-lake coves with established marinas. Artificial lighting from marinas might benefit *Labidesthes* by attracting terrestrial insects in these habitats. We conducted a field experiment to test effects of artificial lighting and abundance of *Menidia* on growth and diet of *Labidesthes*. Dry weight of *Labidesthes* at the end of our experiment was significantly higher in artificially lit treatments than in dark treatments, but there was no significant effect of *Menidia* abundance on weight of *Labidesthes*. We concluded this effect was attributed to greater availability of dipterans, which dominated the diet of *Labidesthes*, under artificial lights. Whereas *Menidia* is a more efficient planktivore than *Labidesthes*, increased abundance of dipterans near marinas likely promotes the coexistence of these 2 species.

RESUMEN—Dos especies Aterínidos, *Labidesthes sicculus* y *Menidia beryllina* (charal de marea), suelen co-ocurrir en los embalses norteamericanos. *Menidia beryllina* es un competidor superior para zooplanctón y ha desplazado a *Labidesthes* en numerosos hábitats. En el lago Texoma (Oklahoma-Texas), se creía que *Labidesthes* había sido extirpado del embalse después de la introducción de *Menidia* en los años cincuenta, pero se han descubierto recientemente poblaciones co-ocurrentes en ensenadas con marinas establecidas. La iluminación artificial de las marinas puede beneficiar a *Labidesthes* atrayendo insectos terrestres en estos hábitats. Llevamos a cabo un experimento para probar los efectos de la iluminación artificial y de la abundancia de *Menidia* en el crecimiento y la dieta de *Labidesthes*. El peso seco de *Labidesthes* al final del experimento fue significativamente mayor en los tratamientos de iluminación artificial que en los tratamientos no iluminados, pero no hubo un efecto significativo de la abundancia de *Menidia* en el peso de *Labidesthes*. Concluimos que este efecto fue atribuido a una disponibilidad más grande de dípteros, que dominaron la dieta de *Labidesthes*, bajo luz artificial. Ya sea que *Menidia* sea un planctívoro más eficiente que *Labidesthes*, la mayor abundancia de dípteros cerca de las marinas probablemente promueve la coexistencia de las dos especies.

Competitive interactions between 2 atherinid species, *Labidesthes sicculus* (brook silverside) and *Menidia beryllina* (inland silverside), have been well studied in North American reservoirs. In Lake Texoma (Oklahoma-Texas), *L. sicculus,* which was native to the region, was the second most abundant species from 1948 through 1952 (Riggs and Bonn, 1959). After the introduction of *Menidia* in 1953, *Labidesthes* numbers diminished and the species was thought extirpated from the reservoir by 1959. An experiment by McCommas and Drenner (1982) clearly demonstrated that, when in direct competition with *Menidia, Labidesthes* had a higher mortality rate than in the absence of competition. They suggested that the ''tube-like'' mouth morphology of *Menidia* allowed them to forage more efficiently on copepods than *Labidesthes*, which have a more ''beak-like'' mouth. Despite these reports of extirpation in Lake Texoma, populations of *Labidesthes* were found in 7 down-lake marina coves in summer 1999 (Pratt et al., 2002). *Labidesthes* either have reinvaded the reservoir or have persisted as small, self-sustained populations in these particular habitats.

One hypothesis why these species are able to co-occur in marina coves is that artificial lighting attracts terrestrial insects, which *Labidesthes* might be more efficient at picking off the water surface than *Menidia* because of its ''beak-like'' mouth morphology. Outside of these coves, however, *Labidesthes* might be forced to rely primarily on zooplankton, which *Menidia* is more efficient at capturing (McCommas and Drenner, 1982). Thus, we performed an experiment to evaluate the interactive effects of competition with *Menidia* and presence of artificial lighting on survival and growth of *Labidesthes.* We hypothesized that 1) *Labidesthes* in artificially lit treatments would grow faster than those in dark treatments, 2) *Menidia* density would only have an effect on *Labidesthes* growth in dark treatments, and 3) *Labidesthes* would forage predominately on terrestrial insects, whereas *Menidia* would prey on zooplankton.

Methods—*Study Site*—An array of enclosures were used to test the interactive effects of artificial lighting and presence of *Menidia* on growth and condition of *Labidesthes.* Experiments were performed at the University of Oklahoma Biological Station (UOBS) on Lake Texoma. The UOBS is located approximately 35 km west of Denison Dam in the Red River arm of the reservoir, where secchi depth typically ranges between 100 and 125 cm (Matthews, 1984) and conductivity regularly exceeds 2,000 μohms/cm (Gido et al., 2002). Enclosures were placed in 2 covered boat docks that were anchored in a small embayment (area approximately 200 m^2) shielded with a rock levy. Eighteen 0.61-m × 0.61-m × 0.61-m enclosures were constructed using 0.5-mm mesh screen. Nine enclosures were placed inside one dock with no artificial lighting (dark treatments), and the other 9 enclosures were placed in an adjacent dock approximately 20 m away with artificial lighting (lighted treatments). Enclosures were grouped in sets of 3 enclosures separated by a ply-board divider and hung in the water in a boat stall. Thus, 2 sides and the bottom of each enclosure were covered by the mesh screen and open to exchange with the surrounding water. In the lighted treatment, 2 100-W lights that were similar to those typically observed in marina coves were placed approximately 2 m above the cages and were on throughout the experiment.

Fishes for the experiments were collected using a 4.6-m × 1.2-m (3.2-mm mesh) straight seine. *Labidesthes* were sampled on 12 June 2001 at Madill Lake, Marshall County, Oklahoma and held overnight in an aerated container. *Menidia* were sampled on 13 June 2001 from Lake Texoma adjacent to the UOBS.

On 13 June 2001, 4 *Labidesthes* that ranged from 26 to 39 mm standard length (SL) were stocked in each cage. *Menidia* (31 to 47 mm SL) were assigned randomly to cages at 3 densities (0, 3, and 6 individuals per cage), with 3 replicates each for both light and dark treatments. Total density of fish in enclosures ranged from 11 fish/m^2 (enclosures without *Menidia*) to 27 fish/m^2 (enclosures with 6 *Menidia*). These densities are comparable to densities of *Menidia* in littoral areas of Lake Texoma, which averaged 14.6/m^2 in the Red River arm of Lake Texoma (Gido et al., 2002). Because of the fragile nature of *Labidesthes*, we used a subset of individuals, selected randomly from the initial sample, to measure length and weight at the beginning of the experiment rather than marking individuals and tracking their growth throughout the experiment. Fish that died on the first day of the experiment (14 June 2001) were replaced. Fish lost after this time were considered a result of the experiment. The experiment was run for 2 weeks and ended on 27 June 2001. At this time, zooplankton were sampled from each cage and from the outside of the cages in each boat dock by taking a 0.5-L grab sample just below the water surface. Because we were interested in fish diets, the removal of individuals was staggered throughout the day and across treatments to account for diel variation in diet and gut fullness. All fish were collected and preserved in 10% formalin. In the laboratory, each fish was eviscerated and gut contents were identified. Abundance of individual items in the diet was quantified by spreading contents on a square grid under a stereomicroscope at 20× magnification and calculating coverage area of each item (1 grid quadrant = 1.88 mm^2). Fish were measured for standard length and dried for 7 days at 65°C before measuring total dry weight (dry weight = dry soma weight).

Data Analysis—A 2-way ANOVA was used to examine the interactive effects of lighting and *Menidia* density on mean dry soma mass, gut fullness of *Labidesthes*, and zooplankton abundance across treatments at the end of the experiment. Post hoc comparisons tested for differences in dry weight of *Labidesthes* among treatments with different densities of *Menidia.* Student's *t*-tests also were used to test for differences in dry weight and gut fullness of *Menidia* between lighted and dark treatments.

Results—There was a strong effect of light treatment on dry weight of *Labidesthes* at the end of the experiment ($F_{1,12} = 47.08$, $P < 0.01$), but no effect of *Menidia* density ($F_{2,12} = 3.18$, $P = 0.08$) or interaction between light and *Menidia* density ($F_{2,12} = 1.16$, $P = 0.35$) (Fig. 1). *Labidesthes* in lighted treatments were about twice as heavy as those caught at the beginning of the experiment or those from dark treatments at the end of the experiment. There was no difference in dry weight of *Menidia* among light or dark treatments at the end of the experiment (mean of lighted treatment = 0.133 ± 0.015 g *SE*, dark

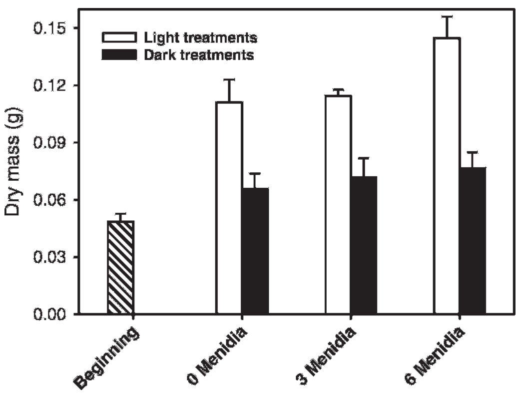

FIG. 1—Mean (±*SE*) dry weight of *Labidesthes sicculus* taken from experimental cages at the beginning and at the end of the experiment in the different lighting and *Menidia beryllina* density treatments.

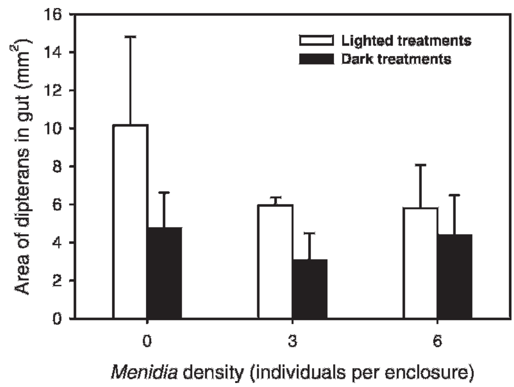

FIG. 2—Mean (±*SE*) gut volume of *Labidesthes sicculus* taken from experimental cages with different lighting and *Menidia beryllina* densities.

treatment = 0.107 ± 0.003 g *SE*; $t = 1.704$, $df = 6$, $P = 0.13$).

Zooplankton densities inside enclosures (mean = 2.2 plankters/L) and outside enclosures (mean = 2.0 plankters/L) were low and consisted of cladocerans (72%) and copepods (18%). Densities were not statistically different among treatments, nor was there an interaction among treatments ($P > 0.27$).

Dipteran pupae and adults were the prominent diet of *Labidesthes* at the end of the experiment; only one individual of 68 examined was found to have consumed zooplankton. Mean area of items in *Labidesthes* guts from lighted treatments was higher than in dark treatments, but this difference was not significant (Fig 2; $F_{1,12} = 2.55$, $P = 0.14$). There also was no difference in area of diet items found in *Labidesthes* among treatments with different *Menidia* densities ($F_{2,12} = 0.79$; $P = 0.48$). Similar to *Labidesthes*, we only found that 1 of 36 *Menidia* examined had consumed a zooplankton and 30 of 36 had consumed dipterans. There also was no difference in mean area of diet items consumed by *Menidia* in lighted and dark treatments ($t = 1.336$, $df = 6$, $P > 0.213$).

DISCUSSION—Our data suggest that artificial lighting had a strong positive effect on growth of *Labidesthes*, because they were able to double their weight in cages under artificial lighting in a 2-week period. Analysis of gut contents at the end of the experiment suggested this rapid growth was due to consumption of terrestrial and pupal dipterans, and that marina lights might benefit this species by attracting these insects. Diet from the end of the experiment contrasted our hypothesis that *Labidesthes* would pick the dipterans off the surface of the water; rather their diet was mostly comprised of larval and pupal dipterans that were attached to the cages. Therefore, attraction of terrestrial and aquatic dipterans to artificial light provided both immediate forage and increased densities of eggs and larvae. It is possible that enclosures provided an added substrate for deposition of eggs or exclusion of other predators that resulted in artificially high abundance of larval dipterans when attracted by light. Thus, marinas with both artificial lighting and an abundance of substrates for dipterans to deposit eggs (e.g., rip-rap, boats, submerged structures) would provide the greatest abundance of prey for *Labidesthes*.

In contrast to *Labidesthes, Menidia* did not grow significantly more under artificial lighting than in dark treatments. Because of mouth morphology and history of occurrence in streams with heavy canopy cover, *Labidesthes* are likely adapted to forage more efficiently than *Menidia* on both terrestrial and aquatic insects (McCommas and Drenner, 1982). As shown by McCommas and Drenner (1982), *Menidia* are efficient zooplanktivores, but might not be able to forage efficiently on terrestrial and aquatic insects. Our study supports this hypothesis because there was no effect of *Menidia* density on growth of *Labidesthes* in our enclosures where zooplankton were only a small part of the diet of both *Menidia* and *Labidesthes*. Thus, the presence of an alternative food source, such as terrestrial insects, could facilitate the coexistence of these species.

Analysis of gut contents showed little use of zooplankton by either species during our experiment, contrary to our expectation that *Menidia* would have a greater percent occurrence of zooplankton in their diet than *Labidesthes*. This pattern was likely due to low zooplankton abundance in the reservoir during the time of our experiment, which is typical for Lake Texoma during summer (Franks, 2000; Lienesch and Matthews, 2000). Nevertheless, it was interesting that *Menidia*, which consumed dipterans, did not increase in weight in treatments with artificial lighting. Competition experiments between these species that vary both prey type (e.g., zooplankton versus dipterans) and fish density would help identify the dependence of these competitive interactions on prey availability. Such an experiment would help predict the capacity of these species to competitively exclude each other across different habitats in the reservoir.

In Lake Texoma, coexisting populations of silversides were found primarily in down-lake marina coves (Pratt et al., 2002). Coves offer an environment different from that of open-water areas in that they are protected from wind and are potentially more productive due to incoming allochthonous materials (Matthews, 1998). Our experiment suggested that both silversides fed primarily on pupal and terrestrial insects, suggesting aquatic and terrestrial stages of these insects are an important food source when zooplankton abundance is low. Because of high growth rates of *Labidesthes* under artificial lighting, we suggest marina lights concentrate resources that are potentially necessary for the persistence of *Labidesthes* in this reservoir.

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