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BEHAVIORAL INTERACTIONS BETWEEN BLACKSTRIPE TOPMINNOW AND OTHER NATIVE INDIANA TOPMINNOWS

Trent M. Sutton[1] and **Rebecca A. Zeiber**[2]: Purdue University, Department of Forestry and Natural Resources, 195 Marsteller Street, West Lafayette, Indiana 47907, USA

Brant E. Fisher: Indiana Department of Natural Resources, Atterbury Fish and Wildlife Area, 7970 S. Rowe St., P.O. Box 3000, Edinburgh, Indiana 46124, USA

ABSTRACT. The stocking of western mosquitofish (*Gambusia affinis*) to control mosquitos has been shown to negatively impact native fishes, especially species with similar ecological requirements such as topminnows. As a result, using fish species (e.g., blackstripe topminnow; *Fundulus notatus*) that are native and rarely exhibit aggressive behaviors toward ecological equivalents may serve as a non-intrusive means of mosquito control. In this study, a series of laboratory microcosm experiments were used to examine intra- and interspecific agonistic behavioral interactions (e.g., chases and nips) between blackstripe topminnow and northern starhead topminnow (*Fundulus dispar*), northern studfish (*F. catenatus*), and banded killifish (*F. diaphanus*) at three different fish density combinations and in the presence or absence of vegetation. Few agonistic behaviors were exhibited toward conspecifics, but interspecific chasing and nipping did occur, albeit it at low levels, in the presence of blackstripe topminnow. The number of these interspecific chases and nips was not influenced by vegetation or topminnow species density. Fin damage incurred by topminnows was minimal, regardless if tanks contained only individuals of the same species or another species (blackstripe topminnow). Three percent of blackstripe topminnows had damage to their caudal fins that was intraspecific in nature, but there was no fin damage for the other three topminnow species. Based on these results, we suggest that blackstripe topminnow be considered as an alternative to western mosquitofish for mosquito control in drainages for which it is a native species.

Keywords: Blackstripe topminnow, northern studfish, banded killifish, northern starhead topminnow, agonistic behavior

The introduction of exotic fishes for biological control of invertebrate pests, such as mosquitos, in aquatic ecosystems requires a thorough evaluation of the risks and impacts imposed on native fish species (Moyle 1986; Fuller et al. 1999; Li & Moyle 1999; Casal 2006). For example, western mosquitofish (*Gambusia affinis;* and its congener eastern mosquitofish *Gambusia holbrooki)* are extensively stocked into freshwater systems for mosquito control and, consequently, are the most widely distributed larvivorous fishes in the world (Krumholz 1948; Bence 1988; Courtenay & Meffe 1989; Pyke 2005). However, western mosquitofish exhibit aggressive behaviors towards other aquatic organisms, and interspecific agonistic interactions have been shown to negatively impact less aggressive fishes (Meffe et al. 1983; Abbott & Dill 1985; Meffe 1985; Barrier & Hicks 1994; Rinco et al. 2002; Laha & Mattingly 2007; Zeiber 2007; Sutton et al. 2009). As a result, western mosquitofish may not be the most appropriate fish species to use for the biological control of mosquitos due to their negative effects on native fishes.

A potential alternative to western mosquitofish for mosquito control in Indiana waterways is the blackstripe topminnow (*Fundulus notatus*). This species is broadly distributed throughout Indiana, has high diet similarity with western mosquitofish, and has a propensity for consuming mosquito larvae (Becker 1983; Pflieger 1997; Zeiber 2007). Despite their ubiquitous native distribution throughout Indiana, the stocking of blackstripe topminnow into additional water-

[1] *Current address:* University of Alaska Fairbanks, School of Fisheries and Ocean Sciences, Fisheries Division, 905 Koyokuk Drive, Fairbanks, Alaska 99775 USA.

[2] *Current address:* New Hampshire Sea Grant, University of New Hampshire, 122 Mast Road, Lee, New Hampshire 03861, USA.

Corresponding author: Trent M. Sutton, E-mail: tmsutton@alaska.edu Phone: 907-474-7285

ways throughout the state could negatively impact other native topminnow species due to their similar ecological niche requirements. For example, both banded killifish (*F. diaphanus*) and northern studfish (*F. catenatus*) have restricted geographic ranges in Indiana and the northern starhead topminnow (*F. dispar*) has experienced a reduction in geographic range in Illinois (Taylor et al. 1994). As a result, blackstripe topminnow could further reduce and restrict the distribution of these topminnows in Indiana if stocked in the same waterways.

In this study, we evaluated the behavioral interactions between blackstripe topminnow and the three aforementioned species of Indiana topminnow. Specifically, we used a laboratory study to quantify intra- and interspecific interactions of blackstripe topminnow and each of the other three topminnow species separately at three fish density combinations and in the presence or absence of vegetation. This research will allow for a greater understanding of how blackstripe topminnow could potentially impact native topminnow species in Indiana, and provide an assessment of the potential for using this topminnow species as an alternative to western mosquitofish for mosquito control in aquatic habitats in Indiana.

METHODS

Field collections.—Adults of the four topminnow species were collected from Indiana waters using a 3.18-mm knotless mesh seine (length: 3.05 m; depth: 1.22 m) or 3.18-mm knotless mesh dip net (diameter: 40 mm). Following collections, fish of each species were transported to Purdue University (West Lafayette, Indiana) in separate 8.9-L buckets of water containing aquatic vegetation. In the laboratory, fish of each species were placed into separate, 30-L plastic aquaria containing artificial vegetation constructed from 16, 45-cm long green plastic strips attached to a 3.18-cm hex nut. Water temperature and photoperiod were maintained at 22°C and 14:10 hours (light:dark), respectively. Fish were fed bloodworms *Chironomus* spp. *ad libitum* daily and allowed to acclimate to laboratory conditions for a minimum of one week.

Microcosm experiments.—A series of behavioral experiments were conducted in June and July 2006 to assess intra- and interspecific interactions between blackstripe topminnows and the other three topminnow species. Experiments were conducted in 24, 110-L static glass aquaria and a plastic divider was used to initially separate fish species. Half of each divided aquarium contained two clusters of artificial vegetation constructed as described previously, while the other half contained no vegetation. Density treatments consisted of eight fish per aquarium at three density combinations: (1) two blackstripe topminnows and six topminnows from another species; (2) four blackstripe topminnows and four topminnows from another species; and (3) six blackstripe topminnows and two topminnows from another species. Thus, a 2×3 (vegetation x fish density) block design was conducted, with each treatment having three replicates (18 aquaria total). Three days prior to the experiment, fish were placed in the aquaria. Water temperature and photoperiod were maintained at 22°C and 14:10 hours (light:dark), respectively, for the duration of the experiment. All fish were fed bloodworms *ad libitum* each day to decrease the likelihood that agonistic behaviors were due to hunger.

At the onset of the experiment, the divider in each aquarium was removed to start the behavioral observations. Each microcosm was observed for a five-minute period, five times each day (distributed out over the course of the day) for seven consecutive days (a total of 175 minutes of observation per microcosm). Behavioral interactions that were recorded included the number of chases and nips, both between species and among conspecifics. Chases were defined as a behavior where one fish followed another individual closely, thereby forcing that fish to move further away to avoid a direct encounter. A chase was categorized as being completed as soon as the pursuer broke away, even when another chase ensued with that individual directly after the encounter. Nips occurred when one fish physically bit another individual. At the end of each observation period, that microcosm was examined for dead fish, which were removed from the aquaria. All dead fish were measured for total length (to the nearest 0.1 mm) and wet weight (to the nearest 0.01 g), and examined for fin damage. At the end of the 7-day experimental period, all surviving fish were sacrificed, measured for total length and wet weight, and the percentage of each fin that was consumed and/or damaged (if any) was recorded for each fish.

Table 1.—Mean total length and wet weight (range in parentheses) of fish used in behavioral observations. Fish species included northern starhead topminnow (NST), northern studfish (NSF), blackstripe topminnow (BST), and banded killifish (BAK).

Species	Total length (mm)	Wet weight (g)
NST	39.98 (23.70–54.45)	0.63 (0.10–2.30)
NSF	57.60 (24.45–106.50)	2.03 (0.14–9.94)
BST	49.96 (33.55–64.20)	0.98 (0.33–1.56)
BAK	53.29 (39.80–76.30)	1.32 (0.41–4.03)

Data analyses.—The mean number of chases and nips per five-minute observation period and standard errors were calculated between species and conspecifics. A Kruskal-Wallis one-way analysis of variance (ANOVA) was conducted to determine if there was a significant difference ($\alpha = 0.05$) in these parameters within and among fish species in each experimental treatment and within fish species in control treatments. In addition, a Kruskal-Wallis one-way ANOVA was used to determine if there was a significant difference in the number of chases and nips initiated by each species among fish density treatments and the presence-absence of vegetation. When significant differences were detected, a Tukey's test was conducted to determine where the differences existed. All statistical analyses were conducted using SigmaStat 3.5 software (Systat Software, Inc., San Jose, California), and followed procedures as described in Zar (1990).

RESULTS

The mean total length and wet weight of blackstripe topminnow, northern starhead topminnow, northern studfish, and banded killifish used in the behavioral experiment varied by species (Table 1). Blackstripe topminnow and banded killifish were larger in length and weight than northern starhead topminnow. Northern studfish were the largest of the four topminnow species, and were at least twice as large as the other topminnow species by weight.

Fin damage in aquaria with blackstripe topminnow and the other topminnow species was minimal. Three percent of blackstripe topminnows had damage to their caudal fins. In contrast, there was no fin damage for northern starhead topminnows, northern studfish, or banded killifish. There were no mortalities in these aquaria due to aggressive behavior by topminnow species.

There were 79 chases in aquaria containing blackstripe topminnows and northern starhead topminnows (Figure 1). The mean number of chases by blackstripe topminnows and northern starhead topminnows toward conspecifics was less than one and zero per period, respectively. The number of chases between blackstripe topminnow conspecifics did not differ for fish density ($H = 0.3$, $P = 0.74$), but differed significantly in the presence-absence of vegetation ($H = 9.5$, $P \leq 0.01$). However, their interaction term was not significant ($H = 0.2$, $P = 0.81$). The number of chases was not significantly different for fish density, vegetation, and their interaction term between northern starhead topminnow conspecifics ($H = 2.9$, $P = 0.06$; $H = 2.2$, $P = 0.15$; $H = 1.7$, $P = 0.21$, respectively), northern starhead topminnows toward blackstripe topminnows ($H = 0.0$, $P = 1.00$; $H = 0.0$, $P = 1.00$; $H = 0.0$, $P = 1.00$, respectively), and reciprocal interaction ($H = 2.1$, $P = 0.14$; $H = 2.1$, $P = 0.16$; $H = 2.1$, $P = 0.14$, respectively).

A total of 39 nips were observed in aquaria with both blackstripe topminnows and northern starhead topminnows (Figure 1). The mean number of nips by each species toward conspecifics was less than one. There were no significant differences in the number of nips by fish density for conspecifics of blackstripe topminnows ($H = 1.2$, $P = 0.36$) and northern starhead topminnows ($H = 3.2$, $P = 0.05$). There was a significant difference in the number of nips based on the presence-absence of vegetation for blackstripe topminnow conspecifics ($H = 5.9$, $P = 0.02$), but not for northern starhead topminnow conspecifics ($H = 3.8$, $P = 0.06$). The interaction term was not significant for nips among blackstripe topminnow conspecifics ($H = 1.2$, $P = 0.33$), but was significant among northern starhead topminnow conspecifics ($H = 6.0$, $P = 0.01$). Fish density, vegetation, and their interaction term did not influence the number of nips by blackstripe topminnows toward northern starhead topminnows ($H = 0.5$, $P = 0.61$; $H = 0.0$, $P = 1.00$; $H = 1.1$, $P = 0.34$, respectively) and the reciprocal interaction ($H = 1.1$, $P = 0.34$; $H = 3.4$, $P = 0.07$; $H = 1.5$, $P = 0.23$, respectively).

There were a total of 588 chases in aquaria containing blackstripe topminnows and northern studfish (Figure 2). The number of chases

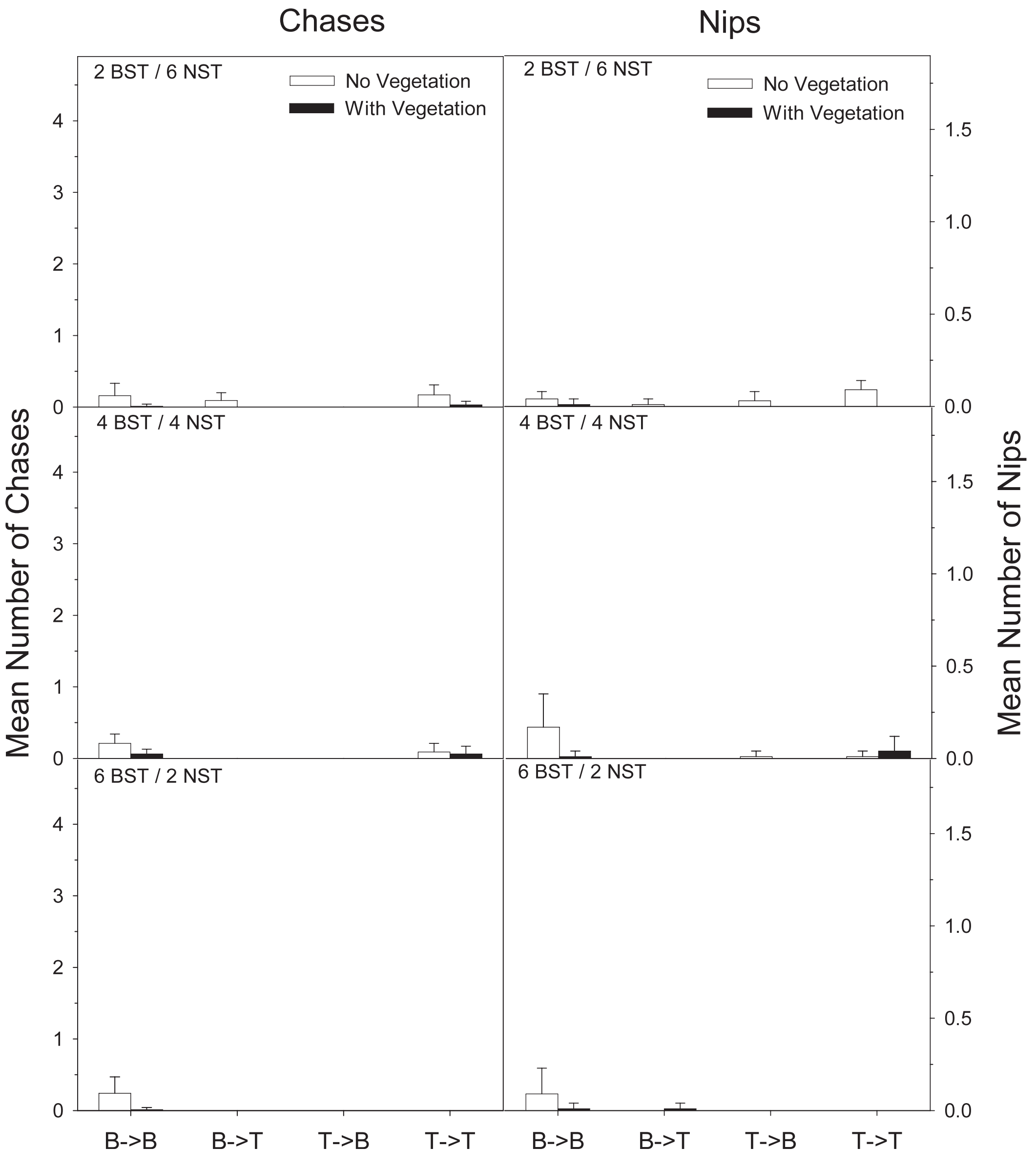

Figure 1.—The mean number (SE) of chases and nips per observation period within and between blackstripe topminnows (BST) and northern starhead topminnows (NST). The direction of aggressive behavior is shown as an arrow (i.e., B->T means BST chasing other topminnow). Density treatments included 2 BST and 6 NST (top), 4 BST and 4 NST (middle), and 6 BST and 2 NST (bottom).

between blackstripe topminnows and northern studfish conspecifics was one and less than one per period, respectively, while the number of chases between species was also less than one per period. There was a significant difference in the number of chases by blackstripe topminnows toward conspecifics for fish density ($H = 35.5$, $P \leq 0.01$), vegetation ($H = 50.2$, $P \leq 0.01$), and their interaction term ($H = 11.9$, $P \leq 0.01$) and for northern studfish toward blackstripe topminnows for fish density ($H = 5.9$, $P = 0.01$), vegetation ($H = 7.8$, $P \leq 0.01$), and their interaction term ($H = 7.1$, $P \leq 0.01$). Fish density, vegetation, and their interaction term did not influence the number of chases between northern studfish conspecifics ($H = 2.8$, $P =$

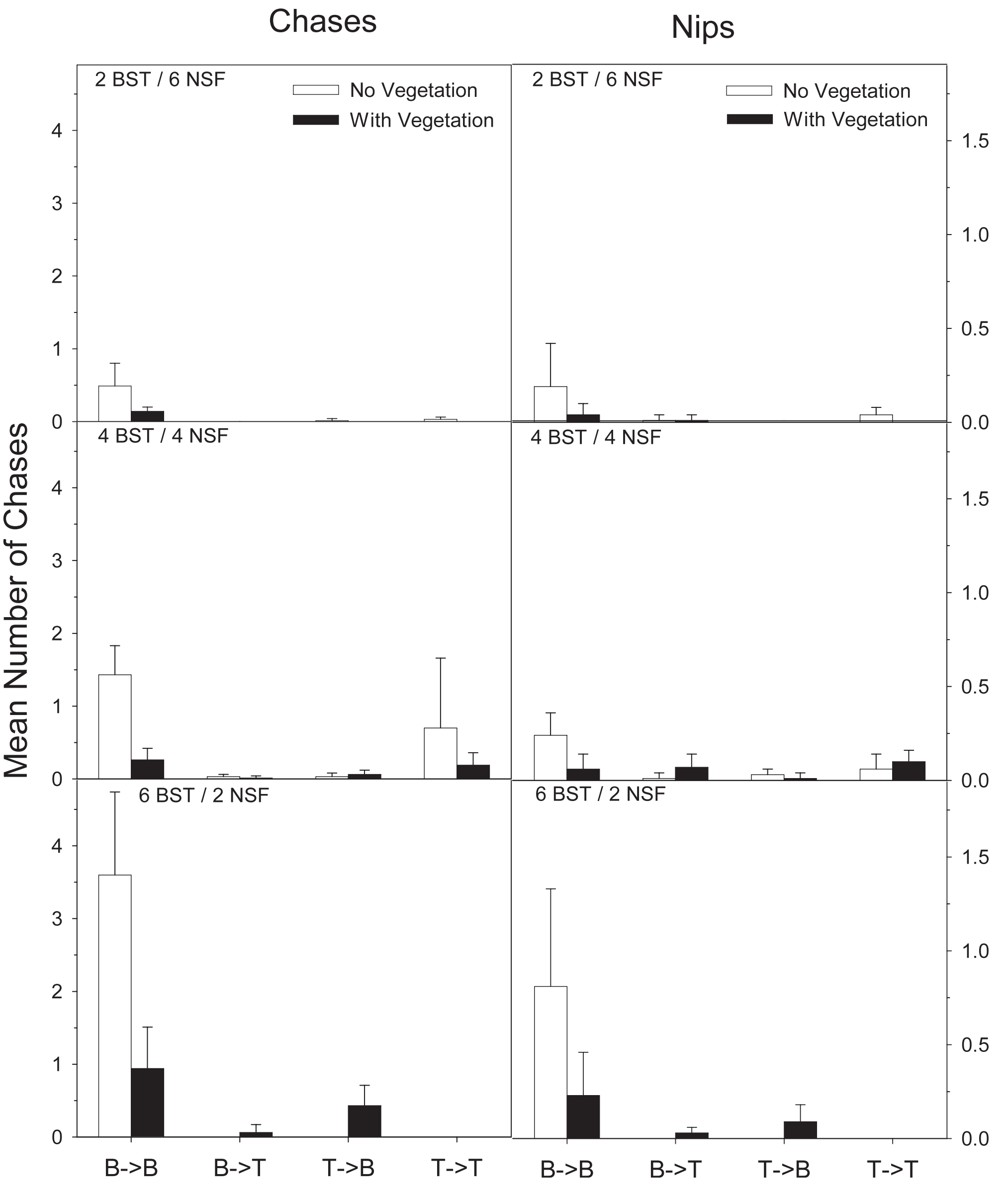

Figure 2.—The mean number (SE) of chases and nips per observation period within and between blackstripe topminnows (BST) and northern studfish (NSF). The direction of aggressive behavior is shown as an arrow (i.e., B->T means BST chasing other topminnow). Density treatments included 2 BST and 6 NSF (top), 4 BST and 4 NSF (middle), and 6 BST and 2 NSF (bottom).

0.07; H = 1.1, P = 0.30; H = 0.9, P = 0.41, respectively) and the reciprocal interaction (H = 0.7, P = 0.51; H = 0.5, P = 0.49; H = 1.1, P = 0.34, respectively).

For blackstripe topminnows and northern studfish, there were 143 nips observed in experimental treatments (Figure 2). The number of nips between conspecifics and species was less than one per period. There was a significant difference in the mean number of nips for conspecifics of blackstripe topminnows (H = 7.9, $P \leq 0.01$) and northern studfish (H = 3.6, P = 0.04) by fish density, but only blackstripe topminnows exhibited significant differences in the number of nips for vegetation (H = 10.8, $P \leq 0.01$). The interaction term was

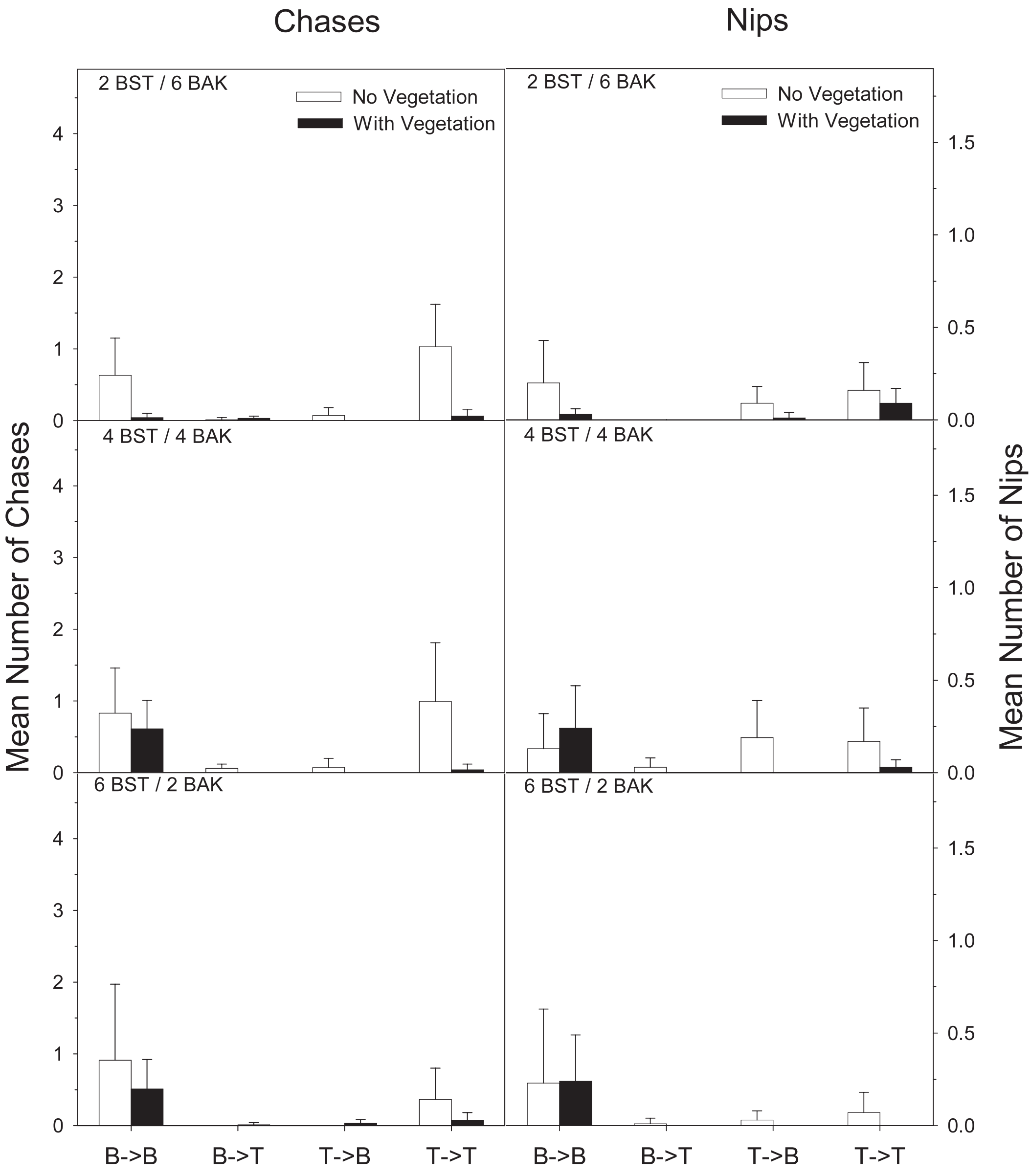

Figure 3.—The mean number (SE) of chases and nips per observation period within and between blackstripe topminnows (BST) and banded killifish (BAK). The direction of aggressive behavior is shown as an arrow (i.e., B->T means BST chasing other topminnow). Density treatments include 2 BST and 6 BAK (top), 4 BST and 4 BAK (middle), and 6 BST and 2 BAK (bottom).

not significant among blackstripe topminnow ($H = 2.3$, $P = 0.11$) and northern studfish ($H = 2.0$, $P = 0.16$) conspecifics. There was no difference in the number of nips for fish density and vegetation by blackstripe topminnows toward northern studfish ($H = 1.5$, $P = 0.25$; $H = 3.2$, $P = 0.08$, respectively) and the reciprocal interaction ($H = 2.1$, $P = 0.14$; $H = 1.9$, $P = 0.17$, respectively). The interaction term was significant for the number of nips by northern studfish toward blackstripe topminnows ($H = 3.3$, $P = 0.05$), but not for blackstripe topminnows toward northern studfish ($H = 1.1$, $P = 0.35$).

There were 445 chases in aquaria containing blackstripe topminnows and banded killifish

(Figure 3). The mean number of chases among conspecifics and between species was less than one per period. For conspecifics of both species, there was a significant difference in the number of chases for vegetation ($H = 4.2$, $P = 0.05$; $H = 19.1$, $P \leq 0.01$, respectively); however, there was no significant difference for fish density ($H = 1.7$, $P = 0.20$; $H = 1.6$, $P = 0.22$, respectively). The interaction term was not significant for blackstripe topminnow ($H = 0.3$, $P = 0.74$) and banded killifish ($H = 1.8$, $P = 0.18$) conspecifics. Fish density, vegetation, and their interaction term did not influence the number of chases by blackstripe topminnows toward banded killifish ($H = 0.7$, $P = 0.51$; $H = 0.4$, $P = 0.54$; $H = 2.4$, $P = 0.10$, respectively) and the reciprocal interaction ($H = 0.3$, $P = 0.73$; $H = 2.3$, $P = 0.14$; $H = 1.7$, $P = 0.19$, respectively).

There were 134 nips in aquaria containing both blackstripe topminnows and banded killifish (Figure 3). The number of nips between conspecifics and species among treatments was less than one per period. Neither fish density nor vegetation influenced the number of nips between blackstripe topminnow conspecifics ($H = 0.9$, $P = 0.40$; $H = 0.04$, $P = 0.85$, respectively), banded killifish conspecifics ($H = 1.1$, $P = 0.34$; $H = 3.8$, $P = 0.06$, respectively), and blackstripe topminnows toward banded killifish ($H = 0.6$, $P = 0.55$; $H = 1.8$, $P = 0.19$, respectively). The interaction term was not significant for blackstripe topminnow conspecifics ($H = 1.3$, $P = 0.28$), banded killifish conspecifics ($H = 0.2$, $P = 0.79$), and blackstripe topminnows toward banded killifish ($H = 0.6$, $P = 0.55$). There was a significant difference in the number of nips for vegetation by banded killifish toward blackstripe topminnows ($H = 11.4$, $P \leq 0.01$); however, there was no difference for fish density ($H = 0.55$, $P = 0.26$) and the interaction term was not significant ($H = 2.8$, $P = 0.08$).

DISCUSSION

Due to the distribution of blackstripe topminnow in Indiana and their diet similarities to western mosquitofish, this species has been identified as a potential alternative to western mosquitofish for mosquito control (Zeiber 2007). However, there have been no previous examinations of the behavioral interactions between blackstripe topminnows and the other native Indiana topminnow species. In our laboratory experiments, chases and nips were relatively infrequent and primarily directed toward conspecifics and not the other topminnow species present. For example, male blackstripe topminnows are known to be aggressive toward other male conspecifics, which may lead to repeated and prolonged intraspecific attacks (Carranza & Winn 1954). Intraspecific aggression by the topminnow species in our study was similar, regardless of the presence or absence of blackstripe topminnow, indicating little change in behavior. As a result, it did not appear that the presence of blackstripe topminnows negatively affected any of the other topminnow species.

Topminnows are not typically aggressive fishes (Becker 1983; Pflieger 1997). However, blackstripe topminnows were the most aggressive of the four topminnow species observed in our study. Nevertheless, this species is considerably less aggressive than western mosquitofish. For example, Zeiber (2007) found that western mosquitofish exhibited more agonistic behaviors and caused a change in topminnow behavior in mixed-species microcosms. Chasing and nipping behaviors by topminnows toward mosquitofish occurred infrequently, and mosquitofish initiated almost all of the chases and nips toward conspecifics and topminnows. While all four topminnows were attacked by mosquitofish, northern starhead topminnows and banded killifish were chased and nipped more frequently than the other topminnow species and exhibited the most behavioral changes and fin damage. Sutton et al. (2009) also found that western mosquitofish could extirpate northern starhead topminnows from outdoor mesocosms, presumably due to agonistic interactions, predation, and competition for food resources. Similar observations have been noted in other studies for mosquitofish effects on other topminnow and trophically similar species (Abbot and Dill 1985; Meffe 1985; Barrier and Hicks 1994; Taylor et al. 2001; Rinco et al. 2002; Mills et al. 2004; Rogowski and Stockwell 2006; Laha and Mattingly 2007).

Higher fish densities have been shown to increase aggression within and among fish species. For example, aggressive intraspecific interactions were positively correlated to fish density for age-0 Atlantic salmon *Salmo salar* and adult parrotfish *Sparisoma viride* (Mumby and Wabnitz 2002; Blanchet et al. 2006).

Further, Spanish toothcarp *Aphanius iberus* were chased and nipped more at higher eastern mosquitofish densities (Rinco et al. 2002). In our study, topminnows did exhibit lower levels of intraspecific aggression, but there were a greater number of chases and nips at higher densities.

The interspecific behaviors of topminnows were not influenced by the presence of vegetation or blackstripe topminnows. Topminnows rarely used vegetation for refuge in the presence of blackstripe topminnows. The passive nature of northern starhead topminnows and the erratic swimming of banded killifish did not increase the number of interspecific chases or nips (Pflieger 1997). Only blackstripe topminnows exhibited fin damage in our trials, and the low number of nips did not cause fin damage to any of the other topminnows. Blackstripe topminnows were rarely aggressive toward other topminnow species, and posed little threat compared to western mosquitofish (Zeiber 2007).

The results of behavioral research conducted in microcosm experiments can be difficult to apply to natural systems. Unfortunately, direct observations in aquatic systems are often not possible due to aquatic vegetation, poor water clarity, and/or water depths that are too great or shallow (Dolloff et al. 1996). Because our research required the quantification of chases, nips, and fin damage, behavioral observations of topminnows in natural systems of Indiana were not feasible. Behaviors in the laboratory may not be representative or may exaggerate behaviors in aquatic systems. For example, aggressive behaviors by eastern mosquitofish were more intense and frequent in microcosms than in open-water areas in a natural system (Martin 1975). However, we believe that the same low level of agonistic behaviors observed by blackstripe topminnows toward other topminnow species would also occur in Indiana systems if the former species was stocked for mosquito control.

Blackstripe topminnows exhibited limited aggressive behaviors toward the other three topminnow species and did not result in changes in behavior of these fishes. As a result, blackstripe topminnows may be an ideal candidate for stocking for biological control of mosquitoes without the negative impacts exhibited by western mosquitofish. Not only are blackstripe topminnows native to Indiana, but they are broadly distributed throughout the state, have co-evolved with other topminnow species in the state, and have the same proclivity for feeding on mosquito larvae as western mosquitofish. However, this recommendation should be viewed with caution until additional research can be conducted to determine if the stocking of this species into aquatic systems would have other unintended consequences.

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