

EFFECTS OF SMALLMOUTH BASS ON HABITAT SELECTION BY A
FISH ASSEMBLAGE OF THE DEVILS RIVER, TEXAS, IN ARTIFICIAL STREAMS

THESIS

Presented to the Graduate Council of
Southwest Texas State University
in Partial Fulfillment of
the Requirements

For the Degree
Master of SCIENCE

By

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San Marcos, Texas

August, 2001

ACKNOWLEDGEMENTS

I would like to thank Dr. Gary Garrett at Heart of the Hills Research Station for allowing me to conduct observations on the artificial streams as well as serving on my thesis committee. I would also like to thank the other committee members Dr. Thomas Arsuffi and Dr. Glenn Longley for their help and patience as I have worked through this and other projects. I consider myself lucky to have had Dr. Bobby Gene Whiteside as a thesis advisor. Who would have thought that being the lab assistant for his Ichthyology class would have lead to travelling to literally every corner of the state to collect fish and meeting some of the most interesting characters along the way!!! I would also like to thank Dr. Timothy Bonner for taking up the reins from Dr. Whiteside and taking me on as his student to finish my research. Tim's enthusiasm for the project helped me get through the home stretch of writing the thesis.

To the graduate students new and old that I have gotten to know and respect, you all have made some of the toughest times at the grad office easy to bear. Last, but not least, thanks to Mom, Dad, and Stacy T. whose unending patience and encouragement has helped me to push on despite the challenges placed before me.

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INTRODUCTION

The presence of a predatory fish in a stream fish typically induces habitat shifts in prey fishes (Schlosser 1982; Cerri and Fraser 1983; Fraser and Emmons 1983; Power et al. 1985; Fraser et al. 1987; Schlosser 1987; Gorman 1988; Schlosser 1988; Schlosser and Ebel 1989; Sazima and Machado 1990; Harvey and Stewart 1991; Brown and Brasher 1995).

Field and artificial stream studies show that potential prey species seek shallow water refuges when a predator is present (Fraser et al. 1987; Schlosser 1987; Schlosser 1988; Harvey et al. 1991; Fraser and Harvey 1991; Fraser and Gilliam, 1992; Brown and Brasher 1995). These predator-induced shifts can have adverse sub-lethal effects (i.e., reduced growth, condition, and reproduction) on prey populations and are more pronounced in a fish assemblage where a predator has been introduced (Meffe 1985).

Smallmouth bass Micropterus dolomieu were introduced in the mid-1970s in the lower reaches of Devils River in Texas and have expanded their range and abundance throughout the Devils River. During this expansion, the Devils River minnow Dionda diaboli has decreased in abundance and distribution in the last 20 years and is listed currently as a federally threatened species. Direct (predation) and indirect (sub-lethal) effects of the M. dolomieu on the D. diaboli population are unknown, but the federal listing of D. diaboli suggests that more information is needed on this predator/prey relationship to properly manage recovery efforts for D. diaboli (US Fish and Wildlife Service 1999).

The purpose of this study was to assess the effects of M. dolomieu on habitat selection by D. diaboli and four other native fishes: manantial roundnose minnow

Dionda argentosa, Texas shiner Notropis amabilis, Mexican mosquitofish Gambusia speciosa, and proserpine shiner Cyprinella proserpina. This study was designed to infer interactions among the current fish assemblage in headwater reaches of the Devil River and multiple prey species were used to allow prey species interactions, if present. For each species, I tested the hypothesis that selection of a habitat type along several gradients was independent of predator presence.

METHODS

Two artificial streams were constructed from fiberglass pools and raceways to form a continuous flow-through system each with six pools, two runs, and three riffles (Figure 1). Artificial streams were located outside at Texas Parks and Wildlife Department Heart of the Hills Research Station (Ingram, TX) in a fenced enclosure to minimize terrestrial predators and covered with a solar net to reduce direct sunlight. Each stream was equipped with a pump and heater/chiller system to recirculate water and maintain temperatures between 18°C and 27°C. Filtered water was added from Fessenden Creek, when needed, to compensate for evaporative losses.

Pool habitats were 1.8 m in diameter and 0.5 m in depth with 0.01 m/s flow. Sand and gravel was placed at the bottom of the pools and each pool contained either a wood snag, aquatic plants (Chara, Luwigia, Potamogeton), or rock pile habitat. Run and riffle habitats were 1.8 m in length, 0.45 m in width, and contained sand and gravel substrate. Run habitats were 0.25 m in depth with 0.03 m/s flow and riffle habitats were approximately 0.05 m in depth with 0.20 m/s flow.

Prey species were collected from Devils River and stocked in each artificial stream prior to the start of each trial. Species and their abundance were similar to the natural fish assemblage in the Devils River (Harrell 1978). A fish census of each stream

was conducted before and after each trial, which allowed for a complete species list and abundance of fish present at the start and end of each trial (Table 1).

Trial I was conducted in August 1999. Eight smallmouth bass, which ranged between 50 to 70 mm in standard length (SL), were introduced into one artificial stream (treatment), leaving one artificial stream without any predators (control). One day a week for three weeks, I observed fish locations in pools, runs, and riffles during the morning, afternoon, and evening. Fish were observed from a 2 m step-ladder located in the middle of each artificial stream configuration with a pair of Tasco 7 x 35 binoculars. A pool and associated run or riffle was selected randomly and observed for 4 minutes until all habitat types in both streams were observed and fish counted. After each observation, the step-ladder was moved to another viewing location with care not to disturb fish. Fish were identified to species, except for D. diaboli and D. argentosa, and their selection for pool, run, or riffle was tabulated. Dionda diaboli and D. argentosa are morphologically similar and could not be distinguished from each other in the artificial streams. Their abundances were combined under one genera, Dionda. In pools, habitat selection was subdivided visually by the investigator into vertical selection (surface, middle, bottom; Figure 2), horizontal selection (edge, open, substrate), and substrate type (wood snag, plant, rock pile).

Trial II was conducted in May and June 2000 and with the same protocol as for Trial I except for a few deviations. The size of smallmouth bass had increased, thus the number of predators was reduced to two (85 and 125 mm in SL) in the treatment stream to provide for a typical predator/prey assemblage. Also, a greater number of G. speciosa was stocked to counter algae blooms occurring in the artificial streams. According to

results from the first trial, G. speciosa was not a major prey species for smallmouth bass and the increase in numbers did not affect predator/prey behavior. Lastly, C. proserpina was substituted for E. grahami. The Rio Grande darter, which was not observed in the system in Trial I due to its benthic behavior and cryptic coloration, was removed for Trial II.

Multiple observations within a day were conducted to determine diel variation; however, no substantial deviation in diel habitat selection was found. Thus, observations within a day (morning, afternoon, evening) were averaged to provide a single number for species abundance within each habitat type for each day of observation. Distribution of species abundance within each habitat type (macrohabitat, vertical selection, horizontal selection, and substrate type) was compared between a population of fish in an artificial stream with predators (treatment) and a population of fish in an artificial stream without predators (control). Chi-square analyses ($\alpha = 0.05$) were used to determine difference in distributions for each species, for each day of observation within a 21-d period, and for each trial.

In addition to timed observations, multiple non-timed observations were conducted for each stream during both trials. These observations were not quantified or standardized, but provided additional insight into each species behavior. When appropriate, these observations are reported with timed observations.

RESULTS

In artificial streams, populations of D. diaboli and G. speciosa generally increased in abundance in the control and treatment streams (unpublished data; TPWD; Table 1). Populations of D. argentosa, N. amabilis, and C. proserpina generally decreased in abundance, but decreases were greater in treatment streams. Notropis. amabilis and C. proserpina were not observed in the treatment streams by Week 3. Census data indicates that both of these species were reduced to one individual each, and thus presumed to be heavily preyed upon by M. dolomieu.

The presence of M. dolomieu did not affect the selection of pool, riffle, or run habitats by N. amabilis in Trial I or II (Table 2). The largest proportion of N. amabilis was observed in pools, and less than 10% of the fish were observed in riffles or runs (Figure 3). For vertical selection, N. amabilis distributions differed between the control and treatment streams during both trials. Fish were observed near the surface in streams with predators, whereas fish in the control stream were observed at surface and middle depths (Figure 4). In horizontal selection, N. amabilis were found more often in open water in the control and treatment streams (Figure 5). Although differences were found in horizontal selections, these differences were not consistent between the two trials. Likewise, distributions differed in substrate selection between the control and treatment streams, but consistency between trials was not observed. In the control stream, N. amabilis varied the use of plants, rocks, or snags (Figure 6). In the treatment stream, N. amabilis tended to concentrate in a specific substrate type, with the specific substrate type

alternating among plants, rocks, and snags. In non-timed observations, N. amabilis exhibited schooling behavior with five to 25 individuals per group. Once M. dolomieu entered a pool, the school would move to a riffle and wait for the bass to move to another pool. At dusk, N. amabilis would feed on small flying insects above the surface of the water. At night, individuals would separate and individual fish would swim independently at the surface and middle depths of pools.

The presence of M. dolomieu did not affect Dionda selection of stream macrohabitats (pools, riffles, runs; Figure 7). With the predator present or absent Dionda was observed in pools with less than 15% of the fish holding in run habitats. Selection of vertical habitats by Dionda was similar between trials in the control streams (Figure 8). The largest abundance of fish was found at bottom depths. In the treatment stream, the largest abundance of fish was found at middle depths during Week 2 and 3 in Trial I. In Trial II, the largest abundance of fish was found at bottom depths with the distributions not significantly different from the distribution of fish in the control stream. For horizontal selection, Dionda in the control streams were evenly distributed among substrate, open, and edge habitats in both trials (Figure 9). In Trial I, a larger abundance of fish in the treatment stream was associated with substrate by Week 3 when compared to fish distribution in the control stream. In Trial II, distributions within horizontal selection did not differ between control and treatment streams. Distributions among substrate types were similar in the control streams between trials (Figure 10). In the treatment streams, Dionda were associated with plants in Trial I and plants and rocks in Trial II. These distributions did not differ from distributions in the control stream.

In non-timed observations, Dionda were found in schools of 10-40 fish and selected pools with plant substrate habitat at middle and bottom depths. These fishes were often observed feeding on filamentous algae attached to the bottom, edge, and substrate habitat of pools. In the presence of a predator, Dionda would seek shelter in the plant substrate habitat. During the night, Dionda were found exclusively in pools with no apparent preference for any of the three pool substrate habitats. Also, fish rarely maintained schools at night and were often located at the bottom of pools in an inactive state.

In the presence of M. dolomieu, distributions of G. speciosa differed between the control and treatment streams within macrohabitats (pools, riffles, runs) by Weeks 2 and 3 (Figure 11). In the treatment streams, G. speciosa were found in pools and riffles whereas in the control streams, G. speciosa were found in pools and runs. In vertical habitat selection, distributions of G. speciosa did not differ between the control and treatment streams; the largest proportion of fish was observed at the surface (Figure 12). Gambusia speciosa were observed in all horizontal habitats (substrate, pool, edge) in the control streams in both trials. In Trial I, distributions in the treatment streams did not differ from distributions in the control (Figure 13). However in Trial II, fewer G. speciosa were observed in the open water in the treatment stream. Gambusia speciosa were observed in all substrate types in the control streams for both trials. In Trial I, distributions of G. speciosa differed from the control stream, with a larger proportion of fish associated with rocks. However in Trial II, distributions did not differ from the control stream (Figure 14).

During non-timed observations, G. speciosa were observed mostly at the surface with no notable horizontal or substrate habitat preference. Gambusia. speciosa were often observed at the interface between pools and riffles and would move in and out of pools when a predator approached. Gambusia speciosa was often sighted feeding on small strands of filamentous algae floating on the surface of pools. Night observations found G. speciosa occupied surface waters of pools with no notable horizontal or substrate habitat.

With only one trial conducted, distributions of C. proserpina did not differ in macrohabitat selection between control and treatment streams, except in Week 3 (Figure 15). The largest proportion of fish was observed in pools. In the treatment stream, the largest proportion of C. proserpina was observed in riffles by Week 3. However, the average observation in Week 3 was only two fish. In vertical selection, the largest proportions of fish were observed at middle and bottom depths in the control stream (Figure 15). These distributions differed in the treatment streams with the largest proportions of fish observed at surface and middle depths during Weeks 1 and 2. By Week 3, C. proserpina were not observed in pools. Distributions in horizontal and substrate selections did not differ for fish in control or treatment streams (Figure 16).

During non-timed observations, C. proserpina was found to select predominately for pools at middle and bottom depths, no notable schooling activity was observed. Cypirnella proserpina were active swimmers and aggressively attacked encroaching fishes and was often observed feeding on filamentous algae attached to the bottom, edges, and substrate habitat of pools. In the presence of the predator, C. proserpina would

seek shelter in the substrate habitat. At night, C. proserpina was rarely seen to form schools and individuals were often positioned at the bottom of pools in a in-active state.

DISCUSSION

Studies in artificial and natural streams have shown that prey species will shift their habitat use from pools to shallow water in the presence of a predator (Fraser et al. 1987; Schlosser 1987; Schlosser 1988; Harvey et al. 1988; Fraser and Harvey 1991; Fraser and Gilliam, 1992; Brown and Brasher 1995). In this study, documented habitat shifts to shallow water due to the presence of M. dolomieu were minimal, but other habitat selection shifts were apparent. Such results may be due to either: 1) the size (standard length, SL) of the predator, 2) the size of prey fishes, 3) the presence of complex substrate habitats benefiting prey fishes in stream pools, 4) complex substrate habitats negatively affecting prey fishes.

The lack of a stream macrohabitat shift is possibly explained by the use of subadult M. dolomieu (40 -125 mm SL) in our experiment. Schlosser (1987), found that small piscivores (~ 160 mm SL) did not induce habitat shifts as a result of being an ineffective predator on adult prey fishes (~ 70 mm SL). Schlosser and Ebel (1989) also showed that creek chubs Semotilus atromaculatus (a small piscivore) did influence on the selection of pools by prey species. The lack of influence is thought to be an effect of gape width as well as body size of the predator present in relation to the size of the prey (Schlosser 1987). However, census data of both trials in our experiment found that M. dolomieu nearly eliminated N. amabilis and C. proserpina fishes which ranged from 40-50 mm SL. These two prey species may have not perceived these small M. dolomieu as a predation risk and therefore did not shift from pools to riffles.

Alternatingly, Mittelbach (1981) noted that prey response to predation risk is most likely based recognition of predator taxa rather than size.

The large size of prey fishes another reason for the absence of a habitat shift from pools to riffles. Excluding *G. speciosa*, prey fishes observed appeared to be of adult size and all approximately 40-50 mm standard length. Fish of this size may avoid shallow habitats such as riffles due to the fact that their large size make them susceptible to terrestrial and avian predation. Harvey and Stewart (1991), comparing survivorship of three species of large cyprinids (75-100 mm SL) in shallow versus deep habitats, found high mortality for all three species in shallow habitats. Angermier's (1992) findings noted that riffles serve as a refuge from predation for small fish by hindering the maneuverability and vision of larger predators that may be hunting in the riffle. This principle also applies to large non-piscivorous fish in that vision and maneuverability needed to feed or maintain the formation of a school is disrupted.

Another reason for the lack of a notable habitat shift may be the presence of complex substrate habitats in pools. Past research has shown that prey fish will select for habitats (plants, rocks, woody debris) that are of a density that the maneuverability and visual acuity of a predator is hindered resulting in a reduction of prey captures (Gotceitas and Colgan 1982; Fraser and Cerri 1982; Andersen 1984; Fraser and Emmons 1984; McIvor and Odum 1988; Savino and Stein 1989; Perrson and Eklov 1995). *Dionda* was noted to shift to complex habitats in the treatment stream during both trials of our experiment. At the middle and bottom depths of pools *Dionda* was often observed residing within both plant and rock substrate habitats throughout trial I and II. In these habitats *Dionda*'s olive-green dorsal-lateral coloration and docile behavior allowed it to

blend in to the alga coated plant and rock substrate habitats. Savino and Stein (1982) noted that the vertical barring on bluegill, Lepomis macrochirus, and its habit of holding stationary in vegetation camouflaged this species from predator detection. In addition to deriving cover from complex habitats, Dionda was also observed to feed extensively on filamentous algae growing on rocks and plants.

In both trials, G. speciosa did appear to utilize "shallow refuges" formed by complex habitats. In pools with aquatic plants, floating clusters of Potamogeton sp. leaves formed canopies just below the surface of the water. Gambusia speciosa was frequently observed to suspend adjacent to the floating leaves or actually occupy the layer of water above the leaves. In pools with rock substrate habitat a majority of G. speciosa observed occupied the shallow ledge formed by the rock outcrops. The use of "shallow" pool refuges by this species is similar to findings of other research (Savino and Stein 1982; Savino and Stein 1989) in that by remaining inactive adjacent to or above plant leaves or snag branches the potential to be sighted by a predator is reduced. The presence of shallow ledges formed by rocks may provide an area that may be avoided by predators due reduced maneuverability and susceptibility to avian and terrestrial predators (Harvey 1991).

While past experiments have generally found that shift to complex habitats can benefit prey species by providing both a food source and a refuge from predators. Our research seems to indicate that prey fishes may not always benefit from such a habitat shift. In the treatment stream, N. amabilis shifted entirely to the substrate habitat of snags in trial I and rock in trial II, but did not reside within the interstitial spaces either of these habitats, instead shifted towards the surface of the open water habitat. Crook and

Robinson (1993) looking at protection afforded by woody debris found that prey species (fish) will move to such a complex habitat to increase survivorship. The fact that M. dolomieu moving in and out of wood snags with relative ease in our study indicate that snags used in these streams may not have been of a density to inhibit the hunting abilities of M. dolomieu. The shift towards the surface of the open water habitat and why N. amabilis did not use complex habitats may be due to this species reliance on schooling as a primary means of defense against predation. Vision has been found to be the main sensory link between fishes when maintaining the formation of a school (Bond 1996; Moyle and Cech 1996). By residing in or near a complex habitat, the visual contact between fishes of a school as well as the ability of the school to observe the approach of a predator may be disrupted. In addition, Savino and Stein (1982) found that schooling fishes may be at a disadvantage when complex habitat is present, with the school providing an easily detected target as opposed to an individual fish hiding in a habitat that requires time and energy to capture. Complex habitats do not seem to be the only cause for the decline of N. amabilis in the treatment stream. Observations at night revealed that the schooling activity of N. amabilis was notably reduced. Cerri (1983) found that as light levels decreased schools of fish broke down into smaller units until schooling ceased entirely. The breakdown of schooling as an antipredatory behavior of N. amabilis as a result of lowered light levels may make this species vulnerable to M. dolomieu a nocturnally active predator (Reynolds and Casterlin 1976).

Cyprinella proserpina in the treatment stream of our experiment did not appear to derive any benefit from shifting to the complex substrate habitat of snags. This may be explained by C. proserpina's selection of surface and middle depths as opposed to middle

and bottom depths of the control stream. Such a difference may be the result of competition with other prey fishes for habitat in the presence of a predator. Fish may be pushed out by competitors (another species of minnow) from choice habitat and be forced to reside in less habitable settings where food resources may be poor or protection from predators is inadequate as in the case of C. proserpina (Fraser and Sise 1980).

Micropterus dolomieu did appear to have lethal and non-lethal effects on a fish assemblage from the Devils River. The shift of fish across pool habitats, particularly by Dionda, in addition to the near elimination of two species suggest that this exotic predator does not only have an on affect the fish assemblage in mainstream sections of the river, but headwater reaches as well. More work with these fishes is encouraged to provide more insight into the effects of an exotic predator on the threatened species of this pristine river basin.

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Table 1.—Fish assemblage of two artificial streams (without M. dolomieu, with M. dolomieu) at the start and finish of two six week predator preference trials. Unpublished data courtesy of Heart of the Hills Research Station, Texas Parks and Wildlife Department.

Common Name	Scientific Name	Trial 1				Trial 2			
		Start		Finish		Start		Finish	
		Without	With	Without	With	Without	With	Without	With
Devils River Minnow	<u>Dionda diaboli</u>	31	31	77	57	29	29	31	27
manatal roundnose minnow	<u>Dionda argentosa</u>	55	55	19	28	52	52	26	28
Texas shiner	<u>Notropis amabilis</u>	50	50	22	1	50	50	36	1
Mexican mosquitofish	<u>Gambusia speciosa</u>	38	38	1,271	446	194	190	355	166
Rio Grande darter	<u>Etheostoma grahami</u>	30	30	3	2	0	0	0	0
proserpine shiner	<u>Cyprinella proserpina</u>	0	0	0	0	20	20	22	1
smallmouth bass	<u>Micropterus dolomieu</u>	0	8	0	8	0	2	0	2

Table 2.—Results of observations of no predator (Ob 1) and predator stream (Ob 2) and Chi Square Analysis ($\alpha = 0.05$) of observational data. Observation numbers represent a mean of three daily observations.

Habitat	Week	<i>Diionda</i> spp								<i>N. amabilis</i>							
		Trial I				Trial II				Trial I				Trial II			
		X ²	P	Ob 1	Ob 2	X ²	P	Ob 1	Ob 2	X ²	P	Ob 1	Ob 2	X ²	P	Ob 1	Ob 2
Macrohabitat	1	2.9	0.233	92	62	0.3	0.954	21	33	3.9	0.145	35	35	1.3	0.511	33	30
	2	9.0	0.011	18	45	0.6	0.894	27	7	1.6	0.211	32	18	4.2	0.122	27	13
	3	1.1	0.573	17	28	0.3	0.967	37	2	-	-	35	0	-	-	35	0
Vertical	1	1.1	0.585	87	53	0.5	0.909	25	33	19.1	<0.001	33	34	22.4	<0.001	33	29
	2	6.8	0.033	15	45	0.7	0.864	25	7	10.1	0.006	30	18	6.5	0.039	25	13
	3	17.3	<0.001	16	28	1.6	0.655	33	2	-	-	33	0	-	-	29	0
Horizontal	1	5.9	0.051	85	53	0.0	0.999	25	32	12.1	0.002	31	34	2.6	0.272	33	29
	2	9.7	0.008	15	45	6.7	0.082	25	7	2.0	0.362	30	18	7.0	0.030	25	12
	3	13.8	0.001	16	28	0.4	0.931	33	2	-	-	33	0	-	-	32	0
Substrate	1	32.0	<0.001	85	57	0.2	0.983	25	32	21.1	<0.001	31	34	3.6	0.168	33	29
	2	27.0	<0.001	15	45	5.4	0.146	25	7	21.5	<0.001	30	18	21.3	<0.001	25	12
	3	21.2	<0.001	16	28	4.2	0.242	33	2	-	-	32	0	-	-	32	0
		<i>G. speciosa</i>								<i>C. proserpina</i>							
Macrohabitat	1	1.3	0.515	76	78	0.6	0.733	21	18					1.6	0.442	14	12
	2	31.0	<0.001	48	111	6.2	0.044	21	21					1.7	0.193	15	3
	3	16.8	<0.001	52	78	7.9	0.019	23	14					18.0	<0.001	16	2
Vertical	1	22.2	<0.001	56	64	0.3	0.873	18	14					7.1	0.029	13	11
	2	2.9	0.239	43	77	2.8	0.250	20	17					9.8	0.007	15	3
	3	3.0	0.227	43	63	2.0	0.360	20	10					-	-	12	0
Horizontal	1	9.0	0.011	57	64	1.4	0.485	18	14					2.9	0.229	13	11
	2	0.6	0.759	38	75	8.9	0.012	20	17					0.0	0.990	15	2
	3	4.4	0.109	43	63	6.3	0.042	21	10					-	-	14	0
Substrate	1	2.8	0.243	57	64	0.3	0.846	18	14					0.9	0.632	13	11
	2	7.9	0.019	41	75	5.6	0.062	20	17					5.2	0.075	15	3
	3	13.5	0.001	43	63	3.5	0.172	21	10					-	-	12	0

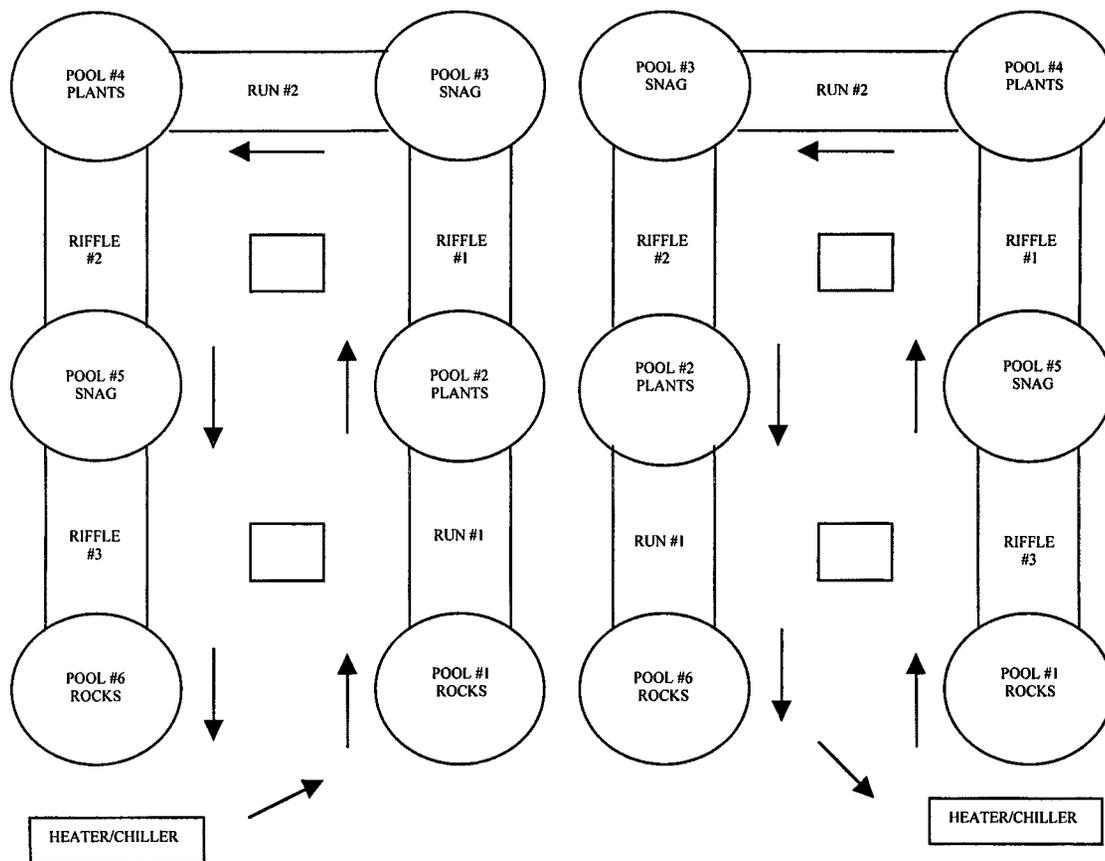


Figure 1.—Diagram of artificial streams with arrows indicating direction of flow.

Squares represent placement areas of observation station (ladder). Diagram is not to scale.

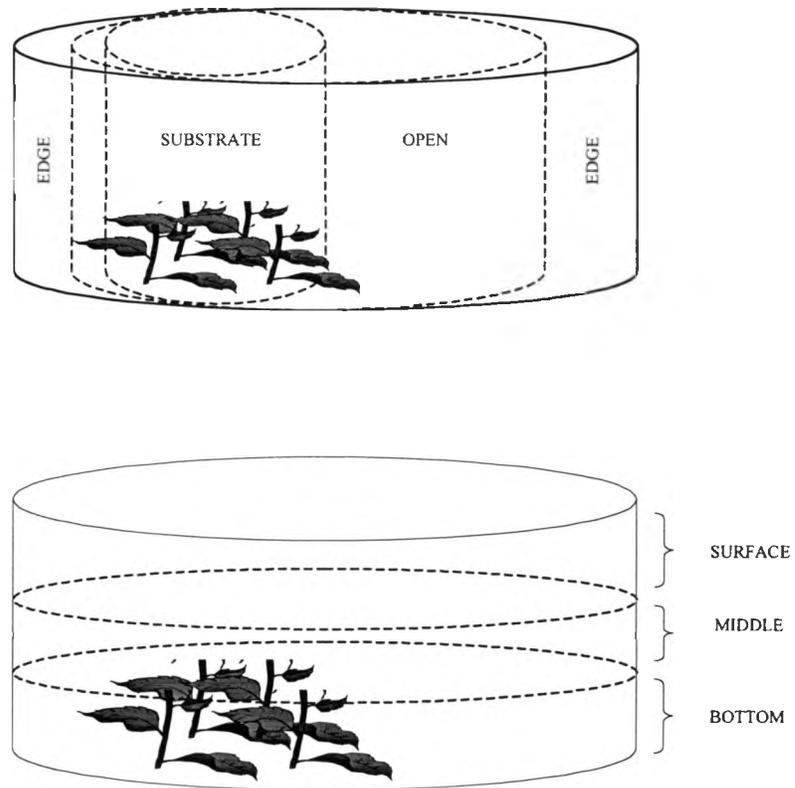


Figure 2. Side view of a stream pool illustrating horizontal habitats (top) and vertical habitats (bottom). Diagram of pool not to scale.

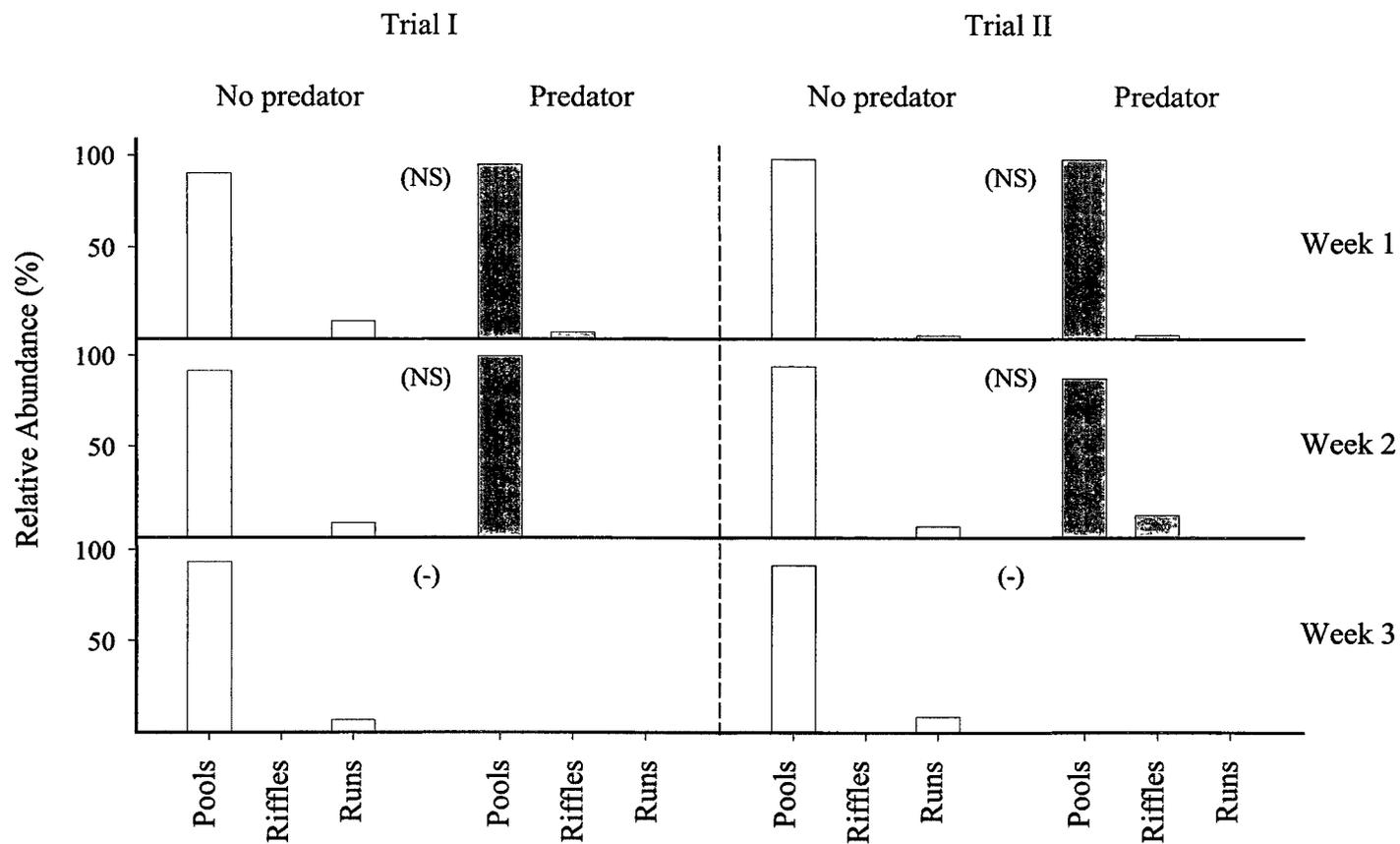


Figure 3.—Relative abundance of *Notropis amabilis* observed in three stream macrohabitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

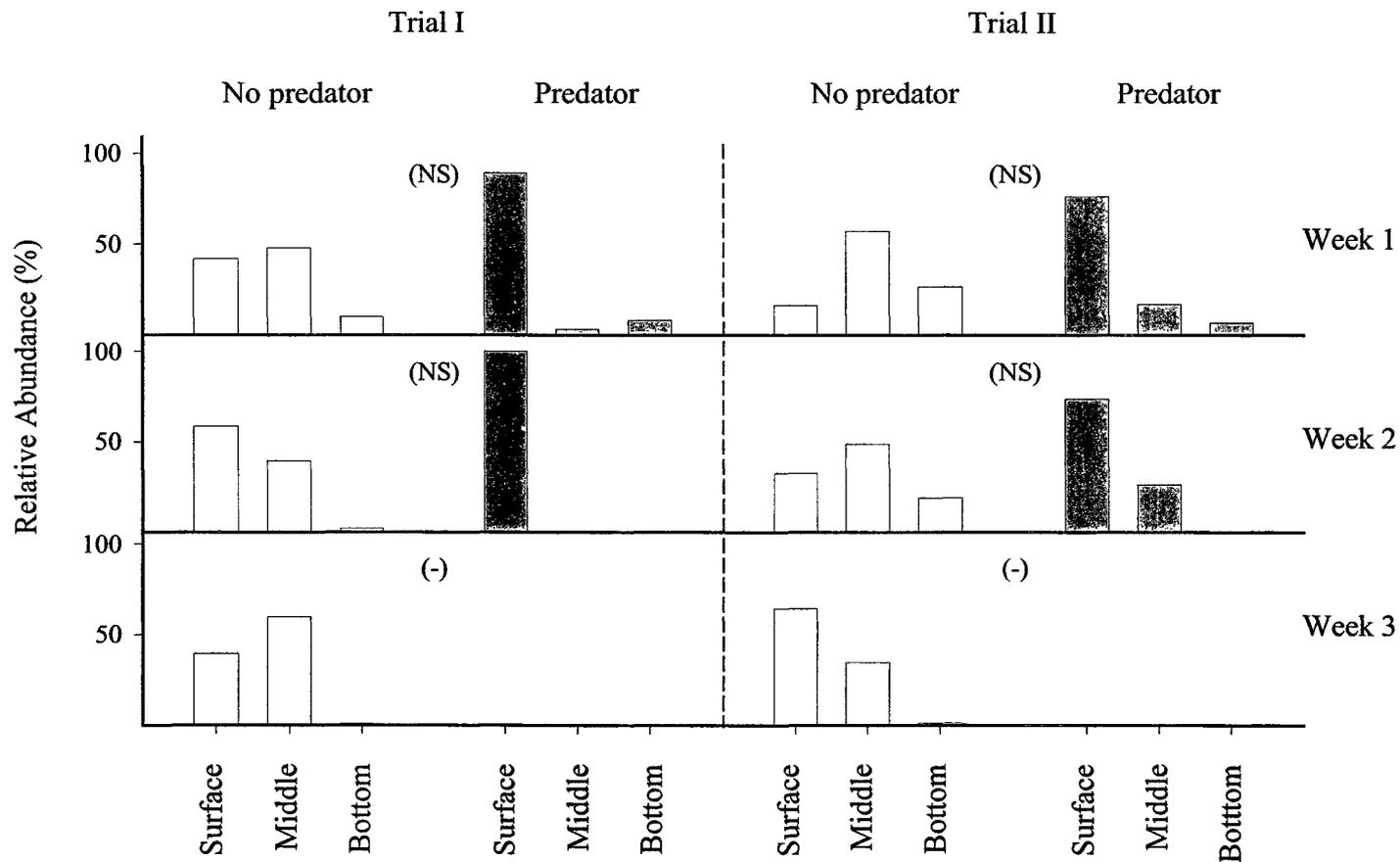


Figure 4.—Relative abundance of *Notropis amabilis* observed in three vertical habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

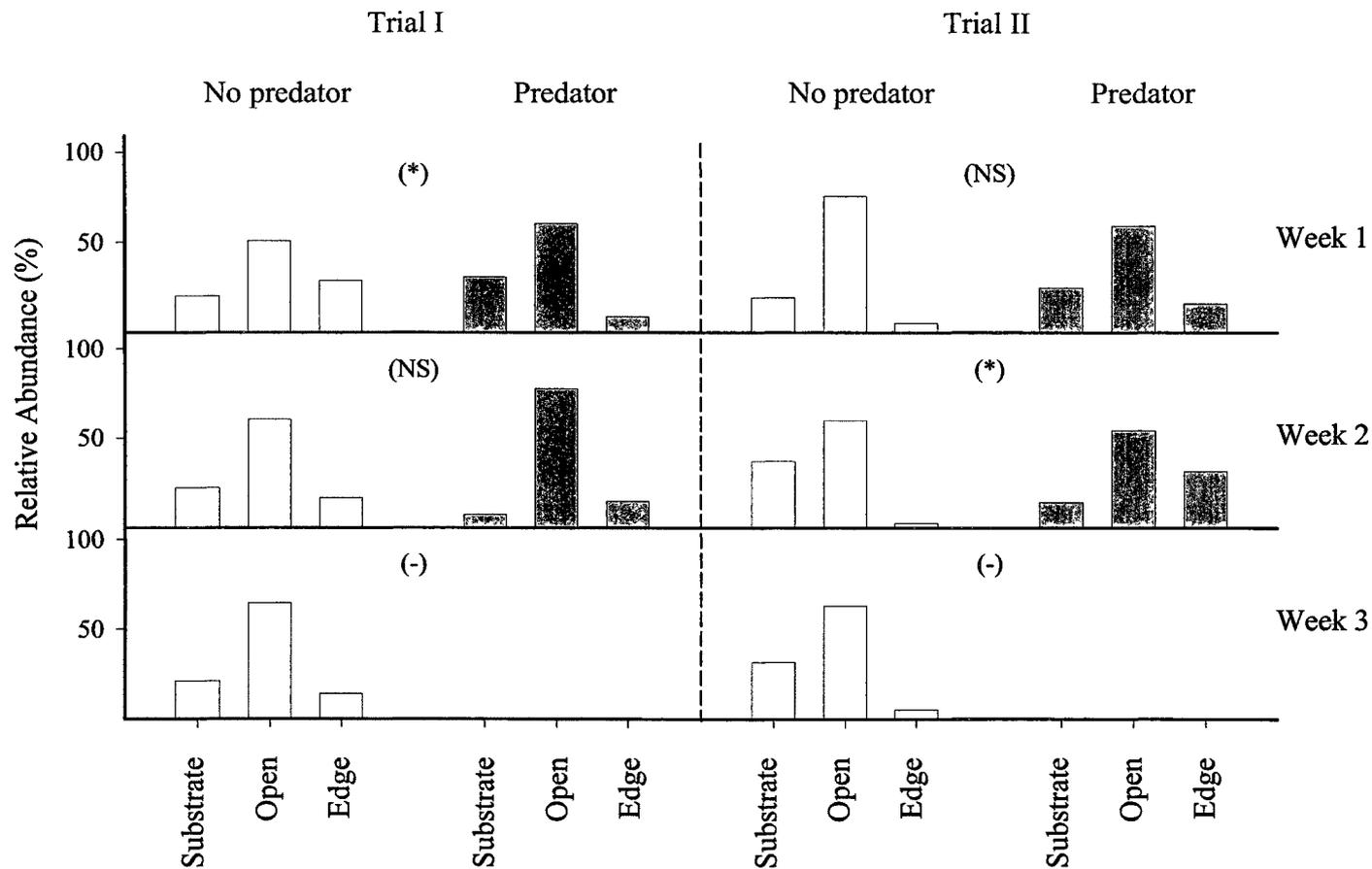


Figure 5.—Relative abundance of *Notropis amabilis* observed in three horizontal habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

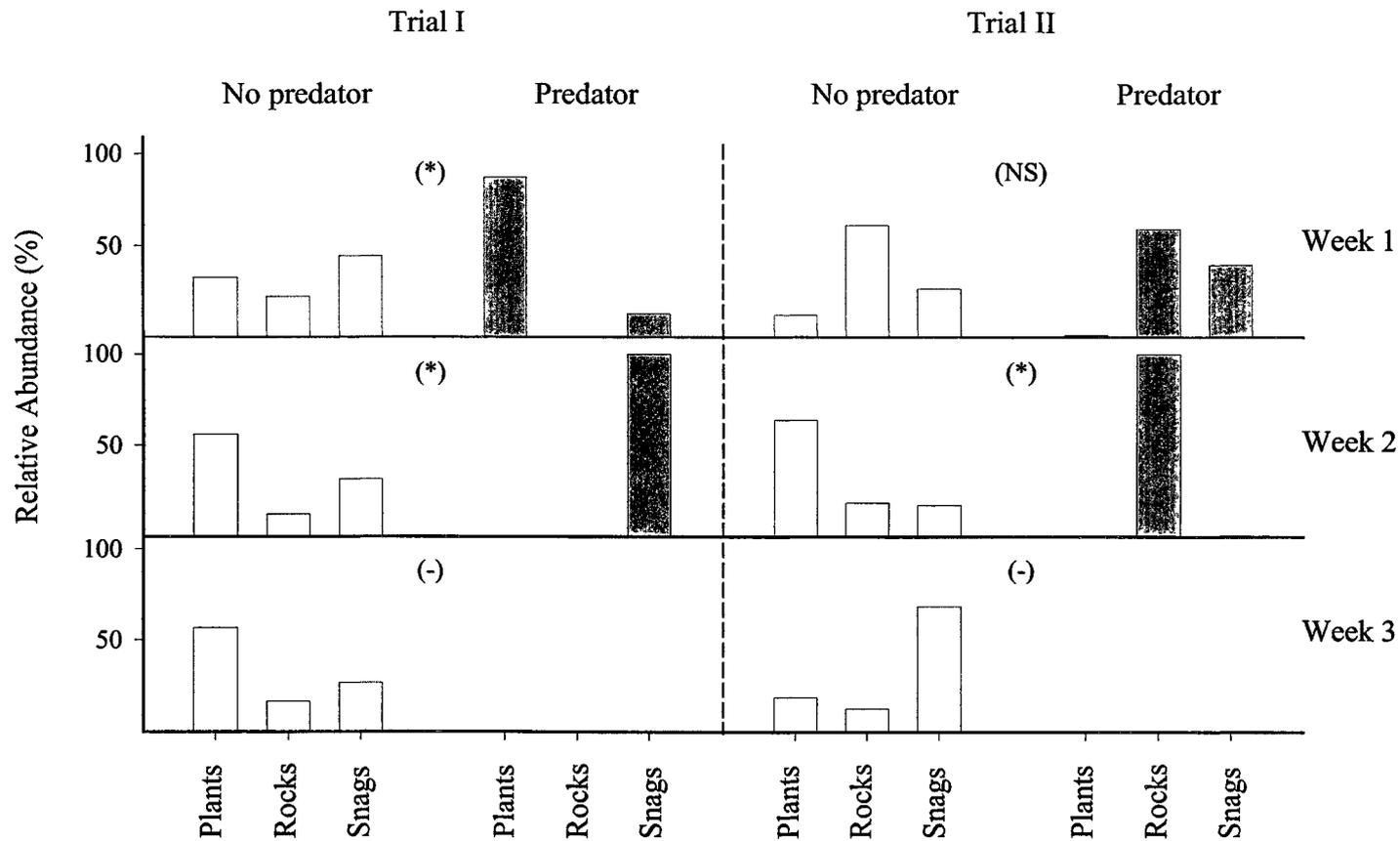


Figure 6.—Relative abundance of *Notropis amabilis* observed in three substrate habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

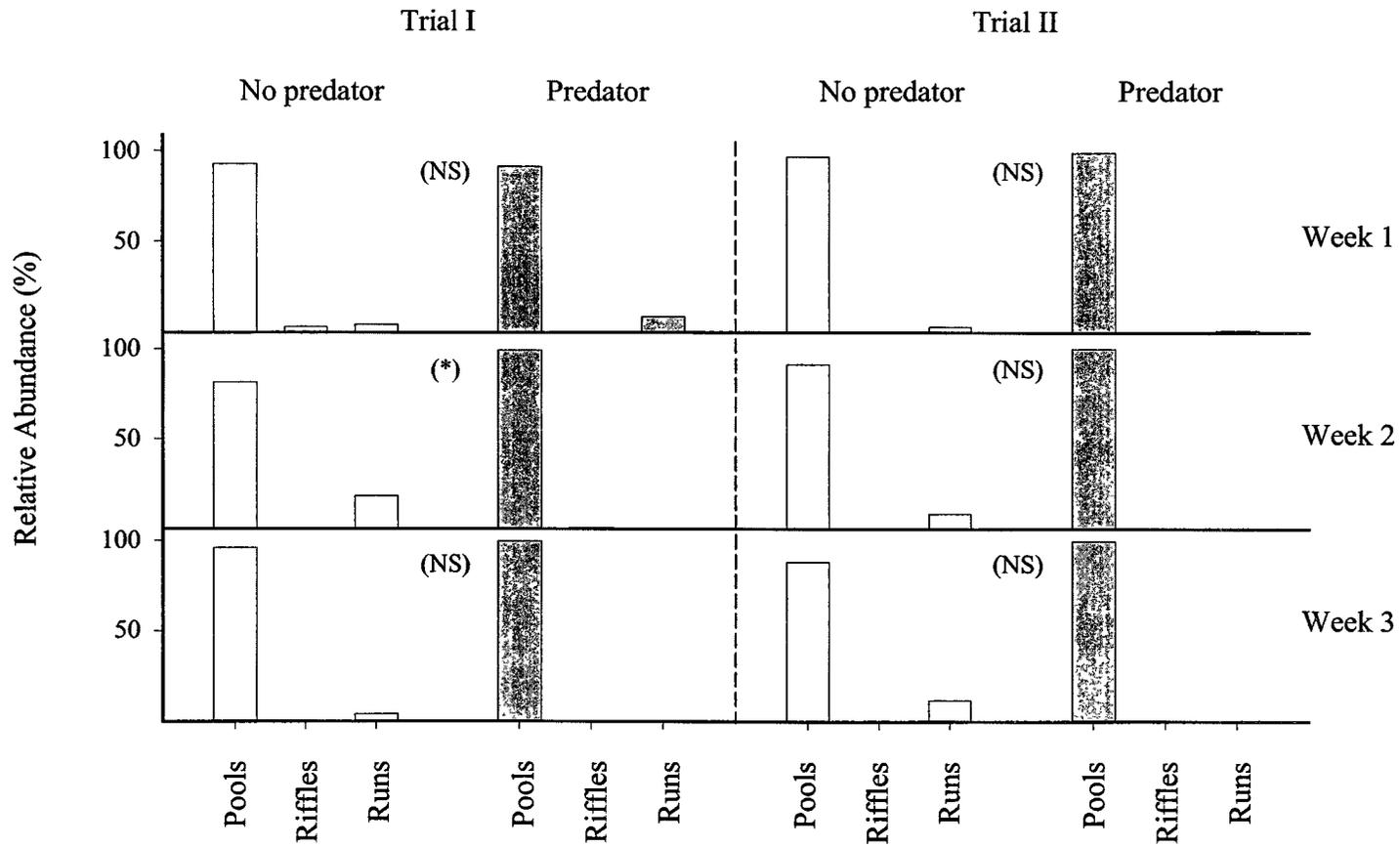


Figure 7.—Relative abundance of *Dionda* spp. observed in three stream macrohabitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

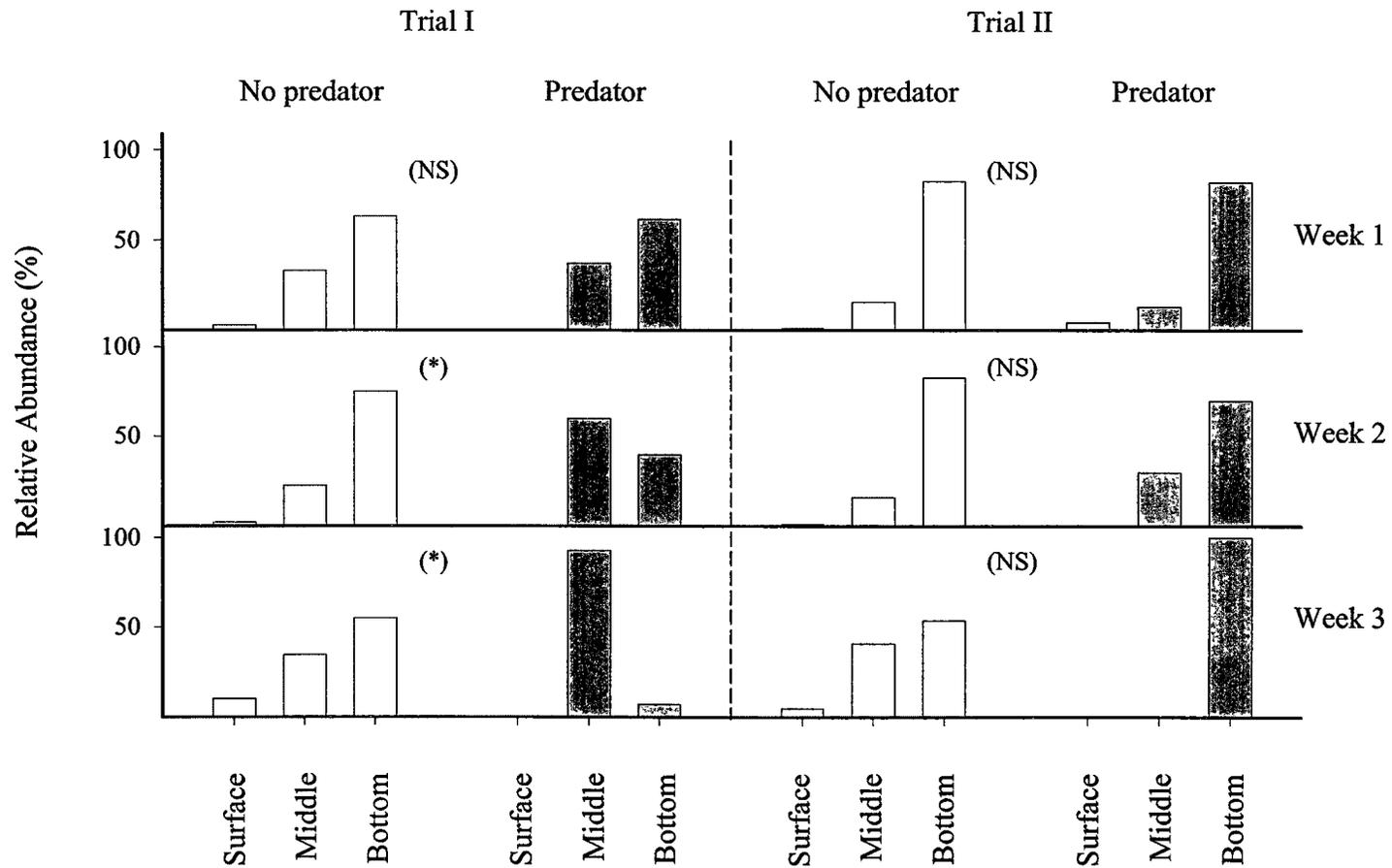


Figure 8.—Relative abundance of *Dionda* spp observed in three vertical habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

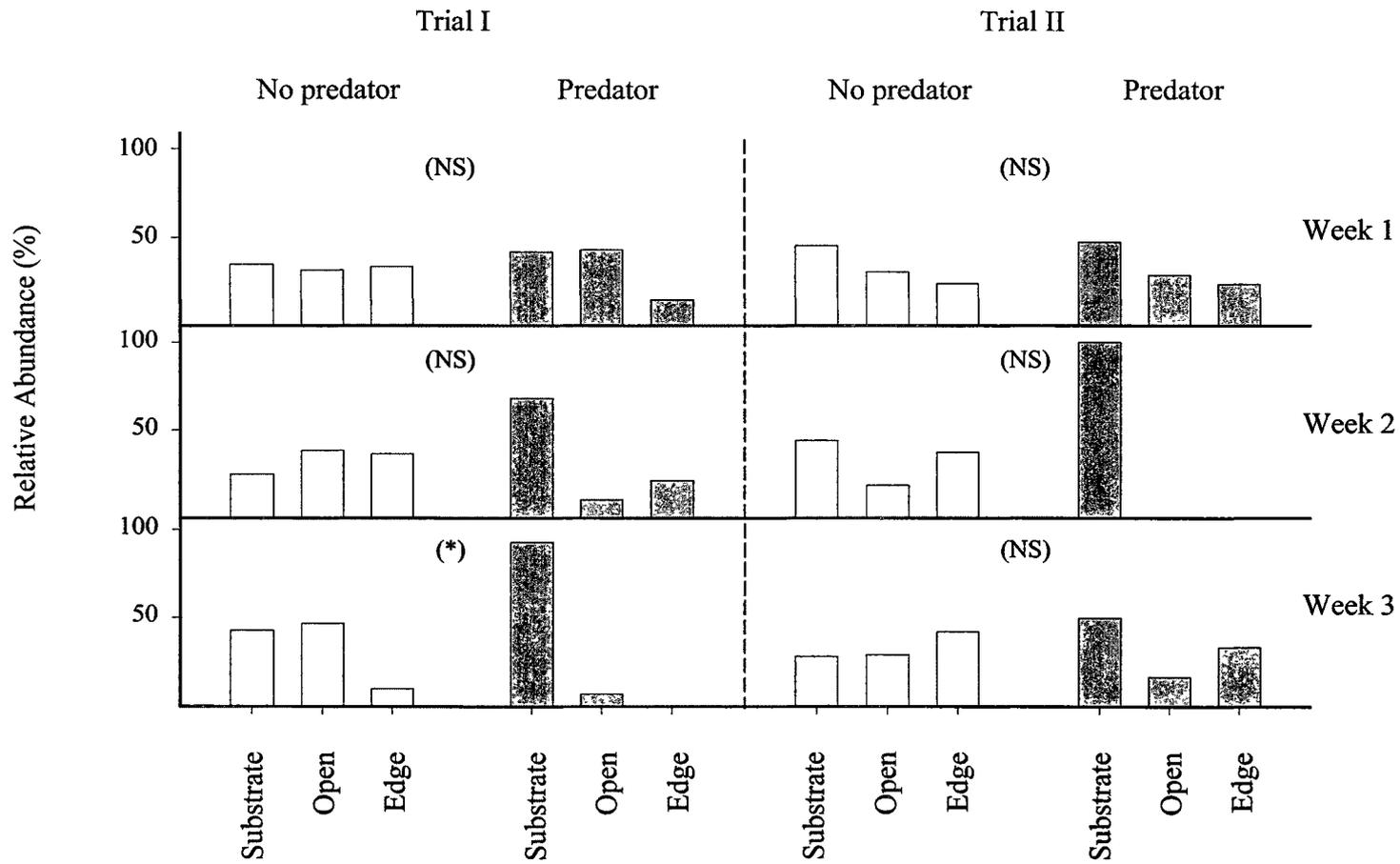


Figure 9.—Relative abundance of *Dionda* spp observed in three horizontal habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

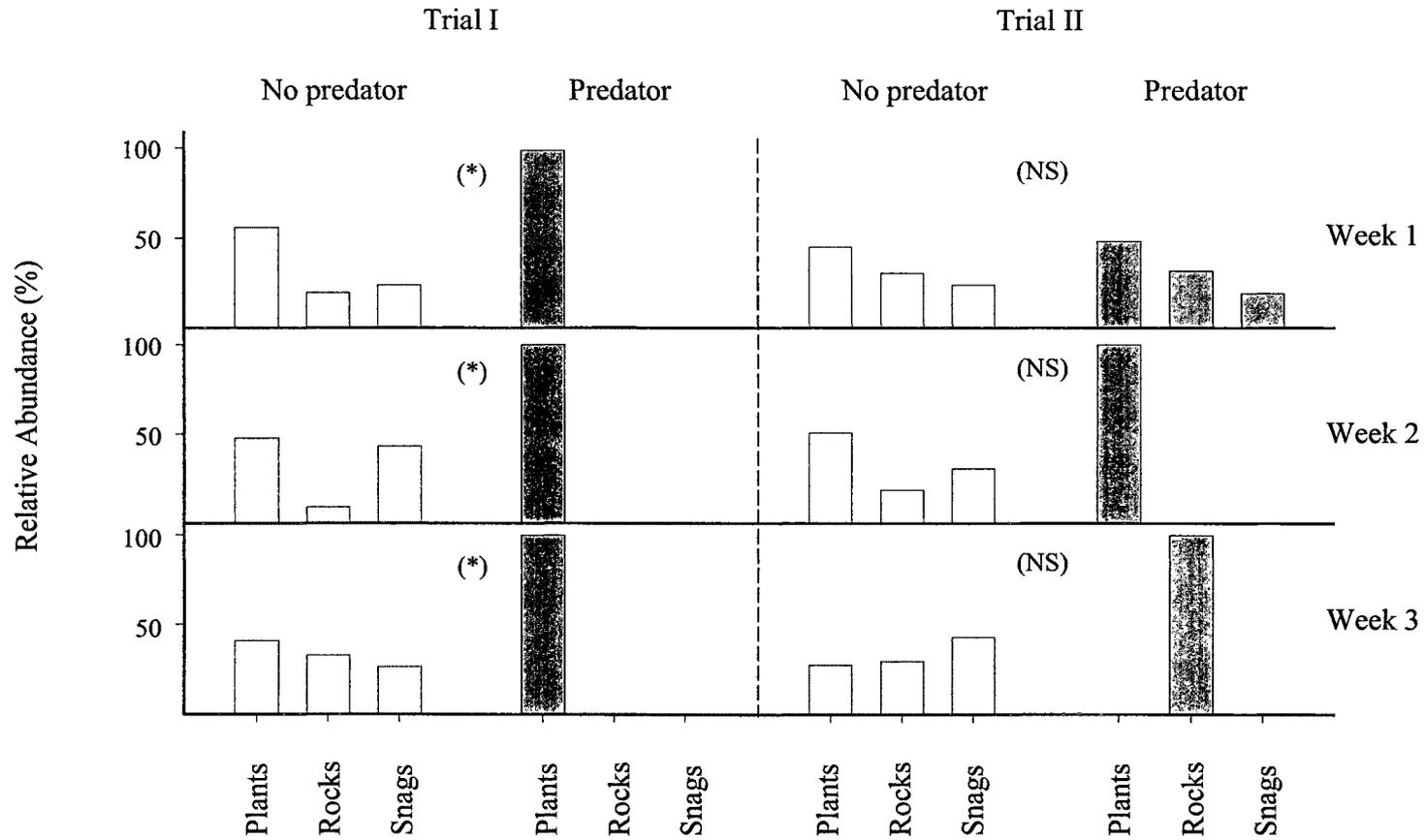


Figure 10.—Relative abundance of *Dionda* spp. observed in three substrate habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

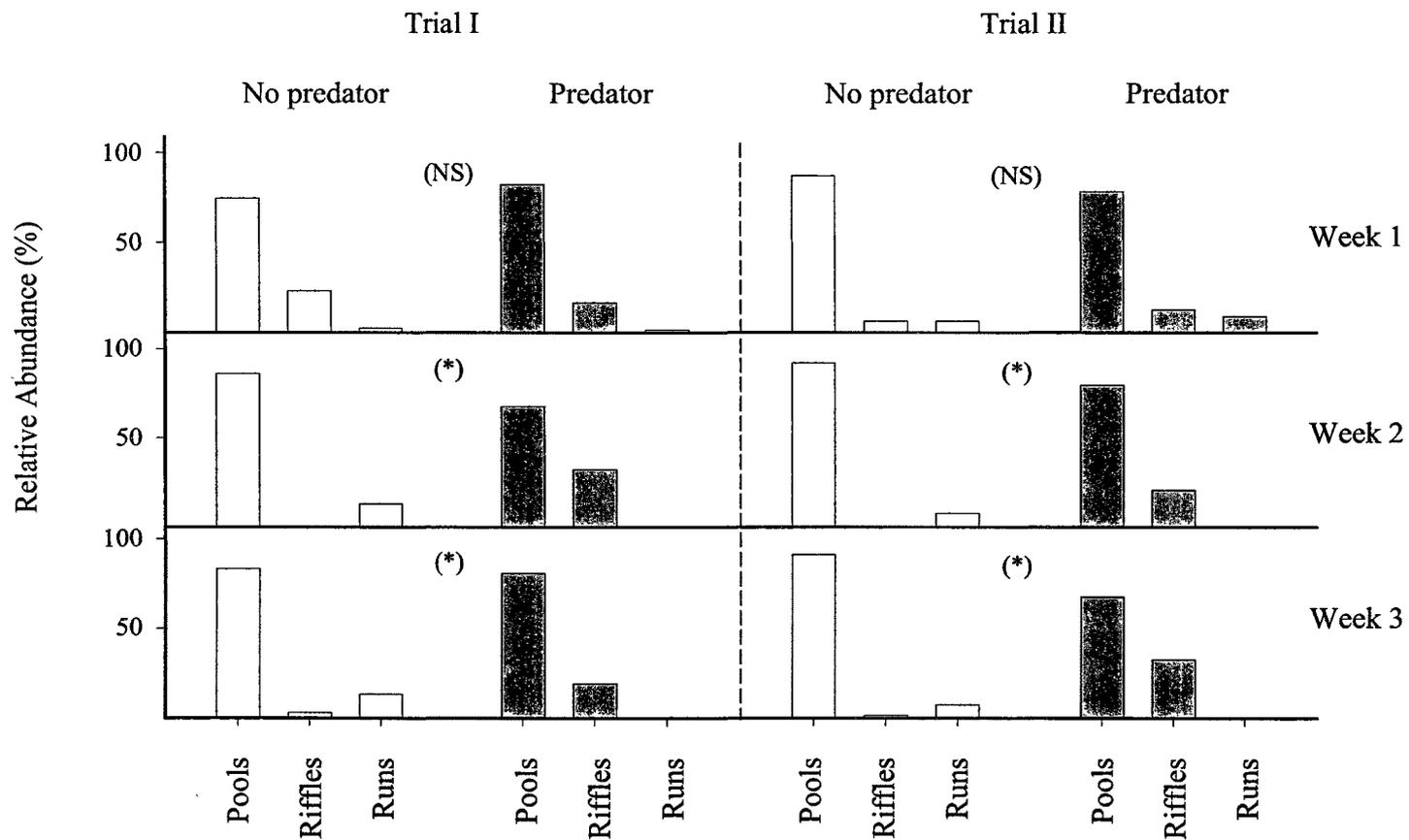


Figure 11.—Relative abundance of *Gambusia speciosa* observed in three stream macrohabitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

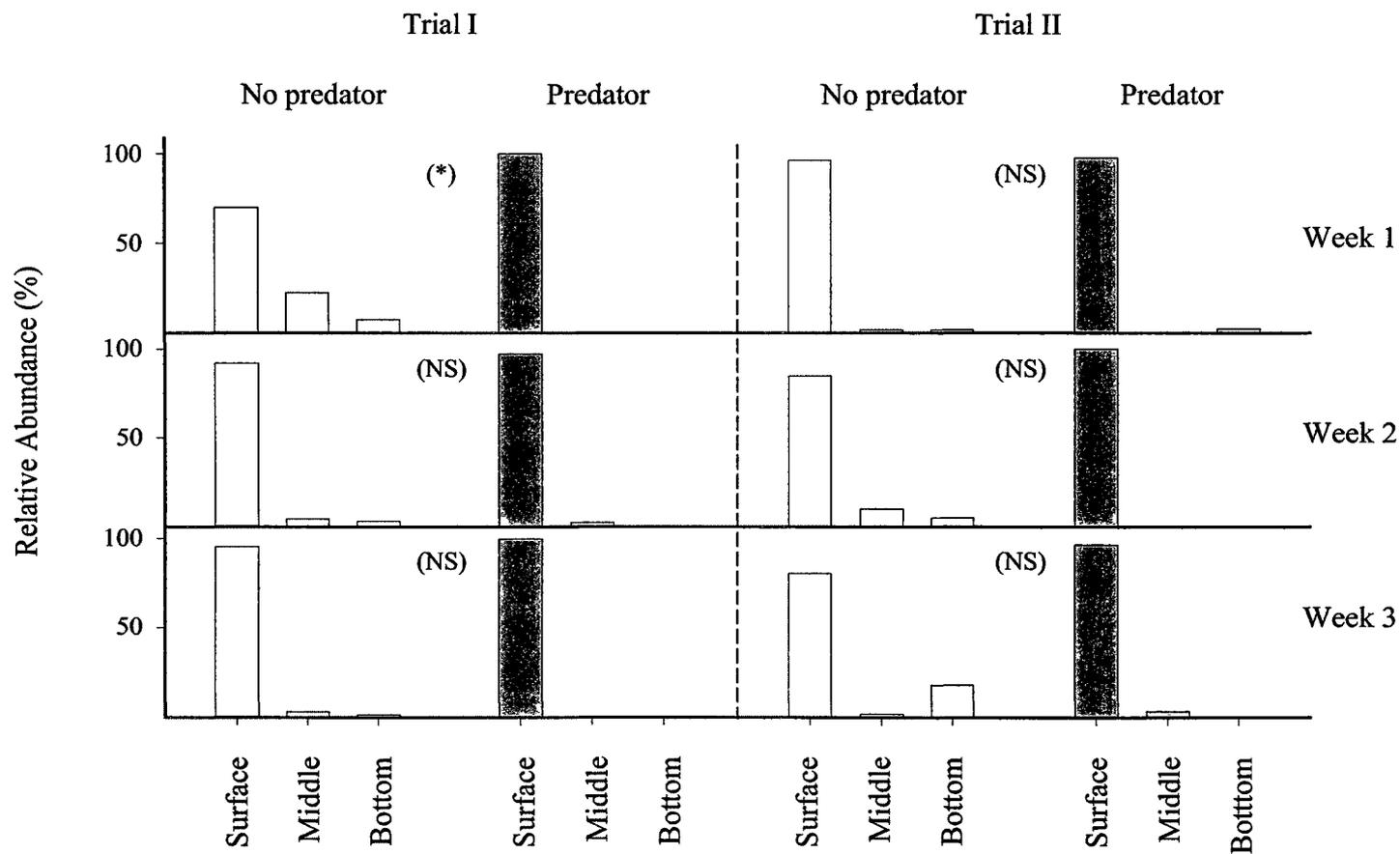


Figure 12.—Relative abundance of *Gambusia speciosa* observed in three vertical habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

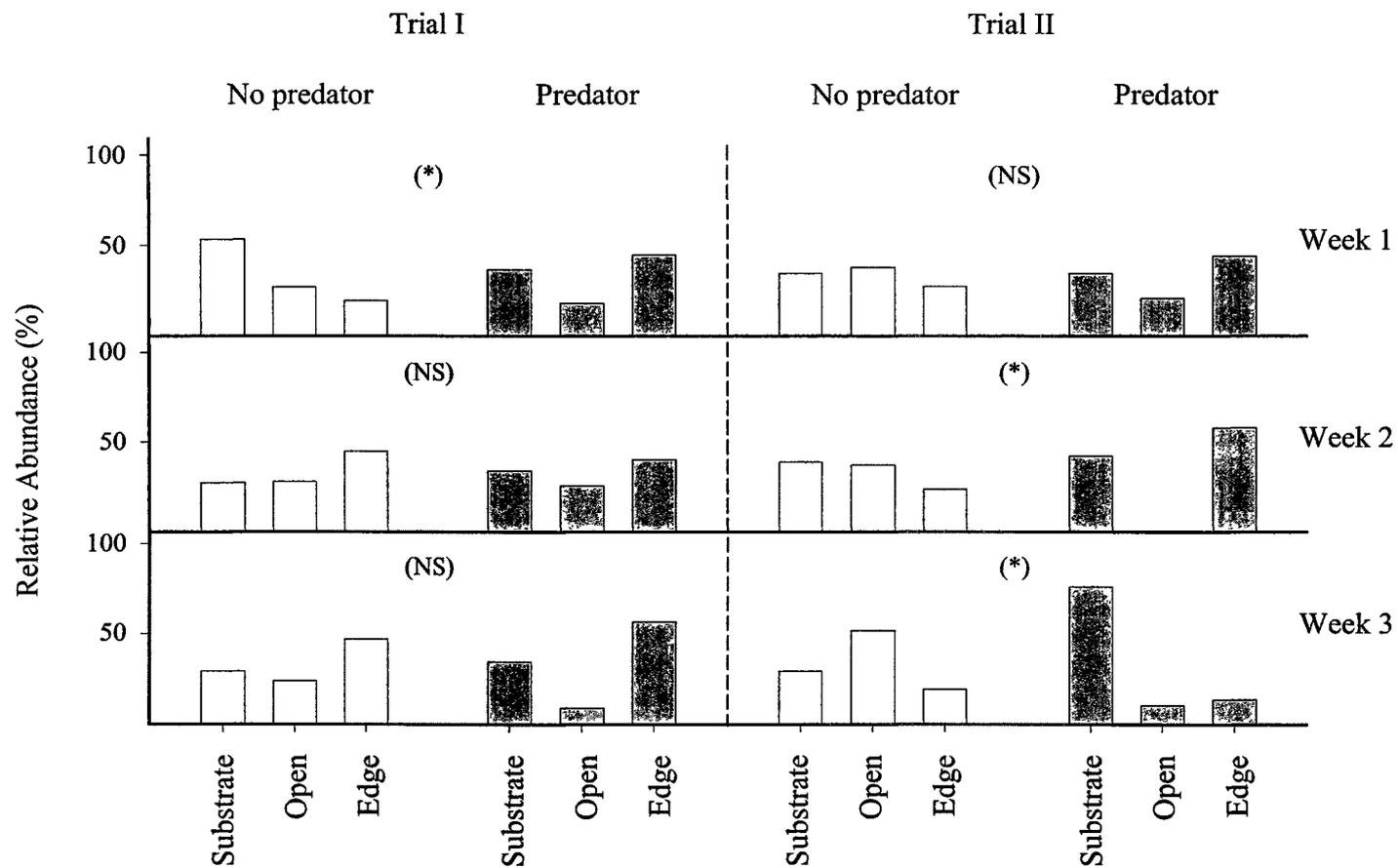


Figure 13—Relative abundance of *Gambusia speciosa* observed in three horizontal habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

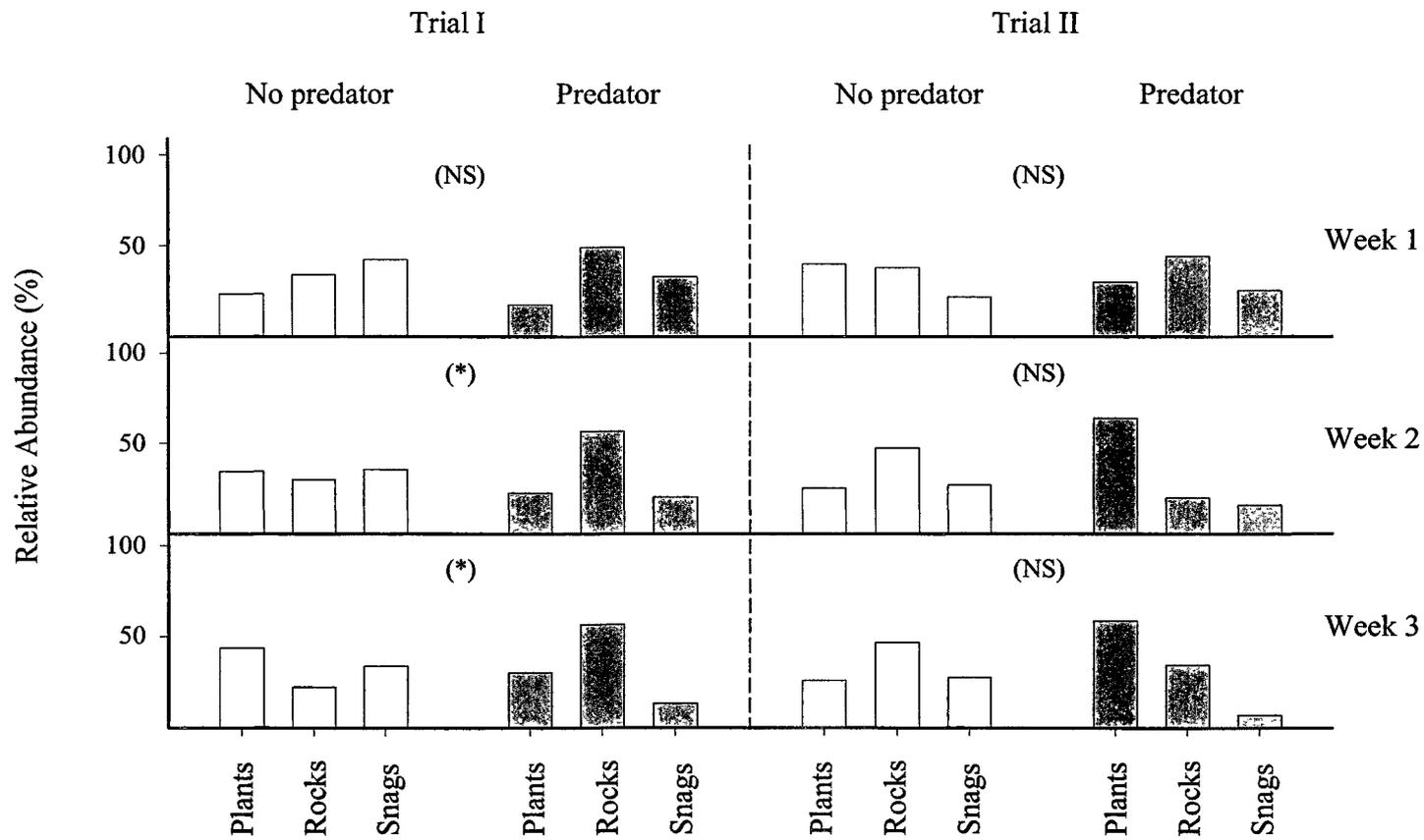


Figure 14.—Relative abundance of *Gambusia speciosa* observed in three substrate habitats of two artificial streams during Trials I and II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

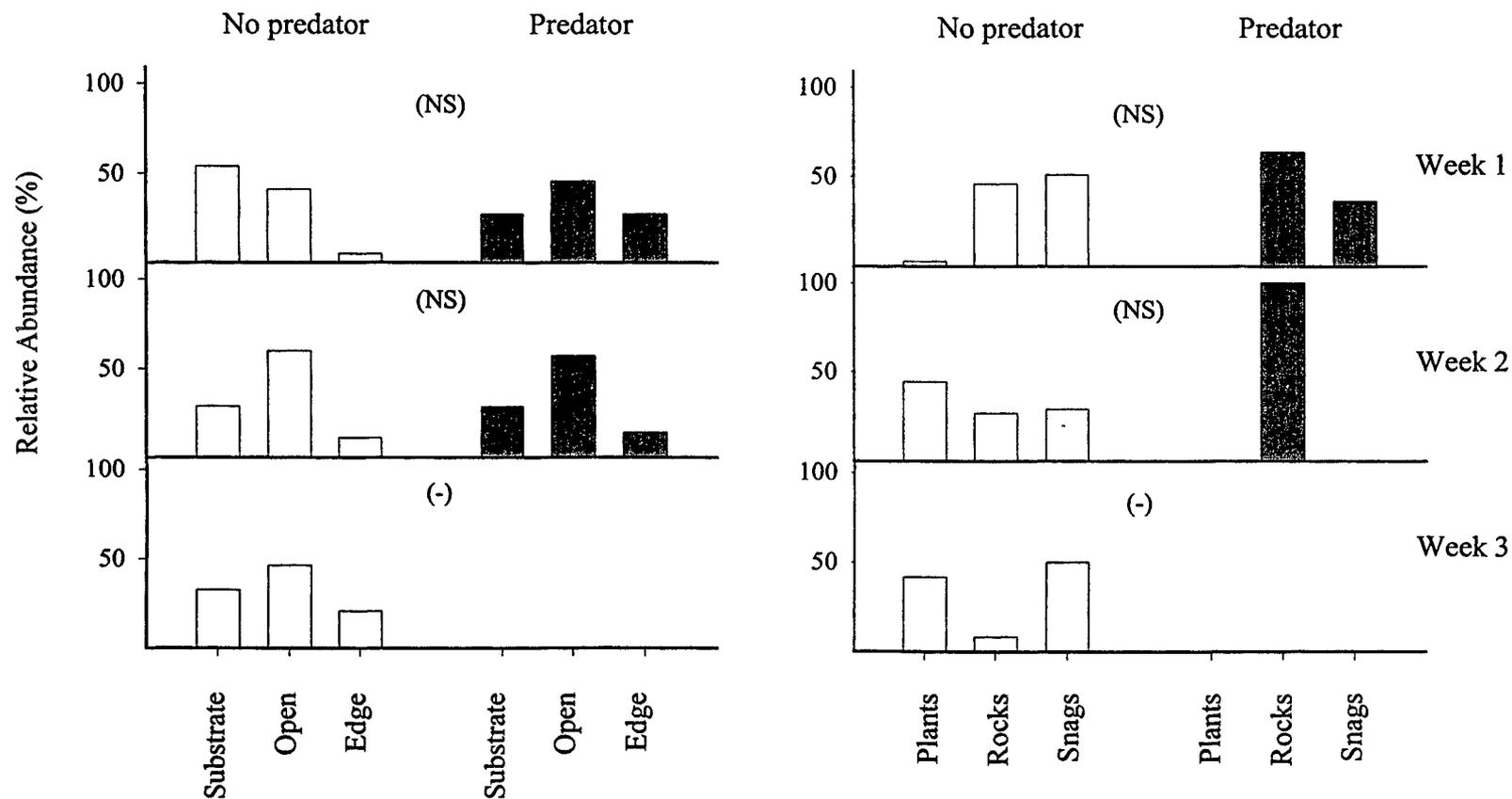


Figure 16—Relative abundance of *Cyprinella proserpina* observed in three horizontal habitats and three substrate habitats stream macrohabitats of two artificial streams during Trial II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

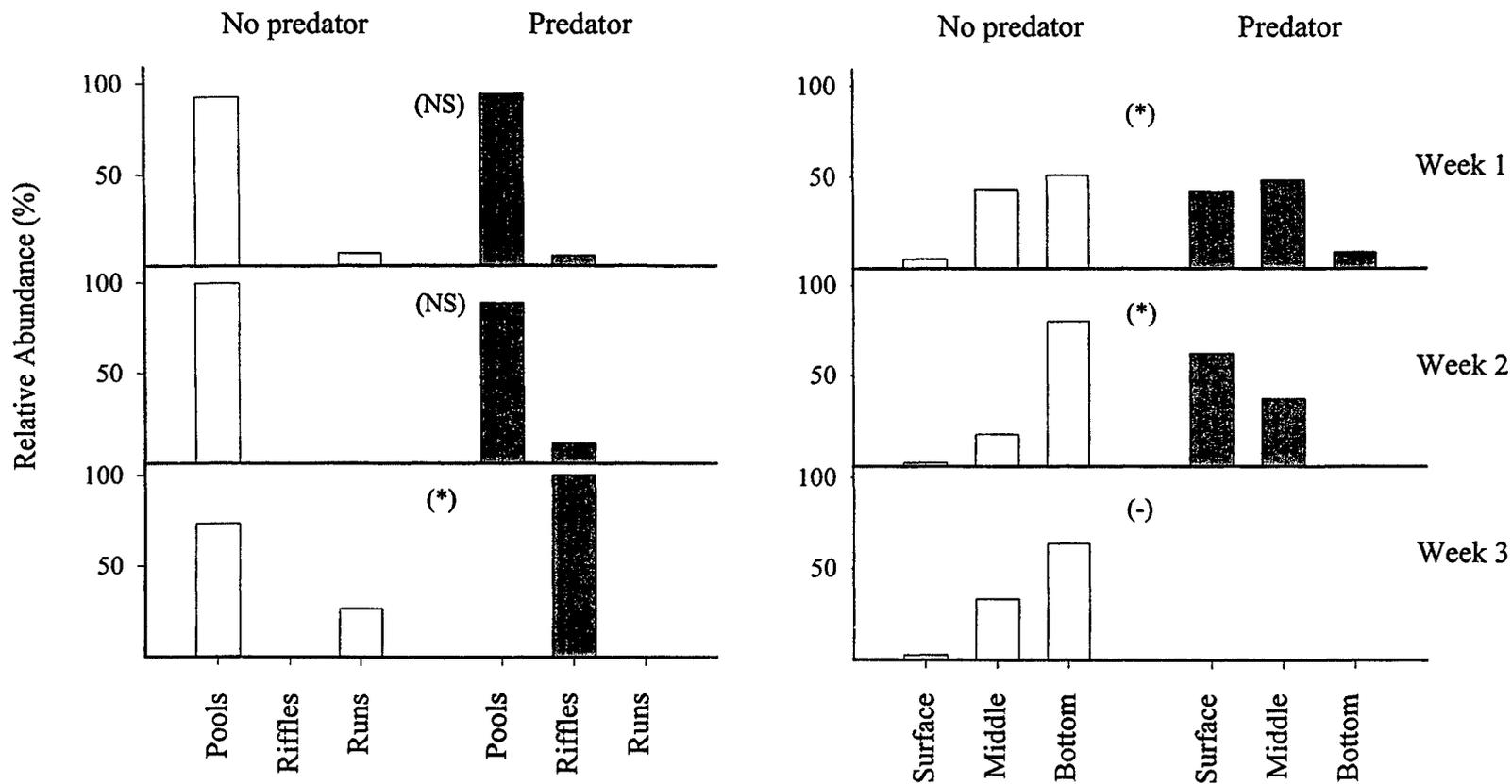


Figure 15.—Relative abundance of *Cyprinella proserpina* observed in three stream macrohabitats and three vertical habitats of two artificial streams during Trial II. Asterisk denotes difference ($\alpha = 0.05$) between fish distributions in the control (no predator) and treatment (predator) streams, "NS" denotes no significant difference and "-" denotes no statistical test performed.

