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Diet and Abundance of Southern Two-lined Salamander Larvae (*Eurycea cirrigera)* in Streams within an Agricultural Landscape, Southwest Georgia

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Abstract - We sampled five stream reaches within an agricultural landscape in southwestern Georgia for benthic macroinvertebrates and larval amphibians from 2002 to 2003 to determine whether cattle grazing impacts these faunal components. Two of the stream reaches had been fenced to exclude cattle (buffered), whereas the other three were not, allowing cattle access to the streams (unbuffered). We captured larval *Eurycea cirrgera* (Southern Two-lined Salamanders) incidentally in our benthic samples and compared salamander capture rates between buffered versus unbuffered streams. We also examined salamander stomach contents relative to the composition and abundance of benthic macroinvertebrates, comparing these data by stream type as well. Overall, capture success for larval salamanders was higher at buffered sites. Midge larvae (family Chironomidae) were the most frequent invertebrate taxon detected, both in the benthic and stomach content samples; however, we also observed cladocerans, copepods, and ostracods in each sampling regime. A linear electivity index revealed that larval Southern Two-lined Salamanders showed slight dietary selection for midge larvae in the subfamily Tanypodinae. This finding, coupled with the observation that chironomid larvae composed over half of Southern Two-lined Salamanders stomach contents, suggests some preference or selection for this benthic group. However, larval Tanypodinae were found at all sites, suggesting that their identification to species level may be necessary to determine whether differences in the prey base explained differences in salamander selectivity between buffered versus unbuffered streams. Factors other than prey selectivity, such as instream habitat quality, may also have influenced larval salamander abundance.

Introduction

Agrarian activities pose a threat to streams by altering natural flow regimes or disrupting instream and riparian habitat through chemical and physical changes (Schultz et al. 1995). These changes can also alter benthic macroinvertebrate assemblages that constitute a major prey base for larval salamanders (Davis 2000, Muenz et al. 2006, Strand and Merritt 1999). Although changes in the macroinvertebrate fauna resulting from agricultural activities have been relatively well documented, the repercussions on aquatic predators such as larval salamanders are largely unknown. Here we report on the diet of larval *Eurycea cirrgera* Green (Southern Two-lined Salamanders) collected in benthic macroinvertebrate samples from Coastal Plain streams in southwest Georgia as part of a larger study examining the

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impacts of cattle grazing on stream health (Muenz et al. 2006). Specifically, we examined (1) stomach contents of larval salamanders in streams with and without cattle access, and (2) prey selection relative to prey available in the environment.

The Southern Two-lined Salamander: Ecological background

Many plethodontid salamanders, including *E. cirrigera*, have aquatic larvae that require instream habitat for development and survival (Petranka 1998). Southern Two-lined Salamanders occupy a wide array of stream habitats throughout their geographic range, from southern West Virginia to eastern Illinois and south into northern Florida and eastern Louisiana. Adult and juvenile Southern Two-lined Salamanders inhabit stream margins, but the larvae are totally aquatic (Duellman and Wood 1954) and typically occur in the benthos of slow-moving pools (Petranka 1998). In general, larvae avoid silty, highly embedded areas of streams and tend to occupy those areas with the greatest amount of available suitable substrate (Smith and Grossman 2003). Throughout their 2- to 3-year larval period, Southern Two-lined Salamanders feed on the streambed using chemical, tactile, and visual cues to locate prey, including various macroinvertebrates such as plectoperans, dipterans, and crustaceans (Caldwell and Houtcooper 1973; Petranka 1984, 1998). Petranka (1984) described larval Southern Two-lined Salamanders as being opportunistic generalists, feeding on the same type and size of prey over the entire larval period. However, Zaret (1980) found that larval Southern Two-lined Salamanders are gape limited.

Materials and Methods

Study-site description

All streams were located on a diversified row crop and beef cattle farm in Early County, GA, in the Fall Line Hills physiographic district. The area is characterized by frequently meandering streams underlain by easily eroded sands, clays, and gravel. Streams are typically located 15–75 m below the adjacent ridge tops, experience extensive erosion (Southwest Georgia Regional Development Center 2005), and receive considerable amounts of ground-water discharge (Couch et al.1996). Average monthly temperatures in the region range from 3–15 °C in January to 21–33 °C in July (SERCC 2004). Average annual precipitation is 142 cm, with the average minimum monthly rainfall occurring in October (7 cm) and the maximum in January (16 cm) (SERCC 2004).

Five 100-m stream reaches were selected for physical, chemical, and biological assessment. All were located in the Factory Creek sub-watershed, a 2nd-order tributary of the Lower Chattahoochee River. Three stream sites were unfenced, permitting cattle access (unbuffered), herein referred to as UB-1, UB-2 and UB-3, and two had been fenced (buffered) for >20 years to limit cattle access, B-1 and B-2 (M. Brownlee, property owner, Blakely, GA, pers. comm.). Total floodplain width in the study area ranged from 15 to 30 m. The canopy cover in the riparian area was dominated by *Magnolia grandiflora* L. (Southern Magnolia), *M. virginiana* L. (Sweetbay Magnolia), *Nyssa biflora* Walter Sarg. (Swamp Tupelo), *Liquidambar styraciflua* L. (Sweetgum), and *Liriodendron tulipfera* L. (Tulip Tree). All streams were perennial, with an average width of 2.0 m, an average depth of 0.09 m, and an average velocity of 0.01 m/s. Stream temperatures ranged from 12.1 °C in December to 23.3 °C in August, and dissolved oxygen from 4.4 mg/L in October to 9.2 mg/L in February.

Macroinvertebrate and larval salamander collection

Invertebrates and salamander larvae were collected bimonthly from February 2002 to February 2003 with a 500-µm mesh Hess sampler (Wildco®, Buffalo, NY). Collections were made between 09:00 hrs and 16:00 hrs (EST). Three randomly selected transects were established within each 100-m reach. At each transect, two composite Hess samples were taken in representative habitat types within the stream channel. Samples were rinsed into plastic bags, preserved in the field with 70% ethanol, and stained with rose bengal dye. In the laboratory, samples were rinsed through a 1-mm and 500-µm sieve. Salamander specimens were identified (Petranka 1998), and their snout–vent length (SVL) measured in mm. Invertebrates from salamander gastrointestinal (GI) tracts as well as Hess-sampler collections were counted and identified to the lowest taxonomic level possible, usually order or family, but in some cases to genus (Berner and Pescador 1988; Epler 1996, 2001; Needham et al. 2000; Pescador et al. 1995; Stewart and Stark 1993; Thorp and Covich 2001; Wiggins 1996). Larval Chironomidae (Diptera) captured in the Hess sampler in February and August 2002 were mounted on slides and identified to genus (Epler 2001). Samples with >500 individuals were subsampled; three 5-ml subsamples (Hax and Golladay 1993) were taken from each original sample. Larval chironomids within salamander GI tracts were processed in a similar manner, and identified to genus when possible.

Chemical and physical measurements

Grab samples (500 mL) were collected biweekly from each stream to determine nutrient concentrations and bacterial and sediment levels (see Muenz et al. 2006). Physical characterizations of each stream included descriptions of general land use, stream origin and type, and measurements of stream bankfull width and depth. Stream flow velocity, depth, temperature, and dissolved oxygen concentrations were also measured at each site (see Muenz et al. 2006). Stream substrate composition (sand, gravel, roots, etc.) was estimated visually across each cross-stream transect using the line-intersect method (Davis 2000).

Statistical analysis

A Kruskal-Wallis Test ($P < 0.05$) (SAS Institute, Inc. 2002) was used to compare physical, vegetative, and water-quality parameters, and macroinvertebrate metrics among sites (see Muenz et al. [2006] for further description of analytical procedures). Salamander abundance by site was also compared using a Kruskal-Wallis Test ($P < 0.05$).

We used Strauss' (1979) linear index of feeding electivity to evaluate prey selection. Strauss' index was selected because it addresses potential biases based on dissimilar sample sizes of gut contents and habitat, and is considered to be a more statistically reliable index with a less complex variance structure (Strauss 1979). The linear index is calculated as follows:

$$L = r_i - p_i,$$

where r_i is the relative abundance of each prey item (i) in the gut, and p_i is the relative abundance of each prey item in the habitat. This index gives a value ranging from -1 to +1, with values near zero indicating neutral selection or opportunistic feeding, positive values indicating selectivity for a prey item (relative to its availability in the habitat), and negative values indicating avoidance. For this study, relative patterns were reported based on whether scores were positive or negative. Only those taxa represented in both the salamander stomach contents and the Hess collections (environment) were used. Due to the mesh size of the Hess sampler and invertebrate sieving methods, smaller crustacean taxa (e.g., Cladocera, Copepoda, and Ostracoda) were not retained in the habitat samples and thus were not available for electivity calculations. Therefore, we focused on larval chironomids.

Results

Salamander abundance

Forty Southern Two-lined Salamander larvae were recovered from the 210 Hess collections, their SVL values ranging from 7 to 35 mm (median = 14.5 mm). Larvae were collected during every sampling date and at all study sites except UB-2, with >90% of larvae collected from the two buffered sites B-1 ($n = 18$) and B-2 ($n = 20$). The total number of captures was significantly higher at buffered sites than unbuffered sites ($P < 0.0001$).

Physical and chemical parameters

Differences in physical and chemical measurements between buffered and unbuffered sites were apparent in this study. As detailed in Muenz et al. (2006), variability occurred among sites and treatments, but overall, buffered sites showed lower and more stable concentrations of nutrients, sediment, dissolved oxygen, and bacterial levels (Table 1). Riparian habitat also appeared more stable at buffered streams, showing greater percentages of vegetative cover and leaf-litter cover (Table 1). Instream habitat also appeared to be more favorable at buffered sites, with higher percentages of leaf debris, wood/roots, and benthic organic matter (ash-free dry mass [AFDM]) (Muenz et al. 2006).

Benthic macroinvertebrate community

A total of 7560 individual organisms were identified, representing 30 genera. Collections were dominated by Diptera (87%), of which 88%

were chironomids, and Coleoptera (8%), of which 73% were in the family Elmidae. Average densities for chironomids, as well as for all taxa combined, were highest in August and December 2002 and lowest in February 2002 (Table 2, Fig 1). Within the Chironomidae, 70% were in the subfamily Chironominae, 27% in Tanypodinae, and 3% in Orthocladiinae. Larval Tanypodinae were present at all streams and did not differ in abundance between sites. The most common chironomid genera were: *Ablabesmyia, Polypedilum, Saetheria, Thienemannimyia, Zavrelimyia,* and members of the tribe Tanytarsini. A detailed explanation of macroinvertebrate variation between sites is provided by Muenz et al. (2006). Overall, buffered sites contained more unique taxa (Muenz et al. 2006), many of which are sensitive to disturbance (Lenat 1993). Buffered sites also harbored higher percentages of certain invertebrate groups that can be valuable indicators of water quality, including percentages of Crustacea, Amphipoda, and Decapoda, as well as more sensitive taxa, e.g., elmid beetles and Ephemeroptera, Plecoptera, and Trichoptera (EPT).

Salamander diet composition

Of the 40 salamander stomachs examined, 34 contained macroinvertebrates, from which we identified 293 prey items (Table 3). The relative number of dietary items varied among sample dates, with highest numbers in late summer/fall (August and October 2002) and lowest numbers in the summer (June 2002) and winter (December 2002 and February 2002/2003) (Fig. 1). Dipterans composed 60% of the stomach contents, of which 98% were chironomids—Chironominae (58.3%), Orthocladiinae (2.4%), and Tanypodinae (39.3%) (Table 3). Although chironomids from GI samples were difficult to identify to genus, possibly due to damage incurred during digestion, we identified the following genera: *Ablabesmyia, Microspectra, Polypedilum, Thienemannimyia,* and *Zavrelimyia.* Crustaceans accounted

Table 1. Average mean values for selected physicochemical measurements from all study sites, 2002–2003 (Kruskal-Wallis test with respective *P*-value; see Muenz et al. 2006).

Parameter	Unbuffered	Buffered	*P* value
Wood/roots, %	5.7	22	<0.0001
Leaves, %	17.7	16	0.0436
Exposed streambed, %	6.3	1	<0.0001
Canopy opening (over stream), %	13.3	7	<0.0001
AFDM, kg m^{-2} †	0.23	0.22	<0.0001
Apparent color, PtCo	70.3	28.5	<0.0001
Suspended solids, mg L^{-1}	4.1	0.8	<0.0001
pH††	5.2	5	N/A
Alkalinity††	7.7	4.3	N/A
F. coliform, col $100mL^{-1}$	410.3	196.5	N/A
NO_3-N, mg L^{-1}	0.54	0.57	<0.0001
PO_4-P, mg L^{-1}	0.02	0.01	<0.0001
NH_4-N, mg L^{-1}	0.05	0.02	<0.0001

† AFDM = ash-free dry mass.
†† Denotes measurements taken once during the entire study.

Table 2. Benthic macroinvertebrates collected by a Hess sampler at 5 stream sites in Early County, GA. Expressed as an average density (average individuals/m^2; rounded to the nearest whole number) with percentage of total organisms in parenthesis.

Taxon	Feb 2002	April 2002	June 2002	Aug 2002	Oct 2002	Dec 2002	Feb 2003
Amphipoda							
Crangonyctidae							
Crangonyx sp.	3 (2.2)	8 (2.4)	6 (1.6)	--	1 (0.3)	2 (0.4)	--
Coleoptera							
Elmidae							
Microcylloepus	1 (0.7)	10 (3.0)	5 (1.3)	1 (0.1)	2 (0.7)	1 (0.2)	1 (0.3)
Stenelmis (adult)	--	1 (0.2)	--	--	1 (0.3)	--	1 (0.4)
Stenelmis (larvae)	7 (4.6)	51 (15.0)	49 (13.0)	29 (3.9)	27 (8.4)	47 (8.6)	18 (5.7)
Decapoda	3 (2.2)	--	--	--	1 (0.3)	5 (0.9)	1 (0.4)
Diptera							
Ceratopogonidae	6 (4.1)	32 (9.4)	6 (1.5)	11 (1.4)	18 (2.6)	18 (3.3)	19 (2.9)
Chironomidae (other)	63 (41.2)	173 (51.1)	262 (69.4)	656 (89.0)	244 (75.7)	332 (60.9)	208 (65.7)
Tanypodinae	52 (34.0)	40 (11.6)	23 (6.1)	15 (2.0)	21 (6.5)	49 (9.0)	43 (13.7)
Simulidae							
Simulium sp.	2 (1.3)	--	1 (0.3)	4 (0.5)	--	1 (0.2)	1 (0.3)
Tipulidae							
Hexatoma sp.	1 (0.7)	1 (0.3)	5 (1.2)	--	--	--	--
Pseudolimnophila sp.	5 (3.3)	1 (0.3)	1 (0.3)	--	--	9 (1.7)	3 (1.0)
Tipula sp.	3 (1.7)	1 (0.3)	--	--	--	--	1 (0.3)
Ephemeroptera							
Baetidae	--	--	1 (0.3)	1 (0.1)	1 (0.3)	16 (3.0)	--
Heptageniidae							
Stenonema sp.	--	1 (0.3)	2 (0.5)	1 (0.1)	2 (0.7)	18 (3.3)	8 (2.5)

Table 2, continued.

Taxon	Feb 2002	April 2002	June 2002	Aug 2002	Oct 2002	Dec 2002	Feb 2003
Hemiptera							
Veliidae							
Rhagovelia sp.	--	2 (0.5)	1 (0.3)	4 (0.5)	3 (1.0)	--	--
Hydracarina	--	--	1 (0.3)	1 (0.1)	--	16 (2.9)	1 (0.3)
Odonata							
Caloptergidae							
Calopteryx sp.	1 (0.7)	--	1 (0.3)	--	--	--	1 (0.3)
Gomphidae							
Progomphus sp.	--	--	1 (0.4)	--	1 (0.3)	6 (1.1)	--
Plecoptera	2 (1.5)	6 (1.7)	--	--	--	--	1 (0.3)
Trichoptera							
Hydropsychidae							
Diplectrona sp.	1 (0.7)	--	1 (0.3)	--	--	--	5 (1.5)
Hydropsyche sp.	--	--	1 (0.3)	--	--	--	1 (0.3)
Lepidostomatidae							
Lepidostoma sp.	1 (0.7)	1 (0.3)	--	--	--	--	2 (0.5)
Leptoceridae							
Ceraclea sp.	--	--	1 (0.3)	--	--	--	--
Odontoceridae							
Psilotreta sp.	--	--	4 (1.1)	1 (0.1)	--	--	--
Average no. individuals	153	338	378	738	322	545	316

for 38% of total stomach contents and included the orders Cladocera (28%), Copepoda (6%), and Ostracoda (4%). Rare taxa (<2% of individuals) included Collembola, Coleoptera (Elmidae), and Hydracarina (Table 3).

Prey preferences

Strauss's linear index showed a wide range of individual and temporal variability in salamander electivity for different taxa (Fig. 2).

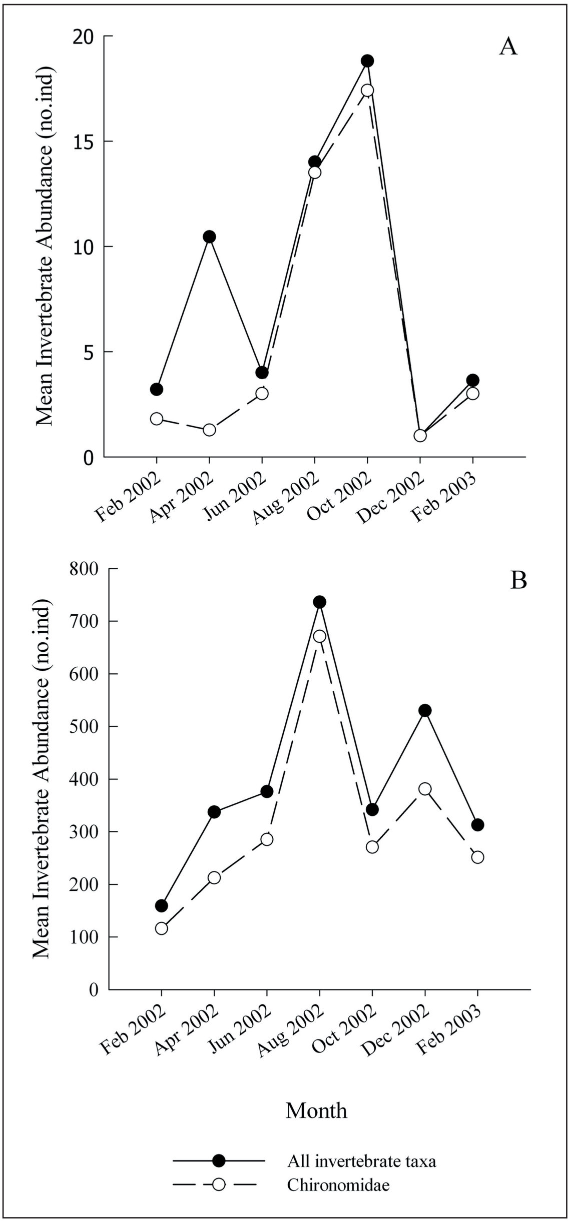

Figure 1. Aquatic invertebrate number of individuals for all taxa combined and for the family Chironomidae within (A) salamander gastrointestinal tracts and (B) benthic macroinvertebrate Hess collections from February 2002 to February 2003.

Table 3. Composition of invertebrate taxa within the diet of larval *Eurycea cirrigera* (Southern Two-lined Salamanders) collected in Early County, GA. The values are expressed as an average of the total number (and percent) of dietary items for each stomach per date. N = the number of stomachs examined.

Taxon	Feb 2002 *n* = 5	April 2002 *n* = 11	June 2002 *n* = 2	Aug 2002 *n* = 2	Oct 2002 *n* = 5	Dec 2002 *n* = 1	Feb 2003 *n* = 8
Coleoptera							
Elmidae larvae	0.2 (5.9)	--	--	--	--	--	--
Microcylloepus sp.	--	--	0.5 (12.5)	--	--	--	--
Unknown larvae	--	--	0.5 (12.5)	--	--	--	--
Collembola	0.2 (5.9)	--	--	--	--	--	--
Crustacea							
Chydoridae	--	7.4 (70.6)	--	--	--	--	--
Copepoda	--	0.9 (8.7)	--	--	--	--	--
Calanoida	--	0.3 (2.6)	--	0.5 (3.6)	--	--	--
Cyclopoida	--	0.1 (0.9)	--	--	--	--	--
Ostracoda	--	0.4 (3.5)	--	--	1 (5.3)	--	0.5 (13.8)
Diptera							
Ceratopogonidae	--	0.1(0.9)	--	--	--	--	2.4(65.4)
Chironomidae (unknown)	--	0.5 (4.3)	--	4.0 (28.6)	11.8 (63.8)	--	0.6 (17.2)
Chironominae	0.4 (11.8)	0.5 (4.3)	0.5 (12.5)	9.0 (64.3)	3.2 (17.0)	--	--
Tanypodinae	1.6 (47.1)	0.4 (3.5)	2.5 (62.5)	0.5 (3.6)	2.8 (14.9)	1 (100.0)	--
Empididae	0.2 (5.9)	--	--	--	--	--	--
Tipulidae	0.2 (5.9)	--	--	--	--	--	--
Unknown pupae	0.2 (5.9)	--	--	--	--	0.2 (1.1)	--
Hydracarina	--	--	--	--	--	0.2 (1.1)	--
Unidentified	0.4 (11.8)	0.1 (0.9)	--	--	--	--	--
Average no. of individuals	3.4	10.4	4.0	14.0	18.8	1.0	3.6

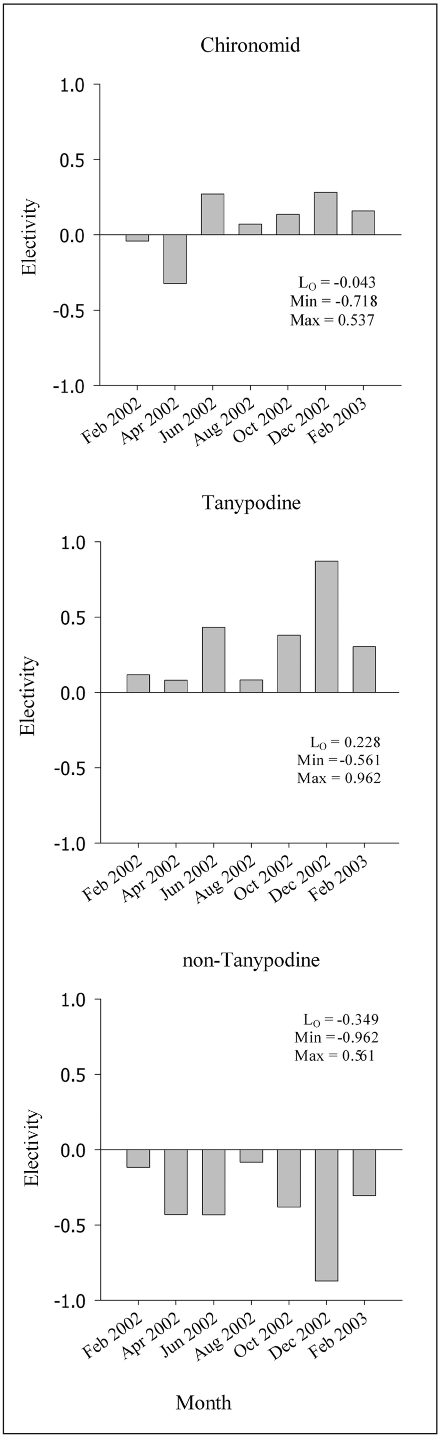

Figure 2. Linear electivity (Strauss 1979) for chironomid, tanypodine, and non-tanypodine midges collected from GI tracts of larval *Eurycea cirrigera* (Southern Two-lined Salamander) in Early County, GA. Electivity index values (L_0) are for all dates combined, and ranges of index values (reported as minimum and maximum values) are from all dates and individual salamander larvae in the study.

Selection for chironomid larvae was generally positive through time, except in February 2002 (no selection) and April 2002 (slight avoidance). Overall, indices suggest no selection for chironomids (L_0 = -0.043); however, selection for larval Tanypodinae was consistently positive through time, suggesting slight selection (L_0 = 0.228) for members of this subfamily, whereas selection for non-tanypodine chironomids was consistently negative, suggesting slight avoidance (L_0 = -0.349) of these taxa (Fig. 2).

Discussion

Eurycea spp. are considered to be opportunistic predators, feeding on whatever prey are available (Petranka 1984, Zaret 1980). However, our linear electivity indices suggested that Southern Two-lined Salamander larvae showed slight selection for tanypodine chironomids in the streams we surveyed. This finding, coupled with the observation that chironomid larvae composed over half of Southern Two-lined Salamander stomach contents, suggests some preference or selection for this group.

Numerous macroinvertebrate taxa collected in benthic samples were not found in salamander GI tracts; however, the dominant group, dipterans and more specifically, chironomids, occurred with similar frequency in both GI tracts and benthic collections. We found small benthic invertebrates, e.g., chironomid larvae, ostracods, copepods, and dipteran pupae to be the most frequently consumed prey, which corresponds with dietary reports for *Eurycea* species in the northern US (Burton 1976, Caldwell and Houtcooper 1973, Petranka 1984). However, Plecoptera (stonefly) nymphs, which were also common to these studies, were not ingested. Burton (1976) noted a seasonal shift in diet for *Eurycea bislineata* (Green) (Two-lined Salamander), with chironomids being an important prey source during warm weather and copepods being a common food source during cooler weather. However, we found chironomids to be a major prey source year round, composing at least 50% of individuals per sampling date, except in April, when chydorid crustaceans were the main prey type. Burton (1976) also found chydorids to be an important food item for *E. bislineata*, composing 61% of the total number of prey during October. In our study, there appeared to be low selection for tanypodine chironomids in April, even though abundances or availability of this taxon was high. In addition, strong negative selection for non-tanypodine midges overall was apparent (Fig. 2), perhaps reflecting the shift of selection to chydorids. Although chydorids were too small to be collected by the Hess sampler, their high abundance in GI tracts suggests that Southern Two-lined Salamanders may at times feed selectively on chydorids, and that prey consumption may reflect seasonal influences of macroinvertebrate distribution and abundance.

Chironomids are among the most widely distributed and abundant insects in freshwater ecosystems (Armitage et al. 1995). They display a multitude of morphological, physiological, and behavioral adaptations, as well as sensitivities to environmental stresses and disturbances (Armitage et al. 1995, Coffman and Ferrington 1996, Epler 2001). Under certain conditions, such as extreme levels of dissolved oxygen, temperature, and pH, common in agricultural systems (Schultz et al. 1995), larval chironomids may be the only abundant macroinvertebrates available as prey in the benthos (Muenz et al. 2006).

Factors other than abundance can play a role in prey selection, including those relating to general life history. For example, tanypodine larvae are epibenthic predators, crawling or swimming freely within the water column as they feed on oligochaetes and other soft-bodied invertebrates (Mason 1998). In contrast, Chironominae are more cryptic, living on or in the benthos in silk-lined tubes (Mason 1998). Petranka (1998) noted Southern Two-lined Salamanders use primarily visual cues to detect prey. Our study suggests that tanypodine larvae, being more conspicuous and mobile, are more likely to enter a larval salamander's visual field compared to other chironomids. Tanypodine larvae are characterized by a rather long bullet-shaped head capsule and an elongated thorax, and fourth instar larvae of certain species attain greater lengths than other midge subfamilies (Wiederholm 1983), perhaps making them more conspicuous.

We found that larval Southern Two-lined Salamanders were significantly more abundant in stream sites where cattle were excluded. Although larval salamander abundance was correlated with tanypodine abundance, these midge larvae occurred at all stream sites, suggesting that factors in addition to prey availability may dictate the abundance of larval *E. cirrrigera*. Muenz et al. (2006) found no relationship between larval salamander and invertebrate abundance, or between larvae and examined water-quality parameters. However, influences from microhabitat requirements, and more specifically, the amount of organic matter present within the stream, may have affected larval differences.

Cattle grazing can alter stream habitat and function by increasing sedimentation and nutrient inputs, degrading riparian and in-stream habitat, and changing aquatic biota community composition. Such changes can decrease overall aquatic insect diversity while increasing more disturbance-tolerant taxa (Strand and Merritt 1999, Thomas 2002). Tanypodine chironomids as a group exhibit a wide range of tolerance levels to the disturbances described above; however, some species are highly sensitive (e.g., *Paramerina*; Lenat 1993). If Southern Two-lined Salamander larvae select prey that are sensitive to disturbance, this salamander species may have utility as a biological indicator of stream health. However, further knowledge of their diet (i.e., species-level identification of prey) and additional data on larval habitat requirements are needed.

Lastly, studies that address life-history requirements of both predator and prey (e.g., microhabitat) and the effects of disturbance on this interaction are needed to determine whether agricultural land uses play a role in shaping their distribution and abundance. If Southern Two-lined Salamanders forage selectively on prey that are sensitive to disturbance, then conservation of stream habitats is important. Knowledge of life-history responses to land-use changes would help identify the utility of larval salamanders as biological indicators of stream health.

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