Dietary Variability of the Rainbow Darter (*Etheostoma caeruleum*) in Northwestern Pennsylvania

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Abstract - *Etheostoma caeruleum* (Rainbow Darter) is a member of a diverse benthic insectivorous feeding guild. In streams with high diversity of fishes, niche partitioning by food items is one method for determining overall resource partitioning. The objective of this study was to gain insights into the foraging habits of Rainbow Darters, specifically in communities where there are varying degrees of overlap with other benthic species. This includes the exotic *Neogobius melanostomus* (Round Goby) and other native darter species. We collected Rainbow Darters and aquatic benthic macroinvertebrate samples at 3 streams located in northwestern Pennsylvania in the late summer of 2013, when prey abundance was seasonally lowest. We dissected fish, removed their stomachs, and identified the gut contents to lowest practicable taxon, which we tallied. Macroinvertebrate samples were sorted, identified to lowest practicable taxon, and enumerated. We used these data to calculate Strauss' linear index of food selection for prey items occurring in greater than 1% of stomachs. Chironomids were consistently an important item in Rainbow Darter diets in Elk Creek, but they consumed a higher proportion of Hydropsychidae when the Round Goby was present. Species of Baetidae were the most important food item when other darter species occurred, with chironomids consumed at the same proportion as found in the stream. These results serve as further evidence of food resource partitioning as a potential mechanism for coexistence with other native species or with the introduction of an exotic species.

Introduction

Etheostoma caeruleum Storer (Rainbow Darter) belongs to the family Percidae, which is the second largest family of fish (in number of species) in North America (Steiner 2000). Percids are found throughout the northern hemisphere, but the tribe Etheostomatini, which includes darters, is endemic to North America (Collette 1967). There are over 200 species of darters (Page et al. 2013), 15 of which exist in the Allegheny watershed. Thirteen species have been collected within a 100-m riffle in certain areas (Stauffer et al. 1996). With such high levels of syntopy, resource partitioning is critical and generally occurs by habitat, food, and time in decreasing order (Schoener 1974). For darters, their niche may be partitioned by substrate (Gray and Stauffer 2001, Gray et al. 2005, Hlohowskyj and Wissing 1986, Klesser and Thorp 1993, Stiles 1972), depth (Chipps et al. 1994, Fisher and Pearson 1987), flow (Fisher and Pearson 1987, Matthews 1985), temperature (Ingersoll and Clausen 1984), and diet (Hlohowskyj and White 1983, Martin 1984, Paine et al.

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1982, Smart and Gee 1979). Microhabitat can be challenging to quantify in aquatic habitats, but partitioning by food items has been documented (Ross 1986, Schoener 1974) and is examined herein.

The Rainbow Darter is a benthic, insectivorous fish that resides in riffles with gravel, pebble, and cobble substrates (Adamson and Wissing 1977, Harding et al. 1998). Rainbow Darters are visual, diurnal feeders (Adamson and Wissing 1977, Greenberg 1991, Vogt and Coon 1990) with the greatest food intake during morning and early evening hours (Adamson and Wissing 1977). Gray et al. (1997) determined that Rainbow Darters have a moderate niche breadth, eating 4 or more taxa of macroinvertebrates including the following families: Chironomidae, Simuliidae, Hydropsychidae, Elmidae, Ephemerellidae, and Heptageniidae. Previous studies have echoed these results emphasizing that Ephemeroptera, Trichoptera, and Diptera (primarily Chironomidae), are often found in diets of Rainbow Darters (see Hlohowskyj and White 1983, Martin 1984, Paine et al. 1982, Stauffer et al. 2016, Stewart 1998, Turner 1921, and Wehnes 1973).

The purpose of this study is to describe the diet variability of the Rainbow Darter in 3 populations with varying degrees of competition. In Woodcock Creek (Allegheny River watershed), 4 species of darters co-occur with the Rainbow Darter. In Elk Creek (Lake Erie watershed) at the downstream site, *Neogobius melanostomus* (Pallas) (Round Goby) were present, with the Rainbow Darter being the only darter species documented there. At the Elk Creek upstream site, neither Round Goby nor other darter species were found.

Field-Site Description

We chose 3 populations of the Rainbow Darters in northwestern Pennsylvania for comparison. We selected 2 sites on Elk Creek, a tributary to Lake Erie in Erie County, PA. The downstream site on Elk Creek is 750 m upstream of the mouth. We selected this site because of the presence of the exotic Round Goby and a lack of other darter and perch species (Stauffer et al. 2016). The extant of the riffle sampled varied depending on water flow. We sampled throughout the riffle beginning at the upstream point near 42°01'11"N, 80°22'18"W (Fig. 1). Elk Creek is divided into 2 parts by a waterfall, which thus far has inhibited the movement of the Round Goby upstream (Stauffer et al. 2016). Therefore, the site upstream of the waterfall was selected because the Round Goby and other darter species were absent (Stauffer et al. 2016). The riffle sampled began near 42°00'26"N, 80°21'16"W (Fig. 1).

Woodcock Creek, a tributary to French Creek (Allegheny River Watershed) was the most southern site, located in Crawford County, PA. The riffle sampled began near 41°41'46"N, 80°06'49"W (Fig. 1). Throughout the sampling period, other percids including *Etheostoma zonale* (Cope) (Banded Darter), *Etheostoma variatum* Kirtland (Variegate Darter), *Etheostoma blennioides* Rafinesque (Greenside Darter), *Etheostoma flabellare* Rafinesque (Fantail Darter), and *Percina caprodes* (Rafinesque) (Logperch) were captured.

Methods

We sampled fishes and macroinvertebrates once a month at each site in July, August, and September 2013 with varying degrees of success due to high water velocity and depth; thus, Rainbow Darters were not collected at every site each month. We collected fishes 10 minutes after collecting of macroinvertebrates, so as to not disrupt collections of aquatic macroinvertebrates. We sampled fishes using a 3 m x 1 m, 0.63-cm mesh seine. We only retained Rainbow Darters from each site and immediately placed all specimens in a buffered MS222 solution to avoid regurgitation of stomach contents. We then fixed the fish in 10% formalin for permanent storage in 70% ethanol at the Penn State Fish Museum following Penn State Institutional Animal Care and Use Committee protocol #42210.

In the laboratory, we removed the entire digestive tract through the ventral side of each fish, and opened and cleared the tracts using dissection tools. We used a dissecting microscope to identify and enumerate stomach contents to the lowest

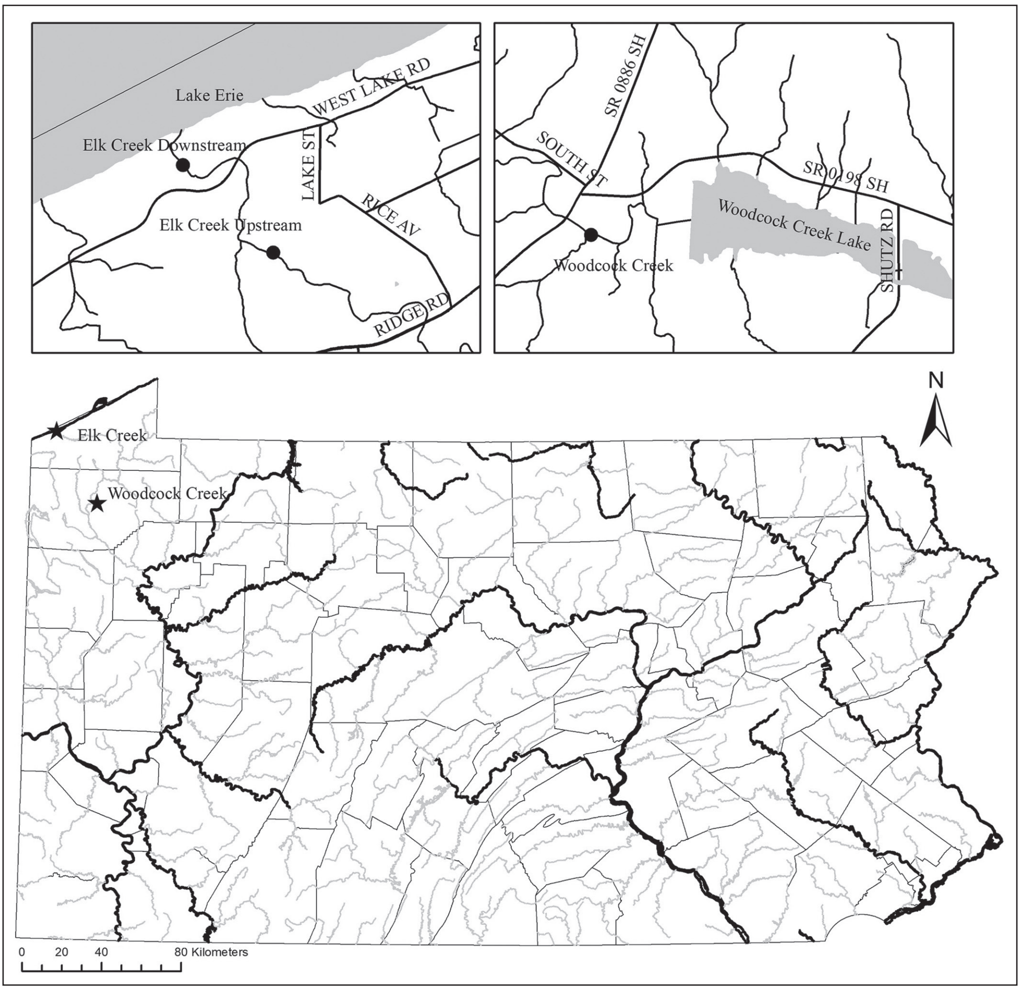

Figure 1. Map of field sites in northwestern Pennsylvania.

practicable taxa. Due to the partial digestion of most prey items, the lowest practicable taxon was often family. We stored stomach contents in 70% ethanol.

For each sampling event, we made nine 20-second kicks into a D-frame kicknet to collect aquatic macroinvertebrates. Frost et al. (1971) demonstrated that a total of 3 minutes using this method sampled at least 90% of the representative benthic macroinvertebrate taxa. We preserved macroinvertebrate collections in 70% ethanol. In the laboratory, we sorted, identified, and enumerated these samples. We placed like taxa in individual vials by site in 70% ethanol for permanent storage. Peckarsky et al. (1990), Merritt and Cummins (1995), and Wiggins (2000) served as primary identification guides for identification of all macroinvertebrate and stomach contents.

We calculated Strauss' (1979) linear index of food selection using the equation $L = r_i - p_i$, where r_i is the proportion a prey item is found in an individual stomach, and p_i is the proportion the same prey item is found in the environment. We determined electivities for each Rainbow Darter based on the macroinvertebrate sample taken during the same collecting event. This method takes into account any differences in resource availability among sites or months. Then, we pooled electivities across months since July–September is categorized as a period of low prey availability by Schlosser and Toth (1984). We calculated this index for prey items that were found in greater than 1% of stomachs (Hlohowskyj and White 1983, Stewart 1988). Strauss' (1979) index varies from -1 to 1, where values less than -0.3 and greater than 0.3 are biologically meaningful.

Results

A total of 193 Rainbow Darters was collected over the sampling period. Rainbow Darters were found at the Elk Creek downstream site in July and August, at the Elk Creek upstream site in September, and at the Woodcock Creek site in August and September 2013. We collected 125 Rainbow Darters from the downstream site on Elk Creek in July (n = 72) and August (n = 53), 3 of which had empty stomachs and were not used in analysis; 20 Rainbow Darters from the upstream site in September, none of which had empty stomachs; and 48 Rainbow Darters from Woodcock Creek in August (n = 43) and September (n = 5), 3 of which had empty stomachs. We detected a total of 17 different prey items in the stomach contents, only 9 of which comprised greater than 1% of the contents by number.

Average Strauss' food selectivity index (L) values can be found in Table 1. Families with the greatest index values include Chironomidae, Simuliidae, Baetidae, and Hydropsychidae. Miscellaneous food items occurring in less than 1% of the stomachs included members of: Perlidae, Elmidae, Gammaridae, Psephenidae, Tipulidae, Leptohyphidae, and Heptageniidae. Additionally, oligochaetes were also found in less than 1% of stomachs. Taxa from the family Chironomidae were consistently an important part of the diets of Rainbow Darter in Elk Creek with index values of 0.55 and 0.68 at the downstream and upstream sites, respectively. Rainbow Darters ate a lower proportion of Hydropsychidae in Elk Creek at the upstream site than was found in the stream (index value of -0.31). Baetidae was the most important food item in Woodcock Creek with an index value of 0.31.

Discussion

The diets of the Rainbow Darters in this study were consistent with previous studies. Only Psychomyiidae was not reported in other studies. When other darter species and Round Gobies were absent, at the upstream Elk Creek site, Rainbow Darters had the highest positive electivity for chironomids (L = 0.68) and ate lower proportions of other families commonly found in the environment. Baetids and hydropsychids comprised 67.56% of the benthic macroinvertebrate community, but were only found in less than 60% of stomachs, with L= -0.25 and -0.31, respectively. These taxa, however, were consumed when Rainbow Darters co-existed with other benthic species. While the proportion of chironomids consumed was still high when sharing habitat with the Round Goby (L = 0.55), the near zero values for Baetidae (L = -0.08) and Hydropsychidae (L = -0.02), which were avoided at the upstream site, suggests that competition for benthic macroinvertebrates may impact Rainbow Darter foraging. French and Jude (2001) indicated that Rainbow Darters, small Round Gobies, and *Proterorhinus semilunaris* (Heckel) (Western Tubenose Goby) overlapped in diet. While Western Tubenose Gobies are not yet found in Elk Creek but are present in Lake Erie, diets of Round Goby from this stream include chironomids, baetids, hydroptilids, leptohyphids, polycentropodids and other miscellaneous food items (Stauffer et al. 2016). Stauffer et al. (2016) reported that Chironomids were the only prey eaten by Round Gobies in Elk Creek at a higher proportion than was found in the stream. This finding may indicate the presence of Round Gobies is causing a dietary shift in Rainbow Darters.

The most likely mechanism for this shift is that Round Gobies are pushing Rainbow Darters into a different habitat within Elk Creek with a different food

Table 1. Average Strauss' (1979) linear index of food selection for prey items occurring in greater than 1% of fish stomachs. An asterisk represents a biologically meaningful value.

Macroinvertebrate	Elk Creek								
	Downstream			Upstream			Woodcock Creek		
Order/Family	r_i	p_i	L	r_i	p_i	L	r_i	p_i	L
Ephemeroptera									
Baetidae	0.15	0.23	-0.08	0.00	0.25	-0.25	0.31	0.00	0.31*
Trichoptera									
Hydropsychidae	0.01	0.03	-0.02	0.12	0.43	-0.31*	0.23	0.31	-0.08
Philopotamidae	0.00	0.05	-0.05	0.00	0.12	-0.12	0.03	0.00	0.03
Psychomyiidae	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.00
Hydroptilidae	0.00	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.02
Diptera									
Chironomidae	0.83	0.28	0.55*	0.80	0.12	0.68*	0.39	0.34	0.05
Simuliidae	0.00	0.00	0.00	0.03	0.00	0.03	0.01	0.18	-0.17
Empididae	0.00	0.00	0.00	0.04	0.00	0.04	0.00	0.00	0.00

base. Downhower and Brown (1979) observed that *Etheostoma olmstedi* Storer (Tessallated Darter) did not occupy riffles due to the presence of adult sculpins. Other studies showed that Round Gobies occupied similar niches as sculpins (French and Jude 2001, Jude et al. 1995). Due to the aggressive behavior of Roud Gobies, it is not unreasonable to surmise that the Round Goby could displace Rainbow Darters in this manner. Rainbow Darters have been shown to seek deeper habitats to avoid predation from larger fishes (Gray et al. 1997, Stauffer et al. 1996), and food sources in deeper pools do not include the rich diversity of macroinvertebrates found in riffles (Kuehne and Barbour 1983).

This shift in diet, however, was not consistent with the diet of the Rainbow Darter when observed cohabitating with other darter species. We sampled Woodcock Creek to represent a moderate level of shared resources, including food items, with native congeners. At this site, the diet of Rainbow Darters was different from that of the other 2 sites, with a biologically meaningful proportion of baetids consumed ($L = 0.31$) despite their low proportion in the environment (Table 1). The observed difference in resource partitioning by darters with an invasive species versus native species is not new. Gray and Stauffer (2001) observed Tessellated Darters shifting their substrate choice based on the introduction of *Etheostoma zonale* (Cope) (Banded Darter) in artificial stream tables. This result was later confirmed in wild populations in the Susquehanna drainage of Pennsylvania (Gray et al. 2005). The shift of habitat likely led to a shift in diet.

Being a member of the benthic invertebrate-feeding guild brings a high degree of resource overlap, as there are many other species belonging to this group including sculpins, dace, and madtoms in the families Cottidae, Cyprinidae, and Ictaluridae, respectively (Greenberg 1991). While these species were not detected or are in low abundance at our study sites, Rainbow Darters were coexisting with either other darter species or Round Gobies at 2 of our study sites, occupying the same areas and with access to the same habitat and food items. Therefore, we measured preference for prey items as an indicator of resource partitioning. This approach was not a direct measure of competition (Colwell and Futuyma 1971), but rather a means of estimating shared resource use (Adams 1980) that may have management implications. Rainbow Darters have successfully partitioned food resources to persist at the Elk Creek downstream site. However, based on the markedly different diet at each site, we predict that this shift may not allow Rainbow Darters to co-exist with the Round Goby at the Elk Creek upstream site should an invasion occur. Food selection may be used as an indicator of habitat shift, but microhabitat should be evaluated when possible to fully determine detrimental effects of competition by both native and invasive species.

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