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Feeding ecology of larval and juvenile American shad (*Alosa sapidissima*) in a small pond

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Summary

Release ponds are used as part of a multifacet effort to restore American shad (*Alosa sapidissima*) in the upper Susquehanna River basin. Little information exists, however, on the feeding ecology of young shad in small ponds. Consequently, we examined feeding ecology and prey selection of 299 larval and 299 juvenile American shad in a small pond during spring and summer. Larval shad mainly consumed copepods (37.7%) and cladocerans (37.4%) whereas juvenile shad ate chironomids (43.1%) and ostracods (28.4%). Larval and juvenile shad exhibited diel variation in diet composition and feeding periodicity. Food consumption by shad was minimal at night; feeding activity was highest during the day, peaking at 2000 h for both larvae and juveniles. Electivity values of shad larvae for prey taxa were highest for cladocerans (+0.27) and lowest for ostracods (−0.07). Electivity values of juvenile shad were highest for chironomids (+0.21) and ostracods (+0.09), and lowest for copepods (−0.08) and baetids (−0.14). Our data indicate differences in diet composition, prey preference and, to a lesser extent, feeding patterns between larval and juvenile American shad in small pond environments.

Introduction

American shad (*Alosa sapidissima*) is an anadromous clupeid indigenous to the east coast of North America. In many river basins spawning runs of American shad are depressed and in some rivers (e.g. Susquehanna River) shad were completely eliminated from up-river areas due to impassable dams (Meade 1976). Efforts to restore American shad in the Susquehanna River include trapping and transport of adults above dams and the release of hatchery-produced larval shad directly into the river or into release ponds. Predation on hatchery-reared larval shad can be substantial because of their small size at release (Johnson and Dropkin 1992). Further, mortality due to handling and transportation (Ross et al. 1993) makes large releases of juvenile shad impractical. Consequently, the release of juveniles from release ponds may be an important component of the success of the Susquehanna River restoration program. The protocol for releases consists of stocking larvae in the spring in fertilized predator-free ponds, permitting a growing period, and either allowing self-release or inducing release of juveniles in later summer or early autumn in time for normal migration. Release ponds are generally fertilized prior to larval stocking.

Although considerable information exists on the food habits of wild larval (Levesque and Reed 1972; Crecco and Blake 1983) and juvenile (Walburg 1956; Massmann 1963; Davis and Cheek 1966; Domermuth and Reed 1980) American shad, little information exists on the food habits of shad in release ponds (Maxfield 1953). Levesque and Reed (1972), Domermuth and Reed (1980) and Crecco and Blake (1983) have examined shad diets in relation to available prey. Limited information is available on diel feeding chronology of young shad (Massmann 1963; Levesque and Reed 1972).

The purpose of this study was to determine the feeding ecology and food selection of larval and juvenile American shad in a small pond.

Methods

American shad larvae, of Delaware River origin, were acquired from the Pennsylvania Fish and Boat Commission's VanDyke Fish Hatchery and stocked in a 0.1 hectare pond in early June of 1991 and 1993. About 7 500 larvae were released each year prior to the onset of exogenous feeding. Pond depth ranged from 0.3 m to 1.2 m. Rooted aquatic vegetation covered about 20 % of the bottom of the pond.

In July 1991, 299 juvenile shad were collected to analyse diel feeding periodicity, diet composition, and prey electivity (Strauss, 1979). In June 1993, 299 larval shad were sampled after about a 1-week acclimation period in the pond to analyse these same variables. Sampling was carried out at 4-h intervals over a 24-h period. Juvenile shad were collected with a minnow seine (7.6 m × 1.2 m, 4.8-mm mesh) and larval shad with a larval seine (7.6 m × 1.2 m, 500–800 μm mesh). Upon collection fish were placed in 10 % formalin.

Food availability in the pond was determined by averaging six 12 L Shindler-Patalas plankton samples taken at 1200 h (3) and 2400 h (3) during both 24-h periods. Water temperature during the study periods ranged from 20 to 27°C in 1991 and 16 to 22°C in 1993.

Total weight and total length measurements were taken from each specimen prior to stomach removal. Stomach contents and Shindler-Patalas samples were examined under magnification; aquatic insects were identified to the family level and crustacean zooplankton were identified to class or order.

The percent contribution of food items in the diet of shad and in the pond was determined using dry weights for each invertebrate taxa. In 1993 only those prey taxa (e.g., zooplankton, chironomids) that were small enough to be consumed by larval shad were considered available prey in the Shindler-Patalas samples. Excluding larger prey taxa (e.g., odonates, ephemeropterans) found in the Shindler-Patalas samples from consideration was warranted since it is unlikely these prey were available to the larvae due to mouth gape limitations.

Electivity values were determined by comparing diurnal samples of shad diets (i.e., 0800 h, 1200 h, 1600 h) to Shindler-

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Patalas samples taken at 1200 h, and the nocturnal diet samples (i.e., 2000 h, 2400 h, 0400 h) to plankton samples taken at 2400 h. Electivity values for the 24-h period were estimated using diel diet information and the average prey availability derived from the 1200-h and 2400-h plankton samples. Analyses of feeding periodicity were based on the ratio of stomach weight to body weight (Keast and Welsh, 1968). Diet composition of larval and juvenile American shad was analysed in 4-h interval samples over the 24-h period. Feeding periodicity was analysed by comparing stomach contents using Duncan's multiple range test (Duncan 1955) to test the significance of changes in feeding activity over a 24-h period.

Results

The feeding ecology of 299 larval American shad and 299 juvenile shad, about 50 per 4-h interval, was examined over a 24-h period. Larval shad averaged 18.4 mm in total length and juvenile shad 44.9 mm (Table 1). Copepods (37.7%) and cladocerans (37.4%) were the major prey of larval shad, whereas juvenile shad consumed mainly chironomids (43.1%) and ostracods (28.4%; Table 2). Chironomids were also important in the diet of larvae (22.9%), while cladocerans (9.8%) and copepods (9.2%) were of secondary importance to juveniles.

Both groups of American shad exhibited diel variation in diet composition. Consumption of cladocerans (20.4% to 77.4%), copepods (0% to 41.0%), and chironomids (0.5% to 36.5%) by larval shad varied over the 24-h period (Table 2). Similarly, consumption of cladocerans (2.6% to 24.0%), copepods (0.3% to 28.3%), ostracods (18.6% to 43.1%), and chironomids (28.3% to 53.7%) by juvenile shad varied during the sampling periods. Baetids were a small but consistently represented component of the diet of juvenile American shad (Table 2). Zooplankton contributed more (91.3%) to the diet of larval shad during crepuscular periods (i.e. 0800 and 2000 h) than during nocturnal (70.4%) or diurnal (68.1%) periods (Table 2). Consumption of zooplankton by juveniles was highest at night (56.2%). Consumption of chironomids by larval (32.9%) and juvenile (51.6%) American shad was highest during the day (Table 2).

Peak food consumption of larval shad occurred between 1200 h and 2000 h (Fig. 1). At 2000 h, stomach content of larval shad was significantly ($P < 0.05$) greater than at other times. Stomach content of juvenile shad at 2000 h was also significantly ($P < 0.05$) greater than during other times. Shad feeding activity was minimal at night and stomach content was lowest ($P < 0.05$) at 0400 h for larval shad, and at 0400 h and 0800 h ($P < 0.05$) for juvenile shad. Larval feeding increased sharply after 0400 h and remained constant until 1200 h whereas feeding activity by juvenile shad was constant at 0400 h and 0800 h and increased from 0800 h to 1200 h (Fig. 1).

Prey availability did not differ substantially in the pond between day and night periods (Table 3). Chironomids ($\bar{x} = 22.5$ %), baetids ($\bar{x} = 19.7$ %), ostracods ($\bar{x} = 19.1$ %) and copepods ($\bar{x} = 17.7$ %) represented the major aquatic invertebrate biomass in the pond in 1991. Of the potential prey that could be eaten by larval shad in 1993, copepods ($\bar{x} = 41.3$ %) and chironomids ($\bar{x} = 26.7$ %) were the dominant taxa.

Electivity values, which range from + 1 (highest selection) to − 1 (complete avoidance), indicated that American shad larvae moderately selected only one prey taxa, cladocerans (+0.27) with values ranging from +0.09 to +0.68 over the six 4-h intervals. Copepods (−0.04), chironomids (−0.04) and ostracods (−0.07) were used by shad larvae in about the same proportion as to their availability (Table 2). Chironomids (+0.21) were the preferred prey of juvenile American shad. Cladocerans (+0.04), ostracods (+0.09) and copepods (−0.08) were eaten in about the same proportion as to their availability. Baetids (−0.14) were the least preferred prey of juvenile American shad.

Discussion

American shad larvae and juveniles exhibited diel variation in diet composition and substantial variation in feeding activity. Zoufal and Taborsky (1991) suggested that variation in diel feeding activity of some fish species may be in response to changes in the energy content of the food source. Although limited information exists on feeding patterns of young American shad (Massmann 1963; Levesque and Reed 1972), no information was available on diel changes in diet composition. Levesque and Reed (1972) found that feeding of larval shad increased from a low at 1200 h to a peak at 2000 h. However, they were unable to collect larvae from 2000 to 0600 h. Similar to larval American shad, juvenile shad have been reported to increase feeding in late afternoon, peaking at about 2000 h (Massmann 1963; Levesque and Reed 1972). Food consumption of juvenile shad has previously been reported to be minimal at night (Levesque and Reed 1972). Our findings are generally consistent with those of Levesque and Reed (1972) for larval shad over comparable time periods (i.e. 1200 to 2000 h). However, we observed a clear increase in feeding activity by 1200 h, compared to the very low night levels. Our findings on juvenile American shad, showing a feeding peak at 2000 h and minimal feeding at night, are consistent with previous observations of feeding patterns.

Our findings, which show that larval and juvenile American shad consumed mainly zooplankton and chironomids and that juvenile shad used a wider variety of prey taxa than larvae, are consistent with previous investigations. Zooplankton and chironomids have been found to comprise most of the diet of American shad larvae (Maxfield 1953; Levesque and Reed 1972;

Table 1. Number (No.), average total length (mm) and length range (in parenthesis), and average wet weight (g) and weight range (in parenthesis) of larval and juvenile American shad examined during each 4-h interval in a 0.1 hectare pond

	Larvae			Juveniles		
Hour	No.	Length	Weight	No.	Length	Weight
0400	50	19.0 (16.5–21.5)	0.032 (0.016–0.046)	50	49.7 (41–62)	0.91 (0.50–1.90)
0800	50	18.9 (13.0–21.0)	0.029 (0.007–0.049)	49	47.3 (34–65)	0.80 (0.30–2.20)
1200	50	18.7 (14.0–21.5)	0.031 (0.011–0.049)	50	42.9 (35–55)	0.65 (0.30–1.30)
1600	50	18.1 (14.0–20.5)	0.033 (0.011–0.042)	50	41.9 (33–54)	0.59 (0.30–1.30)
2000	49	17.2 (13.5–20.0)	0.027 (0.014–0.044)	50	42.3 (35–56)	0.60 (0.30–1.20)
2400	50	18.4 (14.0–20.5)	0.031 (0.007–0.042)	50	45.3 (33–56)	0.77 (0.30–1.40)

Table 2. Percentage dry weight dietary composition of American shad larvae and juveniles at 4-h intervals over 24-h. Numbers in parentheses are electivity values. When prey taxa were missing from the diet at a 4-h interval, electivity values were calculated based on only those prey that made up a substantial amount of the available food

Hour	0400		0800		1200	
Prey taxon	Larvae	Juveniles	Larvae	Juveniles	Larvae	Juveniles
Nematoda		0.5 (0.03)				
Hydracarina				0.2 (+1.00)		0.1 (+1.00)
Cladocera	77.4 (+0.68)	11.9 (+0.08)	56.5 (+0.45)	4.4 (−0.02)	50.9 (+0.39)	9.1 (+0.03)
Copepoda	(−1.00)	0.3 (−0.20)	41.0 (−0.03)	0.5 (−0.14)	15.4 (−0.28)	1.8 (−0.13)
Ostracoda	(−1.00)	43.1 (+0.24)	2.0 (−0.06)	37.7 (+0.19)	(−1.00)	27.0 (+0.08)
Ephemeroptera						
Baetidae		3.4 (−0.14)		8.6 (−0.13)		7.2 (−0.15)
Odonata						
Libellulidae				(−1.00)	(−1.00)	
Coenagrionidae		1.9 (+1.00)				3.3 (+1.00)
Trichoptera						
Leptoceridae		0.6 (+1.00)				
Hemiptera						
Corixidae		0.5 (+1.00)		0.5 (+1.00)		
Notonectidae						0.9 (+1.00)
Diptera						
Chironomidae	22.6 (−0.12)	38.0 (+0.14)	0.5 (−0.18)	46.9 (+0.26)	33.7 (−0.15)	49.4 (+0.29)
Terrestrial Insects		0.3 (+1.00)		1.2 (+1.00)		1.2 (+1.00)
Totals	100.0	100.0	100.0	100.0	100.0	100.0

Hour	1600		2000		2400		24-h total	
Prey taxon	Larvae	Juveniles	Larvae	Juveniles	Larvae	Juveniles	Larvae	Juveniles
Nematoda								0.1 (−0.02)
Hydracarina				0.1 (+1.00)		0.1 (+1.00)		0.1 (+1.00)
Cladocera	20.4 (+0.20)	2.6 (−0.04)	43.3 (+0.34)	7.6 (+0.03)	25.0 (+0.15)	24.0 (+0.20)	37.4 (+0.27)	9.8 (+0.04)
Copepoda	49.5 (+0.06)	8.8 (−0.06)	36.5 (−0.03)	28.2 (+0.08)	33.9 (−0.05)	0.6 (−0.20)	37.7 (−0.04)	9.2 (−0.08)
Ostracoda	(−1.00)	27.0 (+0.08)	3.3 (−0.07)	18.6 (−0.01)	4.6 (−0.06)	32.5 (+0.13)	2.0 (−0.07)	28.4 (+0.09)
Ephemeroptera								
Baetidae		6.9 (−0.15)		2.3 (−0.15)		8.7 (−0.09)		5.9 (−0.14)
Odonata								
Libellulidae		(−1.00)		0.6 (+1.00)				0.1 (−0.07)
Coenagrionidae		0.8 (+1.00)				4.5 (+1.00)		1.8 (+1.00)
Trichoptera								
Leptoceridae						0.4 (+1.00)		0.1 (+1.00)
Hemiptera								
Corixidae								0.1 (+1.00)
Mesoveliidae		0.3 (+1.00)						0.1 (+1.00)
Notonectidae				0.2 (+1.00)				0.2 (+1.00)
Diptera								
Chironomidae	30.0 (−0.11)	53.7 (+0.33)	16.9 (−0.18)	40.6 (+0.16)	36.5 (+0.02)	28.3 (+0.04)	22.9 (−0.04)	43.1 (+0.21)
Tipulidae						0.9 (+1.00)		0.1 (+1.00)
Gastropoda				0.3 (+1.00)				0.1 (+1.00)
Terrestrial Insects				1.5 (+1.00)				0.8 (+1.00)
Totals	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Crecco and Blake 1983). Upon absorption of the yolk sac, larvae initially consume zooplankton and add chironomids to the diet when the shad are about 15 mm (Maxfield 1953). Juvenile American shad consume mostly planktonic and drifting prey (Domermuth and Reed 1980). As with larval shad, chironomid larvae and pupae are important in the diet of juvenile shad, but juveniles also consume a wider variety of aquatic insects and often terrestrial insects comprise a large proportion of the diet (Maxfield 1953; Massmann, 1963; Davis and Cheek 1966; Domermuth and Reed 1980).

Crecco and Blake (1983) found that American shad larvae consistently exhibited positive selection for chironomids and copepods. Ontogenetic differences in preference were indicated for chironomids since food selection values increased with shad size. Larval shad exhibited minor selection for cladocerans. Juvenile American shad have been shown to select zooplankton and avoid chironomid larvae (Levesque and Reed 1972; Domermuth and Reed 1980). We found larval shad to moderately select cladocerans and exhibit neutral selection for chironomids and copepods. Juvenile shad exhibited moderate selection for chironomids (mostly larvae) and neutral selection for cladocerans, ostracods, and copepods. The increase in electivity values by shad for chironomids from larvae (−0.04) to juveniles (+0.21) supports the findings of Crecco and Blake (1983).

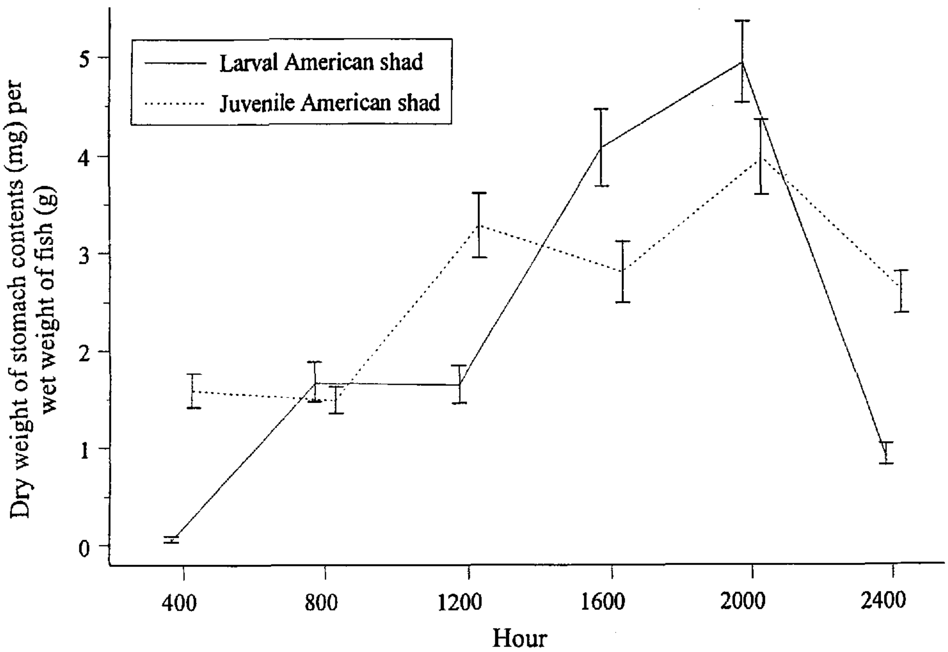

Fig. 1. Diel feeding patterns of larval and juvenile American shad in a small pond during July 1991 (juvenile) and May 1993 (larvae). Vertical bars represent standard errors

Table 3. Percentage dry weight composition of available food in the pond at 1200 h and 2400 h in 1991 and 1993

	1991		1993	
	1200	2400	1200	2400
Nematoda	0.3	3.4	5.2	0.6
Oligocheata	0.5	7.5	9.7	
Cladocera	6.4	4.4	11.9	9.6
Copepoda	14.9	20.4	43.5	39.0
Ostracoda	18.7	19.5	7.6	10.3
Collombola			3.4	
Ephemeroptera				
Baetidae	21.8	17.6		
Odonata				
Libellulidae	14.7			
Diptera				
Chironomidae	20.5	24.4	18.7	34.7
Helidae	2.2	2.8		5.8

Our findings indicate that studies conducted over a 24-h period are necessary to accurately describe the diet composition of young shad, since both larval and juvenile shad exhibited substantial diel variation in diet composition. These studies may be more important in describing the daily diet of larval shad since larvae exhibited a greater amount of variation in food consumption compared to food intake of juvenile shad, which was relatively constant over the 24-h period. Feeding supplementation programs for release ponds containing American shad larvae should be carried out in late afternoon or early evening, and not at night or early morning, to simulate natural feeding patterns. Conversely, feeding supplementation programs for ponds with juvenile shad probably can be carried out at any time during the day.

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References

Crecco, V. A.; Blake, M. B., 1983: Feeding ecology of coexisting larvae of American shad and blueback herring in the Connecticut River. Trans. Am. Fish. Soc. **112**, 498–507.

Davis, J. R.; Cheek, R. P., 1966: Distribution, food habits, and growth of young clupeids, Cape Fear River system, North Carolina. Proc. 20th Ann. Conf. SE Assoc. Game and Fish Comm. 250–260.

Domermuth, R. B.; Reed, R. J., 1980: Food of juvenile American shad, *Alosa sapidissima*, juvenile blueback herring, *Alosa aestivalis*, and pumpkinseed, *Lepomis gibbosus*, in the Connecticut River below Holyoke Dam, Massachusetts. Estuaries **3**, 65–68.

Duncan, D. B., 1955: Multiple range and multiple F-tests. Biometrics **11**, 1–42.

Johnson, J. H.; Dropkin, D. S., 1992: predation on recently released American shad larvae in the Susquehanna River basin. North Am. J. Fish. Man **13**, 504–508.

Keast, A.; Welsh, L., 1968: Daily feeding periodicities, food uptake rates, and dietary changes with hour of day in some lake fishes. J. Fish. Res. Board Can. **25**, 1133–1144.

Levesque, R. C.; Reed, R. J., 1972: Food availability and consumption by young Connecticut River shad *Alosa sapidissima*. J. Fish. Res. Board Can. **29**, 1495–1499.

Massmann, W. H., 1963: Summer food of juvenile American shad in Virginia waters. Chesap. Sci. **4**, 167–171.

Maxfield, G. H., 1953: The food habits of hatchery-produced pond-cultured shad (*Alosa sapidissima*) reared to a length of two inches. Chesapeake Biological Laboratories 98, Solomons, Maryland.

Meade, J. W., 1976: Experimental intense rearing of shad, *Alosa sapi-*

dissima, at VanDyke, Pennsylvania. In: Proceedings of a workshop on American shad, Amherst, Massachusetts.
Ross, R. M.; Backman, T. W. H.; Bennett, R. M., 1993: Evaluation of the anesthetic metomidate for the handling and transport of juvenile American shad. Prog. Fish-Cult. **55**, 236–243.
Strauss, R. E., 1979: Reliability estimates for Ivlev's electivity index, the forage ratio, and a proposed linear index of food selection. Trans. Amer. Fish. Soc. **108**, 344–352.
Walburg, C. H., 1956: Observations on the food and growth of juvenile American shad, *Alosa sapidissima*. Trans. Am. Fish Soc. **86**, 302 306.
Zoufal, R.; Taborsky, M., 1991: Fish foraging periodicity correlates with daily changes of diet quality. Mar. Biol. **108**, 193–196.

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