Nutritional Quality of Foods Consumed by Gizzard Shad in Western Lake Erie[1]

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ABSTRACT. Gizzard shad (*Dorosoma cepedianum*) were collected from four locations in western Lake Erie during summer, 1982. The nutritional quality of foods ingested by these fish was examined. Small (<60 mm standard length), age 0 fish consumed mostly zooplankton with high organic (>80% of dry weight) and nitrogen (>6% of dry weight) contents. The phytoplankton and detritus diets of larger, age 0 and adult gizzard shad were of poorer nutritional quality (organic = 10–30%; nitrogen = 0.7–3.1% of dry weight). However, the nutritional quality of these foods was apparently adequate for gizzard shad, as most fish from all locations exhibited good condition and rapid growth rates. Observed differences in size and condition of age 0 gizzard shad among the collection sites may be due, in part, to variation in the quality of foods consumed during the growing season.

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INTRODUCTION

The gizzard shad (*Dorosoma cepedianum*) was first observed in Lake Erie in 1848 (Miller 1956). The abundance of this species in the lake has increased dramatically since 1950, presumably in relation to increased phytoplankton (food) production, decreased numbers of competing fish species, and/or other factors (Trautman 1981). This increase in gizzard shad numbers has had an important effect on the ecology of western Lake Erie. Age 0 gizzard shad comprise a major portion of the diets of several piscivores, including white perch (*Morone americana*), walleye (*Stizostedion vitreum*), and large yellow perch (*Perca flavescens*) (Knight et al. 1984, Schaeffer and Margraf 1986). However, mass mortalities of gizzard shad occur frequently (e.g. White 1986), and a significant proportion of the lake's primary productivity is diverted into commercially valueless fish (Bodola 1965).

Growth rates and condition of gizzard shad in Lake Erie are among the highest reported for any system (Bodola 1965, Jester and Jensen 1972), suggesting the presence of an abundant, high-quality food supply. Price (1963) and Bodola (1965) documented the types of foods consumed by gizzard shad in western Lake Erie; the quality of these foods has not been examined, however. The objectives of the present study were to examine and compare the quality of foods ingested by age 0 and adult gizzard shad at several sites in western Lake Erie, and to determine the influence of food quality on growth and condition of fish at these sites.

METHODS

During June to August, 1982, gizzard shad were collected at four sites in western Lake Erie (Fig. 1). Two sites (Monroe and La Plaisance Bay) were located at the extreme western end of the lake in Michigan waters. The Monroe site was 3 km offshore and slightly south of the mouth of the River Raisin. The La Plaisance site was approximately 6 km northeast of Woodtick Peninsula. The remaining two sites (Sandusky Bay and Cedar Point) were located near Sandusky, Ohio, on the southern shore. One was within outer Sandusky Bay; the other was just outside the bay offshore from Cedar Point. Gizzard shad were collected by trawling (otter trawl with a fyke, 10-m headrope, and 0.64-cm stretched mesh cod end) during daylight at 3-5-m depths at all sites, and by gill nets (day and night sets of 1.8 m × 91.5 m multifilament nylon nets with equal-sized sections of 8.9-cm, 10.2-cm, and 11.4-cm stretched mesh) in 3 to 4 m of water at Monroe and La Plaisance Bay. Water temperatures during collections ranged from 22 to 26°C. Fish were placed on dry ice immediately after capture, and remained frozen until processed.

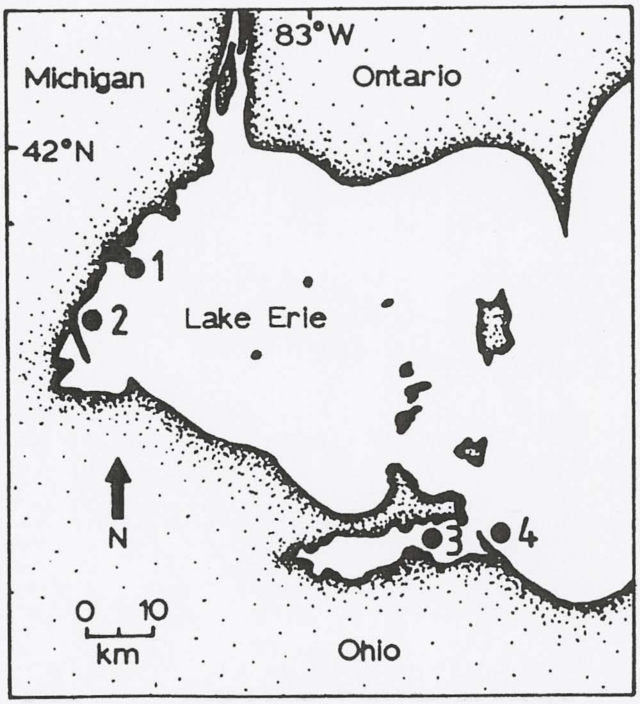

FIGURE 1. Gizzard shad collection sites in western Lake Erie. 1, Monroe, Michigan; 2, La Plaisance Bay, Michigan; 3, Sandusky Bay, Ohio; 4, Cedar Point, Ohio.

In the laboratory, fish were weighed (g wet weight, W) and measured (mm standard length, SL), and a condition factor ($K_{SL} = 10^5 WSL^{-3}$) was calculated for each individual. Scales were removed from each fish for age determination.

The physiological condition of the fish was assessed by analyzing the chemical composition of muscle tissue samples. Lipids stored in the muscles of fish can change the chemical make-up of these tissues (Lagler et al. 1977). Muscle tissue samples were removed from each fish, oven-dried to constant weight at 60°C, and ground to a fine powder with mortar and pestle. Total organic carbon (% dry weight), total organic nitrogen (% dry weight), and a carbon to nitrogen (C:N) ratio were determined for each sample with an elemental analyzer (Carlo-Erba Model 1106) coupled to a data processor (Adams-Smith Model 2000C). The analyzer and data processor were calibrated with a standard of cyclohexanone (51.59% carbon and 20.14% nitrogen by weight).

The nutritional quality of foods ingested by gizzard shad from the four sites was determined by analyzing food materials removed from the gizzard of each fish. The small amounts of food in gizzards of age 0 fish required that the food from three or five fish be combined to

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obtain an adequate amount for analysis. Food samples were oven-dried to constant weight at 60°C. The organic content was determined by a weight difference before and after combustion in a muffle furnace at 550°C for 3 h (Cummins and Wuycheck 1971). The nitrogen content of food samples was determined with the elemental analyzer.

Representative samples of gizzard contents from two or three fish for each age, site, and date were examined (prior to drying) with a light microscope at 25 and 100× magnification. Food materials were identified, and general observations were made on the size and abundance of the major food items.

RESULTS AND DISCUSSION

Two cohorts of age 0 gizzard shad were collected in trawls at each site (age confirmed by the absence of an annulus on any of the scales examined). Multiple cohorts of age 0 gizzard shad have been observed previously in Lake Erie, and are thought to result from early spawning in warmer bays and tributaries by a segment of the gizzard shad population or from precocious, age 1 fish spawning in mid-summer after older fish have completed spawning (Bodola 1965). Multiple cohorts of young gizzard shad have also been reported in other systems (Pierce et al. 1980, Willis 1987). Willis (1987) suggested that multiple cohorts in a large Kansas reservoir may have resulted from differences in food availability for fish hatched at the beginning versus the end of a 6-week spawning period.

Gizzard shad of each cohort were significantly larger (wet weight and SL; ANOVA, $P < 0.05$) in late August at Cedar Point and Sandusky Bay than at Monroe, Michigan (Table 1). In addition, fish collected from Sandusky Bay were smaller than fish of the same age from Cedar Point. Bodola (1965) reported similar size differences between young gizzard shad collected in Sandusky Bay and those from the open lake.

Adult (ages 1-5) gizzard shad were captured only at Monroe and La Plaisance Bay, Michigan, and only in gill nets at those sites. These fish ranged in size from 198 to 1219 g wet weight, and from 196 to 381 mm SL (Table 2). Age-size relationships of these fish showed the rapid, sustained growth of gizzard shad in this system when compared with growth of the species in other U.S. lakes and reservoirs (Bodola 1965, Jester and Jensen 1972).

Condition factors of the gizzard shad were generally high (Tables 1 and 2), and similar to those reported previously for the species in Lake Erie (Bodola 1965). Condition factors of age 0 fish were variable, but only at Monroe and Sandusky Bay in August were there significant differences (t-tests, $P < 0.05$) in mean condition factors between the cohorts at a site. In late August, condition factors of cohort 1 fish from Sandusky Bay and cohort 2 fish from Cedar Point were significantly higher (ANOVA, $P < 0.05$) than those of the respective cohorts at the other sites (Table 1). Adult gizzard shad had condition factors similar to those of age 0 fish, but because of small sample sizes, no significant differences were detected between sites or between age groups (Table 2).

Muscle C:N ratios provided information on the condition of gizzard shad that was often contradictory to that furnished by the condition factors. Although condition factors were similar for age 0 and adult fish, muscle C:N

TABLE 1

Mean (±SE) wet weight (W, g), standard length (SL, mm), condition factor (K_{SL}), muscle tissue carbon to nitrogen ratio (C:N), and quality of ingested foods of age 0 gizzard shad from four Lake Erie sites. N is the sample size.

								Food quality (% of dry weight)	
Site/Date	Cohort	*N*	W	SL	K_{SL}	C:N	*N*	Organic	Nitrogen
La Plaisance Bay, MI 29 Jul 1982	1	10	14.1 (1.0)	83 (2)	2.43 (0.09)	3.22:1* (0.01)	2	33.8	3.1
	2	10	2.1 (0.2)	45 (10)	2.20 (0.09)	3.22:1** (0.02)	1	92.3	10.4
Monroe, MI 22 Jul 1982	1	2	12.3	79	2.54				
	2	24	1.8 (0.1)	41 (1)	2.52 (0.05)				
Monroe, MI 25 Aug 1982	1	15	23.2 (1.5)	98 (2)	2.42 (0.04)	3.22:1*** (0.03)	1	13.6	1.1
	2	10	1.6 (0.1)	45 (1)	1.75 (0.07)	3.25:1 (0.01)	2	79.9	6.5
Sandusky Bay, OH 24 Aug 1982	1	3	34.7 (5.2)	109 (5)	2.63 (0.06)	3.30:1*** (0.05)	1	20.4	1.5
	2	15	3.4 (0.6)	51 (3)	2.20 (0.08)	3.14:1*** (0.01)	3	87.7 (1.6)	10.6 (0.2)
Cedar Point, OH 24 Aug 1982	1	3	46.8 (3.9)	124 (3)	2.46 (0.08)	3.57:1 (0.16)	1	28.6	1.9
	2	6	15.2 (1.2)	85 (2)	2.48 (0.06)	3.32:1 (0.03)	2	45.9	3.4

*$N = 6$
**$N = 5$
***$N = 3$

TABLE 2

Mean (±SE) wet weight (W, g), standard length (SL, mm), condition factor (K_{SL}), muscle tissue carbon to nitrogen ratio (C:N), and quality of ingested foods of adult gizzard shad from two Lake Erie sites. N is the sample size.

Site/Date	Age	N	W	SL	K_{SL}	C:N	N	Food quality (% of dry weight) Organic	Nitrogen
La Plaisance Bay, MI 28 Jun 1982	2	10	452.2 (25.6)	270 (5)	2.28 (0.07)	4.65:1* (0.84)	3	10.3 (1.8)	0.7 (0.2)
	4	2	1020.6	340	2.61				
Monroe, MI 2 Jul 1982	1–2	7	348.3 (26.5)	237 (7)	2.56 (0.05)	4.51:1 (0.35)	4	25.3 (11.9)	2.0 (0.9)
	3–5	5	1054.6 (71.4)	350 (9)	2.45 (0.10)	4.50:1 (0.25)	5	19.0 (7.7)	1.5 (0.6)

*$N = 3$

ratios of adult fish were significantly higher (ANOVA, $P < 0.05$) than those of age 0 fish (Tables 1 and 2). Higher C:N ratios are indicative of lipid storage within gizzard shad muscle tissues (Mundahl and Wissing 1987). Muscle tissues of most adult fish were very oily, and these fish also had large fat deposits in the mesenteries surrounding the digestive tract. Oily muscle tissues and internal fat deposits were not observed in age 0 fish. Mundahl and Wissing (1987) reported similar differences in muscle C:N ratios between age 0 and adult gizzard shad from Acton Lake in southwestern Ohio.

Muscle C:N ratios of adult gizzard shad did not vary with age or collection site (Table 2), nor did those of age 0 fish vary consistently between cohorts (Table 1). Although C:N ratios of age 0 fish collected from some sites were higher than those at others, these patterns were much different than those presented by the condition factors (Tables 1 and 2).

The differing patterns observed in the condition factors and muscle C:N ratios are puzzling. Theoretically, as lipid stores in gizzard shad increase, both muscle C:N ratio and condition factor should also increase. However, in the present study there was no significant correlation between condition factor and muscle C:N ratio for adult ($P = 0.52$, $r^2 = 0.03$, $N = 15$) or age 0 ($P = 0.08$, $r^2 = 0.10$, $N = 33$) gizzard shad. Strange and Pelton (1987) also observed poor correlation between condition factor and percent fat for age 0 and adult gizzard shad in a large Tennessee reservoir. Apparently, the condition factor is a poor indicator of the true physiological condition of gizzard shad (Strange and Pelton 1987). This may result, in part, from the significant influence that a full digestive tract has on a gizzard shad's total weight and, hence, its condition factor (Mundahl and Wissing 1987). The digestive tract filled with inorganic sediments and detritus can comprise up to 25% of the total wet weight of the fish (N. D. Mundahl, unpubl. data).

The good condition of gizzard shad in Lake Erie can be explained in part by fish consuming abundant, high-quality foods. Price (1963) and Bodola (1965) observed that young gizzard shad in western Lake Erie first fed on zooplankton, but switched to phytoplankton and detritus as they grew. In the present study, only the smallest (cohort 2) age 0 fish consumed zooplankton, in addition to phytoplankton and detritus (Fig. 2B); larger (cohort 1) age 0 gizzard shad fed mainly on phytoplankton (e.g. *Ceratium* sp. and *Pediastrum* sp.) and detritus (Fig. 2A). Adult fish ingested mostly detritus, along with some phytoplankton. For fish of similar age, there were no appreciable differences among the collection sites in the types of foods ingested.

The nutritional quality of the foods ingested by gizzard shad in western Lake Erie did vary between age groups, however. The zooplankton-rich diets of cohort 2,

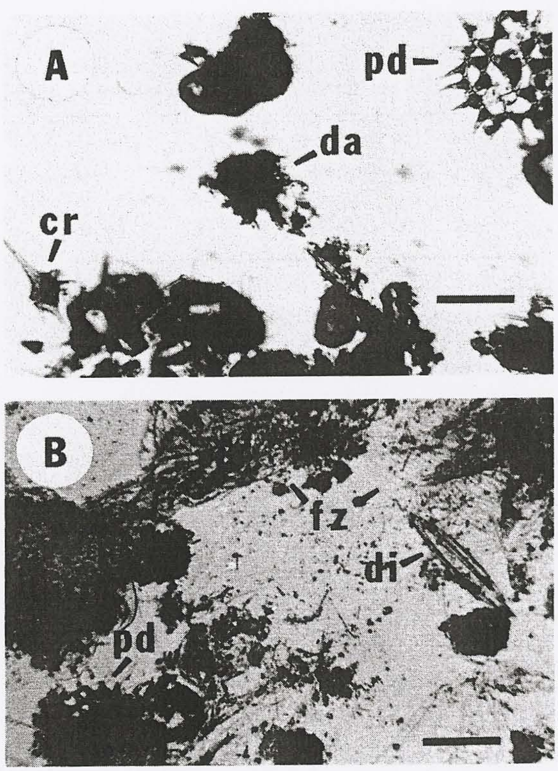

FIGURE 2. Light micrographs of gizzard contents of age 0 gizzard shad from western Lake Erie. Scale bar = 0.1 mm. A, gizzard contents of cohort 1, age 0 fish from Cedar Point in August, 1982; B, gizzard contents of cohort 2, age 0 fish from Sandusky Bay in August, 1982 (cr = *Ceratium* sp.; da = detrital aggregate; di = diatom; fz = fragmented zooplankton; pd = *Pediastrum* sp.).

age 0 fish had higher organic and nitrogen contents than the phytoplankton and detritus diets of larger, age 0 and adult gizzard shad (Tables 1 and 2). Zooplankton are more energy-rich than phytoplankton and organic detritus (Cummins and Wuycheck 1971) and, when abundant, should promote rapid growth in very young gizzard shad. When the fish switched from zooplankton to other foods, growth rates and condition remained the same or increased (Bodola 1965, present study) despite the reduced nutritional quality of the detritus-phytoplankton diet. Higher rates of food consumption may be one possible means by which gizzard shad sustain growth and condition in the face of decreased food quality.

It is not known whether the differences in size and condition of age 0 gizzard shad among the collection sites in western Lake Erie can be attributed to variation in the quality of foods ingested by the fish, as small sample sizes prevented statistical comparisons. The results for cohort 1 fish from Monroe, Sandusky Bay, and Cedar Point suggested that higher-quality (i.e., higher organic and nitrogen contents) foods were consumed by the larger fish in this cohort, and that these fish were also in better physiological condition (higher muscle C:N ratios) than smaller members of the same cohort (Table 1). Bodola (1965) suggested that differences in the size of age 0 gizzard shad collected from different sites in Lake Erie may have resulted from differences in the nutritional quality of available foods. However, differences in food consumption rates between fish from the various sites may be an additional factor influencing growth and condition of gizzard shad in the lake. Only a small difference in daily consumption rates between sites could account for the observed size and condition differences in age 0 fish. Finally, earlier warming of the more southerly waters near Sandusky may have promoted earlier spawning than at Monroe, resulting in larger fish by late August.

Detritus is a major component of the diets of adult gizzard shad in several lakes and reservoirs (e.g., Dendy 1946, Kutkuhn 1957, 1958, Baker and Schmitz 1971, Mundahl and Wissing 1987). In systems where this material is of poor quality (organic and nitrogen contents $<$ 10 and 1% dry weight, respectively), growth and condition of gizzard shad are depressed, and the fish may become stunted (Mundahl and Wissing 1987). In western Lake Erie, the quality of the detritus ingested by adult gizzard shad was variable (Table 2), but apparently high enough to support good growth and condition in most of the fish. This may not be true, however, for gizzard shad in other portions of the lake. For example, L. Knerli (John Carroll University, unpubl. data) observed that size differences among adult gizzard shad from sites in the central basin of Lake Erie near Cleveland may be attributed partially to differences in the organic content of detritus ingested by the fish.

The good growth and condition of gizzard shad in western Lake Erie may result, in part, from the high nutritional quality of their diet. Gizzard shad at some sites may experience nutritional limitations, but these do not appear to be severe enough to greatly depress growth and/or condition.

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