FOOD HABITS AND FEEDING CHRONOLOGY OF RAINBOW SMELT, *OSMERUS MORDAX*, IN LAKE MICHIGAN[1]

Rainbow smelt, *Osmerus mordax* Mitchill, in Lake Michigan originated from a planting in Crystal Lake, Mich., in 1912 (Van Oosten 1937). Since its introduction in Lake Michigan, the smelt has become abundant, serving as forage for larger, predatory species (Wright 1968; Harney and Norden 1972) and sustaining a small seasonal sport and commercial fishery. There has been considerable controversy regarding the smelt's role as a piscivore. Food studies of smelt in Saginaw Bay, Lake Huron (Gordon 1961) and Lake Erie (Price 1963) have shown that smelt consumes fishes, but not the alewife, *Alosa pseudoharengus*. Recently, a fall collection of smelt revealed that it consumes young-of-the-year alewives (O'Gorman 1974).

The food habits of Lake Michigan smelt have not been studied on a seasonal basis and little information exists concerning its food habits during the winter months. Also, feeding chronology has never been considered. The purpose of this study was to examine food habits of smelt during 6 mo representing all four seasons and to consider feeding chronology during two representative months.

Materials and Methods

Rainbow smelt were collected along the western shore of Lake Michigan by gillnetting or trawling on six dates between March 1973 and June 1974 (Table 1). Gill nets were placed on the bottom overnight and 45-min trawl hauls performed at 4-h intervals over a 24-h period. Gill nets were set and retrieved at 4- to 6-h intervals over a 24-h period on 13 October 1973 in order to examine feeding chronology. Smelt were collected at different depths during the course of the study because of their seasonal inshore–offshore movements. Fish were frozen shortly after capture.

Feeding chronology was examined on 23 March and 13 October 1973. Stomachs of smelt used in this portion of the study were dissected out and the contents removed. Fish and stomach contents were dried for 48 h at 60°C and weighed to the nearest milligram. Dried stomach contents were expressed as a percentage of dry body weight. The significance of time of day on the amount of food in stomachs was ascertained with analysis of variance (ANOVA). Means and the ANOVA were calculated from arcsine transformed data (Sokal and Rohlf 1969). A chi-square contingency test was used to ascertain the significance of time of day on the occurrence of empty stomachs. Significance testing was performed at the 0.05 error level.

TABLE 1.—Dates, locations, depths, and methods of capture of Lake Michigan smelt examined in this study.

Collection date	Location (off shore from)	Depth (m)	Method of capture[1]
20 Feb. 1974	Algoma, Wis.	85	Gill net
23 Mar. 1973	Two Rivers, Wis.	74	Bottom trawl[2]
21 May 1974	Milwaukee, Wis.	18	Gill net
18 June 1974	Milwaukee, Wis.	18	Gill net
15 Aug. 1974	Milwaukee, Wis.	27	Gill net
13 Oct. 1973	Port Washington, Wis.	37	Gill net[2]

[1]All collections made on the bottom.
[2]Feeding chronology examined.

Separate smelt were examined for food habits. These fish were measured to the nearest millimeter in length. Stomachs were removed, contents of each stomach were placed in a Petri dish with water, and the organisms enumerated. Food habits were defined in terms of percentage numbers and percent dry weight of stomach contents (Wells and Beeton 1963). Dry weight indices used were fish, 176; *Mysis*, 3; *Pontoporeia*, 1; fingernail clam, 1; Tendipedidae, 0.4; and Cladocera-Copepoda, 0.003 (Morsell and Norden 1968).

Results

Stomachs of 515 smelt were examined. Food of smelt included *Mysis; Pontoporeia;* alewives (young-of-the-year and yearlings); and to a lesser extent, fingernail clams; Tendipedidae pupae; cladocerans; and copepods (Table 2, 3). A marked increase in piscivorous food habits was observed in smelt longer than 180 mm. For this reason, smelt were divided into two size groups.

Smelt shorter than 180 mm consumed primarily *Mysis* during October, February, and March (Table 2). Smelt were found in shallower water during May, June, and August and their stomachs contained yearling alewives, *Pontoporeia*, and Tendipedidae. *Pontoporeia* were consumed most frequently during August, when they represented 35% dry weight of the diet. Tendipeds represented 25, 6, and 2 percentage numbers of the diet during May, June, and August, respectively. However,

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TABLE 2.—Food habits of Lake Michigan smelt shorter than 180 mm total length. Upper values for food organisms represent dry weight and values in parentheses are the percentage numbers.

Collection date	Average and range of lengths (mm)	No. of stomachs examined	% of stomachs empty	Food organisms: *Mysis*	*Pontoporeia*	Alewife	Fingernail clam	Tendipedidae	Copepoda and Cladocera
20 Feb. 1974	147	79	42	98	1	—	1	—	—
	90–179			(95)	(3)		(2)		
23 Mar. 1973	138	80	36	100	—	—	—	—	—
	94–179			(100)					
21 May 1974	162	68	60	62	<1	37	<1	1	—
	109–179			(73)	(1)	(1)	(1)	(25)	
18 June 1974	160	62	61	42	—	58	—	<1	<1
	140–179			(12)		(1)		(6)	(82)
15 Aug. 1973	157	40	1	30	35	30	5	<1	<1
	120–175			(26)	(61)	(1)	(9)	(2)	(2)
13 Oct. 1973	158	88	34	87	3	10	<1	—	—
	115–179			(88)	(9)	(1)	(2)		
Total	154	417	41	70	7	23	1	<1	<1
				(66)	(12)	(<1)	(2)	(6)	(14)

TABLE 3.—Food habits of Lake Michigan smelt 180 mm total length and longer. Upper values for food organisms represent percent dry weight and values in parentheses are the percentage numbers.

Collection date	Average and range of lengths (mm)	No. of stomachs examined	% of stomachs empty	Food organisms: *Mysis*	*Pontoporeia*	Alewife	Fingernail clam
20 Feb. 1974	210	21	43	39	1	60	—
	180–251			(93)	(5)	(2)	
23 Mar. 1973	206	20	25	95	5	—	—
	180–246			(86)	(14)		
21 May 1974	199	27	37	6	—	94	—
	181–238			(78)		(22)	
18 June 1974	206	10	60	1	—	99	—
	196–232			(33)		(66)	
15 Aug. 1973	201	8	12	93	6	—	1
	182–225			(82)	(16)		(1)
13 Oct. 1973	201	12	42	12	1	87	1
	181–248			(75)	(14)	(9)	(2)
Total	204	98	37	41	2	57	<1
				(75)	(8)	(17)	(<1)

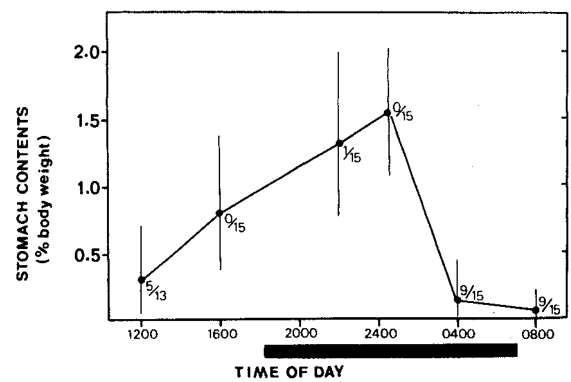

FIGURE 1.—Feeding periodicity of Lake Michigan smelt collected on 13–14 October 1973. Dry weights of stomach contents are expressed as a percentage of dry body weight. Vertical lines represent ±2 SE of the mean and the horizontal black bar the hours of darkness. The number of empty stomachs and number of stomachs examined are given near each average.

these numbers never exceeded 1% dry weight of the diet. Alewives were consumed most frequently during the June collection when yearlings composed 58% dry weight of the diet. Small alewives constituted 30 and 10% dry weight of the diet during August and October, respectively.

Food eaten by smelt 180 mm and longer consisted principally of small alewives and *Mysis,* but included small numbers of *Pontoporeia* and occasionally fingernail clams (Table 3). Yearling alewives represented 94 and 99% dry weight of the diet during the May and June collections, respectively.

Smelt examined for feeding periodicity averaged 158 mm total length. Weight of stomach contents differed statistically over the 24-h period during the October collection ($F = 9.99, P \leq 0.001$, df = 5, 82). Stomachs contained the most food (1.5% body weight) at 2430 h and decreased to 0.2% by 0400 h (Figure 1). In addition, the occurrence of empty stomachs was dependent upon time of day ($\chi^2 = 31.51, P \leq 0.001$, df = 5). Only 1 out of 45 stomachs was empty in the collections between 1600 and 2430 h. In contrast, 23 out of 43 stomachs were empty between 0400 and 1200 h (Figure 1). The March collection showed no significant differences in weight of stomach contents over a 24-h period.

Discussion

Smelt examined in this study were piscivorous, consuming young-of-the-year and yearling alewives. Food habit studies of smelt in Saginaw Bay, Lake Huron (Gordon 1961) and Lake Erie (Price 1963) have shown that smelt consume fishes, but not alewives. Smith (1970) hypothesized that differences in their depth distributions could explain failure to demonstrate predation of smelt upon alewives. Recently, smelt collected from northern Lake Michigan during the fall were reported to contain large numbers of young-of-the-year alewives in their stomachs (O'Gorman 1974). Smelt examined in this study consumed alewives not only during the fall, but also during February, May, June, and August. This study and O'Gorman's confirm the smelt's role as a predator of alewives in Lake Michigan. The high frequency of small alewives and *Mysis* in the diet of smelt suggests a preference for larger food items.

Increased piscivority with size is well known among predatory fishes. Lake Erie smelt longer than 126 mm consumed more fishes than smaller specimens (Price 1963). In this study, smelt 180 mm and longer consumed about three times more fish than the smaller individuals (grand averages of 57 and 23%, respectively). According to O'Gorman (1974), the smallest smelt which had consumed a fish was 143 mm total length. In the present study, the smallest smelt which had consumed an alewife was 157 mm.

Seasonal differences in food habits reflect changes in depth distribution of smelt and annual changes in abundance of prey. Smelt in Gull Lake, Mich., consumed primarily copepods and cladoceran during early winter but from May to August, dipterans were their principal food (Burbidge 1969). Similarly, smelt examined in this study consumed Tendipedidae only during May, June, and August, when the flies were abundant. In Lake Superior, smelt longer than 125 mm consumed mostly *Mysis* except during May and June, when copepods ranked first (Anderson and Smith 1971). Likewise, smelt examined in our study showed a change in food habits from winter to spring but, in this case, from *Mysis* to yearling alewives. Following littoral spawning during April, smelt were captured in shallower water where *Mysis* is not abundant. Schools of small alewives occupying this zone provided an alternative food.

Smelt examined during October fed after dusk and ceased feeding during the night. *Mysis* represented 87% dry weight of the diet during the October collection. This in conjunction with the known fact that *Mysis* undergoes a nocturnal vertical migration (Beeton 1960) suggests that their feeding was associated with the migration, and consequent availability of the smelt's principal food organism. Feeding of young-of-the-year sockeye salmon, *Oncorhynchus nerka*, has been related to diel vertical movements of zooplankton (Narver 1970). A statistically significant feeding periodicity was not demonstrated during the March collection. However, this could be due to reduced feeding intensity as evidenced by very small amounts of food present in their stomachs (e.g., 0.1% body weight).

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USEABLE MEAT YIELDS IN THE VIRGINIA SURF CLAM FISHERY[1]

The weight of surf clam meat landed in Virginia is estimated by the National Marine Fisheries Service, Division of Statistics and Market News (DSMN) by multiplying bushels landed by a constant of 17 lb (7.71 kg) of total meat per bushel. However, total meat weight includes the viscera, a portion of clam not utilized by the industry. Herein is an analysis of the yield of useable surf clam meat weight per bushel and seasonal variability in meat weight relative to seawater temperature for Virginia stocks.

Methods

Monthly mean useable meat weight per bushel (MMUWB) was estimated from 181 daily landings totaling 167,564 bushels in 1974, and 160 daily landings totaling 270,170 bushels in 1975. The surf clams were harvested from Virginia stocks in the region offshore of Cape Henry and south to about False Cape.

Meat weight landings reported by DSMN are in pounds, for conformity useable meat weight estimates are also cited in pounds.

Monthly mean seawater temperature (MMST) was estimated from daily surface water temperatures recorded at Kiptopeke Beach, Va. (lat. 37°10.0′N, long. 75°59.3′W), about 13 n.mi. north of Cape Henry. These data, collected and published by National Oceanic and Atmospheric Administration (NOAA), Oceanographic Surveys Branch, exhibited seasonal trends which were correlated to changes in useable meat yield per bushel. Although these temperatures are not in situ measurements, they are a convenient covariate of meat yield.

The relationship of MMUWB to MMST was estimated by Model II regression analysis since both variables were subject to sampling error. The choice of a particular Model II analysis relative to the source of the variability (measurement errors, inherent variability, or both) is a somewhat unsettled subject recently discussed by Moran (1971), Ricker (1973, 1975) and Jolicoeur (1975). No such theoretical considerations were used in the present analyses. Four models were employed to derive "predictive" equations from the 1974 data: Ricker's (1973) geometric mean analysis (GM regression); Wald's (1940) and Bartlett's (1949) arithmetic mean analysis (termed AM regression by Ricker); and principal axis analysis (although it is recognized that variables do not truly have a bivariate normal association). Empirically, the adequacy of the models in predicting the observed 1975 annual mean useable meat weight per bushel (AMUWB) from the MMST in 1975 was assessed by a randomized block (two-way) analysis of variance in which the predicted and observed MMUWB were the experimental units replicated by months. MMST was recorded to 0.1°C, MMUWB to 0.01 lb.

Results and Discussion

The MMUWB of surf clams ranged from 10.8 to 14.0 lb in 1974, and from 10.6 to 14.5 lb in 1975 (Table 1). AMUWB, 12.5 lb in 1974 and 12.6 lb in 1975, were nearly identical ($P>0.80$). There was a cyclical increase in the MMUWB from the minima in winter months to maxima in July and August 1974 and in July 1975. The correlation coefficients (r) for MMUWB and MMST were 0.64 and 0.79 in 1974 and 1975, respectively; $r = 0.71$ for the pooled data.

The sinusoidal trend in MMUWB is probably related to maturation and subsequent spawning. Ropes (1968) reported a major spawning period in summer and a minor period in fall in New Jersey waters, but the time and duration of surf clam spawning in Virginia waters has not been reported. If increasing MMUWB is indicative of maturation, the data imply that most spawning by

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