FEEDING ECOLOGY OF LARVAL AND JUVENILE WEAKFISH (*CYNOSCION REGALIS*) IN THE HUDSON RIVER ESTUARY

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

The impact of feeding conditions on larval survival and recruitment of fishes can not be properly assessed without an understanding of the feeding ecology of the earliest life stages. Diet composition and feeding incidence of larval and early juvenile weakfish were investigated in the Hudson River estuary. The objectives of this study were (1) to identify the prey of larval and early juvenile weakfish, (2) examine changes in diet with changes in larval length, (3) investigate spatial patterns in feeding, and (4) investigate the diel feeding periodicity of weakfish. Gut content analysis revealed that throughout the lower Hudson River (river miles 0-38), weakfish diets were dominated by copepods and mysid shrimp. As fish size increased, diet composition broadened and the range of prey sizes consumed increased. The percentage of weakfish with full stomachs increased in catches throughout the night and peaked at 22.51 hours. Mean stomach fullness was lowest during daylight hours.

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INTRODUCTION

It has been hypothesized that high and variable mortality rates during larval and juvenile stages contribute significantly to recruitment levels to adult populations (Houde 1987; Taggart and Frank 1990). Factors that govern the success of larvae, such as growth, abundance, and feeding, are of great interest to life history studies and undoubtedly vary among species, locations, and years. Poor feeding success during the larval stage can affect survival by increasing starvation risks and decreasing larval growth rates (Houde 1987). However, the impact of feeding conditions on larval survival and recruitment can not be properly assessed without an understanding of the feeding ecology of the earliest life stages.

Weakfish *Cynoscion regalis* (Perciformes: Sciaenidae) are of considerable economic importance along the Atlantic seaboard. In the New York Bight, spawning occurs in late spring and summer in coastal and estuarine waters (Consolidated Edison 1999). Larvae are retained in the Hudson River and are transported upriver. Juveniles move upstream to lower salinity nursery areas in the Tappan Zee-Haverstraw Bay region and may penetrate freshwater environments, returning downstream in the fall (Martin 2001).

There is an abundance of laboratory and field research on larval and juvenile weakfish diet and spatial differences in feeding, growth, and condition (Szedlmayer et al. 1990, Goshorn and Epifanio 1991a, Goshorn and Epifanio 1991b, Paperno et al. 1997). Feeding success (proportion of feeding larvae and quantity of ingested prey items), growth, and survival have been shown to follow spatio-temporal patterns (Grecay and Targett 1996, Paperno et al. 2000). The suitability of estuarine zones based on physical (temperature and salinity) properties in the Delaware Bay has been experimentally assessed (Lankford and Targett 1994). Researchers showed that there are spatial and temporal shifts between meso- and oligohaline regions for maximal feeding and growth.

Despite the abundance of work associated with weakfish feeding ecology, no research to date has been reported on diel feeding periodicities of weakfish. This knowledge is prerequisite for establishing the appropriate sampling scales for feeding success studies. Inappropriate sampling scale can severely bias the interpretation of data (Taggart and Frank 1990; Pepin and Penney 1997).

A better understanding of feeding by weakfish early life stages in both space and time is essential to delineate and predict spatio-temporal effects on larval survival and recruitment. It is necessary to know how changes in larval distribution influence feeding success and diet composition and the scales at which these factors are important. In addition, estuarine-specific analysis of feeding ecology is required because of the biological and physical differences in estuarine nursery areas and the propensity toward natal homing in weakfish (Thorrold et al. 2001).

The present study examines spatio-temporal differences in the diet and feeding success of larval and juvenile weakfish in the Hudson River Estuary. The objectives of this study were (1) to identify the prey of larval and early juvenile weakfish, (2) examine changes in diet with changes in larval length, (3) investigate spatial patterns in feeding, and (4) investigate the diel feeding periodicity of weakfish.

METHODS

Field sampling

Larval and early juvenile weakfish were collected as part of two different research programs in 1998. Sampling of large-scale spatial and temporal distribution was conducted along the river from May to October of 1998 as part of the Utilities Longitudinal River Ichthyoplankton Survey, referred to as **Along-river sampling**. Sampling was conducted according to a stratified random design that divided the river into 12 regions. Biweekly, nighttime ichthyoplankton sampling was conducted from River Mile (RM) 1 at Battery Park in Manhattan to RM 152 at the Federal Dam at Troy (Figure 1). Fish were sampled using two gear types; a Tucker trawl or a Tucker trawl mounted on an epibenthic sled, both with 505 μm mesh. Samples were preserved in either 10% formalin or 95% ethanol. Consolidated Edison (1999) provides a detailed description of this sampling program.

Additional larval collections were made to investigate the fine-scale vertical (depth) and lateral (cross channel) distribution of larval and early juvenile weakfish at a fixed station in the Hudson River Estuary, referred to as **Fixed-site sampling**. Discrete-depth sampling for weakfish concentration was conducted at Croton Point in the lower Hudson River during July 1998 (RM 34; Figure 1).

Larvae were collected at three stations spanning Croton Point: one in the channel and the other two over the western and eastern shoals. These stations were sampled at 2-hour intervals. Ichthyoplankton sampling was conducted in discrete depth bins by an opening-closing Tucker trawl with 333 μm mesh. In the channel, 4 depth bins were

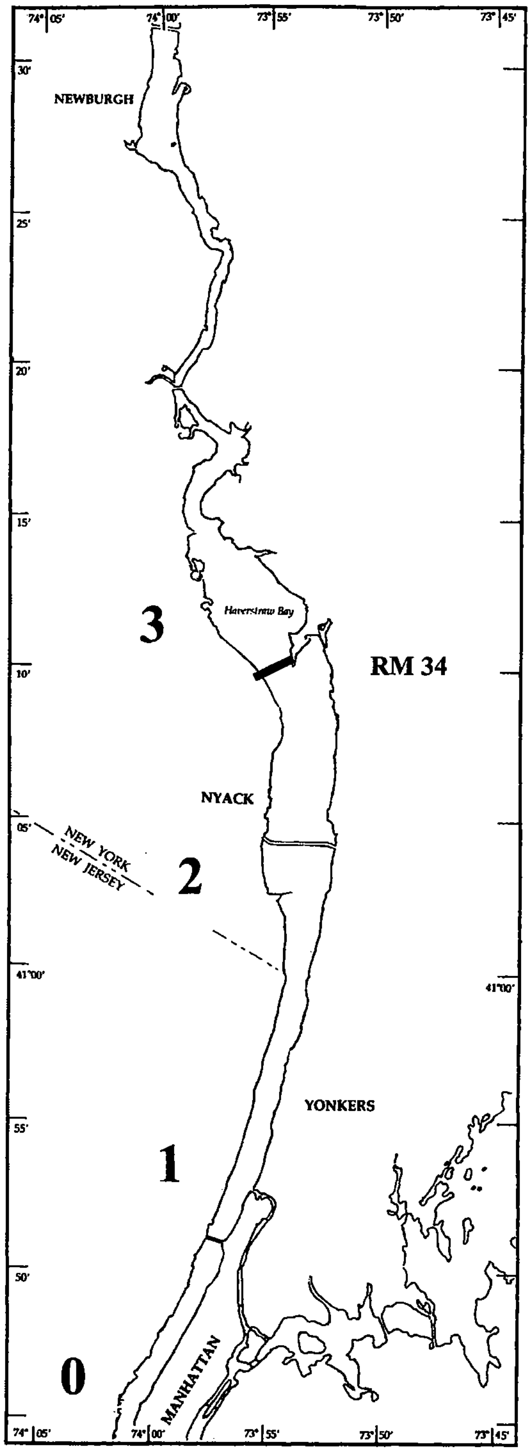

Figure 1. Map of Hudson River. Approximate locations of regions analyzed for Along-river sampling are indicated by the appropriate number; Region 0 (RM 1-11), Region 1 (RM 12-23), Region 2 (RM 24-33) and Region 3 (RM 34-38). Fixed-site sampling was located at Croton Point (RM 34).

sampled (9-7 m, 7-5 m, 5-3 m, 3-1 m). At both the west and east shoals, only a 2 m depth bin (1-3 m) was sampled. All samples were preserved in 95 % ethanol. Schultz et al. (*in review*) provide additional sampling details and physical characteristics of the stations.

Laboratory

Weakfish were removed from samples and individual standard lengths (SL) were measured using an image analysis system (Optimas v. 6.1). Entire digestive tracts (esophagus, stomach, and intestine) were removed and prey items were identified and enumerated. Contents were mostly identified to general taxon (order or suborder). Copepodites were included in the adult copepod category and cephalothorax length was measured on all intact specimens. Length (carapace + abdomen) of complete mysid shrimp was also recorded. Data presented here refers only to the composition of prey in the stomach unless otherwise noted.

Spatial patterns— To examine spatial effects in diet composition, Along-river samples were pooled by region. Larval abundance was greatest in regions 0-3 (Figure 1) therefore spatial analyses were restricted to these regions. Within each region, larvae were randomly sampled for diet analysis. Temporal and size-specific effects on diet are not analyzed here.

The relative importance of each of the four most dominant prey types was calculated as the product of F (percent frequency of occurrence in guts) and N (percent of total number of items in the diet) (Govoni et al.1983). Diet indices were compared across regions.

Diel feeding periodicity—Feeding periodicity of weakfish was assessed by examining a subset of samples collected over one 24-hour period (2-hour sampling interval; Table 1). Gut content analysis was performed on 10 larvae, spanning the size distribution, from each sample collected in the deepest depth bin (channel, 7-9 m; Table 1). If less than 10 weakfish were collected, all were analyzed. Fish were divided into small (< 11 mm SL) and large (> 11 mm SL) size classes. A fullness code between 0 (empty) and 3 (full) was assigned to each stomach. Mean fullness codes were calculated for each sample and compared across collection times. The absence or presence and location (entire, anterior, posterior) of digested material in the intestine were also noted.

Table 1. Summary of samples analyzed for diel feeding periodicity from Croton Point (RM 34). Mean size and range are standard length in mm; n = number of guts analyzed. The mean fullness code is given for each sample by size class.

Date	Time	Mean SL	Range	n		Mean stomach fullness code (range 0 = empty to 3 = full)	
				< 11mm	> 11mm	< 11mm	> 11mm
7/23/98	1758	12.43	6.12 - 26.01	6	4	1.8	1.8
	1955	10.26	7.17 - 13.31	6	4	1.3	2.75
	2251	14.15	6.38 - 25.08	5	5	2	3
7/24/98	0032	11.94	6.10 - 21.97	5	5	2.6	2.6
	0246	28.38	22-02 - 33.03	0	3	N/A	1.6
	0443	12.34	7.92 - 24.61	5	5	0.2	2
	0701	9.69	5.42 - 16.32	6	4	0.5	1
	0911	9.32	5.89 - 12.15	6	4	1.6	1.5
	1114	12.41	9.06 - 17.23	2	8	0.5	1.125
	1324	11.07	5.74 - 17.63	5	5	0.8	2.4
	1518	9.7	6.49 - 14.91	7	3	0.83	0.67
	1716	11.95	3.97 - 16.25	5	5	0.2	1.8

Diet composition and ontogenetic changes— All samples analyzed for gut contents were pooled to examine the overall composition of weakfish diet and changes in diet with larval size. The percent frequency of occurrence was compared across size classes. A predator - prey size relationship was examined by plotting the range in mysid length with increasing predator size.

RESULTS

Diet composition and ontogenetic changes

A total of 222 larval and juvenile weakfish collected from 1998 were analyzed for diet composition. Overall, the most frequently occurring prey items were calanoid copepods [dominated by *Acartia* spp. and *Eurytemora affinis* (52 %)], followed by mysid shrimp (42 %) [mostly *Neomysis americana* (Table 2)]. Zoea larval stages (6.7 %; primarily *Rhithropanopeus harrisii*), amphipods (4 %; *Gammarus* spp.), invertebrate eggs (3.1 %) and cumaceans (2.7 %; unidentified) constituted the next most abundant prey items. An unidentified gastropod, an isopod *Cyathura polita*, and a weakfish appeared in one gut each.

However, diets varied by size-class (Table 2; Figure 2). Small larvae (< 11mm) fed primarily on copepods (49 %). Mysid shrimp were found in 15 % of all small larvae; however, all fish containing mysids were greater than 9 mm SL. Invertebrate eggs were present in 6.6 % of small stomachs, all from larvae less than 6 mm SL.

Mysid shrimp dominated the diet of weakfish greater than 11 mm (66 %), followed by copepods (52 %; Figure 2). When fish reached 20 mm SL, diet became more

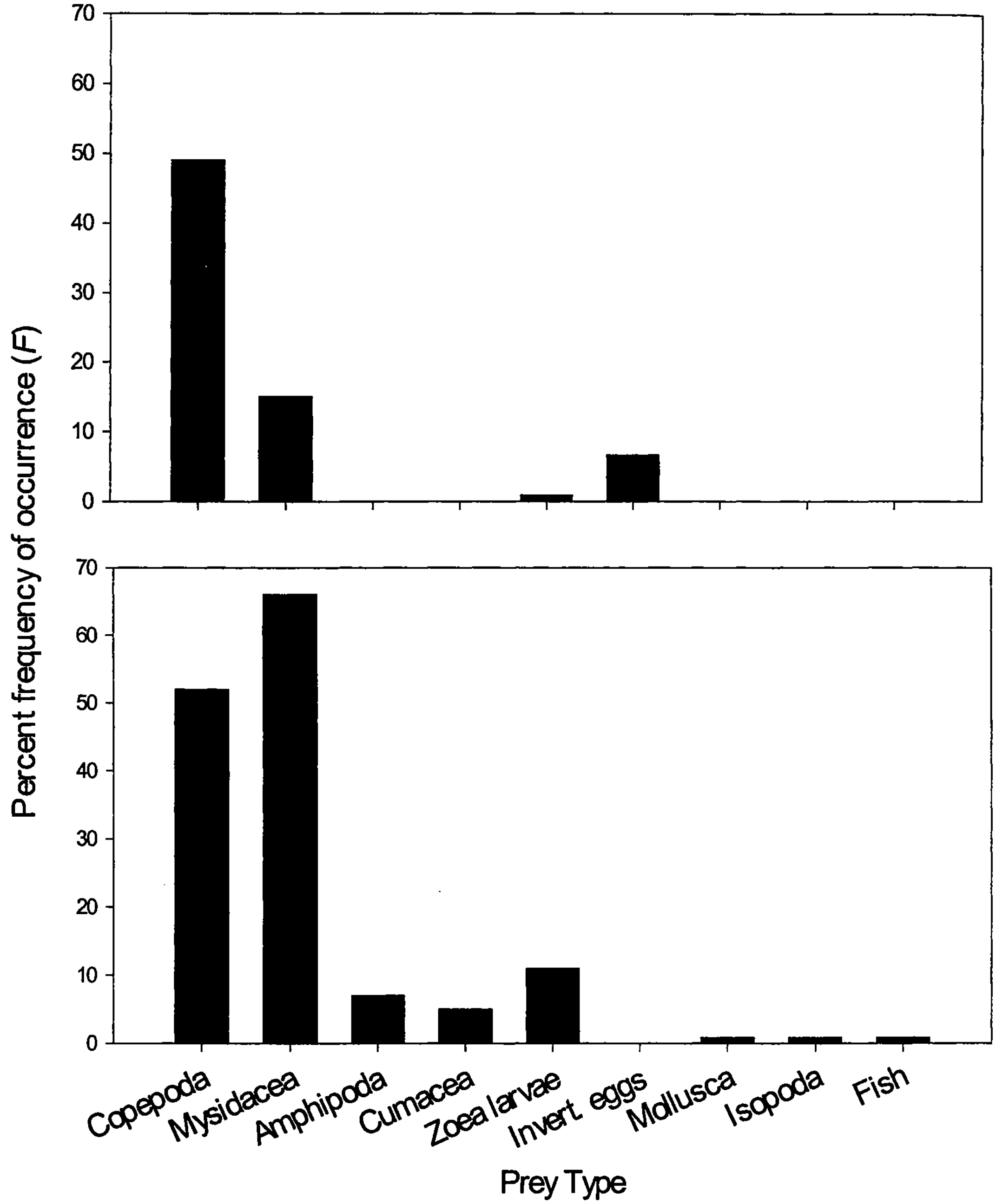

Figure 2. Percent frequency of occurrence (*F*) prey items in (a) weakfish < 11mm and (b) weakfish > 11mm.

Table 2. Diet description for the total of all weakfish sampled and by size group (<11mm; >11 mm). *F* is the percent frequency of occurrence in guts.

Prey	*F*		
	Total	< 11mm	>11 mm
Copepoda	52	49	52
Mysidacea	42	15	66
Amphipoda	4	0	7
Cumacea	2.7	0	5
Zoea larvae	6.7	0.9	11
Invertebrate eggs	3.1	6.6	0
Mollusca	0.4	0	0.8
Isopoda	0.4	0	0.8
Fish	0.4	0	0.8

diverse and included amphipods, cumaceans, and zoea larval stages (Figure 2; Table 2). A weakfish, approximately 7 mm, was found in the gut of a 25.08 mm weakfish.

As fish length increased, individuals preyed upon larger mysids; however, smaller mysids were still consumed (Figure 3). Copepods followed a similar pattern (data not shown). Naupliar and copepodite stages occurred most frequently in the guts of weakfish less than 7 mm. In addition, the number of prey items consumed increased with fish length.

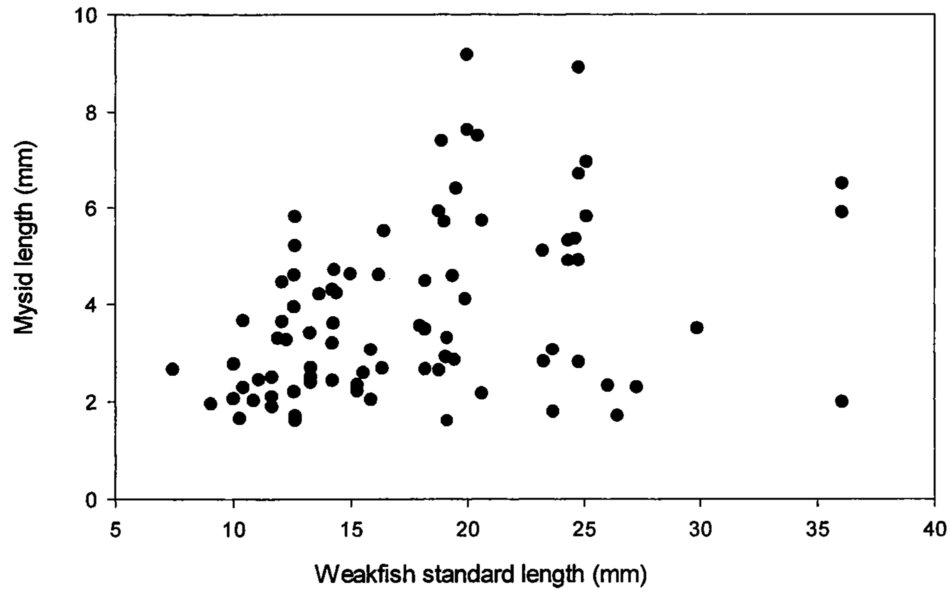

Figure 3. Length (mm) of mysids consumed in relation to the standard length (mm) of weakfish. Each symbol represents a single mysid consumed by a weakfish.

Spatial patterns

Weakfish from 2.29 – 41.45 mm were analyzed for gut contents (n = 109) from Along-river samples collected from 22 June 1998 to 11 August 1998. Of these fish, 96 % had stomach contents. Mean SL of fish analyzed differed significantly by region (ANOVA; $p < 0.001$). The largest fish analyzed were collected in Region 1 (20.24 ± 9.5 mm) and Region 3 (14.68 ± 7.1 mm). Region 0 (8.52 ± 5.8 mm) and Region 2 (9.83 ± 6.44 mm) had a greater occurrence of smaller fish analyzed for gut contents.

Over all regions, copepods and mysids were the most frequently occurring prey items. However, copepods dominated the percentage of prey number (Table 3). An individual that preyed upon copepods typically ate several at a time, whereas an individual that fed on mysids consumed only one or two.

Amphipods and cumaceans- larger prey items- were found only in the guts of fish collected in Regions 1 and 3 (Table 3), the regions where the mean SL of fish sampled for diet analysis was greatest.

Table 3. Regional differences in diet expressed as percent frequency of occurrence (*F*) and percent of total number (*N*) of prey in the diet. The product (*F x N*) was used as a measure of relative importance.

Taxon	Region 0 (n=24)			Region 1 (n=28)			Region 2 (n=22)			Region 3 (n=35)		
	F	*N*	*FxN*	*F*	*N*	*FxN*	*F*	*N*	*FxN*	*F*	*N*	*FxN*
Copepoda	45	60	2700	39	54	2106	81	83	6723	31	39	1209
Mysidacea	50	40	2000	61	37	2257	18	17	306	31	31	961
Amphipoda	0	0	0	17	5	85	0	0	0	6	4	24
Cumacea	0	0	0	14	4	56	0	0	0	6	25	150

Diel feeding periodicity

The percentage of weakfish with full stomachs (fullness code 3; size-classes pooled) increased in catches throughout the night and peaked at 22.51 hours and 00.32 hours when 80 % and 70 %, respectively, of the stomachs analyzed were full (Figure 4). This was also the time period when most prey items were identifiable and intact, which suggests that they had recently been consumed. The majority of individuals analyzed from these collections had intestines that were either empty or contained little digestive material.

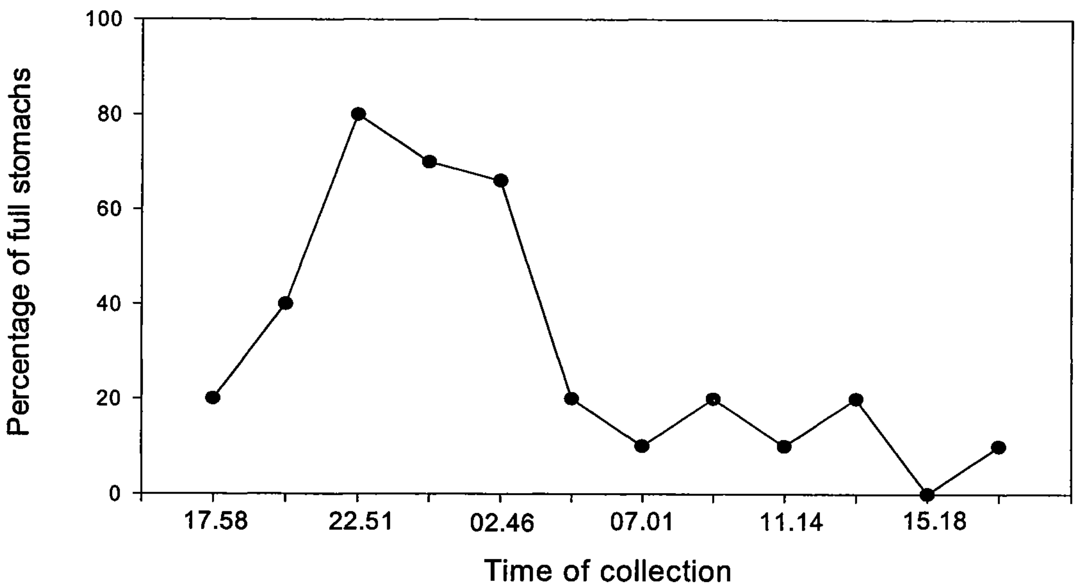

Figure 4. Relationship between collection time and stomach fullness as a percentage of full stomachs (fullness code 3) for weakfish analyzed.

Mean stomach fullness began to decline to less than 20 % in samples collected in early morning (04.43 hours; Figure 4). This decline in stomach fullness was associated with stomach contents in an advanced state of digestion and an increase of digested material in the intestine.

Generally, the mean stomach fullness (average stomach fullness code for each sample by size-class) for small (<11 mm) weakfish was less than that of large (> 11 mm) fish (Table 1). When the mean stomach fullness was low for small fish (indicative of empty stomachs or low feeding success), intestinal tracts were typically full of digested material, suggesting that these individuals had fed recently. Only 4 larvae, ranging in size from 6.24 – 11.25 mm, had digestive tracts that were completely empty (stomach and intestine).

DISCUSSION

Diet composition and ontogenetic changes

Copepods and the mysid shrimp *Neomysis americana* dominated the diet of Hudson River weakfish. Copepods are the most abundant macrozooplankton in the Hudson River estuary (Stepien et al. 1981), so it is likely that smaller weakfish are feeding as generalists. However, this cannot be accurately assessed without data on prey availability. Copepods and invertebrate eggs were the primary dietary items of larval weakfish (< 7 mm) in the Delaware Bay (Goshorn and Epifanio 1991). Mysid shrimp have often been cited as the major contributor to the diet of juvenile weakfish (Mercer 1983; Grecay and Targett 1996). In general, the prey composition of Hudson River weakfish is consistent with previous studies.

The range of prey size eaten expanded with increasing fish length (Figure 3). In other words, larger weakfish continued to feed upon smaller prey. As suggested by Scharf et al. (2000), this is in contrast to optimal foraging models that predict that maximum energy is returned with the consumption of the largest available prey. However, the majority of these models do not include factors that influence encounter rates. The ability of larger weakfish to take a wider variety of prey sizes may reduce their vulnerability to changes in abundance or availability in prey types and size classes (Pepin and Penney 1997).

Spatial patterns

Because of their ubiquitous nature, it is not surprising that copepods and mysids dominated the diet of weakfish in all regions of the Hudson River (Table 3). However, the importance of amphipods and cumaceans in Regions 1 and 3 is most likely an artifact associated with sampling bias. Fish of significantly larger size were analyzed from these regions. Results from the Delaware Bay showed that the percentage frequency of occurrence of mysids in the diet of juvenile weakfish was greatest in the middle Bay (Grecay and Targett 1996). This was attributed, in part, to spatial differences in turbidity and illumination levels. However, the mean SL of weakfish in the middle Bay was significantly greater than other areas. It is possible that the size factor may contribute to the increase in the percentage of diets consisting of mysids of fish from the middle Delaware Bay.

To accurately assess spatial differences in feeding and diet composition, temporal and ontogenetic effects need to be accounted for, especially in fish, like weakfish, where habitat use is size-dependent. A better understanding of spatial and temporal variations in the abundance of prey items is also needed.

Diel feeding periodicity

Both the percentage of weakfish with full stomachs and the mean stomach fullness were greatest near midnight for both size groups. Gut contents were most fresh and intact during these same periods. At this time, the hindgut of smaller fish (< 11 mm) was typically empty or contained little digested material. This suggests that feeding may not be continuous and the onset of feeding and primary feeding times occur during nighttime hours. A similar pattern was detected for juvenile Cape hake *Merluccius capensis* off the South African coast (Pillar and Barange 1995).

This knowledge of weakfish diel feeding periodicity may account for the low percent of empty stomachs (4 %) collected from the Along-river sampling program in this study (night collections only). Goshorn and Epifanio (1991) collected larval weakfish during daylight and almost half of their smallest larvae ($\leq$ 3.5 mm) had no food in their guts. They suggested the possibility that inadequate food supplies or quicker gut evacuation rates of small larvae may explain the high percentage of empty guts. In the present study, mean stomach fullness decreased more rapidly for small larvae (Table 1), which suggests that small larvae have more rapid digestion.

The results of the diel feeding periodicity study, however, should be applied with caution since this is based only on one 24 hour period and other factors (i.e. tidal variations) have not been assessed. Analysis of additional time-series data and more size-specific analyses should be conducted before definitive statements about diel feeding periodicity can be made.

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