FOOD AND FEEDING HABITS OF JUVENILE ATLANTIC TOMCOD, *MICROGADUS TOMCOD*, FROM HAVERSTRAW BAY, HUDSON RIVER

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ABSTRACT

Juvenile Atlantic tomcod from Haverstraw Bay (Hudson River, N.Y.) were found to have a May-June diet of copepods and a July-December diet of amphipods, *Neomysis americana*, and isopods. This dietary shift occurred when mean length reached 90 mm during July. Growth paralleled feeding intensity: elevated during June, October, and November, and depressed July through September; feeding intensity decreased prior to spawning (December). Feeding and growth were inhibited at temperatures >24°C and dissolved oxygen <7mg/l.

The Atlantic tomcod, *Microgadus tomcod* Walbaum, is an inshore marine fish whose range extends from southern Labrador (Bigelow and Schroeder 1953) south to Virginia (Massman 1957); freshwater populations are localized in Quebec and Newfoundland (Scott and Crossman 1973). The Hudson River may represent the southern extent of the tomcod's breeding range since it has not been reported from the Delaware River estuary (de Sylva et al.[2]) and its status in New Jersey waters is uncertain (Miller 1972; Heintzelman[3]). In the Hudson River tomcod were formerly considered to be a seasonal, migratory species (Curran and Ries 1937; Clark and Smith[4]); more recent work, however, suggests that tomcod remain in the estuary for their entire life cycle (Lawler et al.[5]).

Tomcod spawn as young-of-the-year and yearlings (Lawler et al.[6]) with egg deposition typically occurring during December and January (Bigelow and Schroeder 1953; Booth 1967). First year growth, while initially rapid, slows in midsummer (Howe 1971) and resumes in early fall (Lawler et al. see footnote 5; Texas Instruments[7]; Dew and Hecht[8]).

Young-of-the-year Hudson River tomcod undergo a dietary shift, from calanoid copepods to *Gammarus* spp. amphipods, as they increase in size (Texas Instruments see footnote 7). My objectives were to define the diet and feeding intensity of juvenile tomcod within the vicinity of Haverstraw Bay, Hudson River, N.Y.

MATERIALS AND METHODS

Stomach contents of 577 juvenile tomcod were analyzed as part of the postoperational biological monitoring program for a fossil fuel steam electric generating station located at Hudson River milepoint 37.5. The study area (Figure 1) encompassed Hudson River milepoints 37.5-41.5, as measured from the Manhattan Battery.

Tomcod were collected once monthly June-December 1973 and 1974 by a 9.1-m otter trawl with a 64-mm mesh cod end liner, towed against the tide at 1.5-2.0 m/s. Collections of plankton and juvenile fishes were made twice monthly June-August 1974 with a 1-m diameter plankton net of 571-μm mesh mounted in an epibenthic sled and towed against the tide at 0.9-1.2 m/s. Tomcod from May and December 1975 trawl collections were also analyzed to provide a larger data base for these months.

[1]Lawler, Matusky and Skelly Engineers, Pearl River, N.Y.; present address: 95 Ash Street, Piermont, NY 10968.

[2]de Sylva, D. P., F. A. Kalber, and C. N. Schuster, Jr. 1962. Fishes and ecological conditions in the shore zone of the Delaware River estuary, with notes on other species collected in deeper water. Del. Board Fish Game Comm., 164 p.

[3]Heintzelman, D. S. (editor). 1971. Rare or endangered fish and wildlife of New Jersey. N.J. State Mus. Sci. Notes 4, 23 p.

[4]Clark, J. R., and S. E. Smith. 1969. Migratory fish of the Hudson River. *In* G. P. Howells and G. J. Lauer (editors), Hudson River ecology, p. 293-319. N.Y. State Dep. Environ. Conserv.

[5]Lawler, Matusky and Skelly Engineers. 1975. 1974 Hudson River aquatic ecology studies. Bowline Point and Lovett Generating Stations. Prepared for Orange and Rockland Utilities, Inc.

[6]Lawler, Matusky and Skelly Engineers. 1976. Environmental impact assessment-water quality analysis: Hudson River. National Comm. on Water Quality. NTIS PB-251099.

[7]Texas Instruments, Inc. 1975. Hudson River ecological study in the area of Indian Point: 1974 annual report (draft). Prep. for Consolidated Edison Co. of N.Y., Inc.

[8]Dew, C. B., and J. H. Hecht. 1976. Ecology and population dynamics of Atlantic tomcod (*Microgadus tomcod*) in the Hudson River estuary. *In* Hudson River ecology. Hudson River Environ. Soc., Inc.

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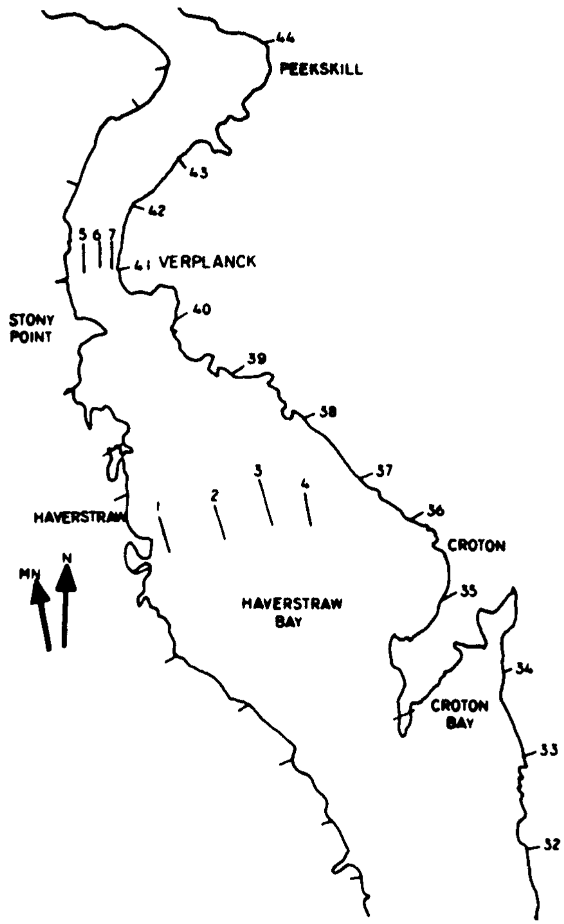

FIGURE 1.—Sampling stations, depths, and collection methods for Atlantic tomcod, Haverstraw Bay 1973-75. Numbers along river indicate mile points above the Manhattan Battery. Station 1: 6.7 m; trawl, epibenthic sled. Station 2: 12.2 m; epibenthic sled. Station 3: 7.6 m; trawl. Station 4: 3.0 m; epibenthic sled. Station 5: 18.3 m; trawl, epibenthic sled. Station 6: 16.8 m; epibenthic sled. Station 7: 13.7 m; trawl, epibenthic sled.

Bottom temperature (Figure 2), dissolved oxygen, and salinity (Table 1) were measured at station 2 (depth 12.2 m).

Fish were preserved in 5% (epibenthic sled collections) or 10% (trawl collections) buffered Formalin.[9] Total length of each fish was measured to the nearest millimeter. Fish >50 mm were weighed to the nearest 0.1 g; fish <50 mm were weighed to the nearest 0.01 g. Stomachs were removed and transferred to a 70% solution of ethanol prior to analysis. One everted fish stomach, indicative of regurgitation, was excluded. Food organisms were identified, counted, and the entire contents, excluding obvious nonfood items (e.g., pebbles), of 401 stomachs were dried to a constant weight at 103°C.

Only postlarval juveniles were studied; the distinction between larval and juvenile tomcod was the completed differentiation of the fins (Balon 1975). Lower limits of adult fin ray counts were taken from Bigelow and Schroeder (1953). Application of this criterion showed that a total body length of 25 mm represented the lower size limit of juveniles. During 1973, young-of-the-year were distinguished from yearlings by examination of length-frequency histograms of larger sample sizes of tomcod (Lawler et al. see footnote 6; Lawler et al.[10]). Fish collected during November and December 1973, 148 and 160 mm, respectively, were considered to represent upper size limits of young-of-the-year. All fish collected during 1974 and December 1975 were condsidered young-of-the-year.

Stomach content data were pooled by month and quantitative results for each taxon calculated as percent occurrence, percent composition, and importance (Windell 1971):

$$\text{Importance} = \sqrt{(\%\ \text{composition})\ (\%\ \text{occurrence})}.$$

Percent relative importance was calculated by summing importance values at the lowest taxonomic level and dividing individual importance values by that sum. A modified similarity index (Windell 1971) was then calculated to compare monthly changes in percent relative importance of various food items, at the lowest comparable taxonomic level. Consecutive months were compared by selecting the lesser of two relative importance values for each food item and then summing them. This sum is the index of similarity and it may range from 0 to 100%.

An index of fullness (I_f) (Nikolsky 1963; Windell 1971), indicative of feeding intensity, was calculated for each fish:

$$I_f = \frac{\text{stomach content biomass (g)} \times 10^4}{\text{weight (g) of fish}}.$$

[9]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[10]Lawler, Matusky and Skelly Engineers. 1974. 1973 Hudson River aquatic ecology studies: Bowline Point and Lovett Generating Stations. Prepared for Orange and Rockland Utilities, Inc.

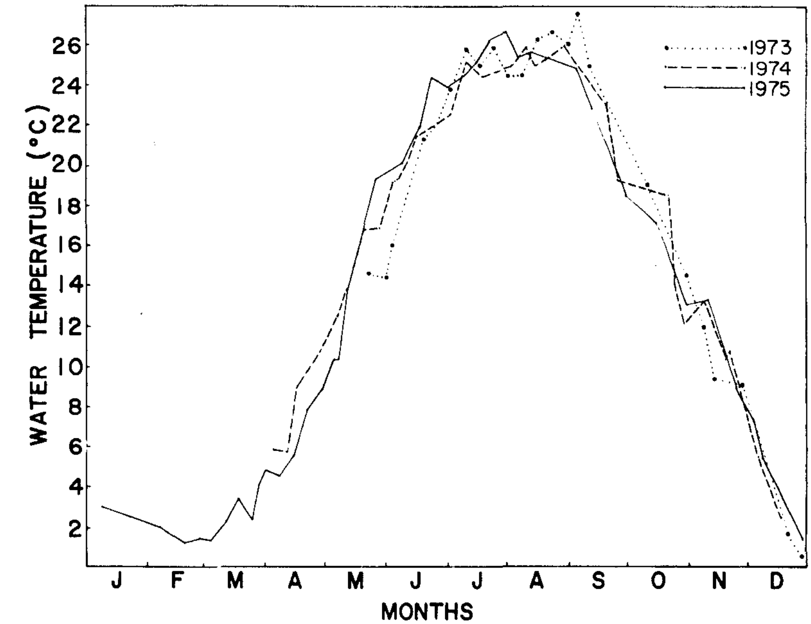

FIGURE 2.—Bottom water temperatures at Station 2, Haverstraw Bay (mile point 37.5).

TABLE 1.—Mean monthly bottom dissolved oxygen and salinity measurements at Station 2, Haverstraw Bay (mile point 37.5) 1973-75.

	Dissolved oxygen (mg/l)			Salinity (‰)		
Month	1973	1974	1975	1973	1974	1975
Jan.	([1])	([1])	9.0	([1])	<0.03	2.65
Feb.	([1])	([1])	12.5	([1])	<0.03	2.92
Mar.	([1])	([1])	12.8	([1])	<0.03	0.97
Apr.	([1])	9.6	12.1	([1])	<0.03	1.16
May	7.8	9.3	9.5	([1])	<0.03	0.93
June	7.1	7.8	6.7	<0.03	1.44	1.48
July	5.9	7.7	5.8	1.32	3.07	3.34
Aug.	5.8	5.5	5.1	([1])	4.14	4.48
Sept.	6.9	9.1	7.8	2.98	1.72	1.39
Oct.	8.6	8.5	7.8	5.72	2.02	0.87
Nov.	9.2	10.2	8.1	3.51	0.85	0.03
Dec.	12.4	12.2	11.7	<0.03	0.04	0.30

[1]Data not available.

RESULTS

Ranking dominant food items by importance (Table 2) revealed two distinct dietary regimes: a May-June diet of copepods and a July-December diet of amphipods, mysids, and isopods. The similarity index for consecutive months emphasized this shift by a markedly low value (39%) for June-July compared with a range of 54-80% for other months.

Pooling June and July fish by 10-mm length intervals indicated that copepod importance decreased and that of amphipods increased as mean length increased. At 90 mm, transition to an amphipod-dominated diet was complete (Table 3).

A seasonal feeding cycle was distinguished by trends in I_f, percentage of empty stomachs, and average number of food items per stomach (Table 4), with feeding greatest during May, June, October, and November, and lowest during July-September. Feeding also decreased during December. Growth of the 1974 year class paralleled seasonal alterations in I_f (Figure 3).

The trends of the above parameters suggested that seasonally fluctuating environmental variables (e.g., temperature and dissolved oxygen) might be affecting feeding intensity and, therefore, growth. Statistical tests to discriminate the

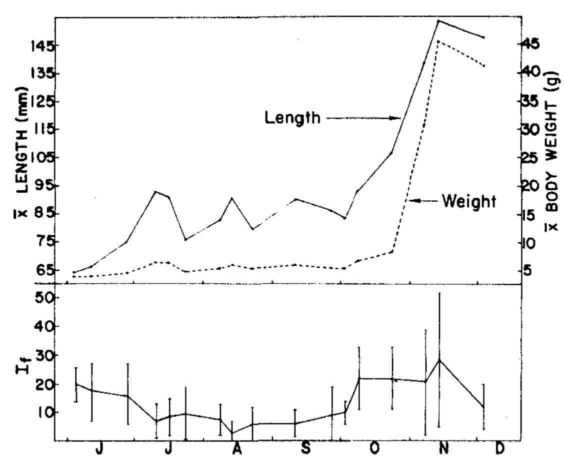

FIGURE 3.—Index of fullness (I_f) and growth of juvenile Atlantic tomcod, Haverstraw Bay, June-December 1974.

TABLE 2.—Monthly summary of five most important food items of juvenile Atlantic tomcod from Haverstraw Bay, 1973-75.

Month	Sample size	Taxon	Percent occurrence	Percent composition	Index
May	38	Copepoda	100.0	99.2	99.6
		Eurytemora affinis			
		Ectocyclops sp.			
		Halicyclops sp.			
		Gammarus daiberi	10.5	0.6	2.5
		Monoculodes edwardsi	2.6	0.1	0.5
		Ostracoda	2.6	0.1	0.5
June	210	Copepoda	54.8	82.4	67.2
		E. affinis			
		Cyclopoida			
		Harpacticoida			
		Unidentified nauplii			
		G. daiberi	64.8	6.9	21.2
		M. edwardsi	37.6	2.7	10.0
		Bosmina sp.	22.4	3.0	8.2
		Neomysis americana	19.5	0.9	4.3
July	69	*G. daiberi*	63.8	38.9	49.8
		N. americana	30.4	19.8	24.5
		M. edwardsi	31.9	18.4	24.2
		Cyathura polita	23.2	4.7	10.5
		Scolecolepides viridis	11.6	3.0	5.9
Aug.	58	*M. edwardsi*	37.9	45.8	41.7
		G. daiberi	41.4	18.2	27.4
		N. americana	25.9	15.0	19.7
		Edotea triloba	22.4	5.2	10.8
		C. polita	12.1	3.1	6.1
Sept.	43	*G. daiberi*	72.1	53.1	61.9
		M. edwardsi	34.9	28.6	31.6
		N. americana	20.9	5.4	10.6
		C. polita	14.0	2.1	5.4
		Chaoborus punctipennis	11.6	1.8	4.6
Oct.	43	*G. daiberi*	93.0	70.9	81.2
		M. edwardsi	34.9	20.2	26.5
		C. polita	25.6	2.2	7.6
		Rhithropanopeus harrisii	14.0	1.5	4.6
		Corophium lacustre	2.3	0.6	1.2
Nov.	42	*G. daiberi*	73.8	86.8	80.0
		Crangon septemspinosa	40.5	7.1	16.9
		N. americana	11.9	3.3	6.3
		R. harrisii	16.7	1.4	4.8
		M edwardsi	4.8	0.3	1.2
Dec.	74	*G. daiberi*	95.9	68.9	81.3
		Copepoda	9.4	24.9	15.3
		M. edwardsi	16.2	2.3	6.1
		Chironomidae larvae	18.9	1.4	5.1
		Cyathura polita	16.2	0.7	3.3

TABLE 3.—Importance values of copepods, amphipods, and *Neomysis americana* in stomachs of June and July juvenile Atlantic tomcod pooled by 10-mm size intervals.

Size interval (mm)	Sample size	Copepods	Amphipods	*Neomysis americana*
40-49	3	36.3	47.9	0.0
50-59	48	65.9	29.8	3.5
60-69	65	74.9	27.3	5.7
70-79	80	59.7	29.8	6.7
80-89	40	39.8	38.9	4.5
90-99	38	0.0	83.7	16.8
>100	5	8.8	75.5	0.0

effects of temperature from those of dissolved oxygen were not applied since the two parameters were highly correlated ($r = -0.96$). I_f was, however, lowest when water temperatures were >24°C and dissolved oxygen (DO) <7 mg/l and increased at temperatures <19°C and DO >7 mg/l (Table 5).

DISCUSSION

Howe (1971) characterized tomcod as opportunistic feeders; the data presented here qualify that hypothesis. Smaller tomcod, present during May and June, preyed upon copepods (Table 2) which have been the most abundant zooplankters collected by 76- and 150-μm mesh nets in this reach of the Hudson River (Lawler et al. see footnotes 5, 10; Lawler et al.[11], Lauer et al.[12]). When total length reached 80-90 mm (June-July), food preference shifted to larger prey, e.g., amphipods (Table 3). Such a shift has been documented in a variety of species (Nikolsky 1963; Stickney et al. 1974; Werner 1974; Stickney 1976), including the related species *Gadus morhua* (Kohler and Fitzgerald 1969). This shift did not appear to be a response to changes in prey density, since abundance of copepods increased while that of amphipods decreased during June-August 1973-75 (Lawler et al. see footnotes 5, 10, 11).

Copepods were a supplementary prey during December, occurring as frequently as the larger decapods *Crangon septemspinosa* (5.4%) and *Rhithropanopeus harrisii* (4.1%) which were relatively important during November (Table 2). Selection of smaller prey with the concomitant decrease of larger prey may be a response to the constriction of the alimentary canal by maturing gonads noted by Schaner and Sherman (1960). In Hudson River tomcod, gonadal biomass prior to spawning averages between 15 (males) and >30% (females) of the body weight minus the gonad weight. In contrast, female gonads in Hudson River *Morone americana* (Lawler et al. see footnote 10) average about 8%, *Alosa sapidissima* about 22% (calculated from Lehman 1953), *Trinectes maculatus* less than 6% (calculated from Koski 1974), while those of *Tautogolabrus adspersus* from Long Island Sound averaged about 7% (Dew 1976) of the body weight minus the gonad weight.

A decrease in prey (*C. septemspinosa*) availability was not considered a factor in this change. In the Haverstraw Bay area, *C. septemspinosa*

[11]Lawler, Matusky and Skelly Engineers. 1976. 1975 Hudson River aquatic ecology studies: Bowline Point and Lovett Generating Stations. Prepared for Orange and Rockland Utilities, Inc.

[12]Lauer, G. J., W. T. Waller, D. W. Bath, W. Meeks, R. Heffner, T. Ginn, L. Zubarik, P. Bibko, and P. C. Storm. 1974. Entrainment studies on Hudson River organisms. *In* L. D. Jensen (editor), Proceedings of the second entrainment and intake screening workshop, Feb. 5-9, 1973, p. 37-88. Johns Hopkins Univ., Baltimore, Md.

TABLE 4.—Mean length, weight, index of fullness, number of food items per stomach, and percent frequency of empty stomachs for juvenile Atlantic tomcod from Haverstraw Bay 1973-75.

Month	Number[1]	Total length (mm)		Weight (g)		Index of fullness		Number of food items per stomach		Frequency of empty stomachs (%)
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	
May[2]	36/38	28.9	3.2	0.3	0.1	21.809	14.630	29.3	14.1	0.0
June[3]	100/210	68.8	11.0	3.5	1.8	17.224	9.645	68.4	178.5	0.0
July[3]	68/69	86.8	11.0	6.9	2.4	7.272	6.214	7.2	7.4	5.8
Aug.[3]	39/58	86.5	10.2	6.3	2.2	5.387	5.333	5.0	6.2	10.3
Sept.[3]	30/43	90.9	9.9	7.4	2.8	7.820	7.453	9.2	9.4	2.3
Oct.[3]	40/43	98.6	12.2	9.8	3.7	25.317	41.485	18.7	16.9	2.3
Nov.[3]	42/42	139.2	14.2	33.0	11.8	24.403	22.657	15.2	17.0	2.4
Dec.[4]	46/74	143.8	12.9	35.2	12.2	12.902	7.550	55.4	67.7	2.7

[1]Number of stomachs analyzed for index of fullness/total number of stomachs.
[2]Two dates, 1975 only.
[3]1973 and 1974.
[4]1973-75; no index of fullness for 1973 fish.

TABLE 5.—Index of fullness of 1974 juvenile Atlantic tomcod, bottom water temperatures, and dissolved oxygen measurements, Haverstraw Bay.

Date	Sample size	Index of fullness		Temp (°C)	Dissolved oxygen	
		Mean	SD		mg/l	% saturation
4 June	17	20.195	6.226	17.5	8.2	85
11 June	44	16.839	10.040	20.3	8.4	91
26 June	25	17.977	12.066	21.7	7.2	82
29 June	14	13.482	5.499	([1])	([1])	([1])
10 July	24	7.062	5.872	24.8	7.1	85
16 July	7	8.694	6.593	24.8	7.0	83
23 July	9	9.798	9.264	24.8	6.8	81
8 Aug.	12	7.895	5.986	25.9	6.9	84
13 Aug.	18	3.288	3.667	25.5	5.6	68
22 Aug.	9	6.241	6.087	26.7	5.4	79
10 Sept.	13	6.261	4.610	23.4	6.8	79
26 Sept.	14	9.394	9.583	19.4	6.7	72
2 Oct.	4	10.194	3.634	18.9	7.6	81
8 Oct.	13	22.336	10.859	17.9	7.8	82
23 Oct.	11	22.065	11.226	14.2	9.8	94
5, 8 Nov.	14	20.695	18.794	14.6	9.4	91
13 Nov.	13	27.898	22.372	12.2	10.2	94
3 Dec.	22	12.370	8.107	5.6	11.6	92

[1]Data not available.

were relatively abundant in trawl collections August through November 1973 and 1974 (Lawler, Matusky and Skelly Engineers unpubl. data). Haefner (1976) found that greatest abundance of *C. septemspinosa* in channel areas of the York River and lower Chesapeake Bay occurred when water temperatures were 5°-10°C and was a result of migration from littoral areas to deeper, more saline areas; such a temperature regime occurs in Haverstraw Bay between mid-November and mid-December (Figure 1).

Feeding intensity and growth followed similar seasonal patterns. Rapid growth and relatively intense feeding occurred during May, June, October, and November (Table 4; Figure 3); growth and feeding were depressed during July-September. Prey density was not considered limiting during summer months since *Neomysis americana* was generally abundant. Also, resumption of feeding and growth occurred during October when macrozooplankton standing crop was lower than previous months (Lawler et al. see footnotes 5, 10, 11; Lauer et al. see footnote 12). Seasonally fluctuating abiotic factors, then, may be affecting growth and feeding. Food consumption in other species of gadids has been observed (Tyler 1970) or postulated (Sikora et al. 1972) to be inhibited at temperatures >20°C.

Tomcod are considered to have a low thermal optimum (Huntsman and Sparks 1924; Bigelow and Schroeder 1953; Howe 1971). Retardation of growth during summer months when water temperatures exceed 24°C has been observed in the Hudson River (Lawler et al. see footnote 5; Texas Instruments see footnote 7; Dew and Hecht see footnote 8) and Weweantic River, Mass. (Howe 1971), populations. Growth of juveniles from the Woods Hole area during 1962 (maximum surface water temperature = 21.1°C) did not appear to cease during midsummer (Lux and Nichy 1971); however, only 22 young-of-the-year fish were caught between June and August.

Concomitant with elevated water temperature is decreased dissolved oxygen. In separate reviews of dissolved oxygen requirements, Doudoroff and Shumway (1970) noted that feeding and growth responses to low DO levels have been variable, while Davis (1975) suggested that inhibition occurred at 50% of air saturation. Warren et al. (1973) found that growth and feeding of *Oncorhynchus kisutch* and *O. tshawytscha* were inhibited when saturation was <100%, but that only a 10% decrease in production would occur at 70% saturation. Thatcher (1975; cited in McKim et al. 1976) found that *O. kisutch* acclimated at 15°C did not reduce food consumption or growth when DO was >5 mg/l (49% saturation).

Tomcod feeding, measured by I_f, was minimal at DO <7 mg/l during 1974; July-September percent saturation ranged from 68 to 85% (Table 5). In light of the above studies on salmonids, it seems unlikely that DO levels encountered in Haverstraw Bay are the primary variable affecting feeding and growth. The summer temperature regime of the Hudson River, then, appears to be near maximum for this species and may be capable of inhibiting feeding and retarding growth.

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