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**Early life history and population dynamics of Atlantic tomcod
(*Microgadus tomcod*) in the Hudson River estuary, New York**

Dew, Carter Braxton, Ph.D.

City University of New York, 1991

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EARLY LIFE HISTORY AND POPULATION DYNAMICS OF ATLANTIC TOMCOD
(MICROGADUS TOMCOD) IN THE HUDSON RIVER ESTUARY, NEW YORK

by

CARTER BRAXTON DEW

A dissertation submitted to the Graduate Faculty in
Biology in partial fulfillment of the requirements
for the degree of Doctor of Philosophy, The City
University of New York.

1991

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This manuscript has been read and accepted for the Graduate Faculty in Biology in satisfaction of the dissertation requirement for the degree of Doctor of Philosophy.

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Abstract

EARLY LIFE HISTORY AND POPULATION DYNAMICS OF ATLANTIC TOMCOD
(MICROGADUS TOMCOD) IN THE HUDSON RIVER ESTUARY, NEW YORK

by

CARTER BRAXTON DEW

Adviser: Professor C. Lavett Smith

The early life history of winter-spawned Atlantic tomcod (Microgadus tomcod) in the Hudson River estuary, New York, remained poorly understood after large-scale study efforts by the electric utility industry during the 1970's. The present ichthyoplankton study, conducted during winter-spring 1973-1976, describes for tomcod larvae and post-larvae 1) growth, 2) mortality, 3) biomass production, 4) location and timing of hatching, and 5) vertical and longitudinal distribution in relation to salinity and freshwater flow. Peak tomcod densities were observed most frequently at the George Washington Bridge (Milepoint 11), and the magnitude of peak densities was greatest in waters of 8.0-11.0 parts per thousand salinity. The relationship between population location and freshwater flow predicted ($R^2 = 0.71$) that, in any given year, the tomcod population epicenter will be located seaward of the Tappan Zee Bridge (Milepoint 30), under all normal flow regimes from mid-March to early May, and near or downstream from the George Washington Bridge as spring flows

approach and exceed 40,000 cfs. Cumulative degree-days explained yearly variation in tomcod growth better than time or temperature alone. In late May 1976, at a length of 53 mm, tomcod growth rate decreased by 53% as water temperatures surpassed 13°C. Analysis of the changes in coefficient of variation and skewness of length-frequency distributions suggested a continuous trailing behind of slower-growing fish after hatching. Size-selective mortality apparently thinned the ranks of these smaller fish during May 1976. Initial standing crop in early March was estimated as 1.8 billion tomcod larvae in 1975 and 3.0 billion in 1976. During May 1976, while growing from 25 to 53 mm, tomcod mortality increased by 27%, and the population died at a rate of 6.3% per day to a level of approximately 34 million fish by late May. To explain these patterns in length-frequency and mortality data, I present the hypothesis that Atlantic tomcod, which are well-suited as prey on the basis of their spatiotemporal availability and their growth characteristics, may serve as primary forage fish for yearling striped bass during spring, prior to the availability of other forage fishes of suitable size.

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INTRODUCTION

The Atlantic tomcod (Microgadus tomcod) is a boreal, winter-spawning species of the cod family (Gadidae), and it is distributed in coastal and brackish waters from southern Labrador to Virginia (Scott and Crossman 1973). Although a personal communication (F. J. Schwartz) in Scott and Scott (1988) reported unusually large tomcod up to 42.1 cm from North Carolina, tomcod occurrences south of New York appear to be rare, and, even in New Jersey, the fish's status is uncertain (Heintzelman 1971; Miller 1972). This estuarine breeder almost certainly relies heavily on the Hudson River for recruitment to the southern sector of its range, although undocumented spawning may occur in and near small tributaries along the shores of northern New Jersey, New York (Westchester County), Long Island, and southern Connecticut, as well (J. R. Waldman¹, pers. comm.). Winter-spring ichthyoplankton surveys in the Sandy Hook (NJ) estuary (Croker 1965), the Indian River Inlet, Delaware (Pacheco and Grant 1973), and the Delaware River estuary (de Sylva et al. 1962), collected neither tomcod larvae nor juveniles. No breeding populations of tomcod have been reported for major estuaries south of the Hudson (Massman 1957; de Sylva et al. 1962; Schwartz 1964), nor has tomcod spawning been reported for Long Island Sound (Richards 1959) or the Connecticut River estuary (Marcy 1976).

¹Dr. John R. Waldman, Hudson River Foundation, 122 East 42 Street, Suite 1901, New York, NY 10168.

(1926) made their observations. Because fish age is generally proportional to fish size, it is logical to conclude that the Hudson River tomcod population has sustained a decrease in mean and maximum age, concomitant with a reduction in mean and maximum size.

Certainly tomcod from the Hudson River appear to have a shorter life span than tomcod from more northern populations. Howe (1971) reported that age composition for the 1966-67 Weweantic River, Massachusetts population was: Age 0, 67%; Age I, 23%; Age II, 9%; Age III, 1%, Age 0 being defined as the first year of life. Using the same definition, Roy et al. (1975) indicated that maximum age for tomcod populations from tributaries to the St. Lawrence River was eight years (Age VII). McLaren et al. (1988) suggested that age estimates for St. Lawrence tomcod by Roy et al. (1975) may have been artificially high due to inaccurate ageing techniques, but there is no real reason to suspect that a gadoid fish living near the mid-point of its geographical range would not exhibit a maximum life span of 7-8 years. Data from McLaren et al. (1988), if one adjusts their age designations so that Age 0 represents the first year of life, showed that Age 0 tomcod comprised, on average, 91% of the Hudson River spawning population during 1975-80. Furthermore, in five winters of sampling large numbers of spawners, only three tomcod which had survived into their third year of life (to Age II) were collected. I reported similar findings for the Hudson River tomcod population as far back as 1971 (QLM 1974). Even

allowing for some bias in age estimates, it is evident that the life span for Hudson River tomcod is substantially less than that for their more northern counterparts. In any event, it is clear that the probability for population extinction increases as mean age at maturity and mean life span (age at death) converge.

Additional evidence for a mid-1960's discontinuity in the age-size structure of the Hudson River-New York Bight tomcod stock may be found in U.S. Fish and Wildlife Service commercial fisheries records for New York and New Jersey. For each year from 1937 to 1965, poundage and dollar value for tomcod caught by fyke, hoop, drift gill net, and trot line were listed, with no mention of tomcod for the years 1945-1946 and 1949-1954. All New York tomcod catches for which counties were named were from the Hudson River counties of Ulster, Columbia, Orange, Dutchess, Rockland, and Westchester, with the largest catches from Westchester County, which includes Haverstraw Bay and the Tappan Zee region of the estuary. Since 1965 there has been no mention of tomcod in the fisheries statistics for New York, and it is probable that if Hudson River tomcod spawners had averaged little more than 6 inches (158 mm) in length during the years prior to 1965, as they apparently do now, they would not have appeared in commercial records at all. There was also an otter trawl fishery for tomcod in New Jersey coastal waters from 1940 through 1944. No mention has been made of tomcod catches in New Jersey waters since 1944, when 21,100 lbs were reported;

and, based on my experience with trawling in the New York Bight area during the Westway sampling, one would be hard-pressed to collect 21,100 lbs of tomcod of any size there today. In contrast, the tomcod was considered an important commercial and sport fish in Quebec, where some 100,000 lbs were taken annually (Vladykov 1955), and in the Miramichi estuary, New Brunswick, where annual landings have been just under 200 tons in recent years (Scott and Scott 1988).

Examination of Hudson River literature for clues as to possible causes of the hypothesized decline in tomcod longevity revealed that maximum summer water temperatures in the Hudson probably have been stressful to tomcod for at least the last century. Mearns (1898) reported that during several years of observation prior to 1883 he found moribund tomcod floating on the surface near shore during August and September. To my knowledge, thermal analyses have shown that no significant rise in ambient Hudson River water temperatures was detected or expected as the total thermal discharge from power plants on the Hudson increased rapidly between 1972 and 1976. Thus it is probably safe to assume that present-day maximum summer water temperatures are no more or less stressful to Hudson River tomcod than they were 100 years ago.

However, there has been an environmental change in the Hudson that might explain the decline in tomcod longevity, as suggested by evidence I have presented. Limburg (1986) plotted a disturbing trend of estimated discharges of PCB

(polychlorinated biphenyl) by the General Electric Co. into the Hudson River from 1957 to 1975; the graph showed a dramatic increase in estimated PCB discharges beginning in 1963 or 1964 and peaking in 1968. Furthermore, compelling evidence has shown that Hudson River tomcod suffer an extremely high incidence of liver cancer which affects 45% of the fish in their first year of life and 90% of those in their second year (Smith et al. 1979; Klauda et al. 1981; Dey et al. 1984; Cormier 1986) — all of which indicate an age-specific progression with obvious implications for longevity.

Despite the fact that more than 90% of the present-day annual reproductive contribution is from Age-0 fish which have never left the estuary, the Hudson River tomcod population continues to be characterized as anadromous by some authors (e.g., Beebe and Savidge 1988; Gladden et al. 1988). Still others refer to the Hudson River tomcod as a population in which semelparity (spawning only once) has evolved as a response to "a predictable environment in their early life stages or to an unpredictable environment as adults" (McLaren et al. 1988). If, as the evidence suggests, most Hudson River Atlantic tomcod die after their first and only spawning as a result of liver cancer caused by environmental toxicity, it follows that discussion of anadromy and semelparity as life-history "strategies" would be conceptually absurd.

The hypothesis that the present-day biological status of Atlantic tomcod in the Hudson River estuary is precarious may

not have aroused much controversy among knowledgeable investigators, but the hypothesis presented by Dew and Hecht (1976) that "tomcod may form a critical link in the food chain necessary to perpetuate a viable stock of Hudson River striped bass" has done so. In the following thesis I present results from my study of the abundance, distribution, growth, mortality, and biomass production of the early life stages of tomcod, upon which I elaborate the latter hypothesis.

Literature focusing on Hudson River Atlantic tomcod life history is sparse and, in large part, obscure. For example, in the first published paper on tomcod in the Hudson River estuary (Grabe 1978), which dealt with food habits, 75% of the life-history material cited by the author had been written by me in the form of unpublished reports to the utilities or non-refereed Hudson River symposia papers; the other 25% was from equally "gray" literature that had been prepared for the utilities by Texas Instruments, Inc. (TI). Beyond the Hudson, two literature sources most frequently relied on by investigators have been Booth (1967), a Ph.D. dissertation on tomcod in the Mystic River estuary, Connecticut, and Howe (1971), an unpublished M.S. thesis on tomcod in the Weweantic River, Massachusetts. In one of the more important papers on tomcod to appear during the 1980's, Peterson et al. (1980) carefully described for New Brunswick, Canada tomcod, the disposition of newly spawned eggs, egg survival, time from spawn to hatch, and larval length at hatching, which were areas left largely untouched in the earlier literature.

During the 1980's several publications appeared that dealt with various aspects of tomcod life history in the Hudson River. In 1981 the results from a 1972 ichthyoplankton survey were published (Dovel 1981), which showed tomcod larvae distributed from MP 66 (River milepoint 66 from Manhattan Battery) in the vicinity of the Roseton and Danskammer power plants to Manhattan (MP 3) during late March-early April. Dovel (1981) showed further that from mid-April to early June 1972, a period of exceptionally high freshwater flows, the entire young-of-the-year tomcod population was consistently located between the Statue of Liberty (MP 0) and Piermont (MP 25), with peak abundance found most often at MP 11-14. Similar findings for spring high-flow periods had been reported previously by Dew and Hecht (1976) at a Hudson River symposium. In 1988, all of TI's tomcod research carried out during the 1970's was published in Klauda et al. (1988) and McLaren et al. (1988). These two papers are reviewed in detail in the discussion section of this thesis, and their findings are compared and contrasted with mine.

During the decade of the 1970's the scientific community, including academia, was apparently in general agreement that scientific inquiry into the ecological health and dynamics of one of the largest estuaries in North America could well be left in the hands of the electric utility industry, its regulators, and its consultants. In the spirit of privatization, federal and state regulators did not participate in the research themselves, but pressured

utilities and their private consultants to provide the manpower, money, and expertise to conduct what has been billed by Barnthouse et al. (1988) as "one of the most ambitious environmental research and assessment programs ever performed." The end result, however, was a scientific sampling design forged by committee, flawed by compromise, and, as a result of emphasis on a single species (striped bass), conducted in a "virtual ecological vacuum" (McDowell 1986).

It always appeared curious to me that, during the feverish spate of study activity throughout the 70's, there was no provision made for systematic field sampling during the winter months or within that region of the lower estuary from the Manhattan Battery to George Washington Bridge-Yonkers, a 12-18 mile segment which represents 30-40% of the estuary downstream from the Indian Point nuclear station. The lack of winter sampling was especially curious considering that impingement fish kills at water intakes for the Bowline, Lovett, and Indian Point power plants were often higher by orders of magnitude during winter than they were during the rest of the year.

Decisions by the utilities, their consultants, and by regulatory overseers, not to sample the most seaward 12-18 miles of the estuary may have been founded, in part, on the assumption that this region was too polluted to serve as fish habitat. This misapprehension had been reinforced by such

documents as that produced by Alpine Geophysical Associates in the form of a fisheries and water-quality technical supplement to the environmental impact statement on the ill-fated Westway Project. This 1974 Technical Report, referred to a decade later by the State of New York Commission of Investigation (Lupinetti 1984) as patently inadequate and insufficient beyond argument, characterized the River in the vicinity of Manhattan as an area that serves "a minimal useful function in the biological ecosystem of the river" and "exists today as a biological wasteland".

Our belief that an officially sanctioned myth was being perpetuated by summer scientists provided me and my co-investigator with the stimulus to carry out the present study on the early life history of winter-spawned Atlantic tomcod in the Hudson River estuary. The primary objective of this study was to determine the spatiotemporal distribution of larval and early juvenile Atlantic tomcod and to define perennial high-usage areas within the estuary. The premise underlying this study was that the early dynamics of birth, death, growth, and larval transport — dynamics which each year determine the success of the Hudson River Atlantic tomcod population — had escaped quantitative assessment by previous investigators.

MATERIALS AND METHODS

I. SAMPLING

The sampling area of this four-year (1973-1976) study encompassed the 75-mile stretch of the lower Hudson River and its plume between Milepoints -6 and 69 (Manhattan Battery/Statue of Liberty = Milepoint 0). A total of 529 plankton tows were made at 19 stations during the course of the study. Inasmuch as the sampling distribution generally followed the tomcod distribution, the allocation of sampling effort among stations was unequal (Table 1). During 1975 and 1976, weekly sampling was conducted from mid-February to mid-May (1975) and mid-June (1976). Measurements of temperature, salinity, and conductivity were made at sample depths immediately after each tow was completed.

All tows were made with 6.1 m long, 1 m diameter, cylinder-cone Henson nets, designed according to Tranter and Smith (1968) to optimize filtration efficiency. Each net was equipped with a center-mounted TSK flowmeter and a quick-release plankton bucket. Tows were of 5-min duration, and the average volume filtered for 490 5-min tows during 1975-76 was 202 cu.m. (Fig.1). A net-mesh size of 571μ was standard for all stations, and both 571μ and 3000μ mesh sizes were used for comparison tows at bottom stations late in the 1975 and 1976 sampling seasons. All nets were rigged with large floats attached to the juncture of the net bridle and tow line with just enough float line to allow the nets to fish at the desired depth. In addition, bottom and midwater nets

were rigged with a Scripps depressor (Isaacs 1953) attached to the bridle-tow line juncture so that it depended about 1 meter from the ring.

Tow lines were of low-stretch, poly-plus nylon, and a tow-line:sample depth ratio of 4.5-5.0 : 1 was used for mid-depth and bottom tows. The surface net was towed 30-45 m behind the boat and it sampled that portion of the water column approximately 0.3-1.2 m deep. All nets were retrieved by hand, and available hands dictated a maximum of two nets towed simultaneously. This was standard operational procedure during 1975 and 1976. On the last two sampling dates in 1976, the bottom net was attached to an epibenthic sled with concrete-filled runners. When attached to the sled, the net fished to within 8-10 cm of the bottom.

The allocation of sampling effort to depth strata changed between and within years as the accumulated data more closely defined seasonal changes in depth distribution of tomcod larvae. On the single sampling date in 1973, surface and bottom tows were conducted. During 1974, only bottom tows were conducted. During 1975, surface and bottom tows were conducted from 22 February to 20 April, when surface tows were discontinued in favor of replicate bottom tows. Only trace concentrations of tomcod were present in surface tows after 23 March 1975. The 1976 program consisted of surface and bottom tows from 14 February through 14 March, mid-depth and bottom tows from 21 March through 9 May, and

only bottom tows from 15 May through 13 June. Table 2 is a calendar showing depth strata and sampling gear used throughout the four years of this program.

This changing distribution of effort between depth strata reflected the changing distribution of tomcod, and the decision to discontinue sampling within a depth stratum implied that there were no longer any larvae within that stratum. To prevent any upward bias in standing crop estimates, inasmuch as the 0-density values from these strata were no longer represented in the riverwide average densities, water volumes within non-sampled depth strata were eliminated from standing crop calculations as sampling within them was discontinued.

II. SAMPLE ANALYSIS

Sample treatment began with washing down the nets carefully to ensure that all larvae had been sluiced into the cod-end plankton buckets. Squirt bottles were used to wash the contents of each plankton bucket into jars for immediate preservation with 10% buffered formalin. Samples often contained enough plankton, algae, and detritus, to necessitate several quart jars for preservation. Samples were most often sorted in their entirety; less than 2% were subsampled because of especially heavy detritus/algae loads.

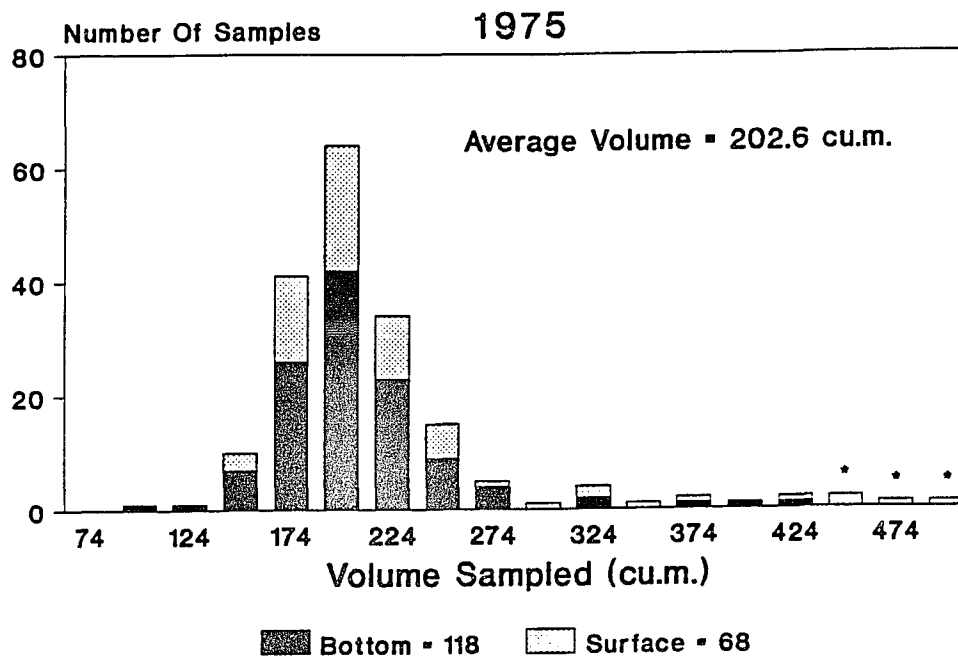
Table 1. Summary of total effort for 1.0-meter net tows during 1973-1976.

Table 1. Summary of total effort for 1-meter net tows for tomcod larvae in the Hudson River, 1973-1976

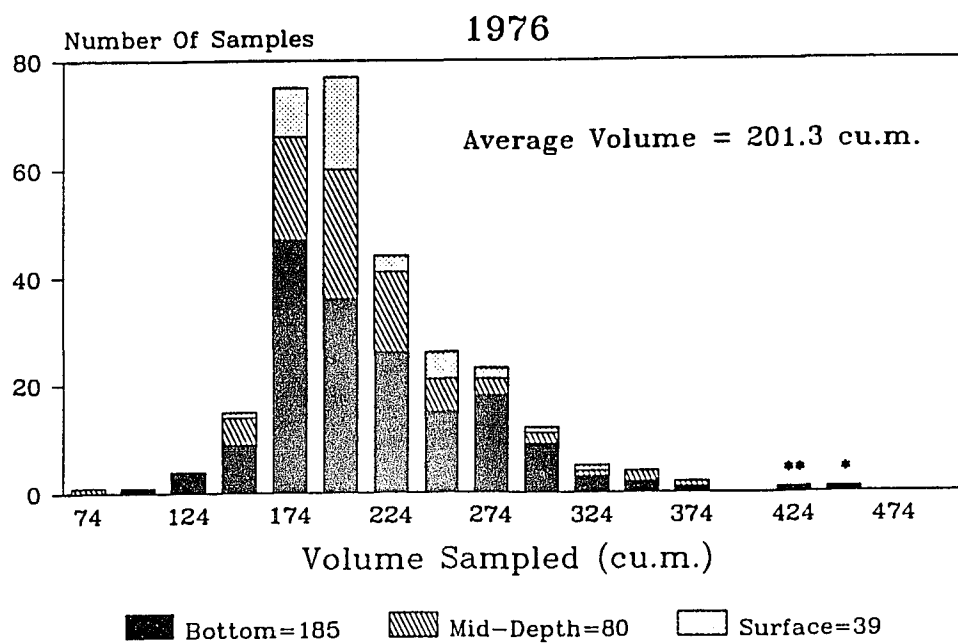
LOCATION	RIVER MILE FROM BATTERY	1973			1974			1975			1976		
		NO. OF TOWS	VOLUME STRAINED (M3)	NO. OF TOMCOD LARVAE COLLECTED	NO. OF TOWS	VOLUME STRAINED (M3)	NO. OF TOMCOD LARVAE COLLECTED	NO. OF TOWS	VOLUME STRAINED (M3)	NO. OF TOMCOD LARVAE COLLECTED	NO. OF TOWS	VOLUME STRAINED (M3)	NO. OF TOMCOD LARVAE COLLECTED
Danskammer North	69							2	409	3			
Newburgh-Beacon Br.	62							2	367	9			
Pollepel Island	58							10	1833	62	6	1281	22
Con Hook	50							10	2040	290	10	1903	207
Indian Point	43							16	3039	486	17	3317	261
No. Haverstraw Bay	39							21	3815	964	25	4625	938
Bowline	37				1	335	29				1	424	3
Croton Point	34				3	681	4	20	3538	354	29	5317	2624
Hook Mountain	32										4	652	666
No. Tappan Zee Br.	30	2	345	0	5	1112	99	21	3929	2020	31	5845	3024
Piermont	24				10	2409	1468	22	4429	3772	27	5171	2300
Hastings	21	2	322	39							26	5368	5001
Yonkers	18							18	3349	5010	29	5889	4413
Harlem River	14	2	348	197							23	4712	4910
Geo. Washington Br.	11				6	1318	883	18	3855	3984	28	5794	4151
79th St. Boat Basin	6										19	4138	1789
Manhattan	3	2	349	658	6	1439	254	16	3600	464	21	4965	895
Statue of Liberty	0										8	2002	87
Verrazzano Bridge	-6							10	3488	0			
TOTALS		8	1,364	894	31	7,294	2,737	186	37,691	17,418	304	61,403	31,291

Figure 1. Distribution of 1.0-meter net tow volumes. 1975
and 1976.

Distribution Of 1.0-Meter Net Tow Volumes



• Verrazzano Narrows surface



• Outlier changed to 230.8 Yonkers 1 May

•• 10-min tow Bowline 13 June

Table 2. Calendar of sampling dates and sampling gear used for the 1973-1976 Hudson River Atlantic tomcod study.

Table 2. Calendar of weekend sampling dates and sampling gear used for the 1973-1976 Hudson River Atlantic tomcod study.

Month/Day	Surf 571u	Mid 571u	Bottom 571u	Bottom 3000u	Bottom 3000u Sled
<u>1973</u>					
Sun 4/15	+		+		
<u>1974</u>					
Sun 4/7			+		
Sat 4/13			+		
Sat 4/27			+		
Sat 5/4			+		
Sat 5/11			+		
Sun 5/19			+		
<u>1975</u>					
Sun 2/22	+		+		
Sat 3/1	+		+		
Sun 3/9	+		+		
Sun 3/16	+		+		
Sun 3/23	+		+		
Sat 3/29	+		+		
Sun 4/6	+		+		
Sat 4/12	+		+		
Sun 4/20	+		++		
Sat 4/26	+		++		
Sat 5/3	+		++		
Sat 5/10	+		++		
<u>1976</u>					
Sat 2/14	+		+		
Sat 2/21	+		+		
Sat 2/28	+		+		
Sun 3/7	+		+		
Sun 3/14	+		+		
Sun 3/21		+	+		
Sun 3/28		+	+		
Sun 4/4		+	+		
Sat 4/10		+	+		
Sat 4/17		+	+		
Sat 4/24		+	+		
Sat 5/1		+	+		
Sun 5/9		+	+		
Sat 5/15			+	+	
Sun 5/23			+	+	
Sat 6/5				+	+
Sun 6/13				+	+

++ Denotes replicate sampling

Larvae were sorted by species or type and placed in labelled vials. Tomcod larvae were later measured for total length to the nearest 0.1 mm and assigned a life stage code according to gross characteristics of the yolk sac as follows:

LS00 = no code (yolk sac destroyed)

LS02 = 3/4 filled to full yolk sac (assumed to be newly hatched)

LS03 = 1/4 to 3/4 filled (yolk partially absorbed)

LS04 = remnant yolk sac

LS05 = post yolk-sac juvenile.

All tomcod in samples of less than 100-150 larvae were measured except when damage prevented accurate measurement. Samples with more than 100-150 tomcod were usually subsampled to obtain a random sample of 100-200 larvae for measurement. Measurement was performed with the aid of binocular dissecting microscopes fitted with frequently calibrated ocular micrometers. When larvae were too large (generally more than 30 mm) to be measured conveniently and accurately with an ocular micrometer, they were measured with rulers under magnifier lamps. During the course of this study, approximately 14,900 larvae and early juvenile tomcod were measured from meter-net collections.

III. DATA ANALYSIS

A. Density and Standing Crop

The density or concentration of larvae for each meter-net sample was expressed as the number of larvae per 1000 cu.m. of water sampled. TSK meter readings were converted to sampled water volume by the formula:

$$V_s = \alpha NA$$

where

V_s = volume sampled (m^3)

α = manufacturer's avg. meter calibration factor
(0.15)

N = number of meter revolutions

A = area of net mouth ($0.7854 m^2$).

For the analysis of general abundance and distribution trends, total-collection densities were used. For the analysis of life stage trends during hatching, total-collection densities were partitioned into densities for each of four life stages by the relationship:

$$d_{ls} = p_{ls}D$$

where

d_{ls} = density of larvae in life stage of interest

- p_{LS} = proportion of larvae in Life Stage of interest
 = $LS/(m-LS00)$
- LS = number of larvae assigned the Life Stage of interest
- m = total number of larvae measured for length
- $LS00$ = number of larvae with yolk sac destroyed, i.e., no Life Stage assigned
- D = total # larvae collected in sample/ $(V_s/1000m^3)$.

For age, growth, and mortality analyses, total-collection densities were partitioned into densities for each 1.0 mm increment of length represented in the collection as follows:

$$d_i = p_i D$$

where

- d_i = density of larvae in length class i
- p_i = proportion of total larvae measured in a given sample that were in length class i
- D = total-collection density, i.e., total number of larvae collected in a given sample/1000cu.m.

The sampling area density for each length-class was estimated as the average density for that length-class based on all the samples of a given sampling date. Average densities were converted to standing crop estimates by multiplying each average density by a river volume appropriate for that sampling date (Appendix III). During

the early part of the hatching season, I included segment volumes in which larvae were certain to have been present, but in which no sampling had occurred on that date. Failure to include the unsampled segment volumes, inasmuch as they were adjacent to sampled segments with larvae present, would have resulted in a downward bias to early standing crop estimates. The 10 river segments and associated core volumes used in calculating standing crop estimates may be found in Appendix II. Each standing crop adjustment is documented in Appendix III. A standardized average riverwide density was then calculated by dividing the adjusted standing crop by the total river core volume from Milepoint 0 to Milepoint 58. This standardization permitted density comparisons between sampling dates characterized by unequal sampling effort.

Length-class standing crop estimates were calculated for each sampling date and plotted over time. Trapezoidal integration or summation was then used to obtain an approximation of the area under the resulting curve for each length class, in units of larvae-days. To obtain an estimate of the total number of larvae which passed through the length interval, the area under the curve was divided by the number of days required for an average larva to grow through the length interval as follows:

$$N = (\Sigma(t_{i+1} - t_i) ((N_i + N_{i+1}) / 2)) / ((\ln X_{i+1} - \ln X_i) / G)$$

where

N = total number of larvae that passed through length class X_i

$t_{i+1} - t_i$ = number of days between i^{th} and $(i+1)^{\text{th}}$ sampling date

N_i = number of larvae in length class X_i on the i^{th} sampling date

N_{i+1} = number of larvae in length class X_i on the $(i+1)^{\text{th}}$ sampling date

X_i = mid-point of length class (eg. $X_i = 0.0 - 7.4 = 7\text{mm}$;

$X_{i+1} = 7.5 - 8.4 = 8\text{mm}$)

G = growth coefficient calculated for individual growth.

The Hudson River Atlantic tomcod larval and early juvenile population was considered to be a closed population except for the parameter of death, i.e., population size for a given year-class, after the completion of hatching, was changed only by the effect of mortality and not by birth, emigration out of, or immigration into the estuary. It was also assumed that the entire larval and early juvenile population was to be found within that river region bounded by Pollepel Island (MP 58) and the Statue Of Liberty (MP 0) during February-May 1975 and 1976. This 58-mile sampling region was divided into 10 river segments of unequal core volume, each with one to three sampling stations (Appendix II). There was no basis for longitudinal stratification of sampling regions into high-density or low-density areas, because the spatial distribution of the population changed randomly with respect to the fixed locations sampled weekly.

Thus, the entire core volume from MP 0 to MP 58 was treated as a single longitudinal stratum and each 5-min tow was treated as a random, replicate sample from the population.

The single-stratum volume used in standing crop estimates was reduced as the season progressed, in order to reflect changes in the depth distribution of sampling as the tomcod moved toward the bottom. On 20 April 1975, when surface and bottom sampling was changed to bottom sampling only, the total longitudinal volume was reduced by 1/2. On 21 March 1976 the total core volume was reduced by 1/3 when surface and bottom sampling was changed to mid-depth and bottom sampling; total core volume was reduced by 2/3 on 15 May when mid-depth and bottom sampling was changed to bottom sampling only.

B. Growth

Two methods of data analysis were used to characterize the growth of Atlantic tomcod larvae and early juveniles, to provide estimates for population growth and individual growth.

1. Population Growth

Estimates of average growth rates for all members of the population were obtained by plotting mean length by sampling date. Because the plotted means comprised fish of several different ages, depending on their hatching date, the

resulting growth estimates included the effects of recruitment and were average rates for the entire year-class.

2. Individual Growth

Using methods similar to those presented by Hackney and Webb (1978) and DeAngelis et al. (1980), individual growth rates were estimated by calculating, for each length class, the density-weighted mean date on which the average individual in that length class achieved a given size. This method provided age-at-length (t_l) data for newly hatched larvae (<7.5mm), and for each 1.0 mm length-class thereafter. The regression coefficient (slope of the line) of L plotted against t_l , where L was length and t_l was age in days after peak hatch, represented the average growth rate of individuals during the season. Date of peak hatch, which was designated the starting time (t_s), was calculated as that density-weighted mean date when the average larva attained 7 mm. The quantities t_s and t_l were calculated by:

$$t_s = \Sigma(ND) / \Sigma D$$

and

$$t_l = (\Sigma(ND) / \Sigma D) - t_s$$

where

N = study day numbered consecutively from 7 Feb
(Day 1)

D = riverwide average density for the length class
of interest on Day N.

C. Biomass Production

For a population characterized by exponential rates of growth and decrease in numbers, the formula developed by Ricker (1946) and later developed independently by Allen (1950) can be used to estimate production. Following Chapman (1966), the model can be illustrated by

$$dB/dt = (G-Z)B$$

where

$G = (\ln W_1 - \ln W_0)/(t_1 - t_0)$ = instantaneous daily rate of increase in weight

$Z = (\ln N_1 - \ln N_0)/(t_1 - t_0)$ = instantaneous daily mortality rate

and

B = biomass of the population, or total weight of the stock.

The differential equation is integrated as

$$B_1 = B_0(e^{(G-Z)(t_1-t_0)})$$

Mean biomass from t_0 to t_1 is

$$B^* = B_0(e^{(G-Z)} - 1)/(G-Z)$$

or, more simply,

$$B^* = (B_0 - B_1)/2$$

and daily production is

$$P = GB_0(e^{(G-Z)} - 1) / (G - Z) = GB^*$$

The sum of P for all days is the total production for the period.

Tomcod lengths were converted to weights using

$$\ln W = -13.1527 + 3.34746 \ln L$$

calculated by Dew and Hecht (1976) for 785 tomcod, 7-168 mm in length. Daily instantaneous rate of increase in weight, $G_{(Weight)}$, was calculated as

$$G_{(Weight)} = 3.34746 G_{(Length)}$$

RESULTS

I. HATCHING AND LIFE STAGE TRENDS

A. Onset and Duration of 1976 Hatch

The 1976 sampling program began on 14 February, with surface and bottom samples collected at four stations within a 15-mile river segment between the Tappan Zee Bridge and Indian Point. Although hatching was already underway when sampling began, data indicate that 14 February was near the beginning of the hatching period. Between 14 February and 7 March, average larval density at these four stations increased by a factor of 28.5, despite the salt front having been pushed well downstream of the sampled area after 14 February (Figs.2-6). Net downstream movement of larvae out of the sampled area, especially in the surface layer, would have been rapid during this period of high river flow, which pushed the salt front to about MP 19 on 7 March. It is apparent that the observed increase in larval concentrations within the sampled area was sustained by recruitment from an increased rate of hatching during this time.

Further evidence that hatching began around 7-14 February and peaked during the first week of March is provided by analysis of larval life stages present in the Tappan Zee to Con Hook segment (MP 28-50) between 14 February and 14 March. Larval density trends (Fig.7), specific for three life stages, show that abundance of the youngest

larvae, i.e., those larvae with a 75-100% filled yolk sac (Life Stage 02), was lowest on 14 February and peaked on 7 March. The presence on 14 February of some older larvae with only partial yolk sacs remaining (Life Stages 03 and 04) indicates that a small amount of hatching occurred during the week of 7 February. Because no post-yolk-sac (LS 05) larvae appeared in collections until 7 March, the fifth week of hatching (Fig.5), it is doubtful that this early hatching cohort made any significant contribution to total recruitment.

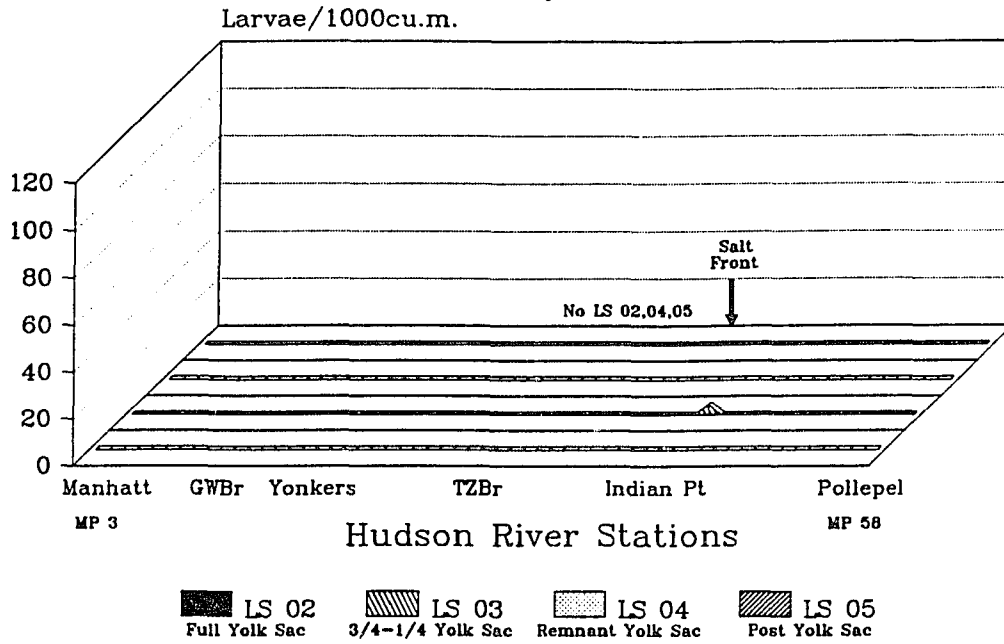
The percent of newly hatched larvae in the population was highest at the end of February and declined thereafter as the rate of decay into subsequent life stages exceeded the rate of hatching production (Fig.7). The relative rates of transition into older life stages vs. the rate of hatching are evident from the slopes of the curves in Fig.7, in which the slope for transition into Life Stages 03 and 04 exceeded the hatching slope during the first week of March.

The shapes of these life-stage curves and their slopes are influenced to some extent by differences in life-stage duration, inasmuch as larvae tended to accumulate at those stages with greater duration. This is obviously the case for Life Stage 05, which was the terminal, or post-yolk-sac stage, the one that accumulated the production from all the earlier life stages. During the second week of March, a

Figure 2. Surface and bottom distribution for four tomcod life stages during second week of hatching. 1976.

Distribution Of Four Life Stages During Second Week Of Hatching Period

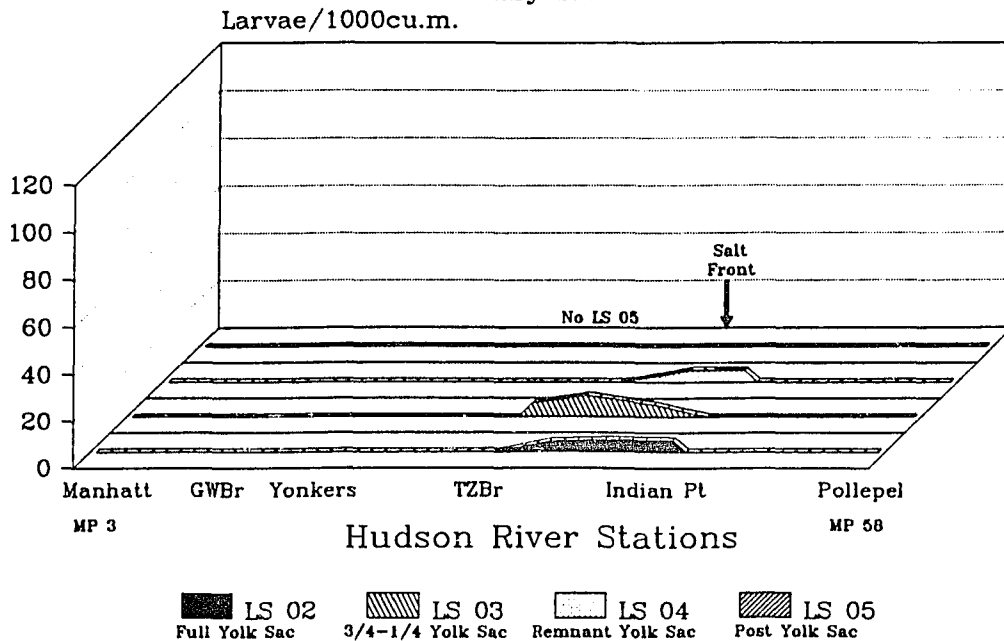
14 February 1976 - Surface



MP = Milepoint from Manhattan Battery

Distribution Of Four Life Stages During Second Week Of Hatching Period

14 February 1976 - Bottom

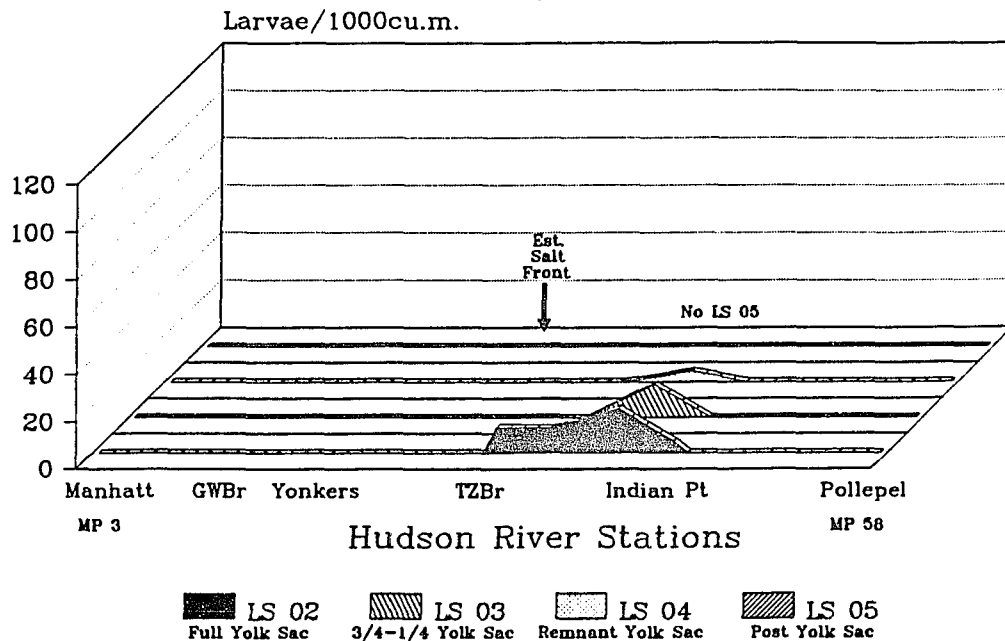


MP = Milepoint from Manhattan Battery

Figure 3. Surface and bottom distribution for four tomcod life stages during third week of hatching. 1976.

Distribution Of Four Life Stages During Third Week Of Hatching Period

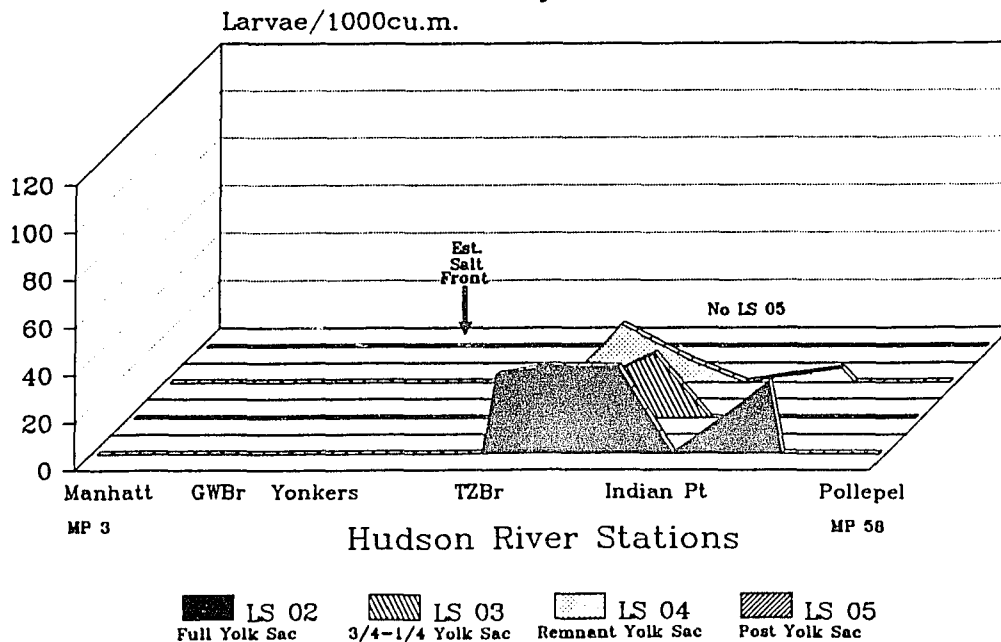
21 February 1976-Surface



MP = Milepoint from Manhattan Battery

Distribution Of Four Life Stages During Third Week Of Hatching Period

21 February 1976-Bottom

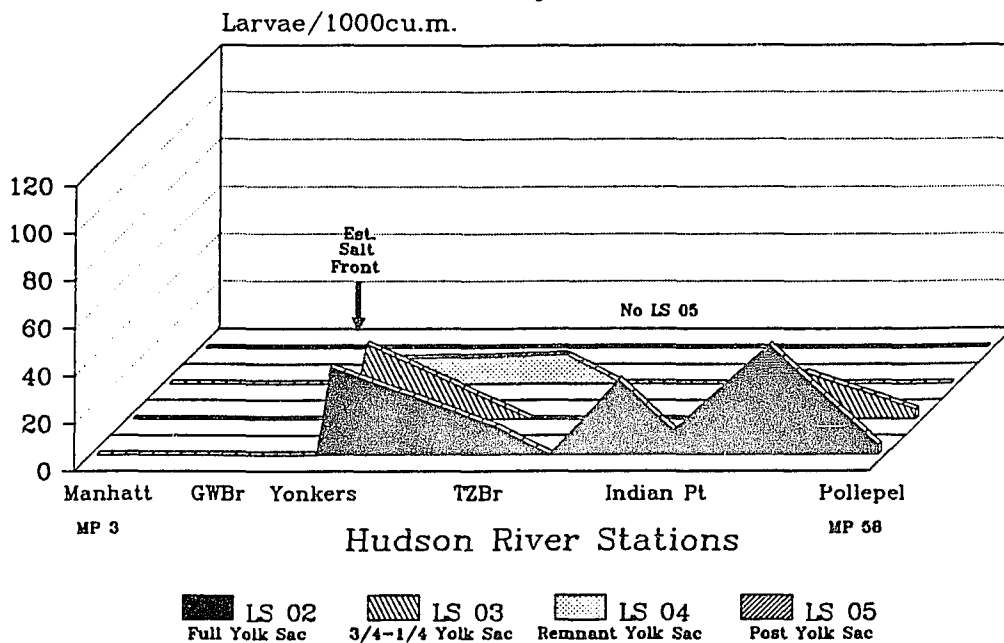


MP = Milepoint from Manhattan Battery

Figure 4. Surface and bottom distribution for four tomcod life stages during fourth week of hatching. 1976.

Distribution Of Four Life Stages During Fourth Week Of Hatching Period

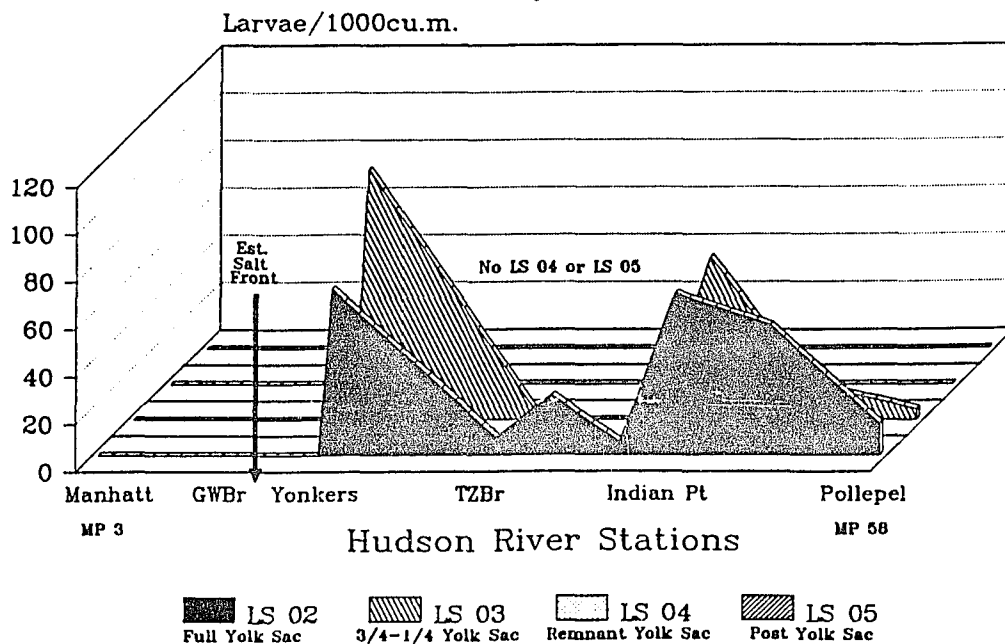
28 February 1976—Surface



MP = Milepoint from Manhattan Battery

Distribution Of Four Life Stages During Fourth Week Of Hatching Period

28 February 1976—Bottom



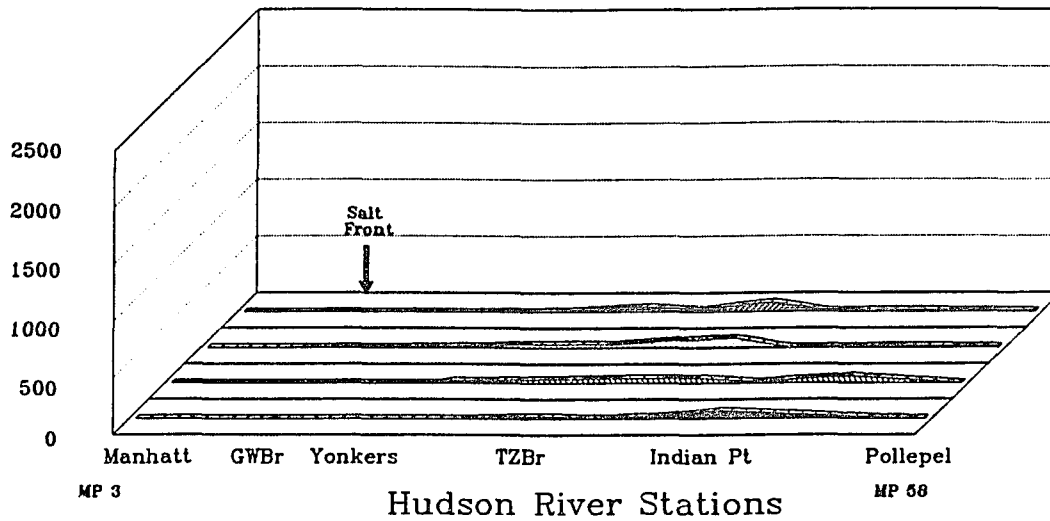
MP = Milepoint from Manhattan Battery

Figure 5. Surface and bottom distribution for four tomcod life stages during fifth week of hatching. 1976.

Distribution Of Four Life Stages During Fifth Week Of Hatching

7 March 1976-Surface

Larvae/1000cu.m.



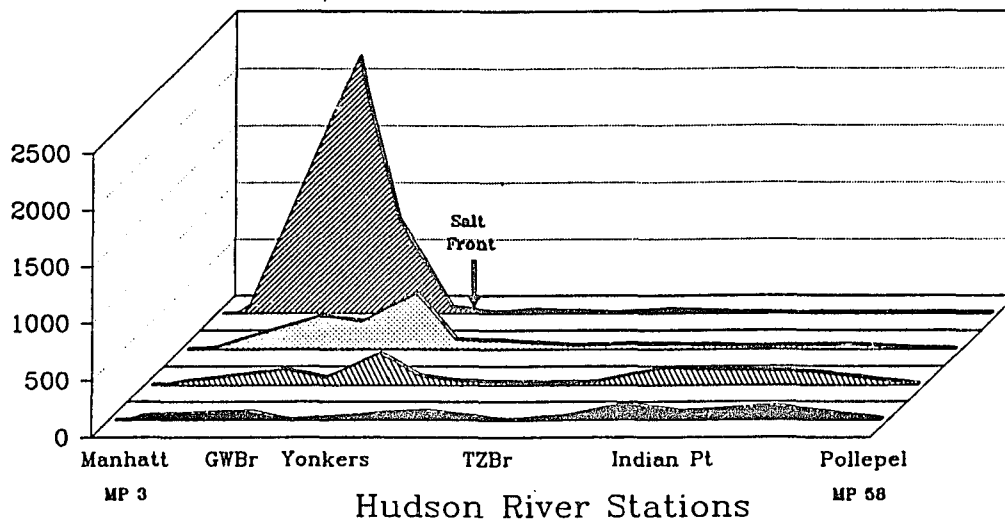
LS 02 Full Yolk Sac
 LS 03 3/4-1/4 Yolk Sac
 LS 04 Remnant Yolk Sac
 LS 05 Post Yolk Sac

MP = Milepoint from Manhattan Battery

Distribution Of Four Life Stages During Fifth Week Of Hatching

7 March 1976-Bottom

Larvae/1000cu.m.



LS 02 Full Yolk Sac
 LS 03 3/4-1/4 Yolk Sac
 LS 04 Remnant Yolk Sac
 LS 05 Post Yolk Sac

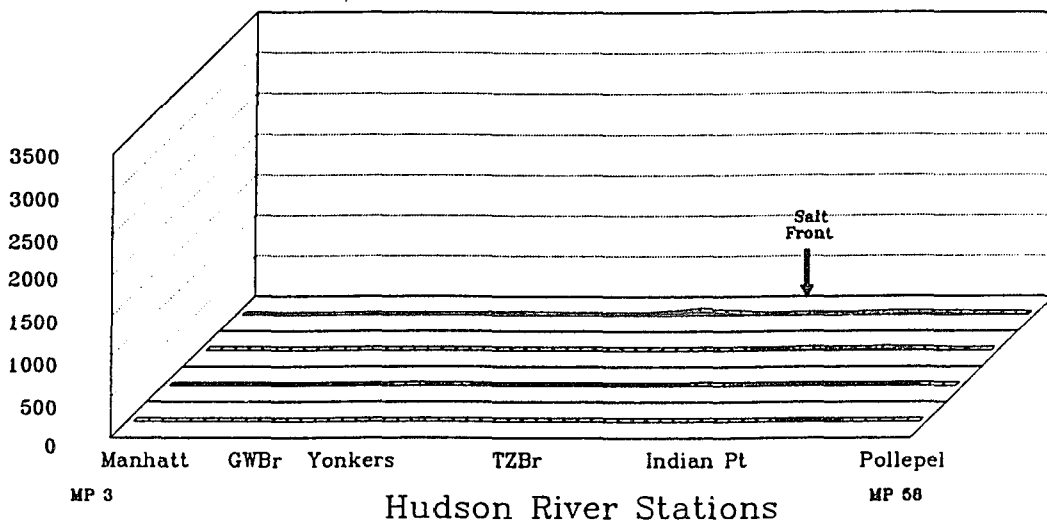
MP = Milepoint from Manhattan Battery

Figure 6. Surface and bottom distribution for four tomcod life stages near end of hatching. 1976.

Distribution Of Four Life Stages Near End Of Hatching Period

14 March 1976-Surface

Larvae/1000cu.m.



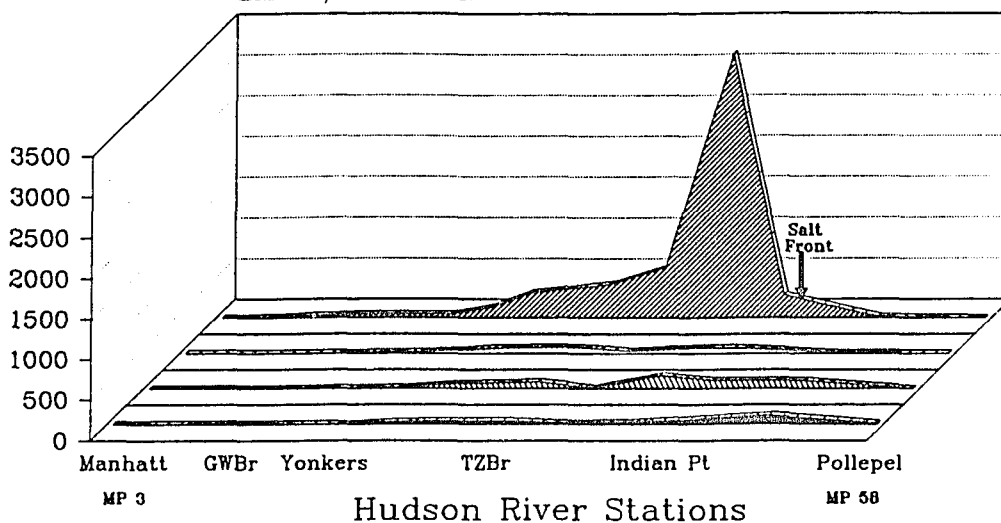
LS 02 Full Yolk Sac
 LS 03 3/4-1/4 Yolk Sac
 LS 04 Remnant Yolk Sac
 LS 05 Post Yolk Sac

MP = Milepoint from Manhattan Battery

Distribution Of Four Life Stages Near End Of Hatching Period

14 March 1976-Bottom

Larvae/1000cu.m.

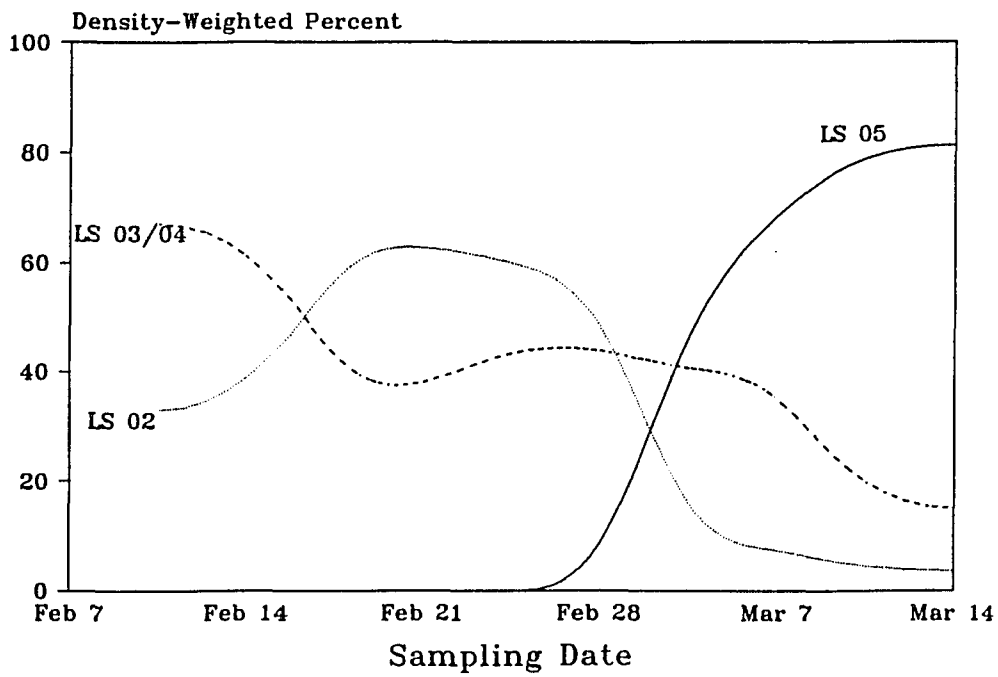
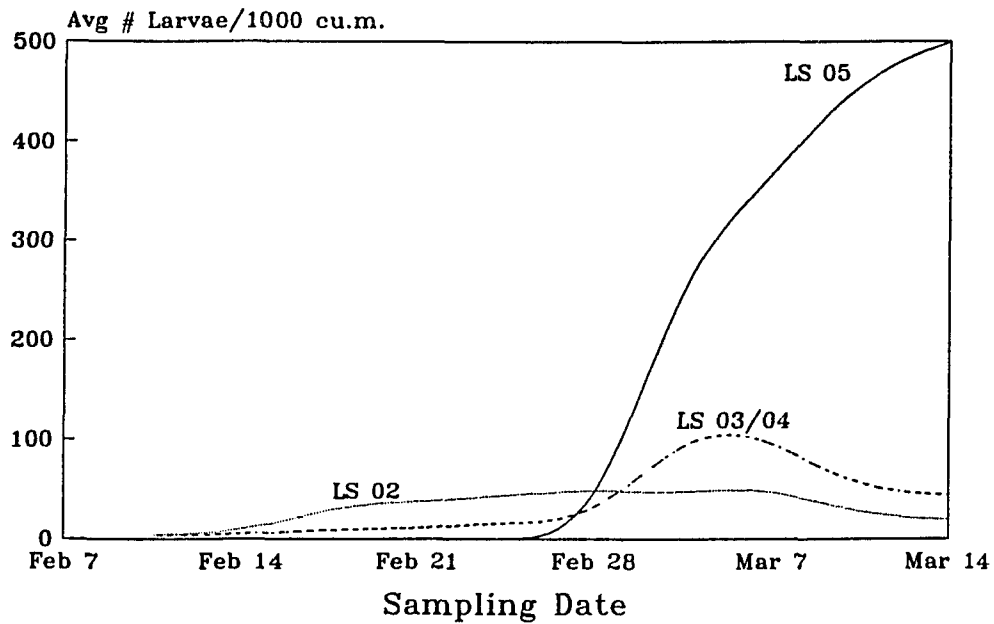


LS 02 Full Yolk Sac
 LS 03 3/4-1/4 Yolk Sac
 LS 04 Remnant Yolk Sac
 LS 05 Post Yolk Sac

MP = Milepoint from Manhattan Battery

Figure 7. Life stage trends with time during the 1976 hatch.
Measured as density (# larvae/1000 cu.m.) and
density-weighted percent.

Life Stage Trends With Time All 1976 Bottom Samples



decline in the density curve for Life Stage 02 and a decline in the rate of recruitment to the LS 03-04 stage, contrasted with a sharp increase in recruitment to Life Stage 05 (Fig.7), indicates that most of the hatching production had been completed by 14 March. No LS 02 larvae were collected after 14 March. These data define a 5-week hatching period for 1976, from 7 February to 14 March, with most of the eggs hatching during the 2-week period from 21 February to 7 March.

B. Location of 1976 Hatch

Determination of river locations where hatching occurred would have been more definitive had tomcod eggs been sampled quantitatively, but eggs represented a life stage that was conspicuous by its absence throughout this study. Fertilized tomcod eggs are demersal and non-adhesive (Watson 1987), and Peterson et al. (1980) showed that they are denser than water by 0.03 sp.gr. units at all incubation salinities from freshwater to 30 ppt. Peterson et al. (1980) collected up to several thousand tomcod eggs per 24-hr drift net set, but they were collecting in a small stream that was 2-4 m wide and no more than 60 cm in depth. Although some eggs were drifting in this small system, they noted that most of the spawned eggs settled into substrate interstices. Howe (1971) used a benthic plankton sled in the Weweantic River, Massachusetts, but collected no tomcod eggs during February sampling. Mean diameter of freshwater-incubated eggs was reported as 1.87 mm by Peterson et al. (1980), so it is

likely that available tomcod eggs would have been retained by the 0.571 mm mesh nets used in this Hudson River study. However, if tomcod eggs were located consistently within 1 m of the bottom, they would not have been available to the bottom nets, inasmuch as these were rigged to collect at depths approximately 1 m from the bottom.

Abundance trends for Life Stage 02 larvae were used to estimate the river locations with the greatest amount of hatching. Although LS 02 larvae were the most recently hatched larvae in the population, identification of their location of origin was confounded by the fact that some larvae collected at this life stage were several days old and may have moved far from where they were hatched. Because tomcod eggs are demersal (Peterson et al. 1980; Watson 1987) and because downstream displacement of newly hatched larvae within the freshwater reach would have been less on the bottom than at the surface, only data from bottom tows were used in this analysis. The sampling dates were 7 March and 14 March, the two dates within the hatching period on which equal sampling effort was conducted at the greatest number of stations, i.e., 11 stations from Manhattan to Pollepel Island (MP 3-58). Moreover, density values for LS 02 larvae were highest on these two dates (Table 3).

The highest densities for the youngest larvae were found at the Con Hook (MP 50) station on both 7 and 14 March (Fig.8). Data from Pollepel Island (MP 58) indicate little

contribution to hatching production from areas upstream of the Con Hook river segment (MP 47-54) (Table 3). Little apparent association can be seen between the peak densities at Con Hook and the salt front (1.0 ppt), which was estimated to be 31 miles downstream from Con Hook on 7 March and 7 miles downstream on 14 March. The consistent density levels at Con Hook on both dates, despite a 24-mile movement upstream by the salt front, suggests a source of hatching production near this station.

When compared with peak densities for larvae of later life stages, the relative stability of the Con Hook maxima for LS 02 larvae supports the hypothesis of continuous hatching near this station. The tracking of life stage trends within the 55-mile river segment sampled on 7 March and 14 March was accomplished by tracing the movements of peak sampling-date concentrations, movements of peak two-date average concentrations, and movements of the salt front. In general, the magnitude of peak densities and association with the salt front increased as larvae accumulated in later life stages. When tracked via a two-date (7 and 14 March) average, there appeared to be a net downstream transport of larvae as they developed into later life stages (solid arrows, Table 4; Fig.9). Superimposed on this net downstream movement was an upstream movement of the salt front between 7-14 March, dictated by a decrease in freshwater flow. This

Table 3. Tomcod life-stage densities (# Larvae/1000 cu.m.) present on five hatching dates during 14 February-14 March 1976.

Table 3. Density (#Larvae/1000cu.m) in each of four life stages (LS) present on five hatching dates during 1976 (% = #LS/#Meas - #LS00).

14 February 1976 BOTTOM										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt										
GW Br										
Harlem R										
Yonkers										
Hastings										
Piermont										
TZ Br	7.6	0.0	100.0	0.0	0.0	5.8	0.0	5.8	0.0	0.0
Croton	7.3	33.3	66.7	0.0	0.0	13.9	4.6	9.3	0.0	0.0
Hav Bay	7.5	33.3	33.3	33.3	0.0	15.8	5.3	5.3	5.2	0.0
Ind Pt	6.8	50.0	0.0	50.0	0.0	10.1	5.1	0.0	5.0	0.0
Con Hook										
Pollepel										
Totals						45.6	15.0	20.4	10.2	0.0
Density-Wtd. %							33.0	44.7	22.4	0.0

14 February 1976 SURFACE										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt										
GW Br										
Harlem R										
Yonkers										
Hastings										
Piermont										
TZ Br						0.0				
Croton						0.0				
Hav Bay						0.0				
Ind Pt	7.4	0.0	100.0	0.0	0.0	4.4	0.0	4.4	0.0	0.0
Con Hook										
Pollepel										
Totals						4.4	0.0	4.4	0.0	0.0
Density-Wtd. %							0.0	100.0	0.0	0.0

Table 3 (cont.)

21 February 1976 BOTTOM										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt										
GW Br										
Harlem R										
Yonkers										
Hastings										
Piermont										
TZ Br	7.0	100.0	0.0	0.0	0.0	33.2	33.2	0.0	0.0	0.0
Croton	6.7	50.0	17.0	33.0	0.0	74.1	37.1	12.6	24.4	0.0
Hav Bay	7.4	50.0	37.5	12.5	0.0	73.4	36.7	27.5	9.2	0.0
Ind Pt					0.0					
Con Hook	7.0	83.0	0.0	17.0	0.0	36.5	30.3	0.0	6.2	0.0
Pollepel										
					Totals	217.2	137.3	40.1	39.8	0.0
					Density-Wtd. %		63.2	18.5	18.3	0.0

21 February 1976 SURFACE										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt										
GW Br										
Harlem R										
Yonkers										
Hastings										
Piermont										
TZ Br	7.3	100.0	0.0	0.0	0.0	10.9	10.9	0.0	0.0	0.0
Croton	NM	100.0	0.0	0.0	0.0	10.8	10.8	0.0	0.0	0.0
Hav Bay	7.3	50.0	37.5	12.5	0.0	37.7	18.9	14.1	4.7	0.0
Ind Pt	7.4	100.0	0.0	0.0	0.0	5.0	5.0	0.0	0.0	0.0
Con Hook						0.0				
Pollepel										
					Totals	64.4	45.6	14.1	4.7	0.0
					Density-Wtd. %		70.7	22.0	7.3	0.0

Table 3 (cont.)

28 February 1976 BOTTOM										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt GW Br Harlem R Yonkers Hastings Piermont	7.1	40.0	60.0	0.0	0.0	176.1	70.4	105.7	0.0	0.0
TZ Br	NM	60.0	40.0	0.0	0.0	12.9	7.7	5.2	0.0	0.0
Croton	7.3	100.0	0.0	0.0	0.0	25.5	25.5	0.0	0.0	0.0
Hav Bay	7.3	100.0	0.0	0.0	0.0	5.9	5.9	0.0	0.0	0.0
Ind Pt	6.9	50.0	50.0	0.0	0.0	136.8	68.4	68.4	0.0	0.0
Con Hook	6.9	77.8	22.2	0.0	0.0	70.8	55.1	15.7	0.0	0.0
Pollepel	7.1	75.0	25.0	0.0	0.0	18.0	13.5	4.5	0.0	0.0
Totals						446.0	246.6	199.4	0.0	0.0
Density-Wtd. %							55.3	44.7	0.0	0.0

28 February 1976 SURFACE										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt GW Br Harlem R Yonkers Hastings Piermont	7.4	46.7	40.0	13.3	0.0	79.6	37.2	31.8	10.6	0.0
TZ Br	7.3	50.0	0.0	50.0	0.0	24.1	12.1	0.0	12.1	0.0
Croton						0.0				
Hav Bay	7.1	100.0	0.0	0.0	0.0	31.7	31.7	0.0	0.0	0.0
Ind Pt	7.4	100.0	0.0	0.0	0.0	10.4	10.4	0.0	0.0	0.0
Con Hook	7.3	70.0	30.0	0.0	0.0	66.4	46.5	19.9	0.0	0.0
Pollepel	6.5	50.0	50.0	0.0	0.0	8.0	4.0	4.0	0.0	0.0
Totals						220.2	141.8	55.8	22.6	0.0
Density-Wtd. %							64.4	25.3	10.3	0.0

Table 3 (cont.)

7 March 1976 BOTTOM										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt	8.1	28.0	16.0	8.0	48.0	157.1	44.0	25.1	12.6	75.4
GW Br	8.6	2.9	4.8	10.6	81.7	2769.9	80.3	133.0	293.6	2263.0
Harlem R	7.9	0.0	5.7	21.1	73.2	1153.7	0.0	65.8	243.4	844.5
Yonkers	7.3	4.0	32.0	57.0	7.0	865.9	34.6	277.1	493.6	60.6
Hastings	7.3	15.4	38.5	42.3	3.8	234.3	36.1	90.2	99.1	8.9
Piermont	7.2	19.0	19.1	42.9	19.0	231.1	43.9	44.1	99.1	43.9
TZ Br	7.5	0.0	33.3	55.6	11.1	54.6	0.0	18.2	30.4	6.1
Croton	7.3	4.8	23.8	38.1	33.3	143.9	6.9	34.2	54.8	47.9
Hav Bay	7.3	29.2	53.8	13.8	3.1	340.3	99.4	183.1	47.0	10.5
Ind Pt	7.2	25.0	61.1	11.1	2.8	242.0	60.5	147.9	26.9	6.8
Con Hook	7.2	37.7	43.4	15.1	3.8	294.8	111.1	127.9	44.5	11.2
Pollepel	7.3	50.0	16.7	0.0	32.3	31.8	15.9	5.3	0.0	10.6
Totals						6519.4	532.8	1151.9	1444.9	3389.4
Density-Wtd. %							8.2	17.7	22.2	52.0

7 March 1976 SURFACE										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt						0.0				
GW Br	NM	0.0	0.0	100.0	0.0	4.4	0.0	0.0	4.4	0.0
Harlem R	7.3	0.0	0.0	100.0	0.0	3.7	0.0	0.0	3.7	0.0
Yonkers	7.7	0.0	0.0	100.0	0.0	10.2	0.0	0.0	10.2	0.0
Hastings	7.7	0.0	50.0	37.5	12.5	43.0	0.0	21.5	16.1	5.4
Piermont	7.5	0.0	36.4	45.5	18.2	71.3	0.0	26.0	32.4	13.0
TZ Br	7.4	16.7	29.2	20.8	33.3	139.6	23.3	40.8	29.0	46.5
Croton	7.4	4.5	31.8	45.5	18.2	140.6	6.3	44.7	64.0	25.6
Hav Bay	7.4	10.9	19.6	34.8	34.8	250.4	27.3	49.1	87.1	87.1
Ind Pt	7.0	73.3	13.3	0.0	13.3	101.2	74.2	13.5	0.0	13.5
Con Hook	7.2	25.0	50.0	12.5	12.5	126.6	31.7	63.3	15.8	15.8
Pollepel	7.0	0.0	0.0	50.0	50.0	16.4	0.0	0.0	8.2	8.2
Totals						907.4	162.8	258.8	271.0	215.1
Density-Wtd. %							17.9	28.5	29.9	23.7

Table 3 (cont.)

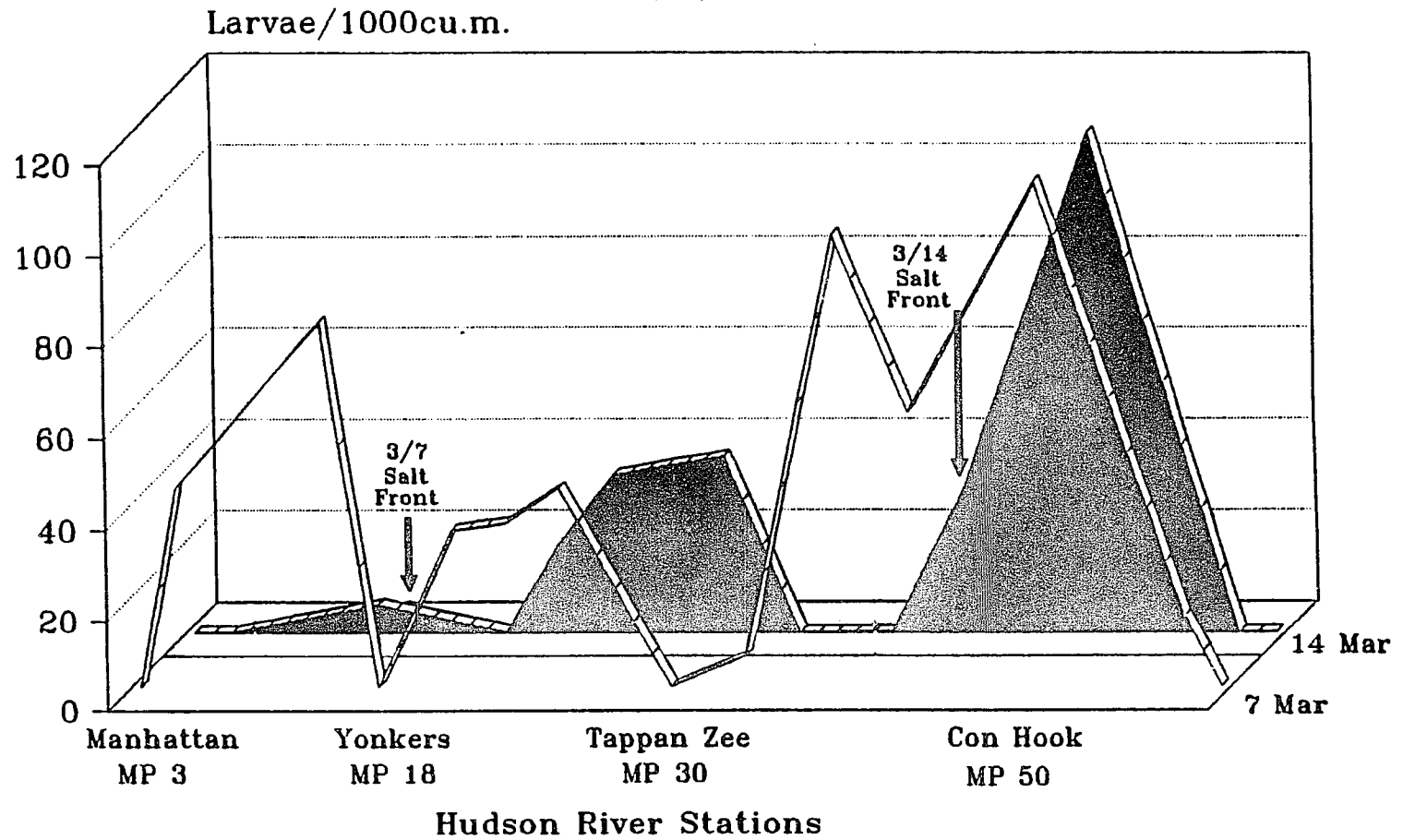
14 March 1976										
BOTTOM										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt						0.0	0.0	0.0	0.0	0.0
GW Br	8.6	11.1	0.0	0.0	88.9	54.6	6.1	0.0	0.0	48.5
Harlem R										
Yonkers	8.2	0.0	11.1	22.2	66.7	79.6	0.0	8.8	17.7	53.1
Hastings	8.1	8.8	11.8	17.6	61.8	224.4	19.7	26.5	39.5	138.7
Piermont	7.9	7.0	14.1	14.1	64.8	492.5	34.5	69.4	69.4	319.1
TZ Br	8.0	6.1	13.1	13.1	67.7	632.9	38.6	82.9	82.9	428.5
Croton	8.4	0.0	1.8	4.6	93.5	681.6	0.0	12.3	31.4	637.3
Hav Bay	8.4	0.0	4.7	2.0	93.3	3497.4	0.0	164.4	69.9	3263.1
Ind Pt	7.7	6.3	21.0	13.7	59.0	507.6	32.0	106.6	69.5	299.5
Con Hook	7.0	46.3	43.9	2.4	7.3	236.5	109.5	103.8	5.7	17.3
Pollepel	6.4	0.0	0.0	0.0	100.0	12.2	0.0	0.0	0.0	12.2
Totals						6419.3	240.4	574.7	386.0	5217.2
Density-Wtd. %							3.7	9.0	6.0	81.3

14 March 1976										
SURFACE										
Station	Mean Length	Percent By Life Stage				Total Density	Density By Life Stage			
		%02	%03	%04	%05		02	03	04	05
Manhatt						0.0	0.0	0.0	0.0	0.0
GW Br						0.0	0.0	0.0	0.0	0.0
Harlem R										
Yonkers	7.1	0.0	100.0	0.0	0.0	5.0	0.0	5.0	0.0	0.0
Hastings	7.7	0.0	40.0	0.0	60.0	25.1	0.0	10.0	0.0	15.1
Piermont						0.0	0.0	0.0	0.0	0.0
TZ Br						0.0	0.0	0.0	0.0	0.0
Croton	8.8	0.0	0.0	0.0	100.0	54.2	0.0	0.0	0.0	54.2
Hav Bay	7.1	0.0	100.0	0.0	0.0	5.0	0.0	5.0	0.0	0.0
Ind Pt	7.7	0.0	33.3	33.3	33.3	24.1	0.0	8.0	8.0	8.0
Con Hook	7.4	9.1	18.2	27.3	45.5	62.7	5.7	11.4	17.1	28.5
Pollepel	7.4	0.0	33.3	0.0	66.7	16.1	0.0	5.4	0.0	10.7
Totals						192.2	5.7	44.8	25.1	116.6
Density-Wtd. %							3.0	23.3	13.1	60.6

Figure 8. Longitudinal distribution of newly-hatched larvae on 7 March and 14 March 1976. Used to estimate hatching location.

Abundance Of Newly Hatched Larvae Used To Estimate Hatching Location

1976



Bottom Tows

salt front movement was paralleled by movements in peak daily concentrations for LS 03, 04, and 05 larvae between 7 and 14 March (dashed-line arrows, Table 4). A solid arrow was used for the upstream movement by LS 05 larvae because it was a major population movement by a terminal life stage, in contrast to the transitional movements by intermediate life stages.

Tracking LS 02 larvae was straightforward because, based on the location of daily peaks as well as the two-date average peak, they did not move. On the other hand, peak concentrations of LS 03 larvae, which occurred at Yonkers (MP 18) on 7 March and at Haverstraw Bay (MP 39) on 14 March (Figs.5,6,9; Table 4), indicated some association with the salt front. However, the two-date average peak for LS 03 larvae was located at Haverstraw Bay, where a peak for this life stage might be expected, given an average rate of freshwater transport downstream from the estimated hatching location at MP 50.


LS 05 larvae demonstrated a close association with the salt front during 7-14 March (Figs.5-6). On 7 March a peak density of 2263/1000 cu.m. was recorded for LS 05 larvae just south of the George Washington Bridge (MP 11) when the salt front was estimated to be near MP 19. On 14 March a similar

Table 4. Downstream transport and salt front movement for life-stage peaks 7-14 March 1976.

Table 4. Movements of daily peak densities and peak two-date average densities for each life-stage during 7-14 March 1976.

	MP	Life Stage 02		Life Stage 03		Life Stage 04		Life Stage 05		
		7 Mar	14 Mar	7 Mar	14 Mar	7 Mar	14 Mar	7 Mar	14 Mar	
Statue Lib	0	NS	NS	NS	NS	NS	NS	NS	NS	
Manhattan	3	44.0	0.0	25.1	0.0	12.6	0.0	75.4	0.0	
79th St	6	NS	NS	NS	NS	NS	NS	NS	NS	
GWBr	11	80.3	6.1	133.0	0.0	293.6	0.0	2263.0	48.5	
Harlem River	14	0.0	NS	65.8	NS	243.4	NS	844.5	NS	
Yonkers	18	34.6	0.0	277.1	8.8	493.6	17.7	60.6	53.1	SALT
Hastings	21	36.1	19.7	90.2	25.5	99.1	39.5	8.9	138.7	7 Mar
Piermont	24	43.9	34.5	44.1	69.4	99.1	69.4	43.9	319.1	FRONT
Tappan Zee	30	0.0	38.6	18.2	82.9	30.4	82.9	6.1	428.5	
Croton	34	6.9	0.0	34.2	12.3	54.8	31.4	47.9	637.3	
Haverstraw B	39	99.4	0.0	183.1	166.4	47.0	69.9	10.5	3263.1	
Indian Point	43	60.5	32.0	147.9	106.6	26.9	69.5	6.8	299.5	SALT
Con Hook	50	111.1	109.5	127.9	103.8	44.5	5.7	11.2	17.3	14 Mar
Pollepel Is	58	15.9	0.0	5.3	0.0	0.0	0.0	10.6	12.2	FRONT

NS = No Sample

 peak One-Day density

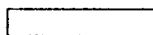
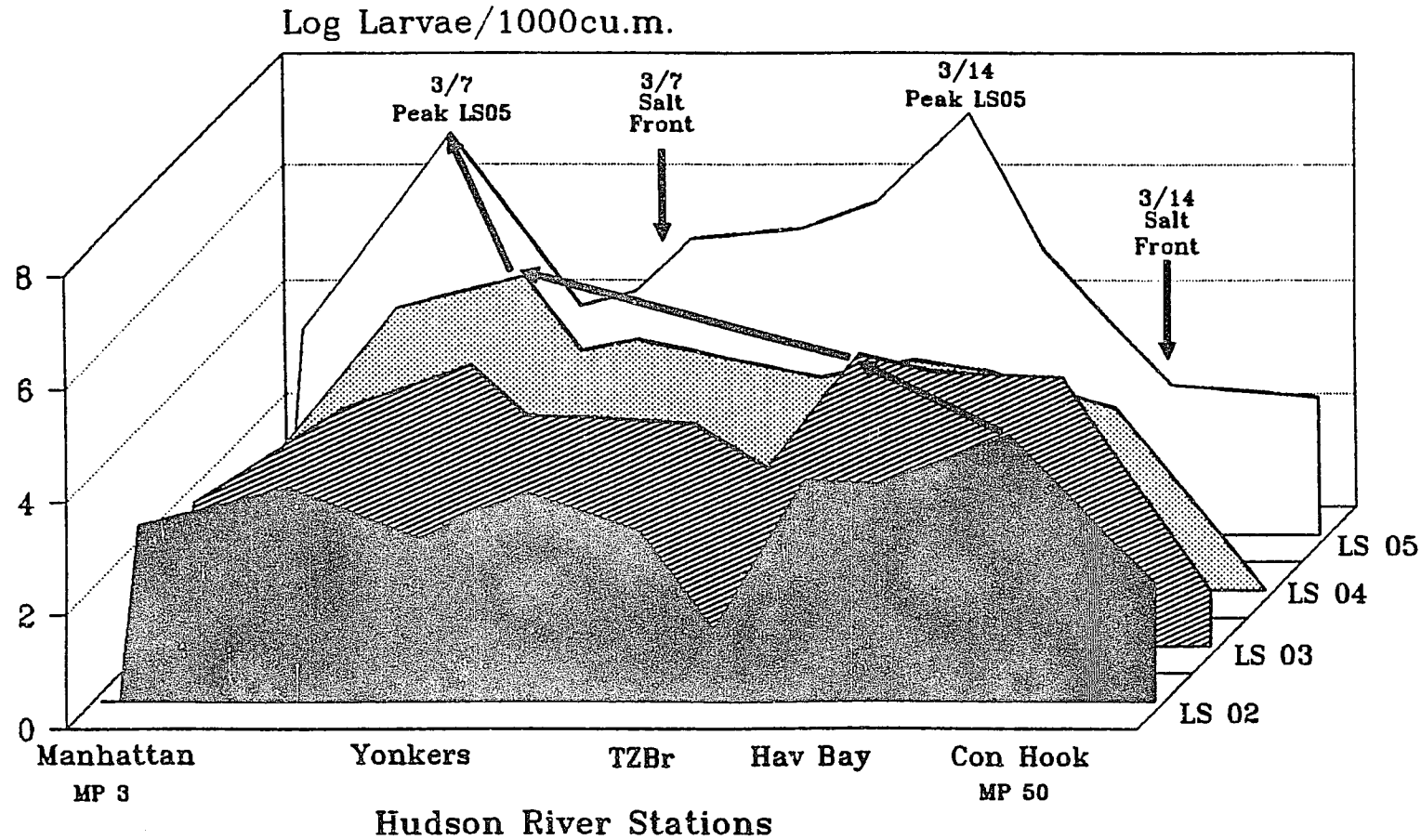
 peak Two-Date average density

Figure 9. Movement of peak two-date average density for each life stage during 7-14 March 1976.

Movement Of Peak Two-Day Average Density For Each Life Stage During 7-14 March 1976



Diagonal arrows show net downstream transport
of yolk-sac larvae from hatching region

high-density peak of 3242/1000 cu.m. was located 28 miles upstream at Haverstraw Bay (MP 39), again closely associated with the salt front near Indian Point (MP 43). It is postulated that movement of these LS 05 larvae was, at this stage, fully entrained into the dynamics of density-induced circulation, and that they were now "riding" the salinity intrusion wedge wherever it took them. The high densities observed for LS 05 larvae resulted from the accumulation and concentration of a large proportion of the larval population within a relatively small and well-defined volume of water.

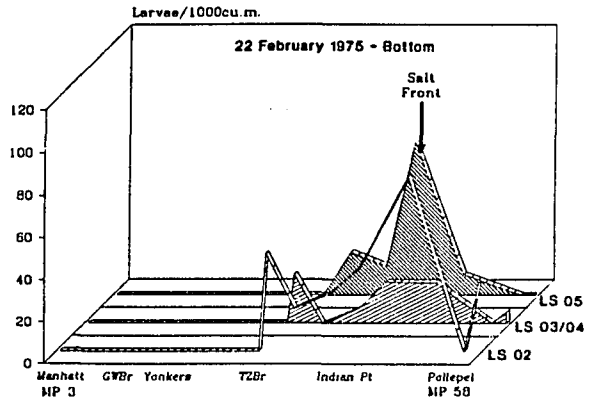
C. Onset and Duration of 1975 Hatch

Sampling during 1975 began on 22 February, with surface and bottom samples collected at seven stations within the 32-mile river segment between the Tappan Zee Bridge and the Newburgh-Beacon Bridge (MP 30-62). The abundance of LS 05 post-yolk-sac larvae present on 22 February (Fig.10) indicates that hatching was well underway at this time. Assuming a three-week duration for the yolk-sac (LS 02,03,04) stage (see Sec.III, B.2), hatching may have been underway for about three weeks by the time sampling began on 22 February.

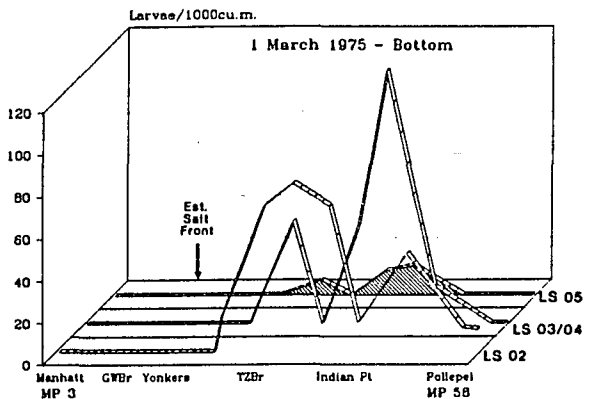
Despite evidence for an early hatching pulse, recruitment from this early production to the larval population was apparently low. Average larval density at four stations between Haverstraw Bay (MP 39) and Pollepel Island (MP 58) was 40/1000 cu.m. on 22 February, but

Figure 10. Distribution of bottom densities for four tomcod life stages during 1975 hatch.

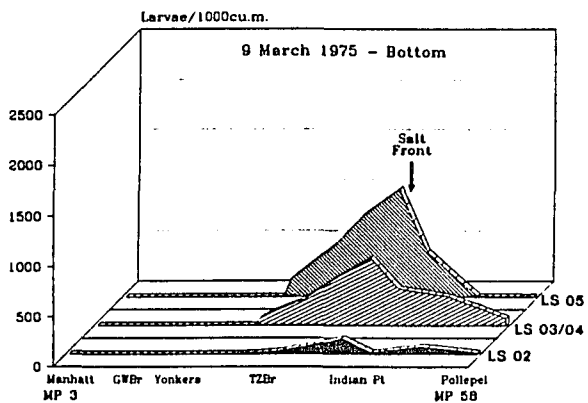
**Distribution Of Four Life Stages
Beginning Third Week Of Hatching Period**



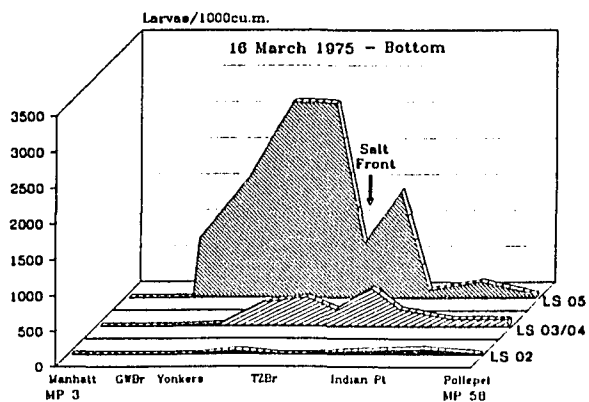
Beginning Fourth Week Of Hatching Period



Beginning Fifth Week Of Hatching Period



Near End Of Hatching Period



increased by a factor of 14.6 (to 585/1000 cu.m.) by 9 March (data for calculations in Table 5). Analysis of the relative and actual abundance of tomcod by life stage from 22 February to 16 March (Fig.11) further suggests a discontinuous pulse of hatching in early February, and indicates that sustained hatching did not begin until mid-February. The presence of an initial, discontinuous pulse was indicated by the decline in percent composition and abundance for LS 05 larvae between 22 February and 1 March. Sustained recruitment of post-yolk-sac larvae did not occur until after 1 March. Peak densities for LS 02 and LS 03/04 larvae occurred on 9 March, and this suggests that peak hatching occurred between 1-9 March and that the hatching rate declined after 9 March. Hatching was essentially complete by 16 March; few LS 02 larvae were collected after this date (Table 5).

D. Location of 1975 Hatch

Density data for LS 02 larvae from all surface and bottom tows from 22 February to 16 March were used to estimate the longitudinal distribution of hatching activity within the river during 1975 (Table 5). This analysis showed that the Indian Point Con Hook segment (MP 42-54) exhibited the highest average density for larvae with full yolk sacs and that stations north of this region (MP 55-70) produced relatively few newly hatched larvae.

Table 5. Density (# larvae/1000 cu.m.) for four life stages present at stations sampled from 22 February to 23 March 1975.

Table 5. Density (#Larvae/1000cu.m) in each of four life stages (LS) present on five hatching dates during 1975 (% = #LS/#Meas - #LS00).

22 February 1975								
BOTTOM								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont								
TZ Br	7.0	66.7	33.3	0.0	70.2	46.8	23.4	0.0
Croton	7.2	50.0	0.0	50.0	40.9	20.5	0.0	20.5
Hav Bay	7.6	57.1	14.3	28.6	48.5	27.7	6.9	13.9
Ind Pt	7.5	30.0	15.0	55.0	131.7	39.5	19.8	72.4
Con Hook	6.8	73.9	17.4	8.7	112.9	83.4	19.6	9.8
Pollepel					0.0	0.0	0.0	0.0
New-Beac Br	6.5	85.7	14.3	0.0	38.4	32.9	5.5	0.0
Totals					442.6	250.8	75.2	116.6
Density-Wtd. %						56.7	17.0	26.3

22 February 1975								
SURFACE								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont								
TZ Br					0.0	0.0	0.0	0.0
Croton					0.0	0.0	0.0	0.0
Hav Bay					0.0	0.0	0.0	0.0
Ind Pt					0.0	0.0	0.0	0.0
Con Hook	6.7	80.0	20.0	0.0	21.7	17.4	4.3	0.0
Pollepel	7.1	100.0	0.0	0.0	5.4	5.4	0.0	0.0
New-Beac Br	6.4	100.0	0.0	0.0	10.8	10.8	0.0	0.0
Totals					37.9	33.6	4.3	0.0
Density-Wtd. %						88.5	11.5	0.0

Table 5 (cont.)

1 March 1975 BOTTOM								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont	7.1	100.0	0.0	0.0	16.8	16.8	0.0	0.0
TZ Br	7.0	55.6	38.9	5.6	124.6	69.3	48.5	7.0
Croton	6.2	100.0	0.0	0.0	80.1	80.1	0.0	0.0
Hav Bay	7.0	54.5	36.4	9.1	127.2	69.3	46.3	11.6
Ind Pt	6.7	9.5	81.0	9.5	147.9	14.1	119.8	14.1
Con Hook	7.1	72.7	27.3	0.0	64.6	47.0	17.6	0.0
Pollepel	7.1	100.0	0.0	0.0	11.5	11.5	0.0	0.0
Danskammer	6.5	100.0	0.0	0.0	10.6	10.6	0.0	0.0
Totals					583.3	318.6	232.2	32.6
Density-Wtd. %						54.6	39.8	5.6

1 March 1975 SURFACE								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont	7.1	66.7	22.2	11.1	40.0	26.7	8.9	4.4
TZ Br	6.9	50.0	30.0	20.0	55.6	27.8	16.7	11.1
Croton	6.5	90.9	9.1	0.0	59.6	54.2	5.4	0.0
Hav Bay	7.1	80.0	20.0	0.0	26.4	21.1	5.3	0.0
Ind Pt	7.1	69.2	30.8	0.0	68.1	47.1	21.0	0.0
Con Hook	7.2	75.0	25.0	0.0	52.8	39.6	13.2	0.0
Pollepel	7.0	100.0	0.0	0.0	9.9	9.9	0.0	0.0
Danskammer	7.0	100.0	0.0	0.0	4.5	4.5	0.0	0.0
Totals					316.9	230.9	70.4	15.6
Density-Wtd. %						72.9	22.2	4.9

Table 5 (cont.)

9 March 1975								
BOTTOM								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont	8.2	0.0	31.7	68.3	260.0	0.0	82.4	177.6
TZ Br								
Croton								
Hav Bay	7.8	8.3	35.4	56.3	1898.6	157.6	672.1	1068.9
Ind Pt	7.5	1.5	44.1	54.4	823.8	12.4	363.3	448.1
Con Hook	7.3	20.4	77.8	1.9	369.2	75.3	287.2	7.0
Pollepel	7.3	14.3	85.7	0.0	81.4	11.6	69.8	0.0
Danskammer								
Totals					3433.0	256.9	1474.8	1701.7
Density-Wtd. %						7.5	43.0	49.6

9 March 1975								
SURFACE								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br								
Harlem R								
Yonkers								
Hastings								
Piermont					0.0	0.0	0.0	0.0
TZ Br								
Croton								
Hav Bay	7.9	16.3	42.5	41.3	611.3	99.6	259.8	252.5
Ind Pt	7.8	13.5	63.5	23.0	518.4	70.0	329.2	119.2
Con Hook	7.3	35.9	64.1	0.0	324.0	116.3	207.7	0.0
Pollepel	7.4	12.5	75.0	12.5	55.7	7.0	41.8	7.0
Danskammer								
Totals					1509.4	292.9	838.4	378.7
Density-Wtd. %						19.4	55.5	25.1

Table 5 (cont.)

16 March 1975 BOTTOM								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br	9.7	0.0	0.0	100.0	830.6	0.0	0.0	830.6
Harlem R								
Yonkers	8.2	0.0	1.7	98.3	1718.0	0.0	29.2	1688.8
Hastings								
Piermont	8.2	1.9	10.5	87.6	3106.4	59.0	326.2	2721.2
TZ Br	8.1	0.0	12.9	87.1	3106.9	0.0	400.8	2706.1
Croton	7.9	0.0	23.9	76.1	991.8	0.0	237.0	754.8
Hav Bay	7.7	1.9	25.9	72.2	2067.7	39.3	535.5	1492.9
Ind Pt	7.5	13.9	58.3	27.8	410.2	57.0	239.1	114.0
Con Hook	7.2	19.5	25.0	55.6	415.3	81.0	103.8	230.9
Pollepel	7.3	10.0	60.0	30.0	167.2	16.7	100.3	50.2
Danskammer								
Totals					12814.1	253.0	1972.0	10589.5
Density-Wtd. %						2.0	15.4	82.6

16 March 1975 SURFACE								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt								
GW Br	8.5	0.0	20.0	80.0	31.2	0.0	6.2	25.0
Harlem R								
Yonkers					0.0	0.0	0.0	0.0
Hastings								
Piermont					0.0	0.0	0.0	0.0
TZ Br	8.6	0.0	0.0	100.0	10.7	0.0	0.0	10.7
Croton	8.0	0.0	0.0	100.0	10.1	0.0	0.0	10.1
Hav Bay	7.9	0.0	50.0	50.0	10.8	0.0	5.4	5.4
Ind Pt	7.6	18.5	37.0	44.4	152.9	28.3	56.6	67.9
Con Hook	7.1	0.0	70.6	29.4	213.8	0.0	150.9	62.9
Pollepel	7.5	11.8	47.1	41.2	113.2	13.4	53.3	46.6
Danskammer								
Totals					542.7	41.6	272.5	228.5
Density-Wtd. %						7.7	50.2	42.1

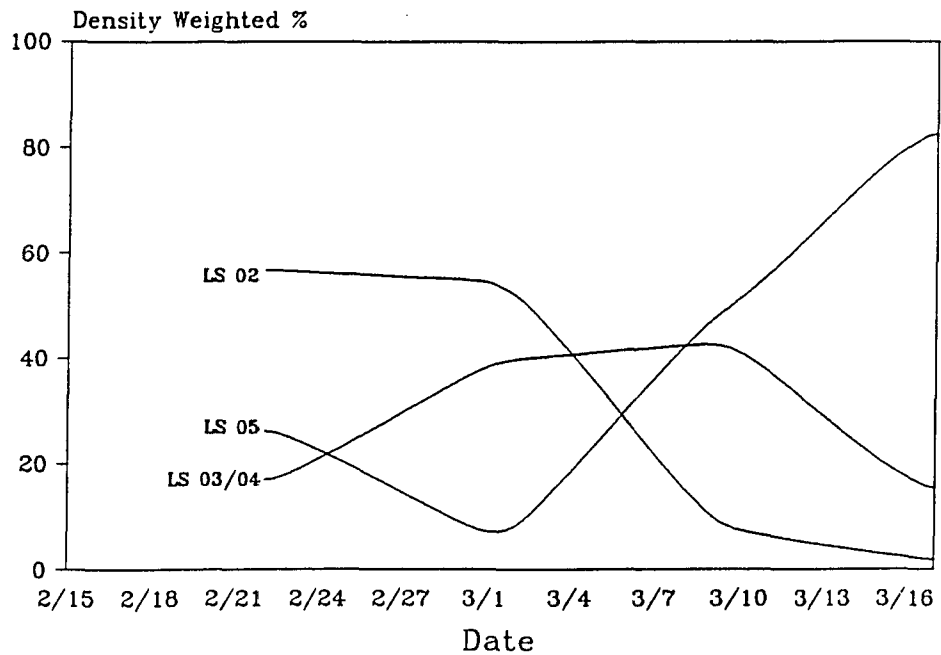
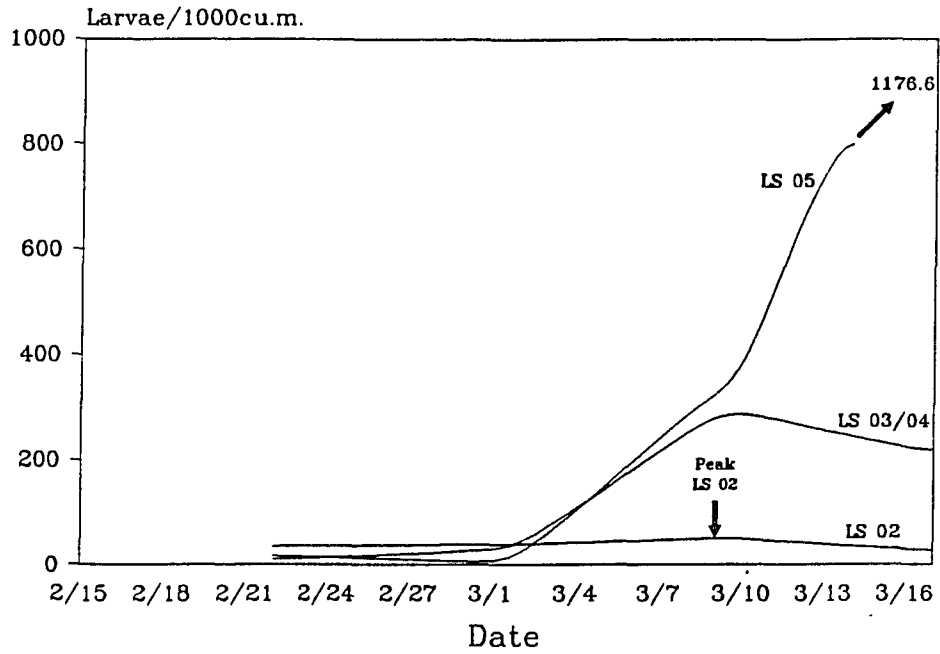
Table 5 (cont.)

23 March 1975								
BOTTOM								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt	9.8	0.0	0.0	100.0	15.4	0.0	0.0	15.4
GW Br	9.0	0.0	2.3	97.7	569.2	0.0	13.1	556.1
Harlem R								
Yonkers	8.8	1.2	4.7	94.2	3932.1	47.2	184.8	3704.0
Hastings								
Piermont	8.1	0.0	5.0	95.0	1403.4	0.0	70.2	1333.2
TZ Br	7.1	0.0	14.3	85.7	48.4	0.0	6.9	41.5
Croton	7.3	0.0	77.8	22.2	79.3	0.0	61.7	17.6
Hav Bay	7.3	11.1	66.7	22.2	50.6	5.6	33.8	11.2
Ind Pt	7.3	0.0	12.5	87.5	39.2	0.0	4.9	34.3
Con Hook	7.6	0.0	0.0	100.0	9.0	0.0	0.0	9.0
Pollepel	7.6	50.0	50.0	0.0	8.3	4.2	4.2	0.0
Danskammer								
Totals					6154.9	57.0	379.5	5722.4
Density-Wtd. %						0.9	6.2	93.0

23 March 1975								
SURFACE								
Station	Mean Length	Percent By Life Stage			Total Density	Density By Life Stage		
		%02	%03/04	%05		02	03/04	05
Manhatt					0.0	0.0	0.0	0.0
GW Br					0.0	0.0	0.0	0.0
Harlem R								
Yonkers					0.0	0.0	0.0	0.0
Hastings								
Piermont	7.4	0.0	50.0	50.0	103.7	0.0	51.9	51.9
TZ Br	7.0	0.0	8.3	91.7	71.6	0.0	5.9	65.7
Croton	7.4	0.0	75.0	25.0	49.4	0.0	37.1	12.4
Hav Bay	7.1	14.3	57.1	28.6	39.6	5.7	22.6	11.3
Ind Pt	7.1	33.3	66.7	0.0	16.6	5.5	11.1	0.0
Con Hook	7.6	0.0	100.0	0.0	9.7	0.0	9.7	0.0
Pollepel	7.6	0.0	75.0	25.0	19.5	0.0	14.6	4.9
Danskammer								
Totals					310.1	11.2	152.9	146.1
Density-Wtd. %						3.6	49.3	47.1

Figure 11. Life stage trend with time during the 1975 hatch. Measured as density and density-weighted percent.

Life Stage Trend With Time During 1975 Hatch (All Bottom Stations 22 Feb-16 Mar)



LS 02 = 3/4-Full Yolk Sac LS 03/04 = 3/4-Remnant Yolk Sac LS 05 = Post Yolk Sac

E. Comparisons for 1975 and 1976

The 1975 and 1976 hatching seasons were remarkably similar with regard to location and timing of hatching (Fig.12). Data from both years suggest an early February hatching pulse of small magnitude, followed by the initiation of sustained hatching in mid-February. In both years hatching rates peaked during the first week of March, and hatching was completed by mid-March. The location of the greatest hatching activity, estimated indirectly from relative abundance of larvae with full yolk sacs, appeared to center around the Indian Point-Con Hook region (MP 42-54), and hatching production upstream from MP 54 was low in both years. A comparison of abundance and distribution of larvae between the two years (Table 6; Fig.13) indicates that newly hatched larvae were more abundant and were distributed farther downstream in 1976 than in 1975. Examination of monthly flow data (Table 7) shows that average freshwater flow during February and March was 46% greater in 1976 than in 1975.

II. POST-HATCH DISTRIBUTION OF LARVAE

A. Vertical Distribution

Simultaneous surface and bottom tows were conducted at each station during the first eight sampling dates of 1975 (22 Feb-12 Apr) and the first five sampling dates of 1976 (14 Feb-14 Mar) in order to study the vertical distribution of

Figure 12. Event timing for hatching period during 1975
and 1976.

Event Timing For Hatching Period During 1975 And 1976

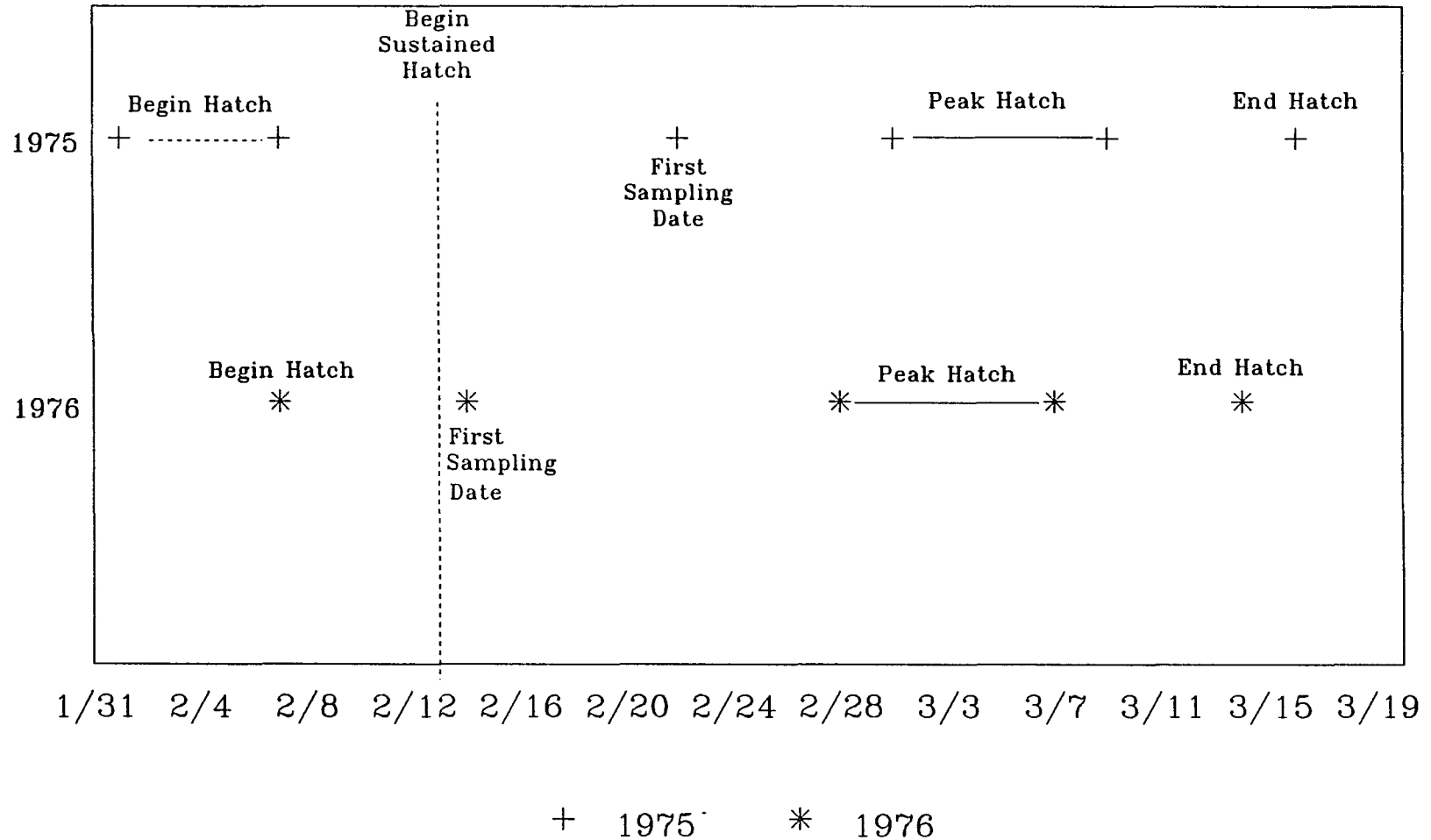


Table 6. Mean density for newly-hatched tomcod larvae (Life Stage LS02) from mid-February to mid-March 1975 and 1976.

Table 6. Mean density for newly hatched tomcod larvae (Life Stage LS02) from surface and bottom tows during mid-February to mid-March 1975 and 1976.

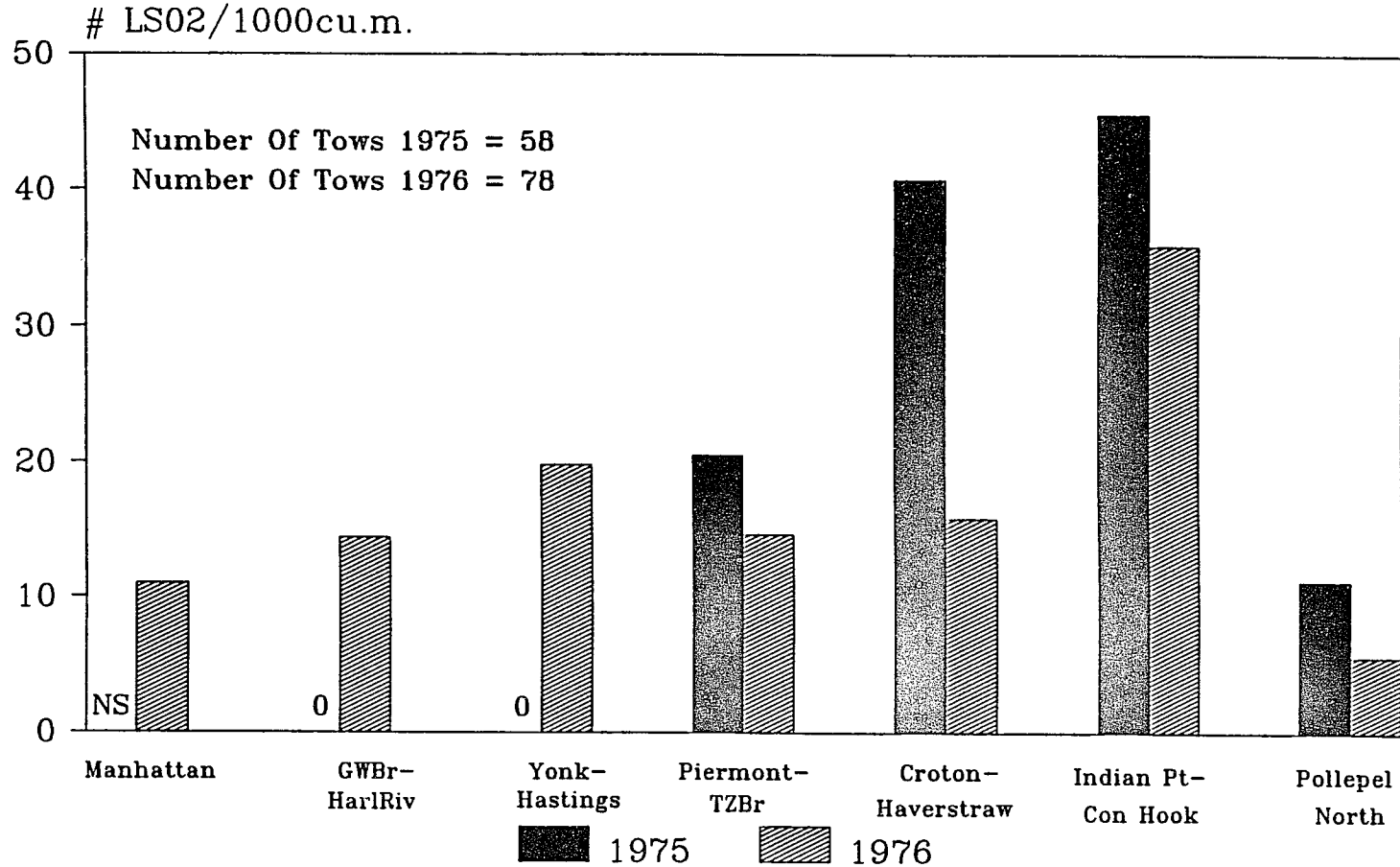
<u>1975</u>				
River Region	Milepoint At Region Midpoint	Mean Density (#/1000cu.m)	Number Of Samples	Standard Deviation
Manhattan	3		0	
GWBr-Harlem River	13	0.0	2	0.00
Yonkers-Hastings	20	0.0	2	0.00
Piermont-TZ Bridge	27	20.5	12	25.55
Croton-Haverstraw	36	40.7	14	47.18
Indian Pt-Con Hook	47	45.5	16	33.38
Pollepel North*	58	11.2	12	8.15
<u>1976</u>				
River Region	Milepoint At Region Midpoint	Mean Density (#/1000cu.m)	Number Of Samples	Standard Deviation
Manhattan	3	11.0	4	22.00
GWBr-Harlem River	13	14.4	6	32.38
Yonkers-Hastings	20	19.8	10	24.29
Piermont-TZ Bridge	27	14.6	14	16.64
Croton-Haverstraw	36	15.8	20	23.67
Indian Pt-Con Hook	47	35.9	18	37.07
Pollepel North*	58	5.6	6	7.28

*Includes stations at the Newburgh-Beacon Bridge (MP 62) and Danskammer (MP 69) during 1975.

Figure 13. Mean density of newly-hatched (LS02) larvae from mid-February to mid-March 1975 and 1976.

Mean Density Of Newly Hatched Larvae Mid-Feb to Mid-Mar 1975 and 1976

Surface And Bottom Tows



LS02 = Life stage 02 larvae with full yolk sac

NS = No sample in 1975

Table 7. Monthly freshwater flows at Green Island, 1971-1979, in comparison to 1918-1976 long-term average flows (from LMS 1980).

Table 7. Monthly average freshwater flows at Green Island, 1971-1979, in comparison to 1918-1976 long-term average flows (from LMS 1980).

Month	1918-1976 Long-Term Avg. Flows									
	(cfs)	1971	1972	1973	1974	1975	1976	1977	1978	1979
January	12879	9002	13410	26210	22010	19070	14740	7956	26310	20162
February	12474	12110	10930	20460	18640	19370	31260	8032	14120	11848
March	22344	20220	26860	29410	20730	23680	31690	43540	21870	44274
April	31155	37270	37960	30960	30170	25580	36760	40560	33560	37100
May	19480	35240	40520	27600	22960	20000	31800	16020	18730	19571
June	9791	7334	29630	13050	8791	12970	15220	7325	9954	8318
July	7040	6233	18380	10390	11780	7464	15280	5735	4643	4643
August	5608	8929	7616	5591	6359	8966	14630	5439	5976	5227
September	6289	9315	6309	4791	10390	17030	9573	14410	6195	7800
October	8125	7811	7291	5650	9049	23400	23230	30140	8450	11340
November	12485	7291	26150	8280	17180	22500	17930	23440	8020	16594
December	13979	17000	27010	26420	19380	18780	14080	26450	10720	15328
Annual Mean	13462	14830	21017	17410	16433	18211	21311	19086	14041	16885

☐ Highest monthly (or annual) average flow recorded since 1918.

▬ Second highest monthly (or annual) average flow recorded since 1918.

larvae during the hatching period. Various authors have reported that tomcod larvae exhibit positive phototaxis and swim to the surface upon hatching (Watson 1987), and that they are physoclists, which gulp air at the surface within 24 hrs of hatching, before the pneumatic duct closes (Peterson et al. 1980).

A comparison of average densities of surface and bottom tows within the Tappan Zee-Con Hook river segment (MP 28-52) during the 1975 and 1976 hatching periods shows that larvae were always more abundant in the bottom tows (Table 8). For both years the ratio of bottom to surface density was high early in the hatching season, decreased to about 2 : 1 as hatching progressed, and then reached a second high point at the end of hatching. My analysis of the proportion of larvae at a given life stage in the 1976 surface vs. bottom tows at no time indicated a preponderance of early life stages in the surface stratum (Table 9). This result is inconsistent with the expectation that all or most of the larvae move to the surface within 24 hrs of hatching. Conversely, on 7 March, the 1976 sampling date estimated to be closest to the hatching peak, a greater proportion of the youngest larvae were on the bottom, and the proportion of larvae found at the surface increased with life stage (Table 9). Such a trend would be expected if tomcod larvae hatched from eggs on or

Table 8. Comparison of average densities in surface and bottom tows from Tappan Zee-Con Hook (MP 28-52) during 1975 and 1976 hatching periods.

Table 8. Comparison of average tomcod densities in surface and bottom tows from Tappan Zee to Con Hook (MP 28-52) for the 1975 and 1976 hatching seasons.

<u>1976</u>					
	<u>Surface (S)</u>		<u>Bottom (B)</u>		Ratio B:S
	Mean	Std Dev	Mean	Std Dev	
14 Feb	1.1	2.20	11.4	4.46	10.4 : 1
21 Feb	12.9	14.60	43.4	31.14	3.4 : 1
28 Feb	26.5	25.43	50.4	54.51	1.9 : 1
7 Mar	151.7	57.43	215.2	115.76	1.4 : 1
14 Mar	29.2	28.34	1111.2	1345.06	38.1 : 1

<u>1975</u>					
	<u>Surface (S)</u>		<u>Bottom (B)</u>		Ratio B:S
	Mean	Std Dev	Mean	Std Dev	
22 Feb	4.3	9.70	80.8	39.90	18.8 : 1
1 Mar	52.5	15.69	92.7	50.59	1.8 : 1
9 Mar	363.4	270.24	837.9	748.09	2.3 : 1
16 Mar	79.7	97.07	1398.4	1169.97	17.5 : 1

near the bottom, were passively dispersed throughout the water column by density-induced circulation, and then actively moved back to the bottom as behavior patterns and swimming ability developed.

On 7 March 1976 the salt front was located around MP 19, some 9-31 miles downstream from the Tappan Zee-Con Hook river segment. Fresh water flow was high at the time, as evidenced by the salt front location. In general, net flow in this freshwater segment consists of a seaward movement at all depths, with a gradient of increasing velocities from bottom to surface (Abood 1974). Neutrally buoyant particles in such a system tend to rise toward the surface as some of the faster-moving water in the upper layers is replaced by slower-moving water in the lower ones. In the case of larvae hatched close to the bottom, this upward vectoring would be enhanced by any taxis toward the surface, e.g., positive phototaxis. Through this process a partial stratification consisting of younger larvae nearer bottom and older ones somewhat downstream nearer the surface might well occur.

Field data for 7 March are consistent with this hypothesis. A schematic arrangement of the data (Fig.14) shows that the highest average concentration of LS 02 larvae,

Table 9. Proportion of larvae by life stage in surface vs. bottom tows during 1976 hatching period.

Table 9. Proportion by life stage of total larvae collected in the Tappan Zee-Con hook segment that were on surface vs. bottom.

<u>14 February 1976</u>				
Life Stage	<u>02</u>	<u>03</u>	<u>04</u>	<u>05</u>
Surface	0.00	0.20	0.00	—
Bottom	1.00	0.80	1.00	—
<u>21 February 1976</u>				
Life Stage	<u>02</u>	<u>03</u>	<u>04</u>	<u>05</u>
Surface	0.28	0.30	0.13	—
Bottom	0.72	0.70	0.87	—
<u>28 February 1976</u>				
Life Stage	<u>02</u>	<u>03</u>	<u>04</u>	<u>05</u>
Surface	0.36	0.16	1.00	—
Bottom	0.64	0.84	0.00	—
<u>7 March 1976</u>				
Life Stage	<u>02</u>	<u>03</u>	<u>04</u>	<u>05</u>
Surface	0.32	0.24	0.44	0.66
Bottom	0.68	0.76	0.56	0.34
<u>14 March 1976</u>				
Life Stage	<u>02</u>	<u>03</u>	<u>04</u>	<u>05</u>
Surface	0.02	0.04	0.07	0.02
Bottom	0.98	0.96	0.93	0.98

— = No larvae of this life stage collected.

which is located near bottom in the Haverstraw Bay-Con Hook segment (MP 37-52), translates into the highest concentration of LS 05 larvae 11 miles downstream at the surface in the Tappan Zee-Haverstraw Bay segment (MP 28-37).

B. Vertical Distribution in Relation to Salinity

Data have been presented that so far are consistent with the observation of a decreasing ratio of bottom-to-surface larval density during the early part of the hatching season (Table 9). Further analysis was needed to determine if the data were consistent with the subsequent increase in the B:S ratio observed during the late hatching season. Sampling during 7 March 1976 showed that surface and bottom densities tracked one another fairly closely until, at the Piermont station (MP 24), approximately five miles upstream from the estimated salt front location at MP 19, tomcod abundance in surface tows began to decrease markedly with increasing bottom conductivity (Fig.15). A similar trend continued on 14 March, although the salt front had moved upstream about 24 miles to the Indian Point region (MP 43) (Fig.15). Similar to 7 March, the 14 March trend of divergence between surface and bottom densities began at the Con Hook station (MP 50), about six miles above the estimated location of the salt front. Data from 16 March 1975 show a similar trend, i.e., a divergence between surface and bottom densities beginning about ten miles upstream from the salt front (Fig.15). Regression analysis of log-transformed surface larval density values for those stations that were

located within the salinity intrusion region during 7-14 March 1976 and 16 March 1975 vs. log-transformed bottom conductivity values showed a significant ($\alpha = 0.01$, $df = 23$) negative correlation between surface abundance and bottom conductivity (Fig.16).

My hypothesis is that at this point in the life history of the tomcod, certain aspects of its larval behavior and the hydrodynamic characteristics of estuarine circulation act in concert to produce the observed data trends. The key elements present here are an active behavioral orientation by tomcod to the more saline waters of the bottom layer, and a downward vertical transport mechanism that would enable small-scale, individual behavior to produce a large, cumulative effect.

The behavioral component of the observed decrease in surface abundance was readily noticeable in the field for those samples in which live post-yolk-sac tomcod were collected. When placed in sample jars filled with surface water of various salinities, these tomcod, often several hundred in number, consistently swam strongly downward to the bottom of the container and continued to swim, head down against the bottom, until formalin was added to the sample.

A vertical transport component is characteristic of the salinity intrusion region within partially stratified

Figure 14. Schematic transition of newly-hatched bottom larvae (LS02) to post yolk-sac juvenile surface larvae (LS05).

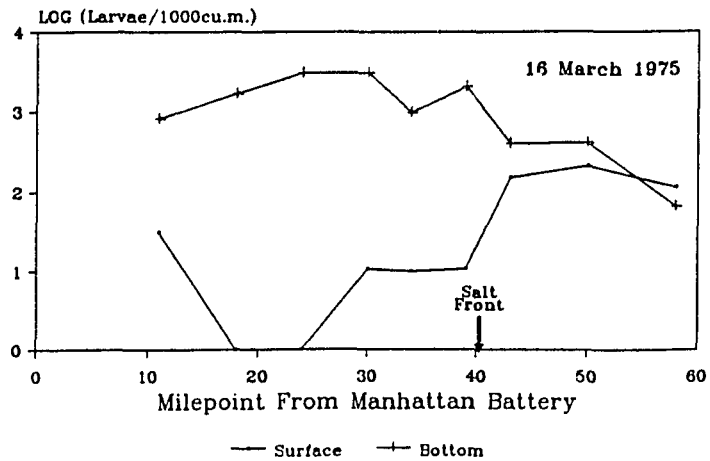
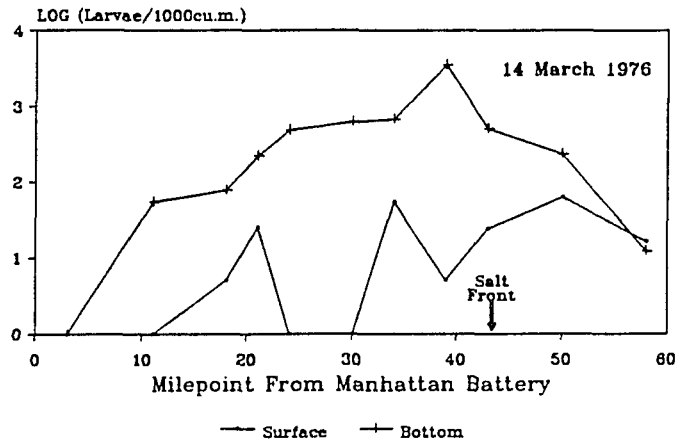
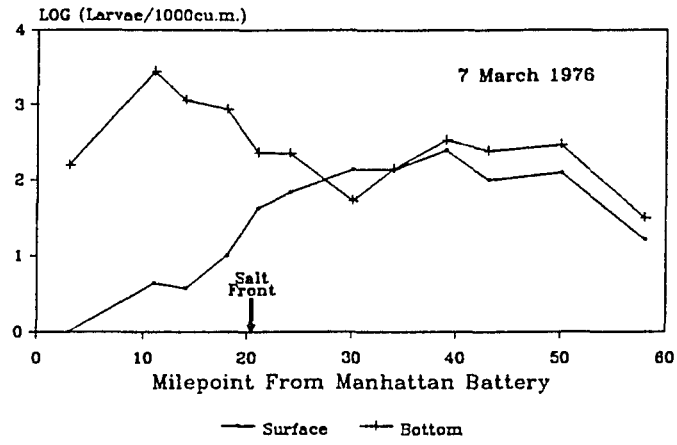
Transition of Newly-Hatched Bottom Larvae (LS 02)
 To Post Yolk-Sac Juvenile Surface Larvae (LS 05)

7 MARCH 1976

Milepoint	30	34	39	43	50
	Tappan Zee	Croton	Haverstraw Bay	Indian Point	Con Hook
Surface	46.5 (05)	25.6 (05)	87.1 (05)	13.5 (05)	15.8 (05)
	23.3 (02)	6.3 (02)	27.3 (02)	74.2 (02)	31.7 (02)
Bottom	6.1 (05)	47.9 (05)	10.5 (05)	6.8 (05)	11.2 (05)
	0 (02)	6.9 (02)	99.4 (02)	60.5 (02)	111.1 (02)

Figure 15. Surface vs. bottom density by River milepoint for 7 and 14 March 1976, and 16 March 1975.

Surface vs. Bottom Density By Rivermile

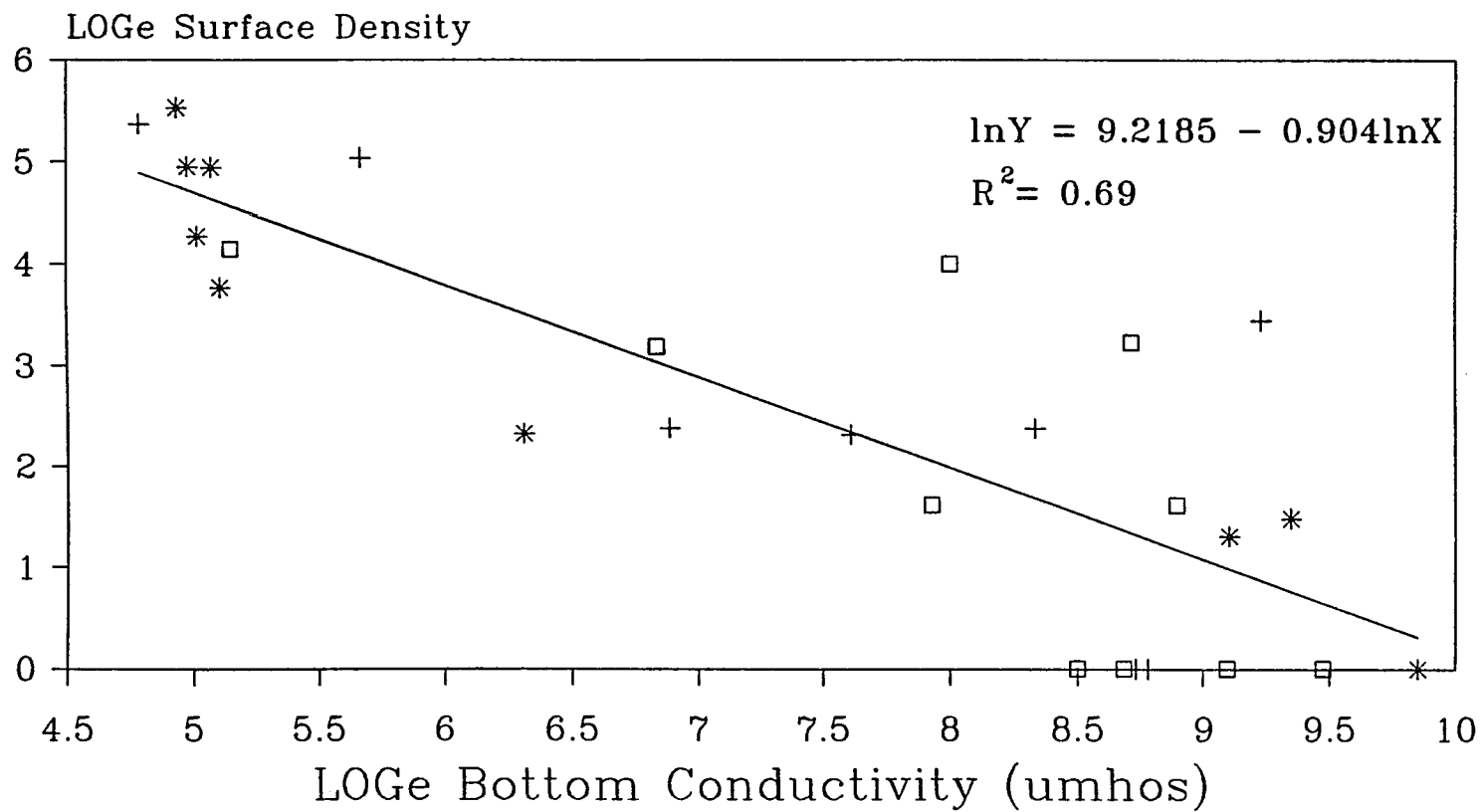


estuaries such as the Hudson River. When tidal currents are strong relative to freshwater flow, as in the lower Hudson, turbulence in the salinity-intruded region causes an upward advection of salt water as well as a downward movement of fresh water into the lower layer (Abood 1974). As juvenile tomcod approached the salt front (defined as 0.1 ppt salinity by Abood in contrast to the 1.0 ppt used in this study), their ability to move into the bottom layer was thus enhanced by a downward vertical component that became stronger in the seaward half of the (0.1 ppt) intrusion region (Harleman and Ippen 1967; cited in Abood 1974).

If tomcod did not move to the bottom layer they would be swept from the estuary because the movement of a given particle in the upper layer (from approximately mid-depth to the surface) of the salt-intruded reach is downstream, while in the lower layer it is upstream. As a note of interest, no tomcod were collected from a total of ten surface and bottom tows at the Verrazzano Bridge (MP -6) during April and May 1975. This attests to the conservative nature of the estuarine transport system. However, inasmuch as no sampling was conducted at the Verrazzano during March, it should be pointed out that the three values which lie furthest above the regression line of Fig.16 may indeed represent larvae that were later swept from the estuary.

Figure 16. Surface tomcod density vs. bottom conductivity within salt-intruded reaches near end of hatching 1975 and 1976.

Surface Density vs Bottom Conductivity Within Salt-Intruded Reaches



+ 16 Mar 75 * 7 Mar 76 □ 14 Mar 76

C. Longitudinal Distribution in Relation to Salinity and Freshwater Flow

1. 1973

This project began with exploratory bottom tows conducted on 15 April 1973, the only sampling date for that year. The highest larval density (3500/1000 cu.m.) was observed at the Manhattan station (MP 3), and the densities steadily decreased north to the Tappan Zee Bridge (MP 30), at which point no larvae were collected (Fig.17). The high concentration near Manhattan was of interest because it provided direct evidence for the magnitude of hydrodynamic transport undergone by larvae of the only major winter-spawning fish species in the Hudson River. Peak tomcod spawning activity during the winter of 1972-1973 was estimated to have occurred north of Danskammer Point (MP 66), and the highest densities observed during a tomcod larvae survey from MP 37 to 95 on 13 March 1973 were in the vicinity of MP 78 (Lawler, Matusky and Skelly Engineers, unpub. data). The concentration near Manhattan should have been of particular interest to authors of the 1977 Westway Environmental Impact Statement, which referred to the Manhattan segment of the Hudson as essentially devoid of aquatic life and a "biological wasteland" (Lupenetti 1984). The sampling date of April 15, 1973 was the only one (among 35 additional sampling dates during this 4-year study) on which peak tomcod concentrations were found as far south as Manhattan. Freshwater flows in the lower Hudson, using a

lag-time of 10 days (Stewart 1958) for daily flows measured at the Green Island gaging station (MP 153), were in excess of 70,000 cubic feet per second (cfs) during mid-April 1973. This was approximately twice the 25-year (1949-1973) average for April (usually the highest-flow month of the year) and is consistent with an extreme downstream displacement of the tomcod larvae population at that time.

2. 1974

The 1974 program consisted of five river transects from Manhattan (MP 3) to Croton (MP 34), sampled on six collection dates (6 April-19 May). The program was then still exploratory in that I had not yet defined the longitudinal distribution of the population within the river. A major flaw in the 1974 sampling design was the lack of any sampling in the 13-mile gap between the George Washington Bridge (MP 11) and Piermont (MP 24) stations, the river segment that turned out to include by the highest frequency of occurrence for peak tomcod abundance during 1975 and 1976.

Physical data and tomcod abundance data for 1974 are included in Appendix I, and population distributions for post-yolk-sac and early juvenile tomcod are shown in Fig.18. Assuming that peak population abundance was associated with and usually located somewhat downstream from the salt front, an assumption supported by data from 1975 and 1976, it is evident from Fig.18 that sampling within the population

Figure 17. Hudson River tomcod distribution for 15 April 1973.

Distribution Of Post Yolk-Sac Tomcod Bottom - 15 April 1973

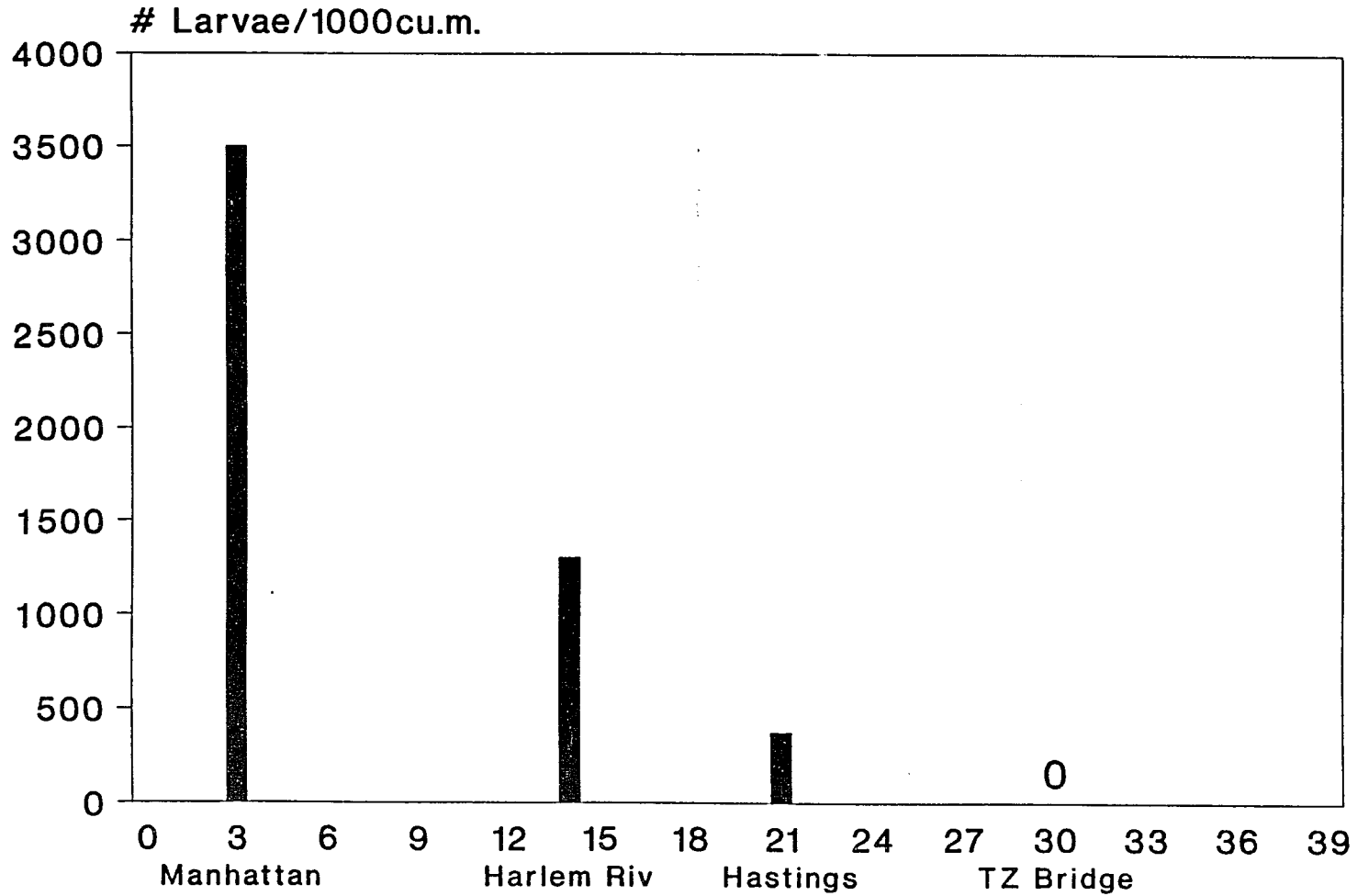
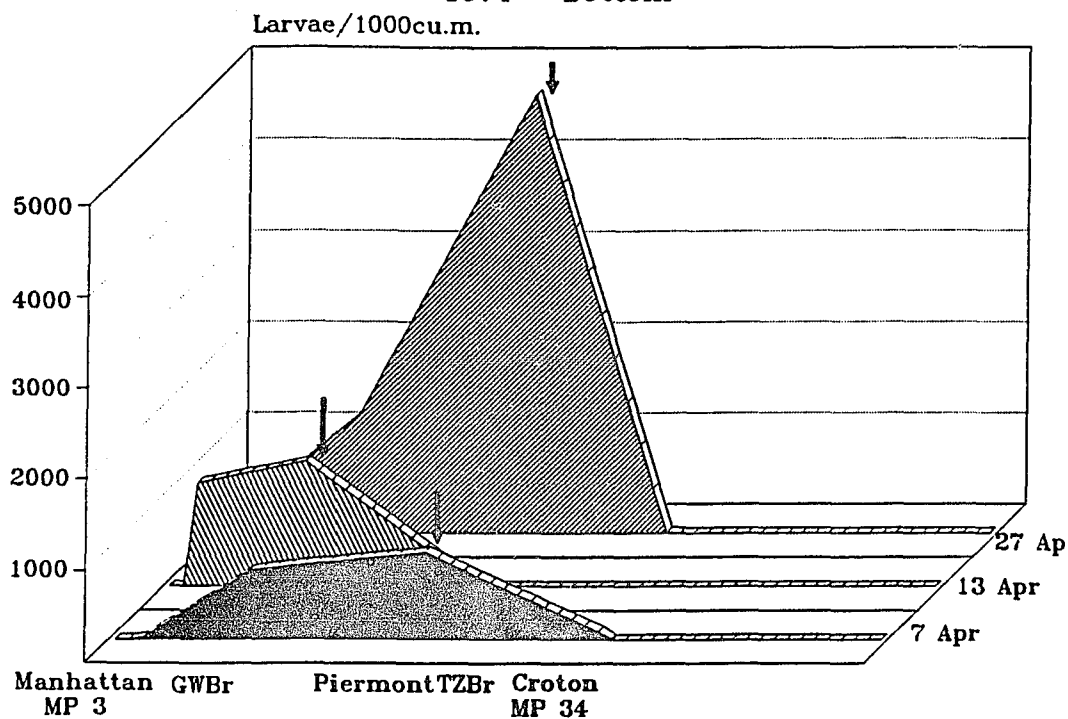
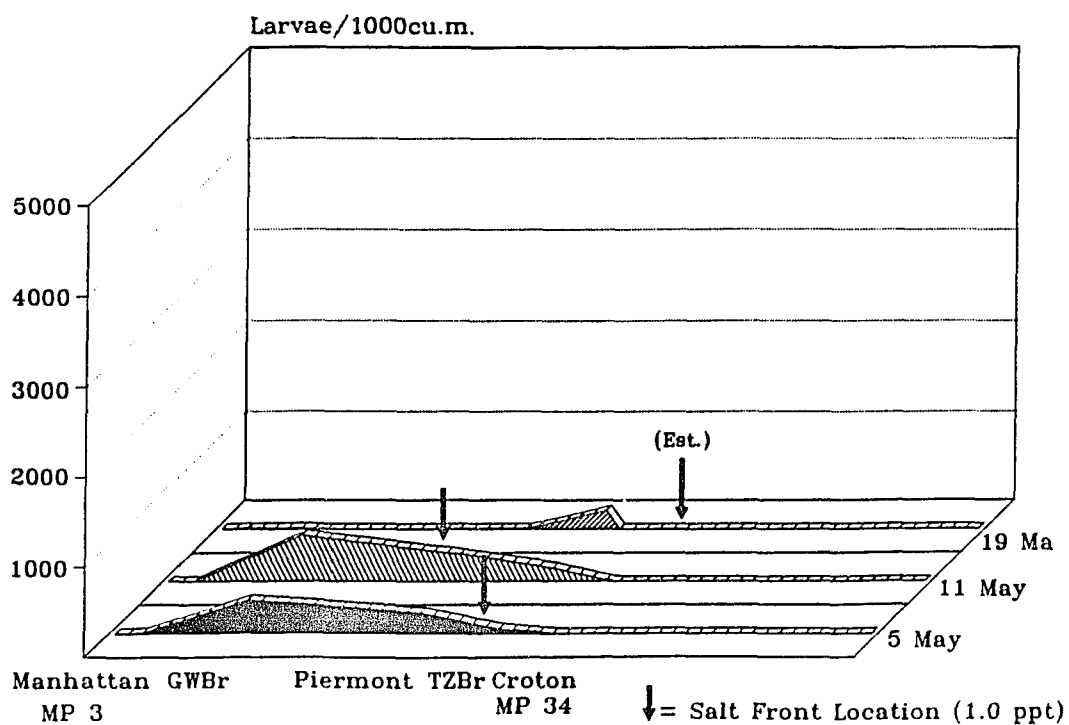


Figure 18. Bottom distribution of post yolk-sac and early juvenile tomcod for April-May 1974.

Distribution Of PYS And Early Juvenile Tomcod 1974 - Bottom



1974 Bottom



coincided with peak abundance on only one of the six sampling dates (27 April), when a peak density of 4798/1000 cu.m. was measured at Piermont (MP 24). On 7 April, 5 May, and 11 May, peak abundance appears to have been located within the unsampled river segment between GWBr (MP 11) and Piermont (MP 24). On 13 April the region of peak abundance probably lay between Manhattan (MP 3) and GWBr (MP 11), and it also seems evident that the population extended below Manhattan. The most significant information obtained from the 1974 sampling design were the data on growth and the idea of where to add new stations in 1975 and 1976.

3. 1975

The 1975 sampling program, carried out on 12 sampling dates (22 February-10 May), consisted of 13 river transects from the Verrazzano Bridge (MP -6) to Danskammer North (MP 69). On four of the eight post-hatch sampling dates between 23 March and 10 May, peak densities were found at the Yonkers station (MP 18), which had been added in 1975 to fill the gap between GWBr (MP 11) and Piermont (MP 24). On three of the eight dates, peak densities were observed at GWBr (MP 11), including the highest density for the year (7892/1000 cu.m.) on 20 April. The second highest density for the year (7177/1000 cu.m.) was observed at Piermont (MP 24) on 6 April.

Weekly riverwide larval population distributions are shown in Figs.19-20, and the associated data may be found in

Figure 19. Surface and bottom distributions for post yolk-sac and early juvenile tomcod during 23 March-12 April 1975.

Distribution Of PYS And Early Juvenile Tomcod March-April 1975

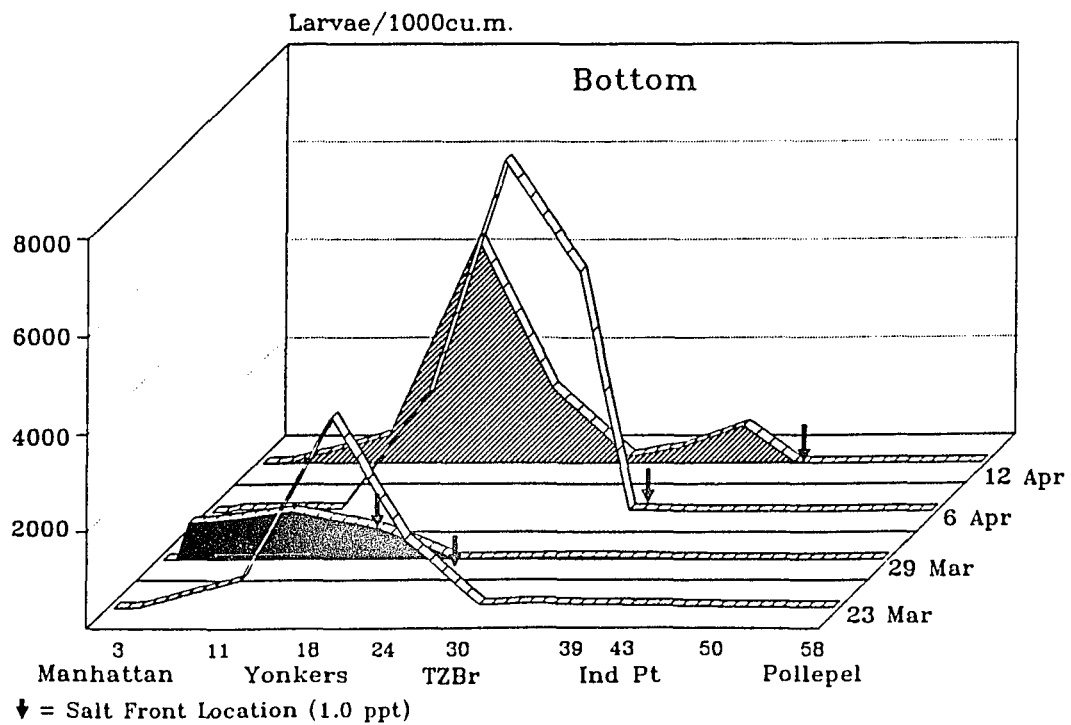
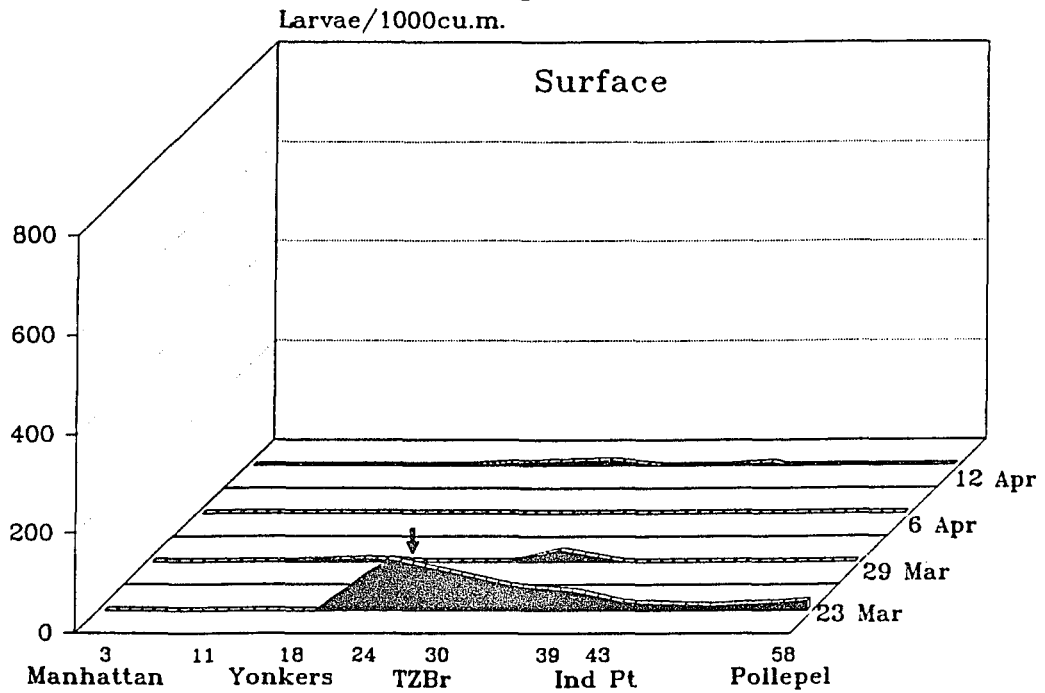
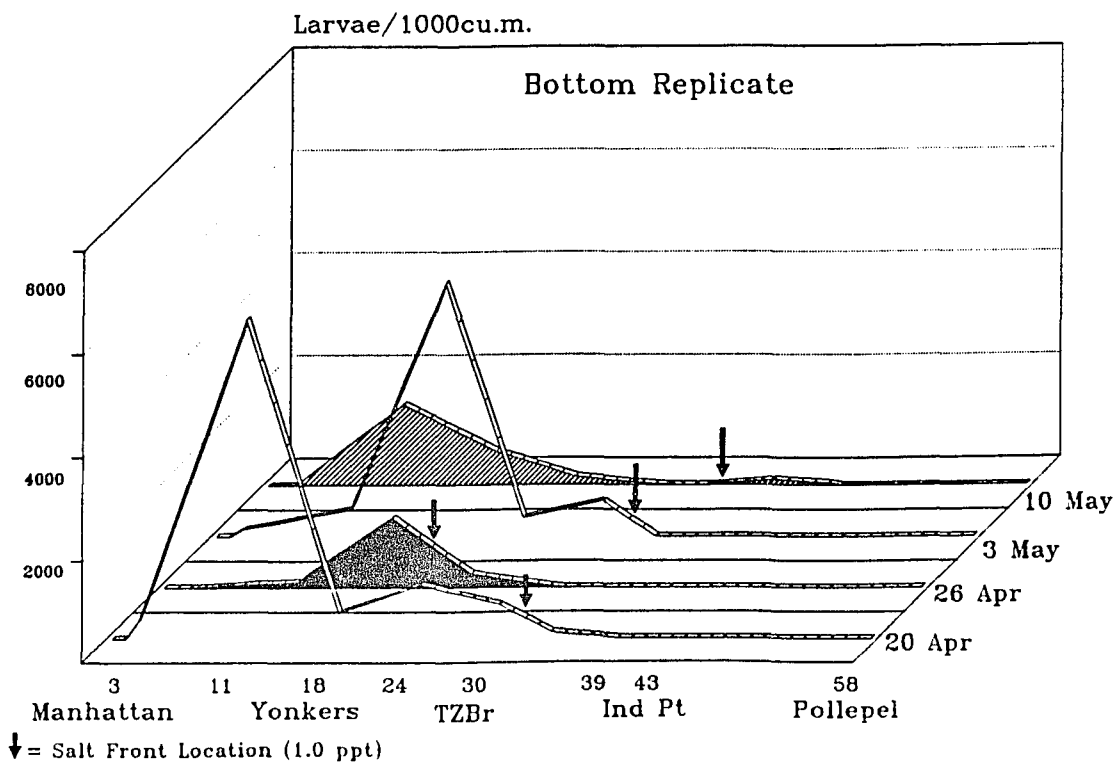
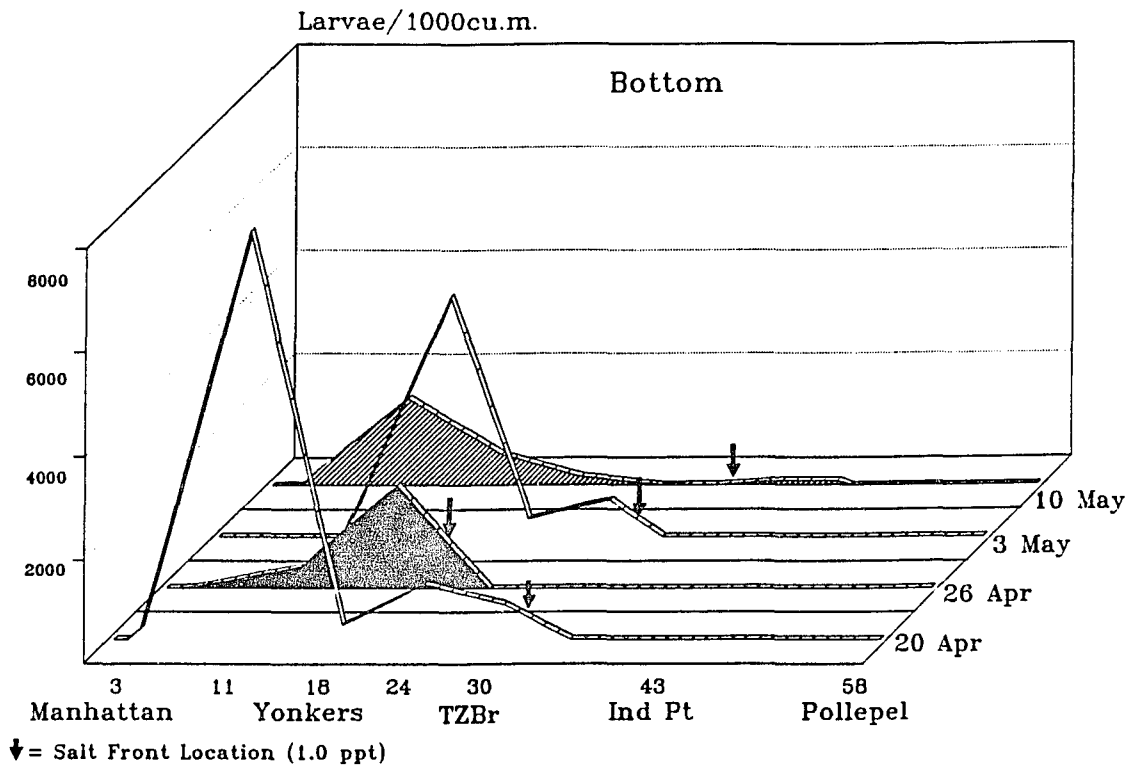


Figure 20. Bottom replicate distributions for post yolk-sac and early juvenile tomcod during 20 April-10 May 1975.

Distribution Of PYS And Early Juvenile Tomcod April-May 1975



Appendix I. Surface densities were negligible after 23 March; surface tows were discontinued after 12 April in favor of replicate bottom tows. It is evident from Fig.20 that the information on abundance and distribution was virtually identical for 24 paired tows that were conducted between 20 April and 10 May. The high degree of similarity between paired tows supported my assumption that I was sampling real population peaks rather than relatively small, high-density patches of larvae.

Arrows in Figs.19-20 show approximate locations for the salt front in relation to peak tomcod densities. In all cases, peak density was located seaward of the salt front (1.0 ppt), within the salinity-intruded reach. Examination of the distributions for the larval population indicates that the area of peak population density for 29 March actually was not sampled. Freshwater flows were high around this date (>40,000 cfs at Green Island, 10 days before), as indicated by the location of the salt front just north of Yonkers (MP 18). On 29 March the Manhattan station (MP 3) was sampled at 0840 hrs, at the end of ebb tide (as evident from current movement on the surface). During the early stages of flood tide, sampling was moved north to GWBr (MP 11) at 0940 hrs and Yonkers (MP 18) at 1030 hrs, now at least 2-3 hours into bottom flood. It is likely that the portion of the population sampled on 29 March was the portion associated with the leading edge of the salinity intrusion wedge, and that the main body of the population was located seaward of

Manhattan. A similar tidal current regime existed on 12 April, when flows were substantially lower. It appears that the tide, which had been flooding from the start of sampling at Manhattan at 0840 hrs to the Tappan Zee at 1155 hrs, had drawn out the population into a skewed distribution, similar to the one I have hypothesized for 29 March. It is of further interest to observe that the distribution for 6 April, when the leading edge of the population was sampled near the end of ebb tide, shows none of the upstream skewness I have associated with a flooding tide.

To better define the location of and the physicochemical characteristics of habitats utilized by post-yolk-sac tomcod, all bottom samples collected during 23 March-10 May 1975 were grouped according to their abundance within a given river segment or a certain conductivity range. Out of 13,481 larvae collected, 64% fell within a conductivity range of 9000 to 15000 umhos/cm (7.6-12.6 ppt salinity), and 92.9% occurred within the zone bounded by 3000-18000 umhos/cm (2.5-15.2 ppt), which is typically classified as mesohaline (Table 10; Fig.21). Inasmuch as the salt front often moved rapidly for longitudinal distances of up to 25 miles (MP 18-43) during the course of this study, it follows that the modal conductivity range of 12001-15000 umhos (10.1-12.6 ppt) shown in Fig.21 was not associated with any particular geographical location on the river. The distribution of average tomcod densities according to river region shows that although the

Table 10. Distribution of post yolk-sac and early juvenile tomcod with respect to conductivity and salinity during 23 March-10 May 1975.

Table 10. Distribution of post yolk-sac and early juvenile tomcod densities (#Larvae/1000cu.m.) with respect to conductivity and salinity* during 23 March - 10 May 1975. Data from Verrazzano Narrows excluded.

Conductivity Range (umhos/cm)	Salinity (ppt)	N	Average Density	Number Of Larvae	Percent Of Total Larvae
0 - 3000	<2.5	30	142.0	842	6.3
3001 - 6000	<5.0	9	805.3	1275	9.5
6001 - 9000	<7.6	12	846.8	1120	8.3
9001 - 12000	<10.1	7	2215.6	3774	28.0
12001 - 15000	<12.6	6	4713.3	4871	36.1
15001 - 18000	<15.2	10	680.0	1447	10.7
18001 - 24000	<20.2	9	83.5	152	1.1

* Salinity (ppt) = $-0.00536 + 0.000842$ (umhos)

N = Number of samples

18001 - 24000 range is twice that of other ranges

Figure 21. Average tomcod concentration within each conductivity range during 23 March-10 May 1975.

Average Tomcod Concentration Within Each Conductivity Range

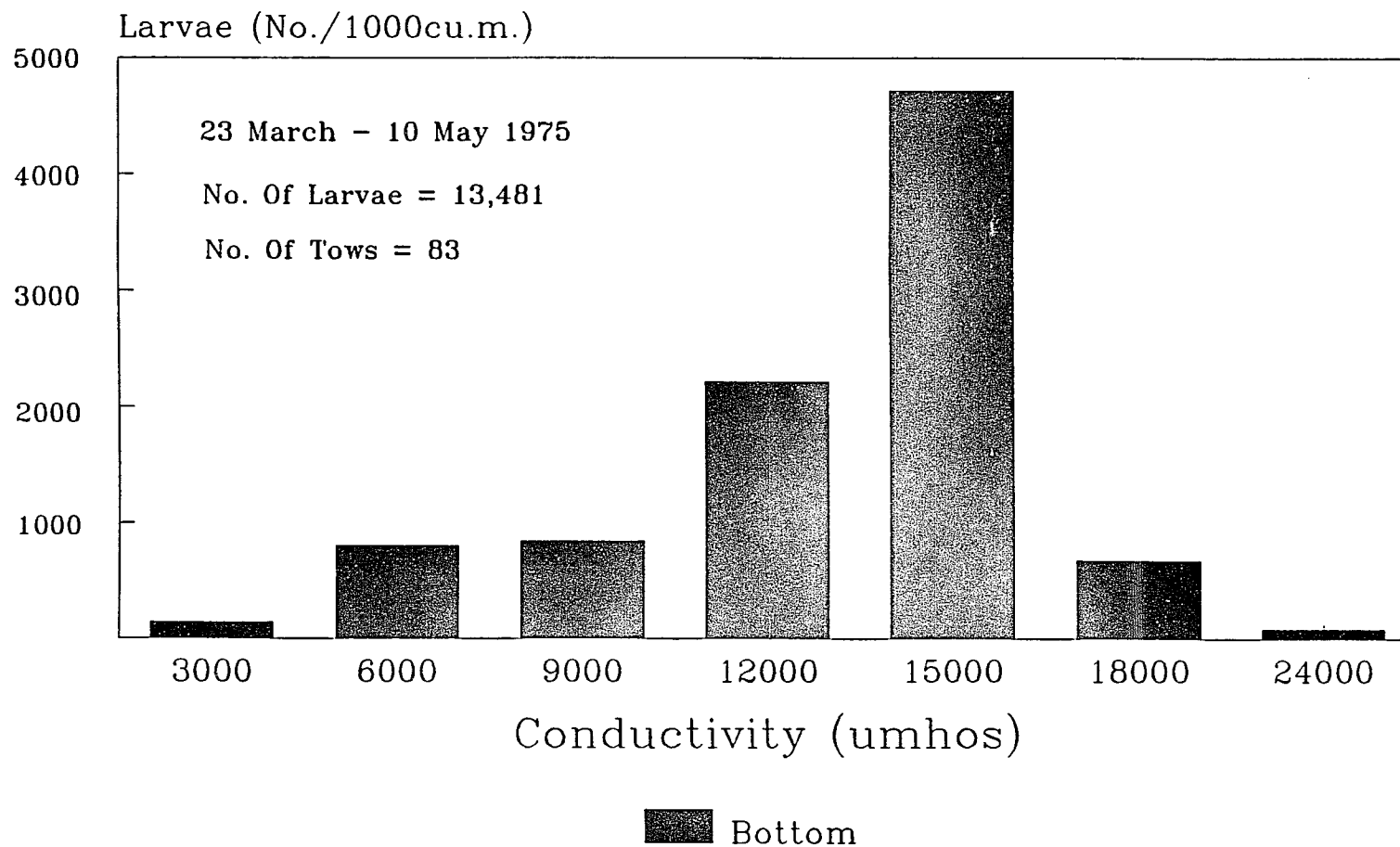
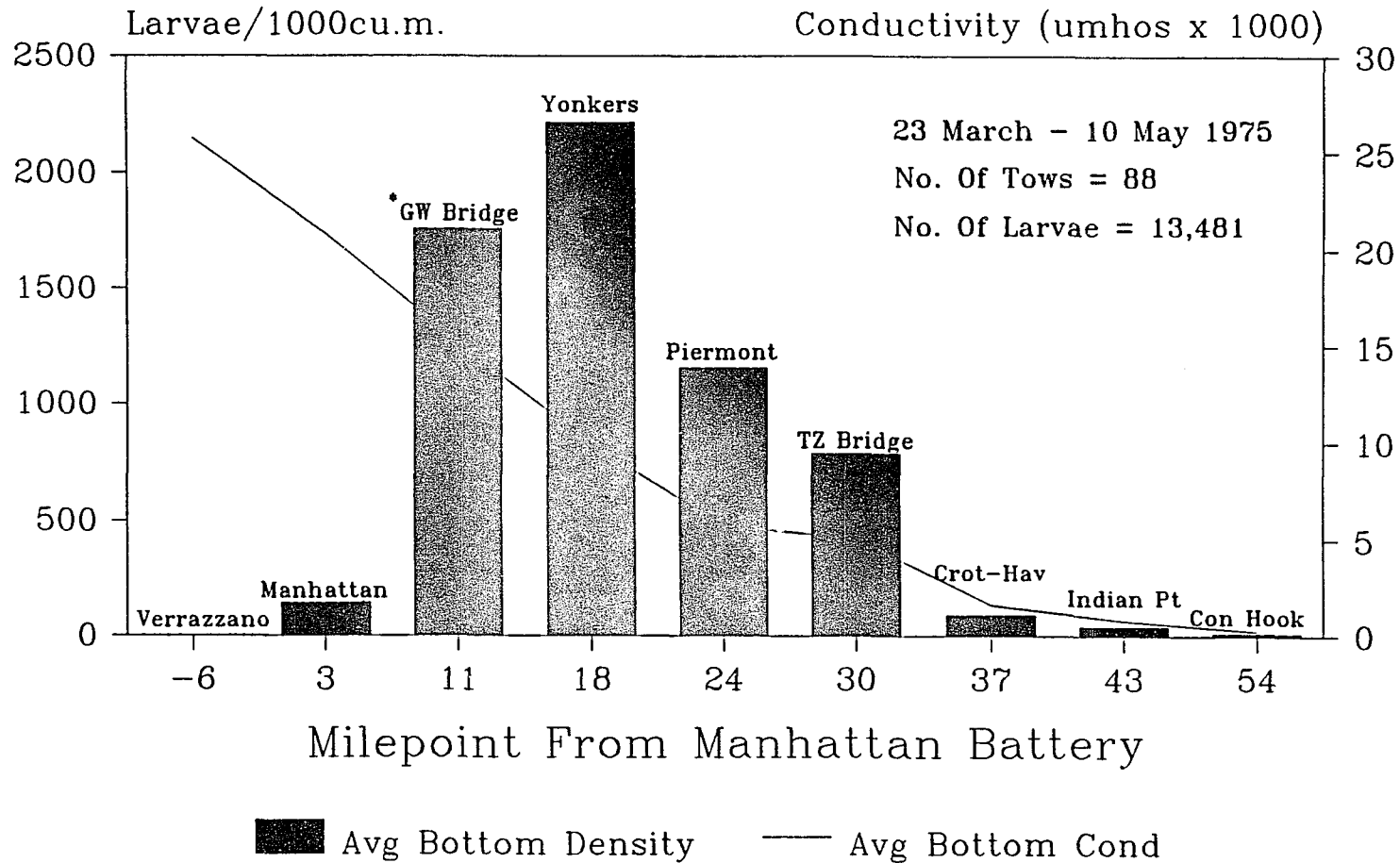


Figure 22. Average tomcod concentration and conductivity
by River segment 23 March-10 May 1975.

Tomcod Concentration and Conductivity By River Segment During 1975



* GWBr = peak 1975 density of 7892/1000cu.m.

highest density value was found at GWBr (MP 11), the modal location for high-density collections during 1975 was Yonkers (MP 18) (Fig.22).

4. 1976

The 1976 program consisted of sampling at 15 river transects from the Statue of Liberty (MP 0) to Pollepel Island (MP 58), carried out on 17 collection dates (14 February-13 June). Stations were added at Milepoints 0, 6, 14, 21, and 32 in order to define larval population distributions more closely. Weekly riverwide population distributions are shown in Figs.23-25, and the associated data may be found in Appendix I.

Average surface density, expressed as a percentage of average bottom density, declined from a high of 49.5% on 28 February to 3.0% on 14 March, when surface tows were discontinued and replaced by mid-depth tows on 21 March. Average density for mid-depth tows was always less than that for bottom tows, but on 21 March and 10 April peak mid-depth density was greater than peak bottom density. The trend of decreasing mid-depth density in relation to bottom density was not steady, however. Mid-depth density eventually reached zero on 9 May (Fig.26).

Analysis of the relationship between mid-depth and bottom tomcod densities provides some insight into the dynamics of density-induced circulation within the salt-

intruded reach of a partially stratified estuary. Station milepoints, weighted by tomcod abundance, were used to estimate weighted mean locations for mid-depth and bottom population epicenters (Fig.27). Because this method utilized all of the station-density data available for a given date (Appendix I), it provided more meaningful information on population location than did the locations of single-station peak densities. As shown in Table 11 and Fig.27, the mid-depth population epicenter was located upstream from the bottom population epicenter on every date except 28 March, when there was no substantive difference between locations, and 4 April, when the location of the mid-depth epicenter was estimated to be about 5 mi downstream from the bottom one. Freshwater flows on these two dates, especially on 4 April, were higher than on other dates used in the analysis.

The existence of a two-layered system in which freshwater moves downstream in an upper layer and ocean-derived water moves upstream in a lower one is a basic concept in the study of estuarine transport. However, based on this simplified concept it appears counter-intuitive to expect mid-depth concentrations of semi-planktonic organisms to remain upstream from bottom concentrations, as seen in Fig.27. A satisfactory explanation for this phenomenon requires a more detailed understanding of the circulation characteristics of this partially stratified estuary.

Figure 23. Mid-depth and bottom distributions for post yolk-sac and early juvenile tomcod during 21 March-10 April 1976.

Figure 24. Mid-depth and bottom distributions for post yolk-sac and early juvenile tomcod during 17 April-9 May 1976.

Distribution Of Post Yolk-Sac And Early Juvenile Tomcod April-May 1976

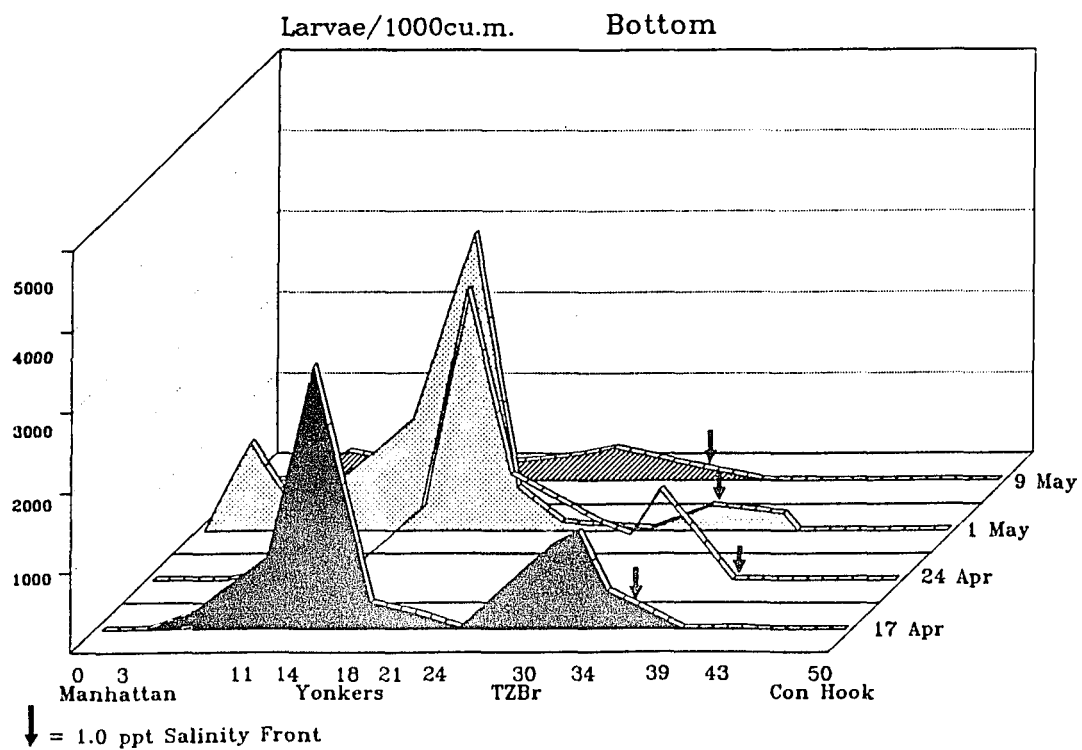
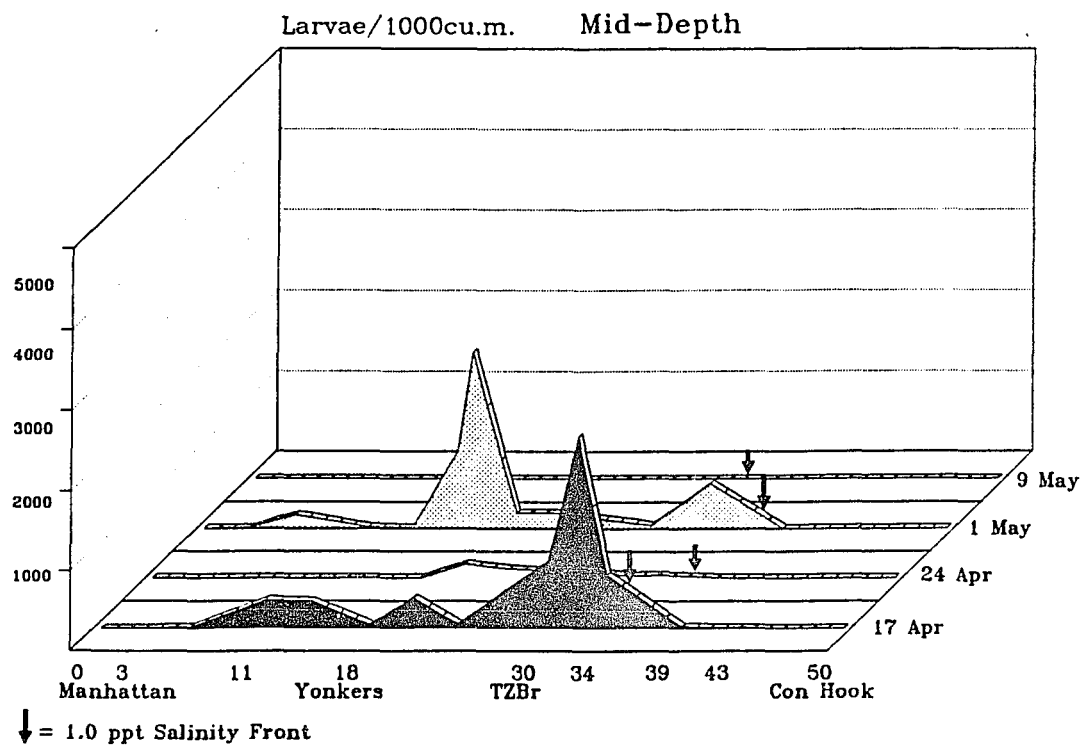


Figure 25. Bottom replicate distributions for post yolk-sac and early juvenile tomcod during 15 May-13 June 1976.

Distribution Of Post Yolk-Sac And Early Juvenile Tomcod May-June 1976

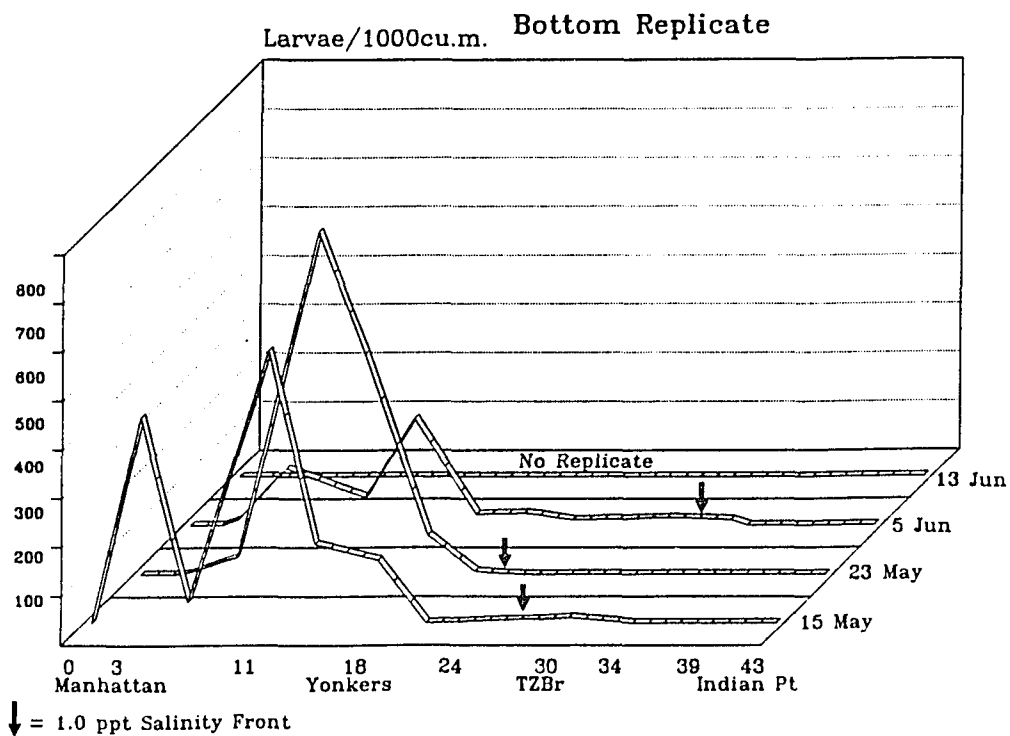
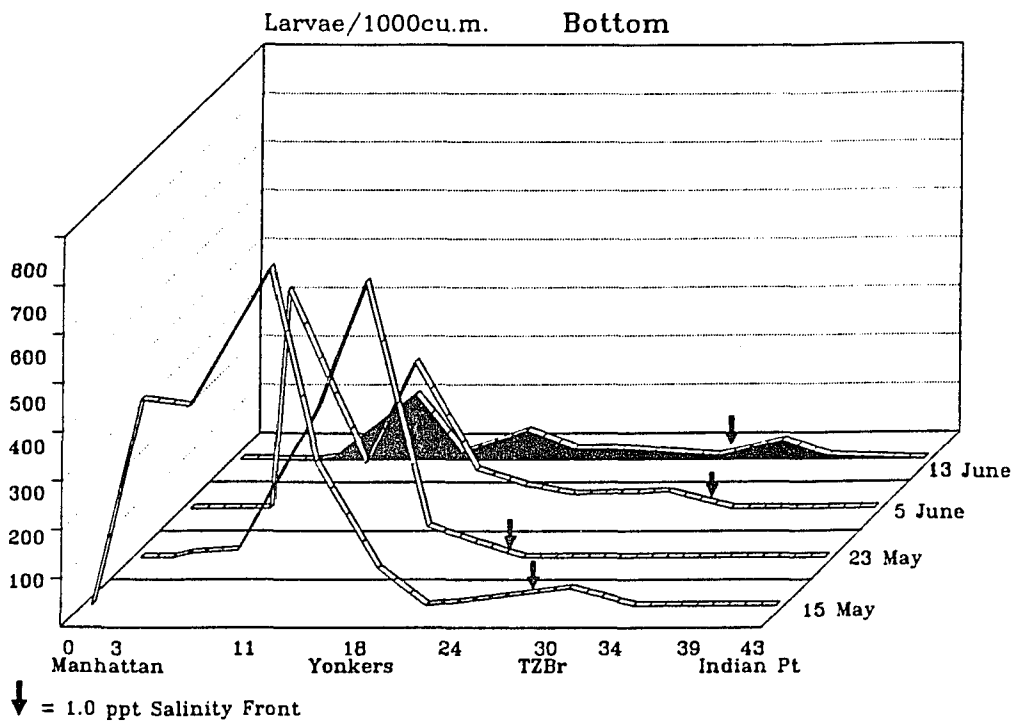


Figure 26. Mid-depth tomcod density as a proportion of bottom tomcod density during 21 March-9 May 1976.

Mid-Depth Density As A Proportion Of Bottom Density

1976

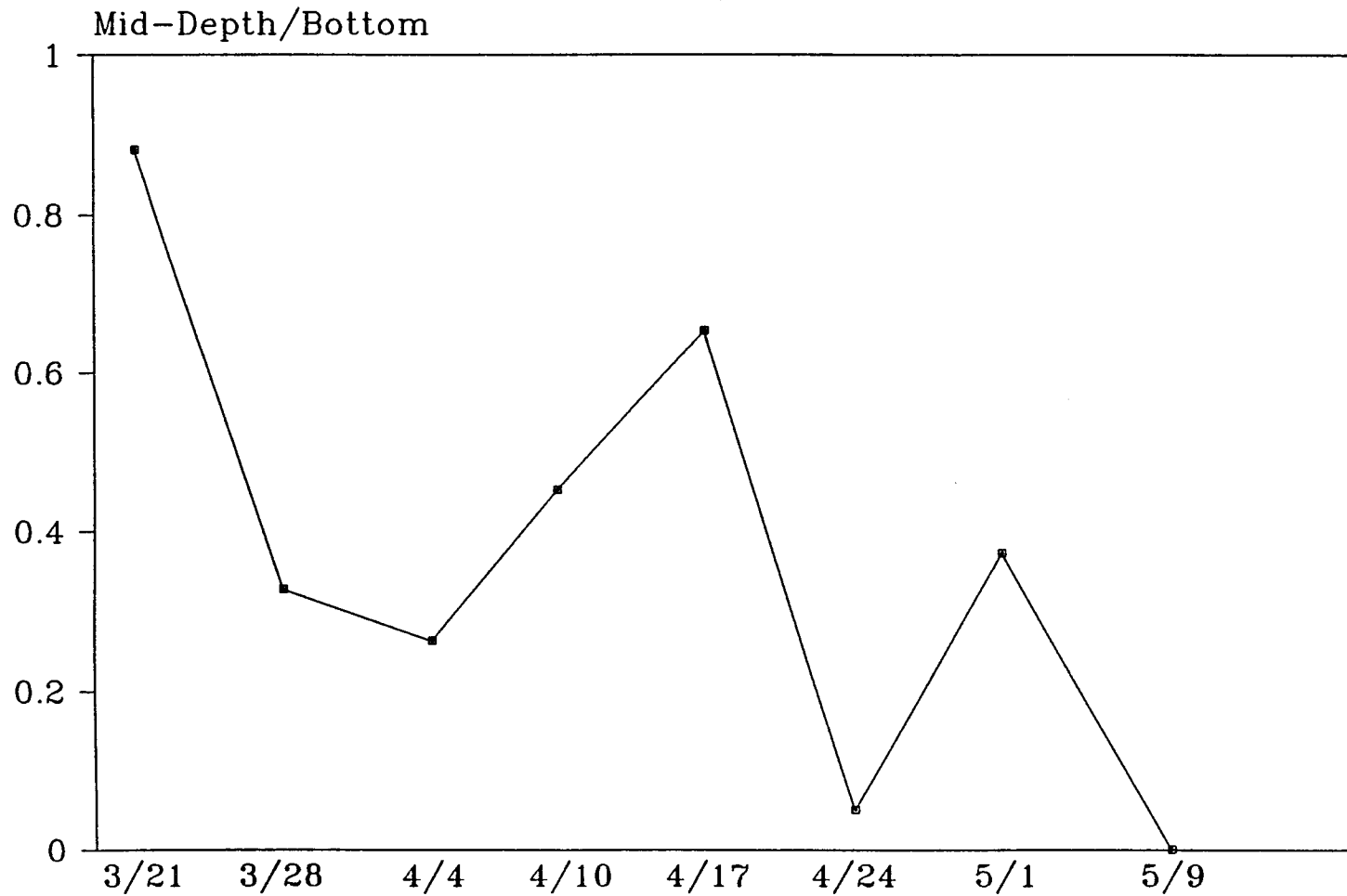
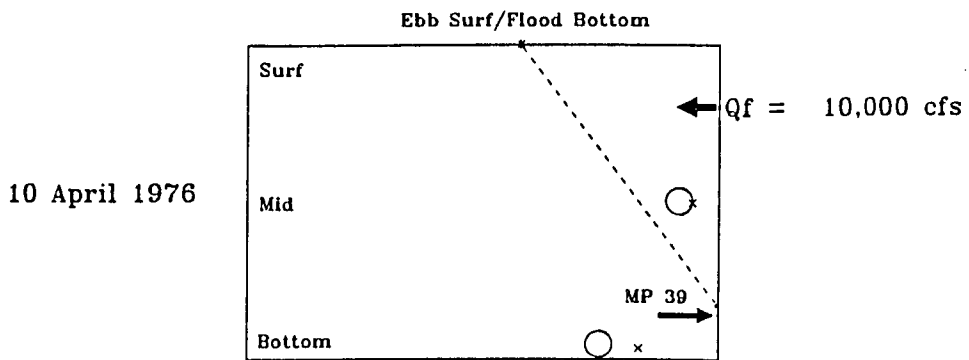
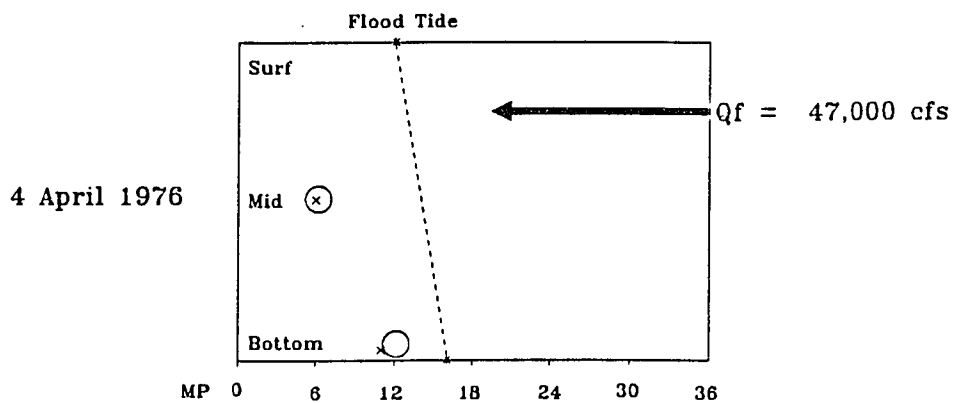
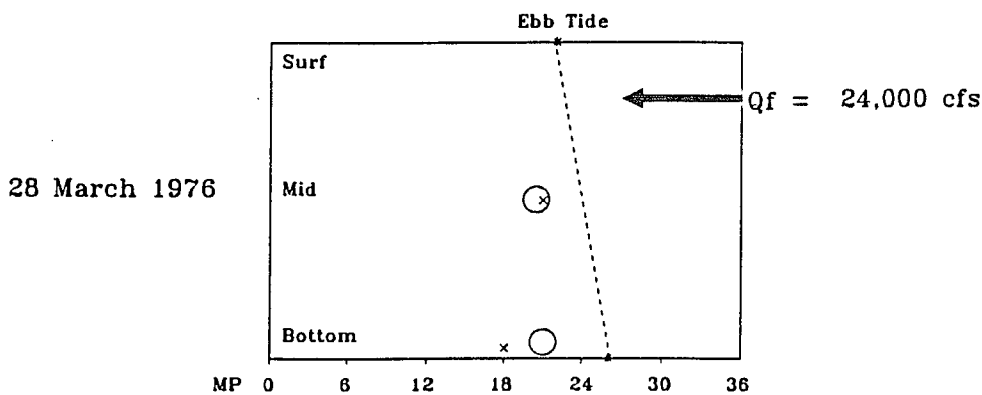
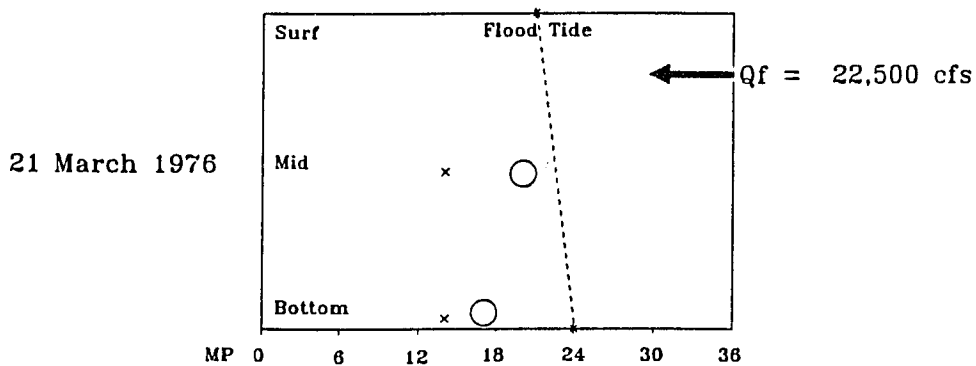


Figure 27. Density-weighted mean locations for mid-depth and bottom tomcod population epicenters in relation to freshwater flow.

Milepoint Of Bottom And Mid-Depth Tomcod Concentrations vs Salinity And Freshwater Flow (Qf)



○ Population Epicenter X Peak Density
 - - - 0.1 ppt Salinity Front ← Relative Magnitude Q_f

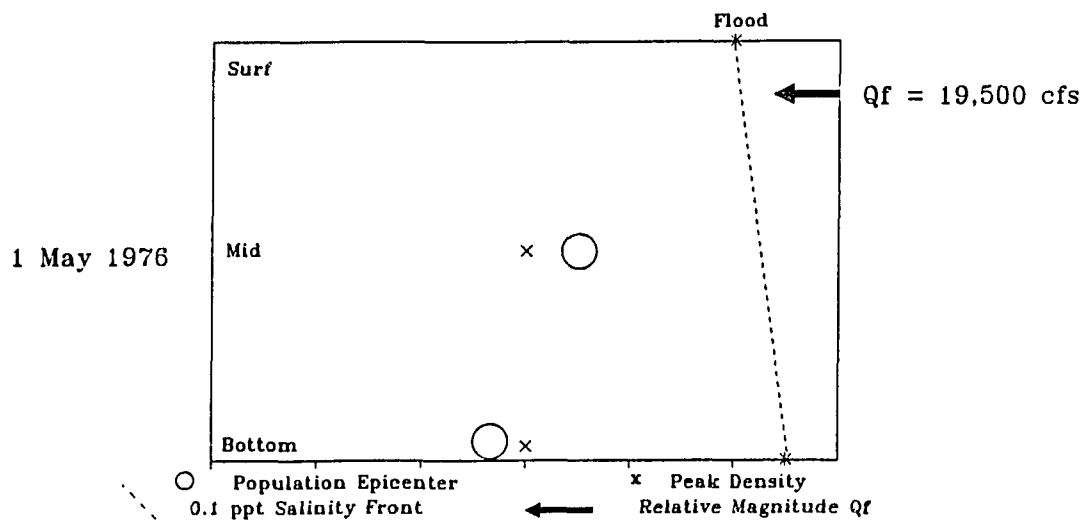
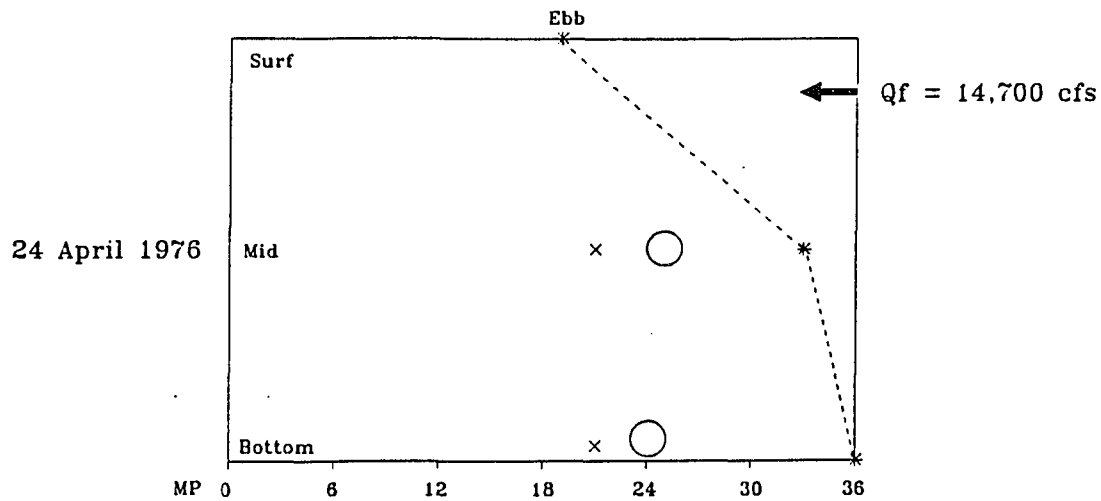
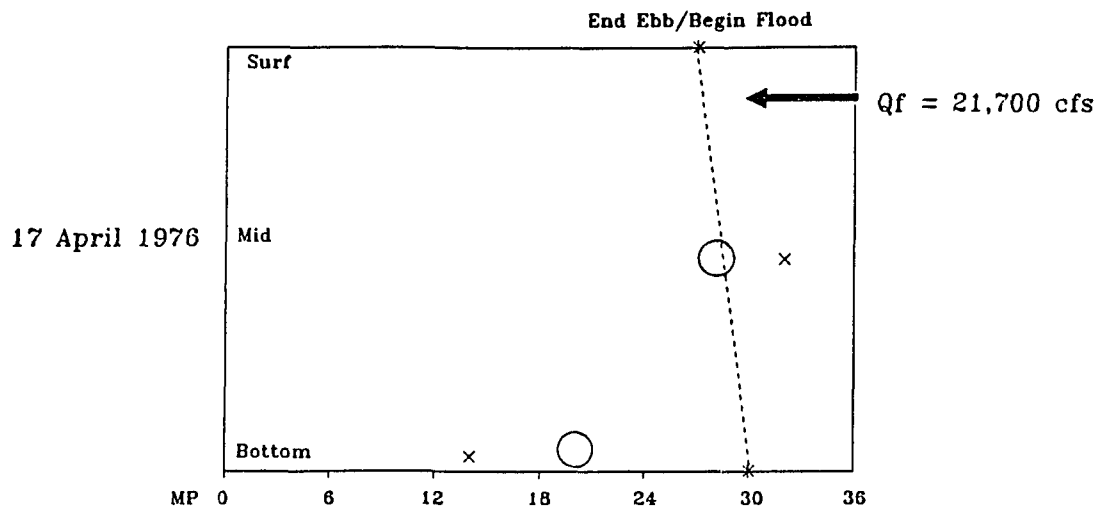


Table 11. Density-weighted mean locations for mid-depth and bottom tomcod population epicenters in relation to freshwater flow and vertical stratification factor.

Table 11. Density-weighted mean locations for mid-depth and bottom tomcod population epicenters and peak densities in relation to freshwater flow (Qf) and vertical stratification during March-May 1976.

Date	Density-Weighted Milepoint			Actual Milepoint		Peak Difference Mid-Bottom	Qf (cfs)	1/VSF*	VSF*	Ratio Mid:Bottom Mean Density
	Mid-Depth Epicenter	Bottom Epicenter	Epicenter Difference Mid-Bottom	Mid-Depth Peak	Bottom Peak					
21 Mar	19.5	17.2	2.3	14.0	14.0	0.0	22,500	0.0978	10.2	**0.88
28 Mar	20.5	21.0	-0.5	21.0	18.0	3.0	24,000	0.1116	9.0	0.33
4 Apr	6.3	11.5	-5.2	6.0	11.0	-5.0	47,000	0.1516	6.6	0.26
10 Apr	33.1	27.3	5.8	34.0	30.0	4.0	10,000	0.0588	17.0	**0.45
17 Apr	28.3	20.2	8.1	32.0	14.0	18.0	21,700	0.1085	9.2	0.65
24 Apr	25.0	23.7	1.3	21.0	21.0	0.0	14,700	0.0735	13.6	0.05
1 May	20.6	15.9	4.7	18.0	18.0	0.0	19,300	0.0898	11.1	0.37

* 1/VSF = Degree of Stratification
 VSF = Vertical Stratification Factor
 (see Table 12)

** Mid-water peak density > bottom peak density

If post-yolk-sac tomcod actively orient to the bottom (see Results II.B. pp. 86-92), a net vertical motion of water from the bottom to the mid-depth layer must be present in order to sustain the observed mid-depth tomcod concentrations that were observed from 21 March to 1 May. Abood (1974) has pointed out that Agnew (1960) and Pritchard (1967) found a net vertical motion from the lower to the upper layers throughout the region of salinity intrusion, and Harleman and Ippen (1967) found that vertical motion was in the downward direction in the seaward half of the salinity-intrusion region, and upward in the landward half, closer to the salinity front. Some idea of the relative magnitude of upward mixing vs. downward mixing in the Hudson during 21 March-1 May can be obtained by estimating the degree of vertical stratification present on each date and then comparing these values with stratification regimes and their attendant circulation characteristics as described by Abood (1974). Based on the estimated vertical stratification factor (VSF) values of 7 to 25 calculated in Table 12, it is apparent that upward mixing predominated over downward mixing in that 17.5-mi (MP 11.5-39) stretch of river within which the bulk of the tomcod population and the 1.0 ppt salinity front oscillated during 21 March-1 May.

Lower-layer flow, as it becomes reduced by entrainment into the upper-layer flow, decreases in an upstream direction until it approaches zero at the salinity intrusion front. From this it follows that larval fish on or near the bottom

would be most subject to upward entrainment at the apex or leading edge of the salt wedge. In this manner the upstream members of a population would be moved upward into the water column at a faster rate than its downstream members, resulting in the relative locations for mid-depth and bottom elements shown in Fig.27. Under conditions of high freshwater flow, the degree of vertical stratification (Q_f/Q_t) is increased, thus inhibiting downward mixing and pushing the upwardly entrained larvae downstream faster than with lower flows. This is consistent with the downstream displacement of the mid-depth concentration relative to the bottom concentration that can be seen on the high-flow date of 4 April and, to a lesser degree, on 28 March.

The locational and physicochemical habitats of post-yolk-sac tomcod were further defined by the distribution of densities among given river segments and conductivity ranges during 21 March-9 May 1976. Of the 19,686 larvae collected in bottom tows, 89.0% fell within a conductivity range of 3000 to 18000 umhos/cm (2.5-15.2 ppt salinity) (Fig.28). For mid-depth tows, 98.5% of 7,210 larvae were collected within a conductivity range of 0-12000 umhos/cm (0.0-10.1 ppt). As would be expected, mid-depth larvae, which were generally distributed somewhat upstream from bottom larvae, were collected from waters of lower salinity than were bottom larvae.

Table 12. Types of circulation associated with vertical stratification factors, including the range of VSF calculated for the Hudson River within MP 11.5-39 during 21 March-1 May 1976.

Table 12. Types of circulation associated with vertical stratification factors (VSF), including the range of VSF calculated for the Hudson River between MP 11.5-39 during 21 March-1 May 1976.

Vertical Stratification Factor* VSF = Q_t/Q_f	Degree Of Vertical Stratification* $1/VSF = Q_f/Q_t$	Type of Circulation
1 - 2	0.5 - 1.0	Highly stratified No mixing
3 - 10	0.1 - 0.5	Weakening stratification Upward mixing No downward mixing
7 - 25	0.04 - 0.14	Hudson River estuary Between MP 11.5 - 39 21 March - 1 May 1976
20 - 200	0.005 - 0.05	Partially stratified Upward mixing Downward mixing

	<u>Data Used For Calculations</u>		Interpolated Values For VSF***
	Qf	MP**	
21 March	22,500	17.2-24	13-16
28 March	24,000	21-26	11-14
4 April	47,000	11.5-16	7
10 April	10,000	27.3-39	15-25
17 April	21,700	20.2-30.4	11-15
24 April	14,700	23.7-36	10-16
1 May	19,300	15.9-33	11-18

* VSF = Q_t/Q_f , or the ratio of tidal flow to freshwater flow. The Degree of Vertical Stratification ($1/VSF$) increases in a landward direction as well as with increasing freshwater flow.

** The milepoint (MP) range denotes that VSF values were calculated at the milepoint of the salt-wedge apex and at the milepoint of the bottom population epicenter.

*** VSF estimated by interpolation (extrapolation on 4 April) using information provided in Table 1, Abood (1974).

The modal geographical location for the high-density collections of bottom larvae during 1976 was the George Washington Bridge-Harlem River segment (MP 11-14) (Fig.29). The geographical distribution for mid-depth larvae showed that they were more evenly distributed than were the bottom larvae throughout the sampling region, and that they were more abundant than bottom larvae near both ends of the sampling range. This may result from the fact that vertical velocity and turbulence mixing is at a maximum near mid-depth within the salinity-intruded regions of partially stratified estuaries (Abood 1974).

5. Synthesis 1973-1976

During the four years of this program, peak density, defined as the single highest density on a given sampling date, was observed most frequently, during the post-hatch period, at the GWBr station (MP 11) (Fig.30). However, had the Harlem River-Yonkers stations (MP 14-18) been sampled during 1974, it is evident from Fig.30 that frequency of peak density over the four-year period may well have been highest for this river segment. During 1975 and 1976, the magnitude of peak tomcod densities was greatest in water of 9500-13000 umhos/cm conductivity (8.0-11.0 ppt salinity) (Fig.31); during 1973-1976, peak densities for post-hatch sampling dates all occurred seaward of the 1.0 ppt (1200 umhos/cm) salinity front.

Figure 28. Average tomcod bottom and mid-depth concentrations within each conductivity range during 21 March-9 May 1976.

Average Tomcod Concentration Within Each Conductivity Range

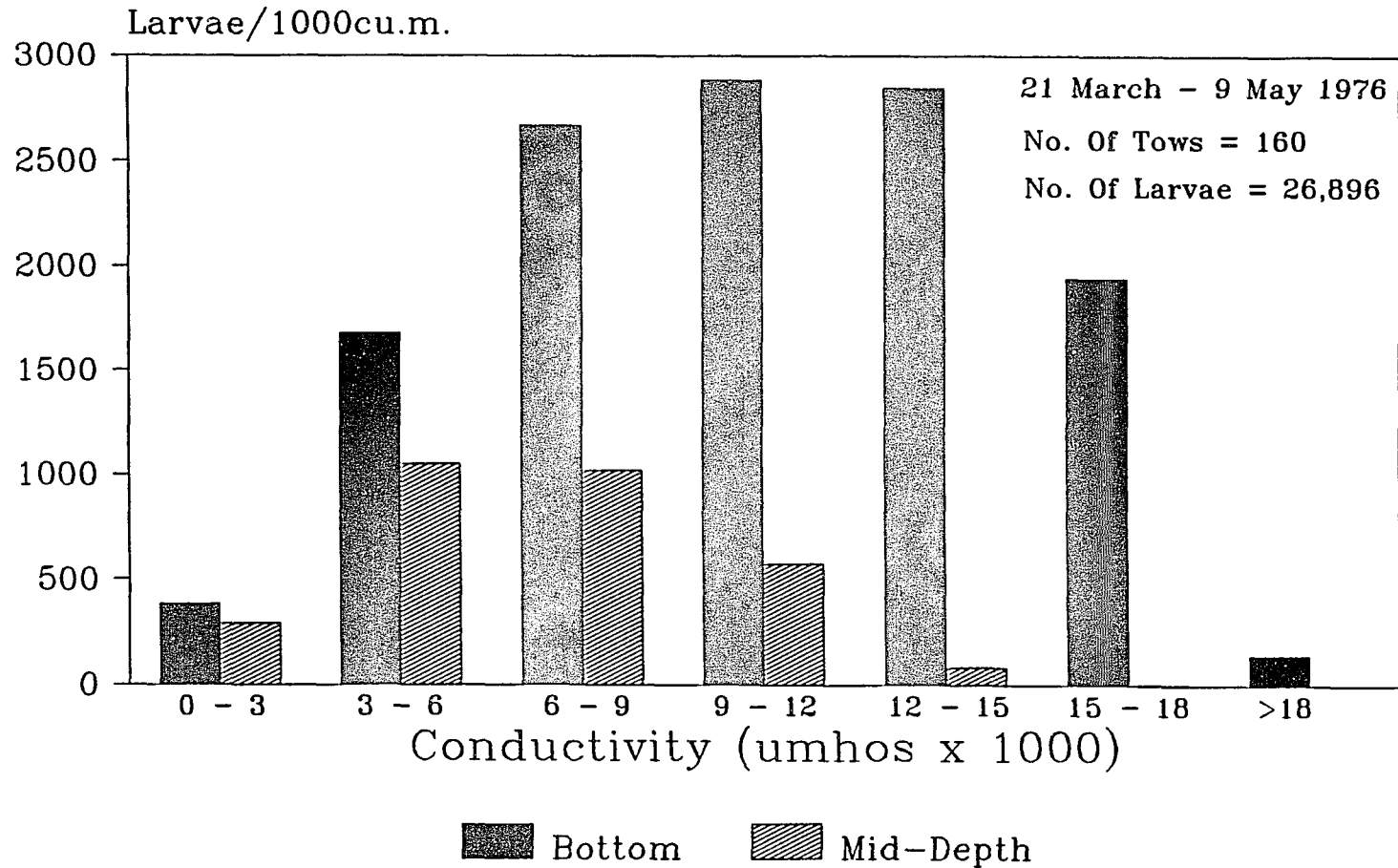
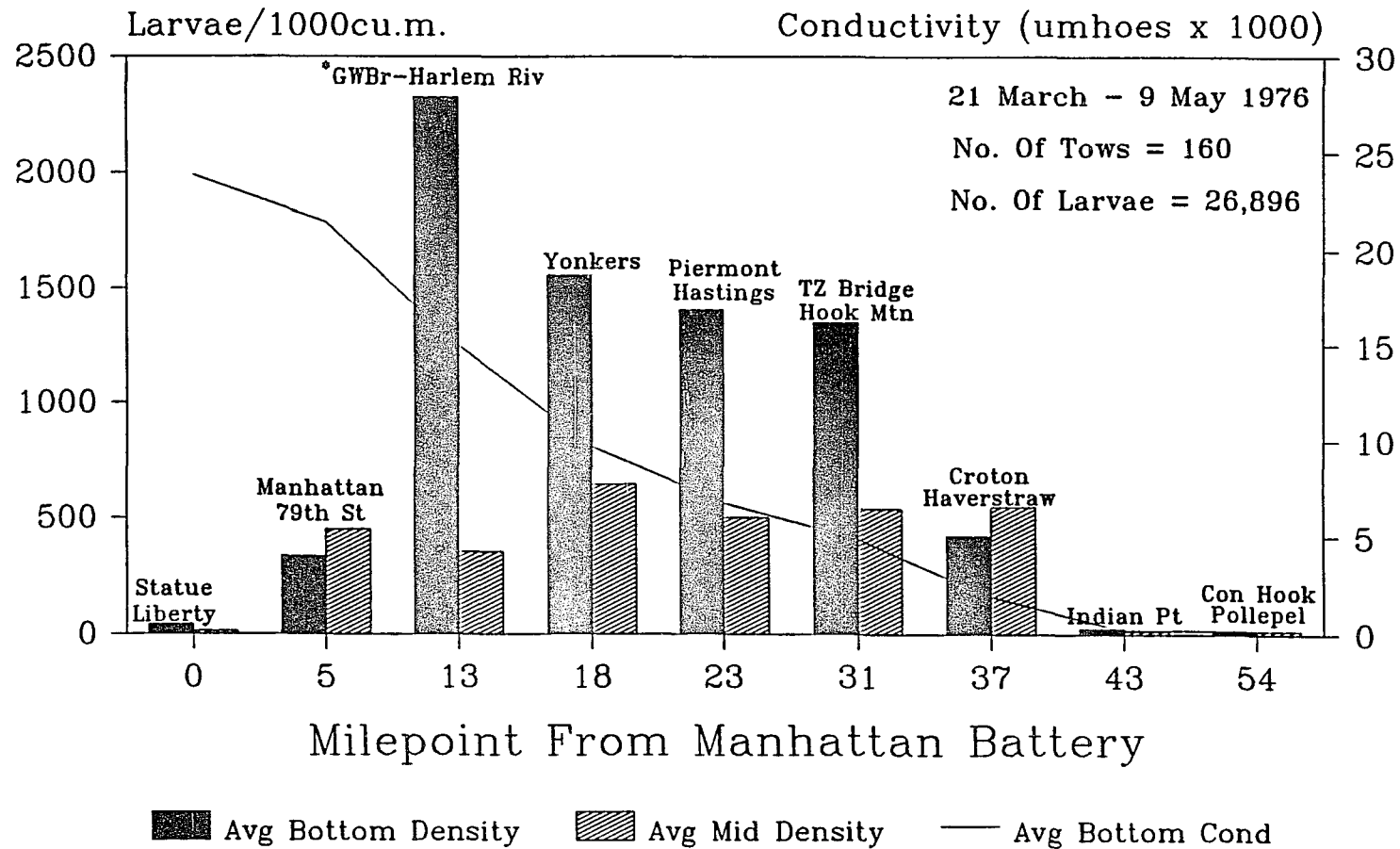


Figure 29. Average tomcod bottom and mid-depth concentrations and conductivity by River segment during 21 March-9 May 1976.

Tomcod Concentration And Conductivity By River Segment During 1976



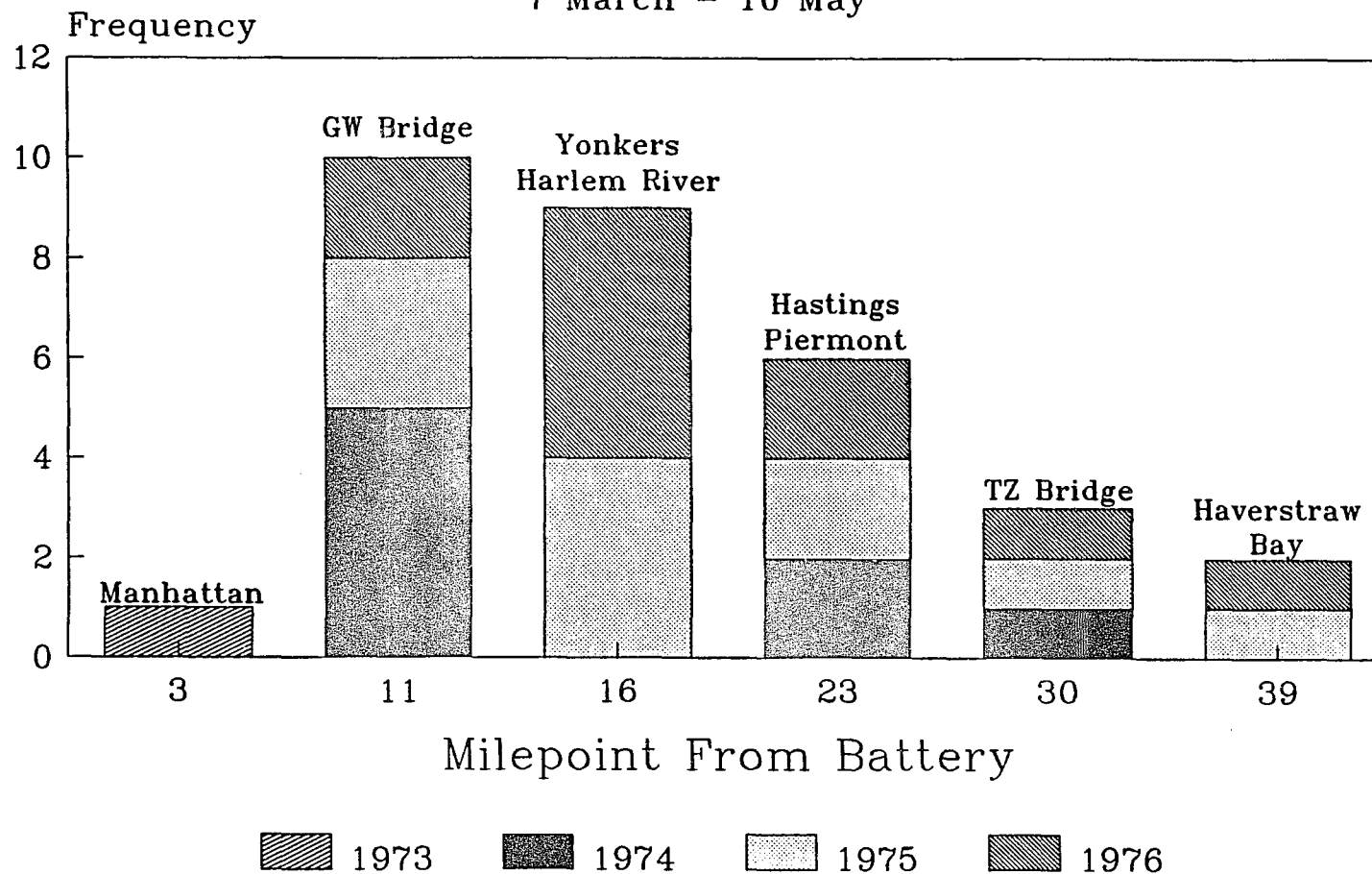
* GWBr = peak 1976 density of 9813/1000cu.m.

Because of the dynamic and predictable nature of the salt front (or any given salinity range for that matter) in relation to freshwater flow, it may be expected that the location of peak tomcod densities could be predicted on the basis of the amount of freshwater flow during the semi-planktonic, post yolk-sac/early juvenile period, prior to development of swimming behavior capable of overcoming hydrodynamic forces. The operative flow for a given sampling date was estimated by calculating the vertical mean salinities of each station from field data (Appendix I), and incorporating them as Y-values into a set of generalized mean salinity profiles, expressed as mean salinity vs. Lower Hudson freshwater flow at fixed locations (Abood, Fig.26 1974). Calculations for mean salinity values and estimated freshwater flows for 1975 and 1976 are given in Table 13. Because salinity was not measured on the single sampling date of 1973, freshwater flow was estimated from the 1973 Green Island flow chart as the three-day average for 3-5 April (71,000 cfs), which was 10-12 days prior to the date of sampling (15 April). The dependent variable, tomcod location, was calculated as the (tomcod) density-weighted average milepoint, and this weighted mean location was considered to be the population epicenter for that date. Because the epicenter was calculated from all station-density data for a given sampling date, it was a more reliable indicator of population distribution than any single-station peak density value.

Figure 30. Frequency of occurrence for peak tomcod density during 1973-1976.

Frequency Of Occurrence And Location For Peak Tomcod Densities 1973-1976

7 March - 10 May



N = 31 Bottom Tows

Figure 31. Relationship between peak tomcod density and conductivity, 1975-1976.

Relationship Between Peak Tomcod Density And Conductivity 1975-1976

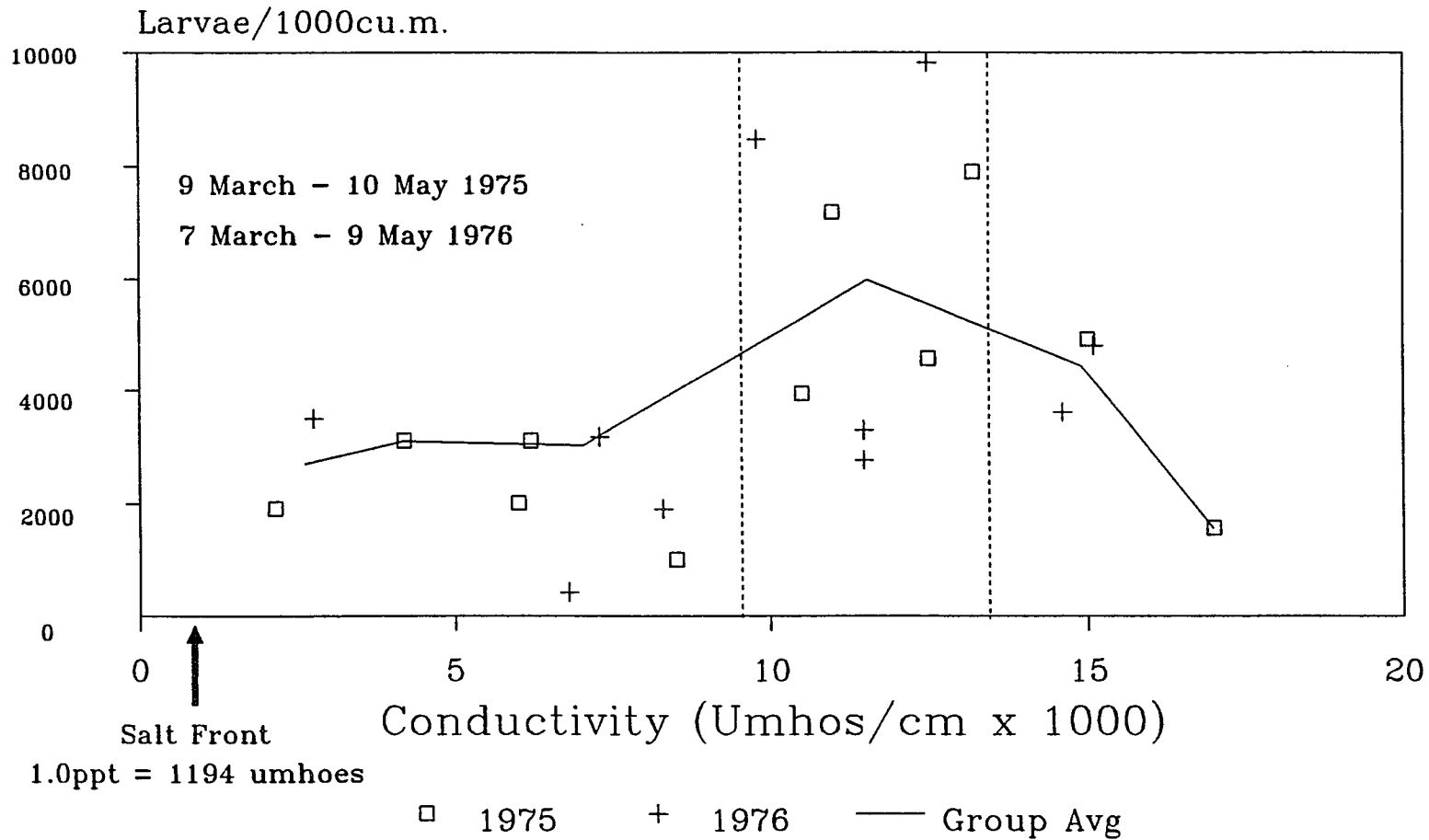


Table 13. Estimation of operative flow for 1975 and 1976 sampling dates based on mean salinity (ppm) from field conductivity data. Flow estimated from Abood 1974 (Fig.26).

Table 13. Estimation of operative flow (Qf) for 1975 and 1976 sampling dates based on mean salinity (ppm) from field conductivity (μ mhos) data.

1976	MP	Surf Cond	Mid Cond	Bottom Cond	PPT*			PPM Mean Sal	Qf**
					Surf Sal	Mid Sal	Bottom Sal		
7 March	21	129		165	0.1033		0.1336	118	48,000
14 March	21	5100		6100	4.2888		5.1308	4710	13,000
	30	3700		4900	3.1100		4.1204	3615	11,000
	39	1220		2770	1.0219		2.3270	1674	15,000
	43	270		930	0.2220		0.7777	500	<u>18,000</u> 14,250
21 March	21	1980		2740	1.6618		2.3017	3133	18,000
	30	830		1010	0.6935		0.8451	769	28,000
	39	204		235	0.1664		0.1925	180	24,000
	43	169		215	0.1369		0.1757	156	<u>20,000</u> 22,500
28 March	21	2670		6000	2.2428		5.0466	3645	16,000
	30	290		440	0.2388		0.3651	302	<u>32,000</u> 24,000
4 April	21	158		185	0.1277		0.1504	139	47,000
10 April	21	1850		18000	1.5523		15.1506	8352	7,000
	30	1090		15100	0.9124		12.7088	6811	6,500
	39	1150		2070	0.9629		1.7376	1350	<u>17,000</u> 10,000

* Salinity (ppt) = $-0.00536 + 0.000842 \text{ cond } (\mu\text{mhos})$ $R^2 = 0.98$ $N = 338$

** Qf estimated from mean salinity (ppm) using Abood 1974 (Fig. 26).

Table 13. (cont.)

1976	MP	Surf Cond	Mid Cond	Bottom Cond	PPT*			PPM Mean Sal	Qf**
					Surf Sal	Mid Sal	Bottom Sal		
17 April	21	3520	3930	4050	2.9585	3.3037	3.4047	3222	18,000
	30	1520	1820	1950	1.2745	1.5271	1.6365	1479	22,000
	39	130		160	0.1041		0.1294	117	<u>25,000</u>
									21,700
24 April	21	1820	10800	14600	1.5271	9.0882	12.2878	7634	8,000
	30	700	2080	10900	0.5840	1.7460	9.1724	3834	11,000
	39	112	152	149	0.0889	0.1226	0.1201	111	<u>25,000</u>
									14,700
1 May	21	4010	4690	5800	3.3711	3.9436	4.8782	4064	14,000
	30	2030	2180	2210	1.7039	1.8302	1.8555	1797	19,000
	39	230	230	203	0.1883	0.1883	0.1656	181	<u>25,000</u>
									19,300
9 May	21	1120	7100	10200	0.9377	5.9728	8.5830	5165	11,500
	30	150	310	1900	0.1209	0.2557	1.5944	657	29,000
	39	132	168	172	0.1058	0.1361	0.1395	127	<u>25,000</u>
									21,800
<u>1975</u>									
9 March	24	2800		6200	2.3522		5.2150	3784	13,000
	39	790		2150	0.6598		1.8049	1232	<u>19,000</u>
									16,000

* Salinity (ppt) = $-0.00536 + 0.000842 \text{ cond } (\mu\text{mhos})$ $R^2 = 0.98$ $N = 338$

** Qf estimated from mean salinity (ppm) using Abood 1974 (Fig. 26).

Table 13. (cont.)

1975	MP	Surf Cond	Mid Cond	Bottom Cond	PPT*			PPM Mean Sal	Qf**
					Surf Sal	Mid Sal	Bottom Sal		
16 March	24	3520		6200	2.9585		5.2150	4087	13,000
	30	3320		4180	2.7901		3.5124	3151	12,500
	39	460		980	0.3820		0.8198	601	<u>21,000</u>
									15,500
23 March	24	375		2100	0.3104		1.7628	1037	32,000
	30	340		340	0.2809		0.2809	281	32,000
	39	310		323	0.2557		0.2666	261	<u>23,000</u>
									29,000
29 March	24	230		230	0.1883		0.1883	188	42,000
	30	200		230	0.1630		0.1883	176	33,500
	39	210		235	0.1715		0.1925	182	<u>24,000</u>
									33,200
6 April	24	1100		11000	0.928		9.2566	5092	11,000
	30	900		8500	0.7524		7.1516	3952	9,000
	39	280		320	0.2304		0.2641	247	<u>23,000</u>
									14,300
12 April	24	6800		8800	5.7202		7.4042	6562	8,000
	30	6000		7500	5.0466		6.3096	5678	8,000
	39	2800		4700	2.3522		3.9520	3152	<u>9,000</u>
									8,300

* Salinity (ppt) = $-0.00536 + 0.000842 \text{ cond } (\mu\text{mhos})$ $R^2 = 0.98$ $N = 338$

** Qf estimated from mean salinity (ppm) using Abood 1974 (Fig. 26).

Table 13. (cont.)

1975	MP	Surf Cond	Mid Cond	Bottom Cond	PPT*			PPM Mean Sal	Qf**
					Surf Sal	Mid Sal	Bottom Sal		
20 April	24	260		3700	0.2136		3.1100	1662	25,000
	30	1600		2020	1.3418		1.6955	1519	22,000
	39	550		620	0.4577		0.5167	487	<u>22,000</u> 23,000
26 April	24	850		950	0.7103		0.7945	752	35,000
3 May	24	1220		10500	1.0219		8.8356	4929	11,000
	30	910		8100	0.7609		6.8148	3788	11,000
	39	408		465	0.3382		0.3862	362	<u>22,000</u> 14,700
10 May	24	5000		8500	4.2046		7.1516	5678	10,000
	30	3750		7000	3.1521		5.8886	4520	9,500
	39	1220		2180	1.0219		1.8302	1426	16,000
	43	210		600	0.1715		0.4998	336	<u>19,000</u> 13,600

* Salinity (ppt) = $-0.00536 + 0.000842 \text{ cond } (\mu\text{mhos})$ $R^2 = 0.98$ $N = 338$

** Qf estimated from mean salinity (ppm) using Abood 1974 (Fig. 26).

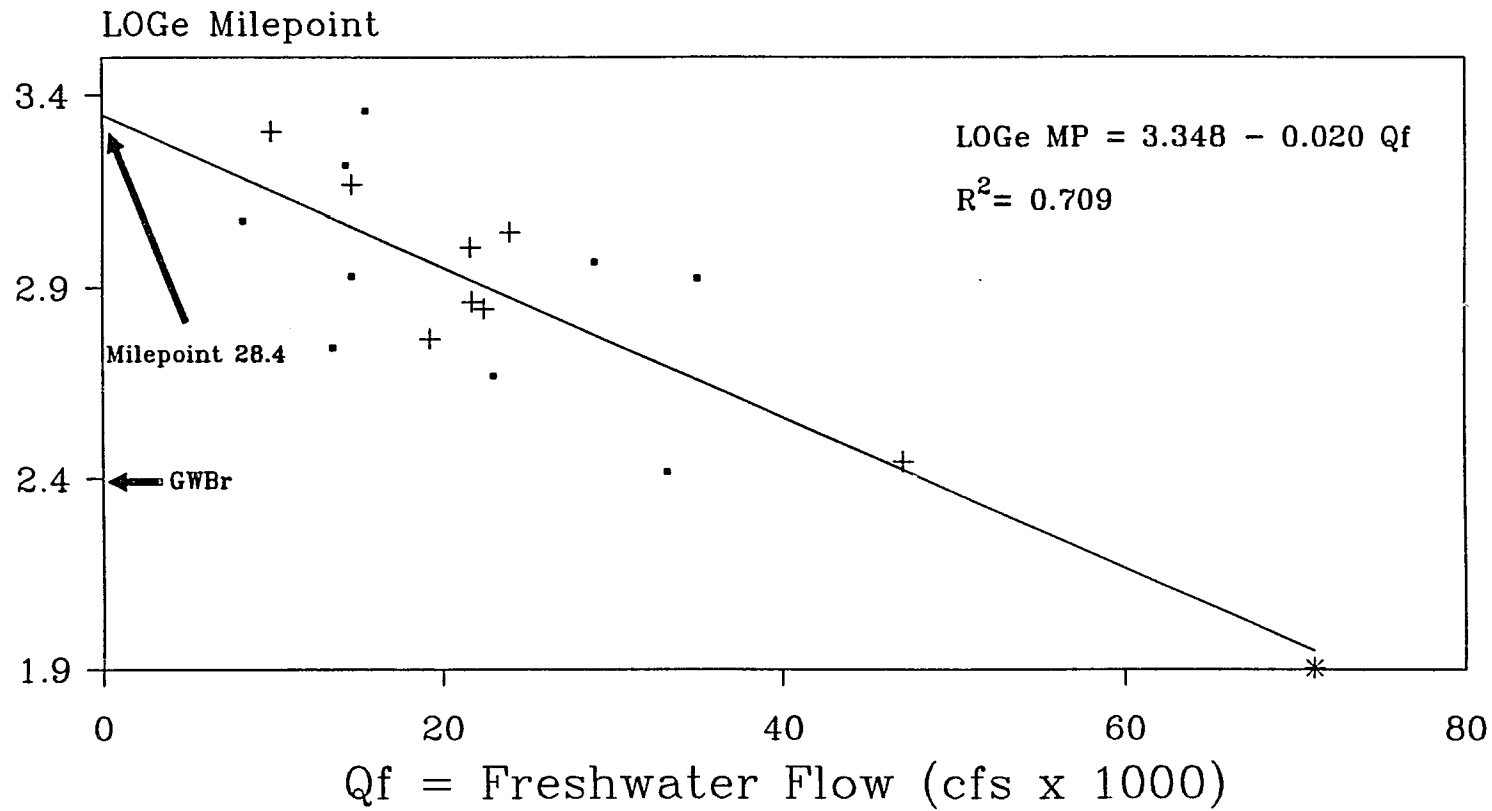
Location of the post-hatch tomcod population epicenter moved downstream as a result of increasing flows (Fig.32). Based on data from 1973, 1975 and 1976, its location, after 15 March, may be predicted from the amount of flow by

$$\ln MP = 3.348 - 0.020 Q_f \quad (R^2=0.709, df=16)$$

where MP = rivermile measured from the Manhattan Battery, and Q_f = freshwater flow (cfs). The relationship proved to be significant ($\alpha = 0.01$), and this indicates that the population epicenter, i.e., the bulk of the population, would be located seaward of the Tappan Zee Bridge (MP 30) under all flow regimes from mid-March to early May. It can also be predicted that under flow regimes in excess of 40,000 cfs, the epicenter would be located near or downstream from the George Washington Bridge. Flow pulses in excess of 40,000 cfs are common in the Hudson during March and April, and it is quite obvious that a March-April sampling program which did not venture seaward of the George Washington Bridge would be inadequate to quantify changes in tomcod abundance between sampling dates or between years.

Figure 32. Location of tomcod population epicenter in relation to freshwater flow (Q_f) after mid-March 1973, 1975, and 1976.

Location Of Tomcod Population Epicenter In Relation To Qf After Mid-March



* 1973 • 1975 + 1976

III. GROWTH

A. Length at Hatching

Life Stage 02 (LS02) larvae were designated as newly-hatched. Mean total length for 260 LS02 larvae, measured during the 1976 hatching period, was 7.03 mm (std dev = 0.409) with a range of 5.7-8.2 mm. Mean total length for 227 LS02 larvae measured during the 1975 hatching period was 6.99 mm (std dev = 0.238), with a range of 5.8-8.3 mm. Separate t-tests for 1975 and 1976 data showed that the mean length for LS02 larvae in the Hudson River was significantly ($P < 0.001$) less than the mean length of 7.56 mm (std dev=0.69; n=165) for tomcod from New Brunswick, Canada, that were laboratory-hatched under freshwater conditions (Peterson et al. 1980). However, the mean length for 1975 and 1976 was substantially larger than the approximate estimate of 5 mm given by Watson (1987) for Hudson River tomcod hatched from eggs incubated in spring-fed quarry water.

An apparent difference in time to hatching may have contributed to the difference in size at hatching of the two laboratory studies. Watson stated (1987) that various roe batches began hatching 34-43 days after fertilization, while the study by Peterson et al. (1980) indicated that hatching did not begin until after day 52 of freshwater incubation.

Peterson et al. (1980) also showed that length at hatching decreased significantly with increasing incubation salinities (7.2 mm at 10 ppt; 6.3 mm at 20 ppt) and that hatching occurred earlier at higher salinities. All but one of the bottom salinity readings in the Con Hook region during February-March 1975 and 1976 were those of freshwater (Appendix I). However, on 22 February 1975, which was the first sampling date for that year, bottom salinities at Con Hook were 1-2 ppt during a low-flow period of 10,000-12,000 cfs. Flows during December 1975 and January 1976 reached lows of about 11000 and 8000 cfs, respectively, and it is certain that water with salinities of 1.0 ppt and more intruded into the Con Hook region during this period, as well as during the winter of 1974-1975. As a general case then, it can be assumed that during cold winters of low freshwater runoff, saline waters will intrude periodically into the Indian Point-Con Hook-Pollepel Island river segments (MP 42-60), which included the region of primary hatching activity in 1975 and 1976 and, depending on the spawning location and degree of downstream egg transport, may have included the primary region of incubation as well.

Hudson River water temperatures during at least the February portion of the incubation period were lower than the incubation temperatures reported in either of the laboratory studies. Watson (1987) incubated eggs at 2.5 to 3.5°C and Peterson et al. (1980) at 2.0 to 4.5°C. Mean bottom temperature within the Tappan Zee-Indian Point segment

(MP 28-43) on 14 February 1976 was 1.2°C ; on 22 February 1975, mean bottom temperature was 1.6°C within the Tappan Zee-Newburgh segment (MP 28-65). Lower water temperatures in the Hudson River would cause hatching time to increase beyond that indicated by Watson (1987) and result in larvae that would tend to be larger at hatching.

B. Population Growth

Population growth is that growth rate calculated from changes in mean length through time for the entire year-class population, without regard to the effect of recruitment. Recruitment effect arises from a protracted hatching period which gives rise to varying numbers of subgroups or hatching cohorts of different ages, which may or may not grow at the same rate. The magnitude of recruitment effect tends to increase as the ratio of hatching duration to life stage duration increases. A year-class of larvae or early juveniles for a species with a long spawning period and a high growth rate (relatively short duration within a given life stage or length interval) would typically comprise several length-cohorts appearing as different length-frequency modes which could be followed through time (Sette 1943). Growth rates estimated from length change per unit of time for an individual cohort are referred to, in this thesis, as individual growth rates (G). Growth rates estimated from length changes for the entire year class without regard to age differences between cohorts are

population growth rates, designated as G_x . This is consistent with the terminology of Ricker (1975).

1. Comparisons 1974, 1975 and 1976

The calculation of population growth rates (G_x) is less complex and less demanding of the data than is the calculation of individual growth rates (G). Because of this, a comparison of tomcod G_x between years can include the 1974 data, which were collected under a less rigorous sampling design than were those of 1975 and 1976. Mean length by sampling date for each year are shown with associated statistics in Tables 14-16. Examination of these tables shows that the common time period suitable for comparisons between years is from 4-7 April to 9-11 May.

A plot of all data suggests that although in each year larvae began life at a similar size, the time of hatching and subsequent growth rates may have differed between years (Fig.33). Growth rates were estimated as the regression slope of log-transformed length vs. time in days from 14 February. Testing for equality of slopes (Zar 1974) showed that G_x was significantly different between years (Table 17), and a Student-Newman-Keuls (SNK) multiple-comparison test showed that G_x was significantly different for all three years, with G_x highest during 1974 and lowest during 1975 (Fig.34). During the first two weeks of April, mean length

Table 14. Mean length and associated statistics for Age-0 Atlantic tomcod collected by 1.0-meter nets during 1974.

Table 14. Atlantic tomcod mean length and associated statistics for all meter-net sampling dates during 1974.

Sampling Date	N	Average Length (mm)		Standard Deviation	Std Error	Coefficient Of Variation		Skewness
		Min	Max			Variation	Skewness	
07-Apr-74	250	8.8	5.9	15.8	1.667	0.105	19.030	1.133 **
13-Apr-74	200	10.7	6.8	17.1	1.929	0.136	17.986	0.692 **
27-Apr-74	273	17.3	9.3	24.6	2.634	0.159	15.260	-0.254 *
05-May-74	191	24.1	9.8	37.1	4.653	0.337	19.321	-0.120 NS
11-May-74	204	30.3	15.9	42.0	4.304	0.301	14.217	-0.224 NS
19-May-74	47	37.9	15.9	48.9	8.151	1.189	21.527	-1.225 NI
TOTAL	1,165							

One-tailed t-test for skewness:

* Significant at $P < 0.05$

** Significant at $P < 0.01$

NS = Not significant

NI Not included in analysis of skewness due to small sample size (47)

Table 15. Mean length and associated statistics for Age-0 Atlantic tomcod collected by 1.0-meter nets during 1975.

Table 15. Atlantic tomcod mean length and associated statistics for all meter-net sampling dates during 1975.

Sampling Date	N	Average Length (mm)		Standard Deviation	Std Error	Coefficient Of Variation		Skewness	
		Min	Max						
22-Feb-75	82	7.1	8.3	0.519	0.030	7.346	0.072	NS	
01-Mar-75	140	6.9	7.8	0.449	0.017	6.553	-0.351	*	
09-Mar-75	474	7.7	10.1	0.506	0.012	6.602	0.786	**	
16-Mar-75	568	8.0	11.7	0.899	0.034	11.174	1.341	**	
23-Mar-75	284	8.2	12.0	1.101	0.072	13.435	1.013	**	
29-Mar-75	242	9.6	18.1	1.662	0.177	17.271	0.674	**	
06-Apr-75	440	11.2	18.0	1.847	0.162	16.533	0.689	**	
12-Apr-75	390	13.1	20.5	1.939	0.190	14.819	0.428	**	
20-Apr-75	791	15.3	22.8	2.486	0.220	16.288	0.366	**	
26-Apr-75	374	18.4	27.0	2.616	0.353	14.206	0.149	NS	
03-May-75	617	22.6	33.6	3.651	0.536	16.132	0.101	NS	
10-May-75	510	27.5	42.2	4.321	0.826	15.726	-0.317	**	
TOTAL	4,912								

One-tailed t-test for skewness:

* Significant at $P < 0.05$

** Significant at $P < 0.01$

NS = Not significant

Table 16. Mean length and associated statistics for Age-0 Atlantic tomcod collected by 1.0-meter nets during 1976.

Table 16. Atlantic tomcod mean length and associated statistics for all meter-net sampling dates during 1976.

Sampling Date	N	Average Length (mm)	Min	Max	Standard Deviation	Std Error	Coefficient Of Variation	Skewness	
14-Feb-76	8	7.3	6.8	7.6	0.292	0.103	3.986	-1.133	*
21-Feb-76	28	7.1	6.4	7.7	0.380	0.072	5.360	-0.480	NS
28-Feb-76	76	7.2	6.0	7.9	0.379	0.044	5.269	-0.962	**
07-Mar-76	786	7.6	5.7	11.1	0.697	0.025	9.201	1.191	**
14-Mar-76	659	8.1	6.0	11.8	0.894	0.035	11.096	0.888	**
21-Mar-76	1177	8.8	6.3	13.5	1.116	0.033	12.655	1.040	**
28-Mar-76	802	9.3	6.4	14.3	1.206	0.043	13.017	0.951	**
04-Apr-76	591	11.5	7.2	19.5	2.026	0.083	17.684	0.886	**
10-Apr-76	1220	13.4	7.5	21.4	1.953	0.056	14.622	0.366	**
17-Apr-76	726	17.0	9.3	27.9	2.780	0.103	16.394	0.376	**
24-Apr-76	548	20.4	10.0	30.8	3.580	0.153	17.572	-0.075	NS
01-May-76	667	25.8	11.5	39.5	4.618	0.179	17.893	-0.023	NS
09-May-76	263	32.1	18.9	43.5	4.821	0.297	15.015	-0.279	*
15-May-76	435	38.7	20.0	51.2	4.691	0.225	12.135	-0.538	**
23-May-76	326	48.0	25.1	61.0	4.765	0.264	9.936	-0.868	**
05-Jun-76	348	58.9	34.0	81.0	6.920	0.371	11.757	-0.385	**
13-Jun-76	78	65.5	40.0	84.0	8.638	0.978	13.184	-0.167	NS
TOTAL	8,738								

One-tailed t-test for skewness:

* Significant at $P < 0.05$

** Significant at $P < 0.01$

NS = Not significant

for 1974 larvae was 18-24% less than the mean length for the larvae of 1975 and 1976, although the faster growth of the 1974 larvae eliminated much of this size deficiency by mid-May (Figs.33-34). The relatively high G_x during 1974, in combination with the relatively small size of the 1974 larvae on 6 April, suggests that hatching may have occurred later in 1974 than in 1975 and 1976.

Temperature differences between years were examined by plotting the tomcod density-weighted mean temperature for each sampling date (Fig.35). Using the mean of all station temperatures, weighted by abundance of tomcod at each station, provided temperature values representative of those estuarine regions that served as tomcod habitat. For the early April-mid May period under examination, the average temperature in 1975 was 46.2°F and 1974 and 1976 averages were 49.6°F and 49.5°F, respectively. A test for equality of slopes and an SNK procedure (Table 18) showed that the temperature-mediated G_x was statistically identical in 1974 and 1976, but that the G_x was significantly lower for the colder 1975 period, i.e., that growth was slower under the colder temperature regime (Fig.34). Moreover, the 1975 G_x did not appear to increase after higher temperature levels of about 45°F were reached.

Because tomcod growth is probably a function of both time and temperature, a better predictor variable than either one of these alone should be the area under the time-

temperature curves in Fig.35, i.e., the cumulative degree days (CDD), estimated by

$$CDD = \sum((t_{i+1}-t_i)((T_{i+1}+T_i)/2))$$

where

$(t_{i+1}-t_i)$ = days between sampling dates

T_i = density-weighted mean temperature on the i^{th}
sampling date

T_{i+1} = density-weighted mean temperature on the $i^{\text{th}}+1$
sampling date.

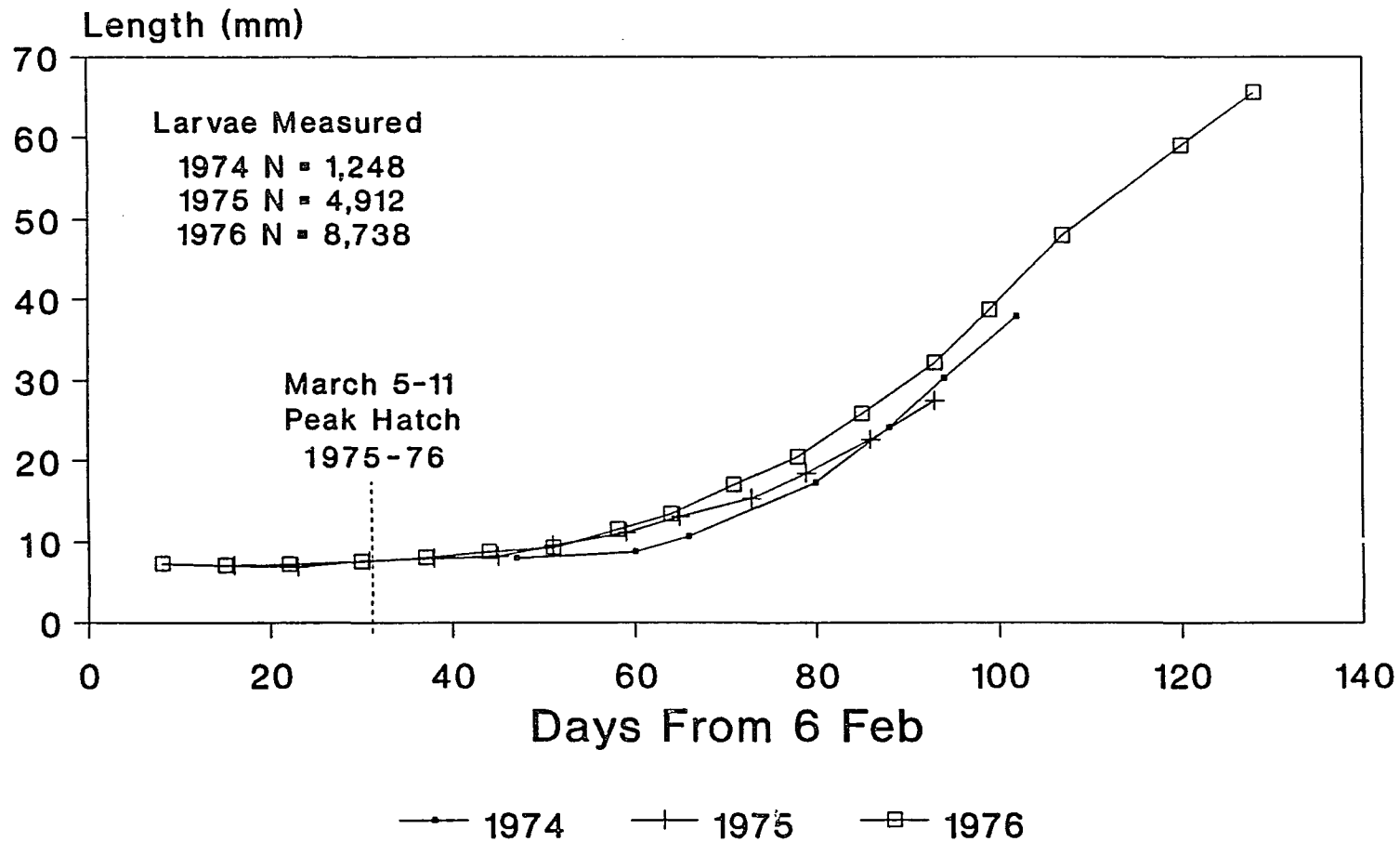
The relationship between length and CDD is shown in Fig.34, and although significant differences still exist between years (Table 19), these differences, as indicated by the relatively low residual sum of squares for the common regression (0.037 vs. 0.048 and 0.156), were less than for either time or temperature alone (Tables 17-18).

2. Recruitment Bias

Analysis of the spatial and temporal aspects of recruitment bias in the Hudson River is instructive for any understanding of the interaction between growth and recruitment. With regard to the temporal aspect, the duration for which each of the yolk-sac life stages were present during the 1976 hatching period is shown in Fig.36, along with their weekly mean lengths. Continuous recruitment into, as well as development out of, each life stage resulted

Figure 33. Comparison of Age-0 tomcod mean length with time for three years of 1.0-meter net collections. 1974-1976.

Comparison Of Mean Length With Time For 3 Years Of Meter-Net Collections



First data point 1974 from entrainment sample Bowline Plant (MP 37)

Table 17. Testing for equality of slopes for three growth equations (ln Length vs. Days from 14 Feb. 1974, 1975, 1976).

Table 17. Testing for significant differences between the slopes (b) for three (k) growth equations (ln Length [Y] vs. Days From 14 February [X]).

	SUM			n	b	Resid SS	Resid DF
	$(X-\bar{X})^2$	$(X-\bar{X})(Y-\bar{Y})$	$(Y-\bar{Y})^2$				
1974	842.80	30.348	1.10	5	0.03601	0.0050	3
1975	816.83	21.548	0.57	6	0.02638	0.0027	4
1976	858.83	25.523	0.76	6	0.02972	0.0009	4

Regressions:

Pooled						0.009	11
Common	2518.47	77.42	2.43			0.04846	13

$$F = \frac{(SS_c - SS_p)/(k-1)}{SS_p/DF_p} = 25.32$$

Therefore reject $H_0: B_1 = B_2 = B_3$ ($P < 0.001$)

Student-Newman-Keuls (SNK) Multiple Comparison:

<u>1974 vs 1975</u>	<u>1974 vs 1976</u>	<u>1976 vs 1975</u>
q sig.@ $P < 0.001$	q sig.@ $P < 0.001$	q sig.@ $P < 0.005$

Therefore:

Smallest		Largest
1975	1976	1974
B1	B2	B3
<u>0.0263803</u>	<u>0.0297187</u>	<u>0.0360082</u>

Figure 34. Comparison of 1974-1976 Age-0 tomcod growth with time, temperature and cumulative degree days.

Tomcod Growth Rates Early April-Mid May 1974-1976

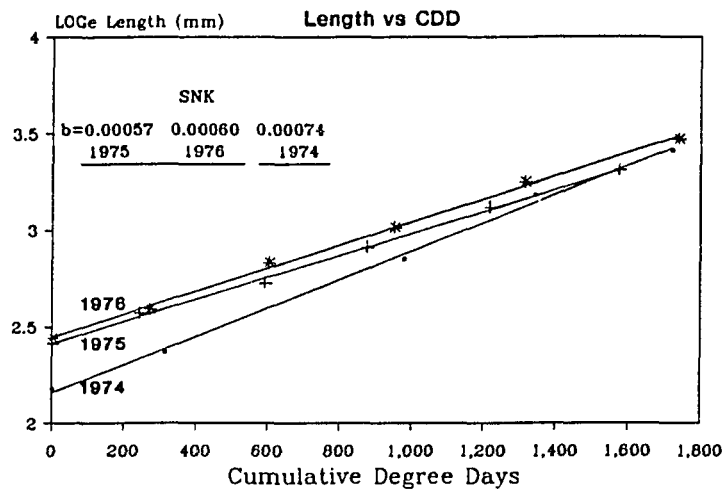
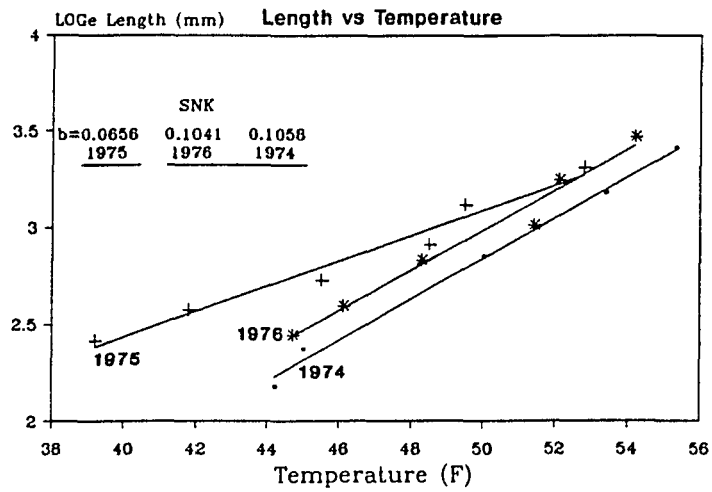
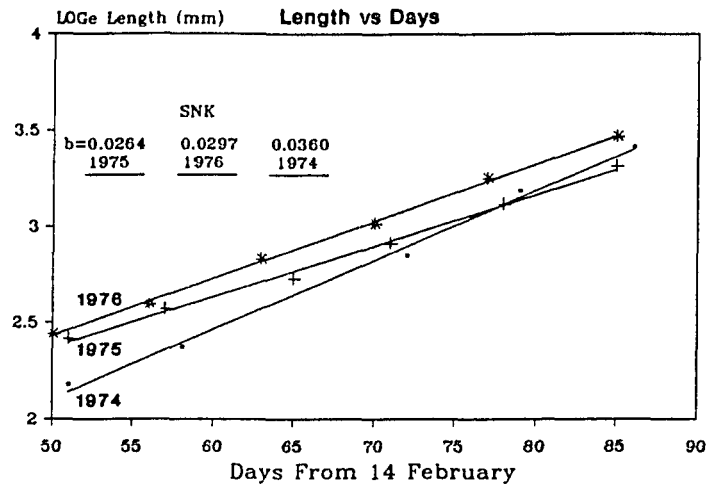
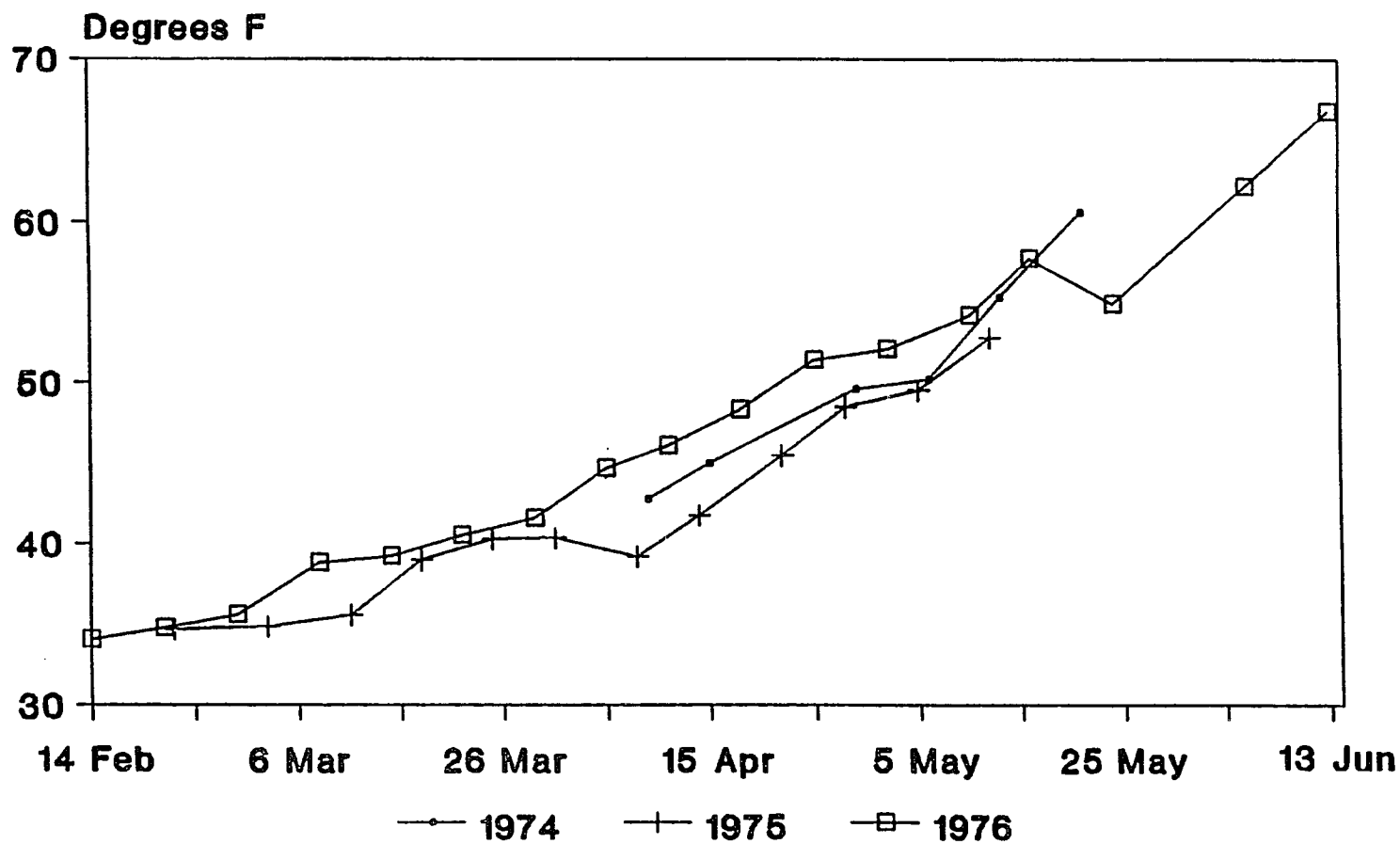


Figure 35. Tomcod density-weighted mean water temperatures, representative for those estuarine regions serving as tomcod habitat.

Weighted Mean Water Temperatures At Stations Where Larvae Were Present



Mean Temp Weighted By Larval Densities

Table 18. Test for equality of slopes for three growth equations (ln Length vs. Temp. 1974, 1975, 1976).

Table 18. Testing for significant differences between the slopes (b) for three (k) growth equations (ln Length [Y] vs. Temperature°F [X]).

	SUM			n	b	Resid SS	Resid DF
	$(X-\bar{X})^2$	$(X-\bar{X})(Y-\bar{Y})$	$(Y-\bar{Y})^2$				
1974	97.41	10.307	1.10	5	0.10582	0.0066	3
1975	128.59	8.432	0.57	6	0.06558	0.0177	4
1976	68.49	7.127	0.76	6	0.10406	0.0183	4

Regressions:

Pooled						0.043	11
Common	294.49	25.87	2.43			0.15593	13

$$F = \frac{(SS_c - SS_p)/(k-1)}{SS_p/DF_p} = 14.44$$

Therefore reject $H_0: B_1 = B_2 = B_3$ ($P < 0.001$)

Student-Newman-Keuls (SNK) Multiple Comparison:

<u>1974 vs 1975</u>	<u>1974 vs 1976</u>	<u>1976 vs 1975</u>
q sig.@ $P < 0.001$	q not sig.@ $P = 0.05$	q sig.@ $P < 0.005$

Therefore:

Smallest		Largest
1975	1976	1974
B1	B2	B3
<u>0.065575</u>	<u>0.104058</u>	<u>0.105817</u>

Table 19. Testing for equality of slopes for three growth equations (ln Length vs. Cum. Degree Days 1974, 1975, 1976).

Table 19. Testing for significant differences between the slopes (b) for three (k) growth equations (ln Length [Y] vs. CDD* [X]).

	SUM			n	b	Resid SS	Resid DF
	$(X-\bar{X})^2$	$(X-\bar{X})(Y-\bar{Y})$	$(Y-\bar{Y})^2$				
1974	2021321.93	1487.338	1.10	5	0.00074	0.0029	3
1975	1759188.31	1001.029	0.57	6	0.00057	0.0011	4
1976	2125499.63	1269.700	0.76	6	0.00060	0.0015	4

Regressions:

Pooled						0.006	11
Common	5906009.88	3758.07	2.43			0.03671	13

$$F = \frac{(SS_c - SS_p)/(k-1)}{SS_p/DF_p} = 28.15$$

Therefore reject H_0 : $B_1 = B_2 = B_3$ ($P < 0.001$)

Student-Newman-Keuls (SNK) Multiple Comparison:

<u>1974 vs 1975</u>	<u>1974 vs 1976</u>	<u>1976 vs 1975</u>
q sig. @ $P < 0.001$	q sig. @ $P < 0.001$	q not sig. @ $P = 0.05$

Therefore:

Smallest		Largest
1975	1976	1974
B1	B2	B3
0.0005690	0.0005974	0.0007358

- * 1974 Cumulative Degree Days (CDD) from 6 April (Day 51) through 11 May (Day 86)
- * 1975 CDD from 6 April (Day 51) through 10 May (Day 85)
- * 1976 CDD from 4 April (Day 50) through 9 May (Day 85)

in no net change in length within life stages until the terminal stage, LS05, was reached. No LS05 larvae were collected until 7 March, three weeks after sustained hatching began. The yolk-sac stanza therefore may be assumed to have lasted approximately three weeks, and one week might be assigned to each of the three yolk-sac life stages. It would then follow that the calculated growth, because of the effect of recruitment, would underestimate the individual growth rate and length-at-age for LS05 juveniles for a duration of about three weeks after peak densities for LS02 larvae were observed on 7 March (Fig.7). If three weeks is a good estimate of the duration of the yolk-sac stanza, then recruitment into the post-yolk-sac LS05 stanza should be essentially complete, and the growth rate for juvenile tomcod should have rebounded from the effect of recruitment, during the fourth week after the peak abundance for LS02 larvae had been observed on 7 March. This "rebound", or apparent growth resurgence, was evident between 28 March and 4 April 1976 (Fig.36). As an aside, it is of interest to note that the early (pre-14 Feb) hatch, which produced low densities of LS03 larvae on 14 February, apparently degenerated into LS04 (remnant yolk sac) larvae only 6.8 mm long, which probably did not survive much beyond 21 February.

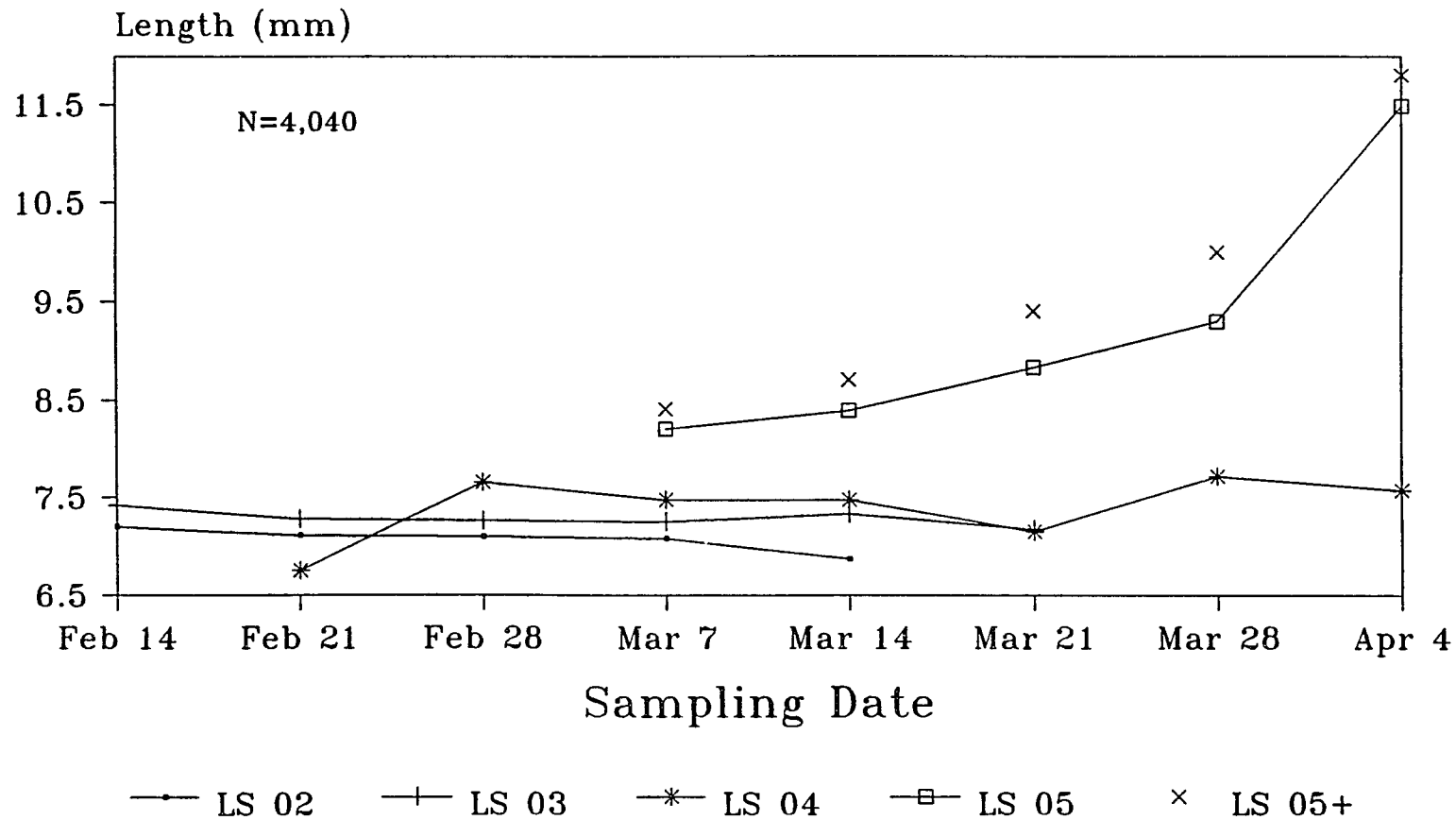
Given that (G_x) estimates of juvenile growth rates were depressed by hatching recruitment and that most hatching occurred within the Con Hook segment (MP 47-54), the effect of recruitment on growth estimates should tend to decrease

within the freshwater reach as one moves downstream away from the source of recruitment. The systematic movement of older larvae downstream, concurrent with the recruitment of younger larvae from upstream areas, should result in a size gradient of increasing magnitude as the length difference between the oldest and youngest larvae became greater during and after recruitment. Such a gradient would be most noticeable under the conditions of, and within the regions of, high freshwater flow, and may tend to have been disrupted during periods of relatively low freshwater flow, when the salt front approached the recruitment region and rates of mixing of recruits and older larvae were increased. Howe (1971) briefly mentioned this phenomenon in the Weweantic River, when he commented that "The more downstream specimens were longer and more developed than those taken in the upper estuary."

Evidence for this spatial gradient during 1976 is provided in Fig.37. The gradient reached a maximum during 21-28 March, one to two weeks after recruitment was complete and at a time when the 1.0 ppt isosal was in the area of MP 25-30. It was at a minimum during the early and mid-recruitment period of 14-28 February, when the difference in length between the oldest and youngest larvae was at a minimum. The longitudinal sorting process that produced the gradients appeared to be disrupted on 14 March when the salt front had moved upstream to the region of MP 46, and a noticeable hump of larger, older juveniles was found in the

Figure 36. Mean length for each life stage by date for all 1976 stations combined.

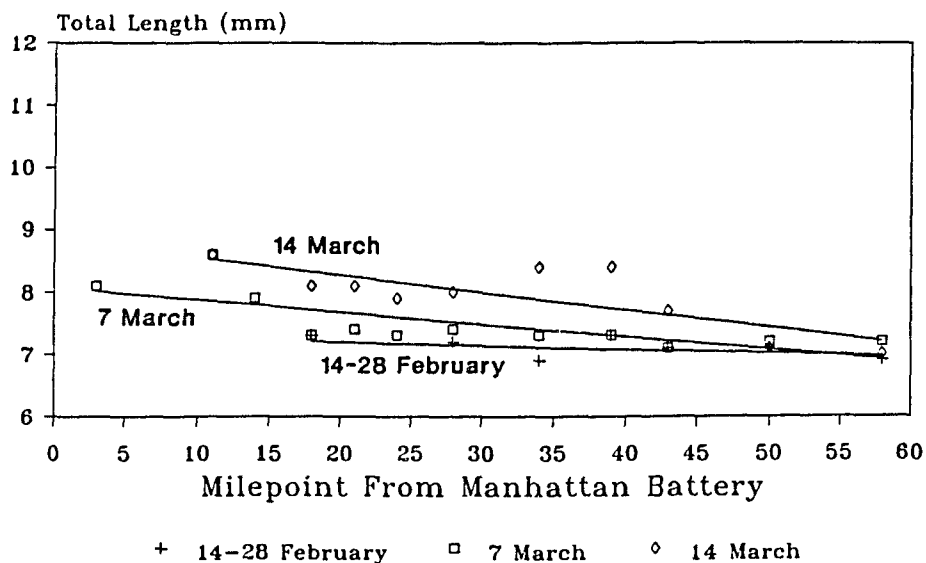
Mean Length For Each Life Stage By Date For All Stations Combined



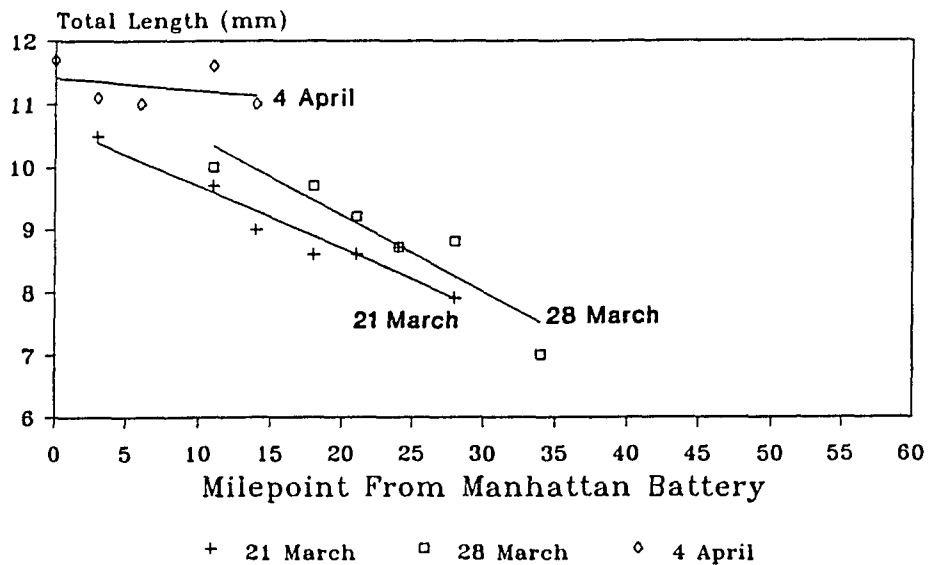
X=LS 05 From Yonkers and Below Only
Bottom Tows Only

Figure 37. Change in mean length by River milepoint during the 1976 hatch.

Change In Mean Length By Rivermile During 1976 Hatch



Change In Mean Length By Rivermile After 1976 Hatch



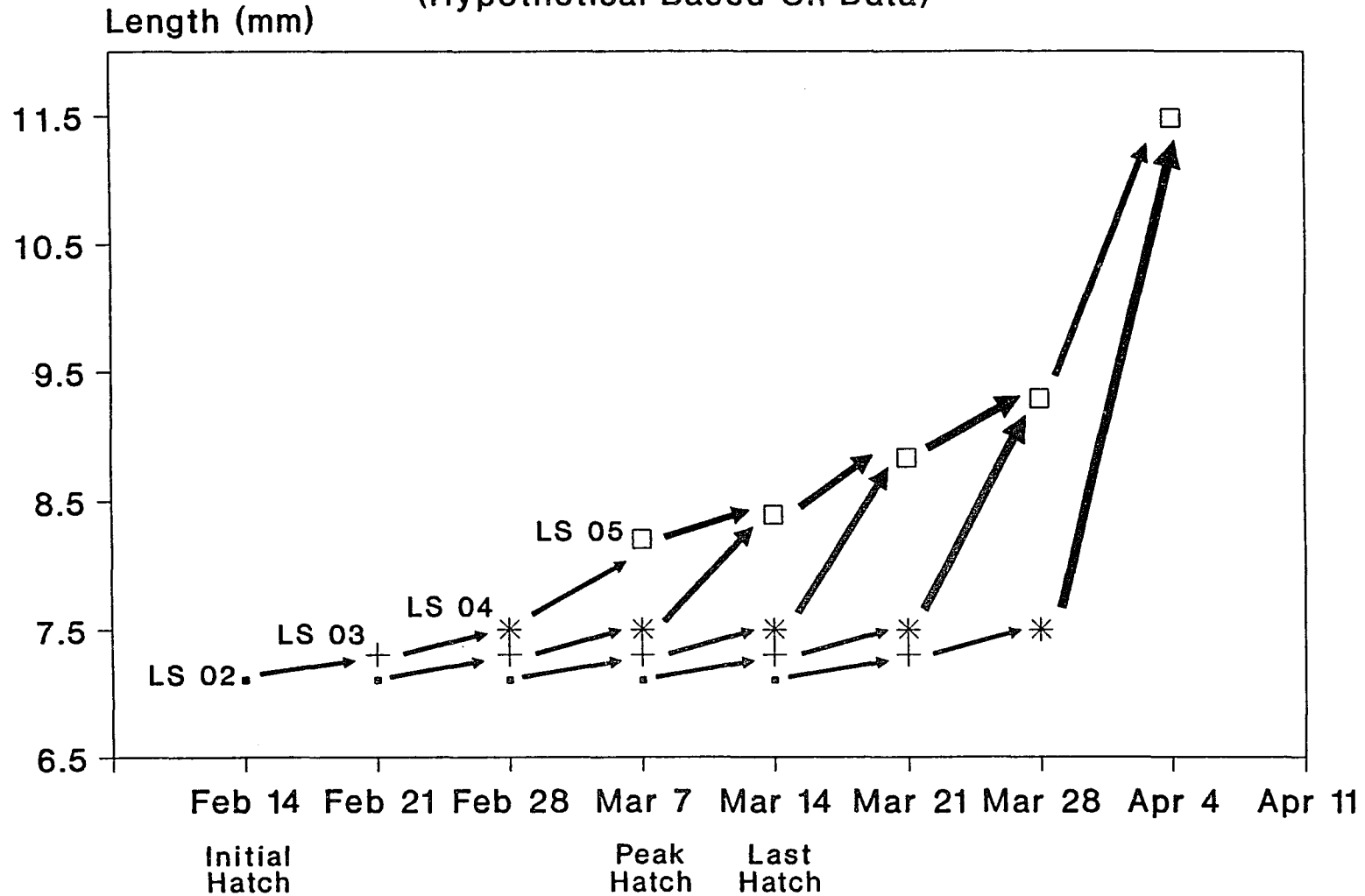
Croton-Haverstraw Bay region (MP 34-39), as well as in the Yonkers-GWBr region (MP 11-18). The slope of the gradient reached its final minimum on 4 April, and because there was no longer any recruitment of recently hatched larvae to maintain the gradient, it is assumed that a mixing of older and younger larvae into a relatively homogeneous population was nearing completion.

The effect of recruitment on estimates of individual growth rate for juveniles would tend to be most pronounced during the period of greatest recruitment into the LS05 stage, i.e., beginning approximately three weeks after the peak hatch was observed on 7 March. A partial correction for the effect of recruitment on growth and length-at-age estimates can be obtained by using only the larger, older larvae from the lower estuary in the growth calculations. The juvenile growth correction (X-values) obtained by using only LS05 larvae collected from Yonkers (MP 18) and below is shown in Fig.36. As expected, the greatest difference between the apparent length for a juvenile and its "corrected" length was on 28 March, three weeks after peak hatching occurred. The correction was smallest at the beginning of recruitment into the LS05 category on 7 March, which was, in effect, recruitment of the initial cohort hatched on 14 February. Subsequent uncorrected mean lengths for this cohort were depressed by recruitment of younger individuals from subsequent weekly cohorts, as idealized in Fig.38.

Figure 38. Cohort analysis for tomcod recruitment from early yolk-sac to early juvenile (hypothetical based on data).

Cohort Analysis For Tomcod Recruitment From Early Yolk Sac To Early Juvenile

(Hypothetical Based On Data)



3. Analysis of Sampling Gear Bias

Estimates of growth and mortality are particularly subject to systematic error resulting from size-selectivity of the sampling gear used to provide such estimates. Size-selectivity that arises from characteristics of the gear itself (in contrast to methods of fishing the gear) has two possible sources: 1) escapement, which results in a loss of smaller members of the sampled population through the net mesh, after they already are inside the net; and 2) avoidance, which results in the loss of larger, faster-swimming individuals in the path of the net. The 571-micron (0.571 mm square) mesh nets used during this study appear to have precluded any substantive error caused by escapement of newly-hatched tomcod larvae, which are relatively stout-bodied³ and are generally acknowledged to be greater than 5 mm long at hatching (Booth 1967; Peterson et al. 1980; Watson 1987).

As the sampling season progressed, however, the probability increased for the occurrence of systematic error from avoidance. Size-frequencies of larvae in meter-net catches were examined and compared with bottom trawl catches

³Average eye diameter of tomcod 6.2 mm in length, as measured by Booth (1967), was 0.31 mm. The head depths of the 6.0 and 7.0-mm tomcod in Booth's (1967) Plate 1 appear to be 3.2 times greater than eye diameter, resulting in an estimated head depth of 0.99 mm for newly-hatched tomcod larvae, i.e., the head appears to be too large to pass easily through the 0.81-mm diagonal opening of a square, 0.571-mm mesh.

to determine trends in coefficient of variation, skewness, and Kolmogorov-Smirnov divergence — all of which can act as indicators of the degree of net avoidance by larger larvae.

a. Coefficient of Variation

The coefficient of variation (CV), which expresses the standard deviation as a percentage of the mean, was used to compare the relative amounts of variation in samples from the tomcod population as the mean length of the fish increased. It was expected that CV would be low near the beginning of hatching (actually 0 for the first larva hatched), inasmuch as it reflected only the variation in size at hatching. The range between the oldest and the most recently hatched larvae would increase, however, along with the CV, as hatching progressed. If mortality were not size-selective and growth rates were approximately equal for all sizes of larvae, CV would be expected to reach some equilibrium level upon cessation of hatching, i.e., the population then would have reached a stable size distribution. A continued increase in the CV after the cessation of hatching would suggest the existence of different growth rates for small and large larvae, the smaller larvae growing slowly and the larger ones more rapidly. On the other hand, a decrease in the CV after hatching would suggest: 1) some kind of size-selective mortality acting to reduce the size range from one or both ends of the size spectrum, 2) different growth rates for the small and large larvae, with small larvae growing faster and

larger growing more slowly, or 3) gear avoidance by the larger larvae, a bias which would increase with time and growth of the larvae.

As expected, CV increased throughout the hatching period (Day 0 to Day 45) (Fig.39). It then remained at an "equilibrium" level of 14-19% for about five weeks after cessation of hatching (Day 45 to Day 80), and declined thereafter. If meter net avoidance by larger tomcod was a major factor in the observed trend of declining CV after Day 80, a resurgence of CV to the 14-19% level might have been expected for collections made with a 30-ft otter trawl that was known to be efficient in the collection of juvenile and adult tomcod. Eight bottom trawl collections between Piermont and Haverstraw Bay during 1974-1976 show no such resurgence (Fig.39) and suggest that the trend of declining CV after Day 80 was caused by factors other than gear avoidance.

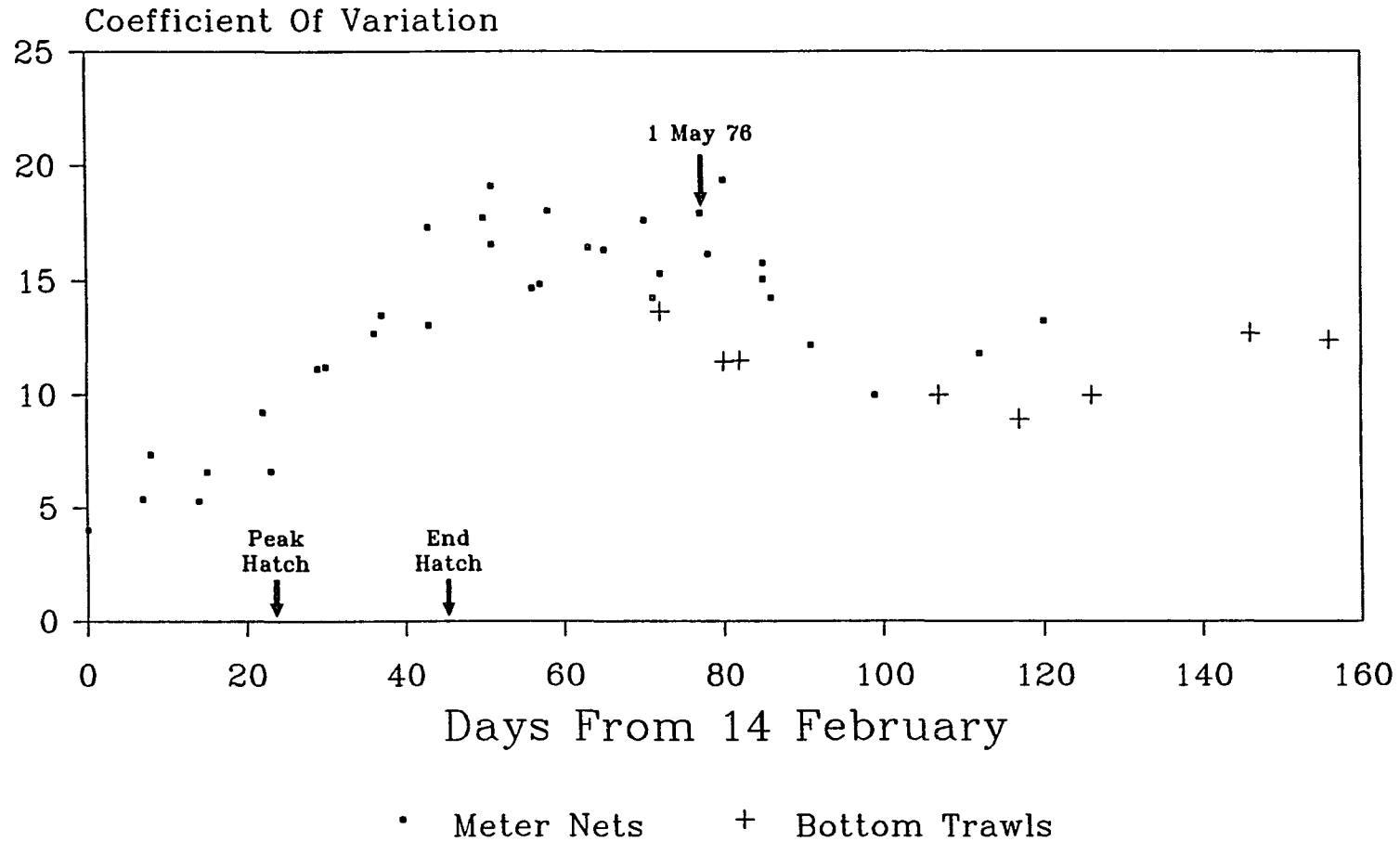
b. Skewness

Early during the course of hatching, with a continuous and increasing stream of small, newly-hatched larvae moving into the population, it would be expected that length-frequency distributions taken representatively from the population would be skewed to the left, i.e., g_1 would be negative. This situation could persist only as long as the rate of recruitment into the smallest length intervals exceeded the growth rate out of the largest length intervals,

Figure 39. Trend in coefficient of variation for tomcod length-frequency distributions with time for 1974-1976 collections.

Trend In Coefficient Of Variation With Time

1974 - 1975



thus maintaining a population with a tail to the left. A declining recruitment rate in the presence of the exponential growth of post-yolk-sac larvae would dictate that this early phase of negative skewness would be only a transitory phenomenon. This scenario appears to be supported by Fig.40, which shows a saltatory move to positive skewness just prior to the calculated dates of peak hatching for 1975 and 1976.

The next phase apparent from Fig.40 is a well-defined and comparatively gradual (Day 30 through Day 100) movement from distributions that were positively skewed, through a period of normal distributions ($g_1=0$), and on into one of negative skewness. Such a trend could result from 1) net avoidance by the largest fish and/or 2) increasing numbers of slow-growing fish falling behind the modal length for the population. If the trend is to be attributed to net avoidance, it must be assumed that avoidance began shortly after peak hatch, when the mean length of the larvae was approximately 8 mm and the largest larvae collected were only 12-14 mm. Moreover, gear avoidance sufficiently intense to produce such a well-defined trend from positive to negative skewness should show an increased effect as the mode of the population approached the critical avoidance length; the trend then would not appear to be linear as it does in Fig.40. Nevertheless, length distributions from comparison bottom trawls remained for the most part positively skewed, and this indicates that some form of gear selectivity was indeed present.

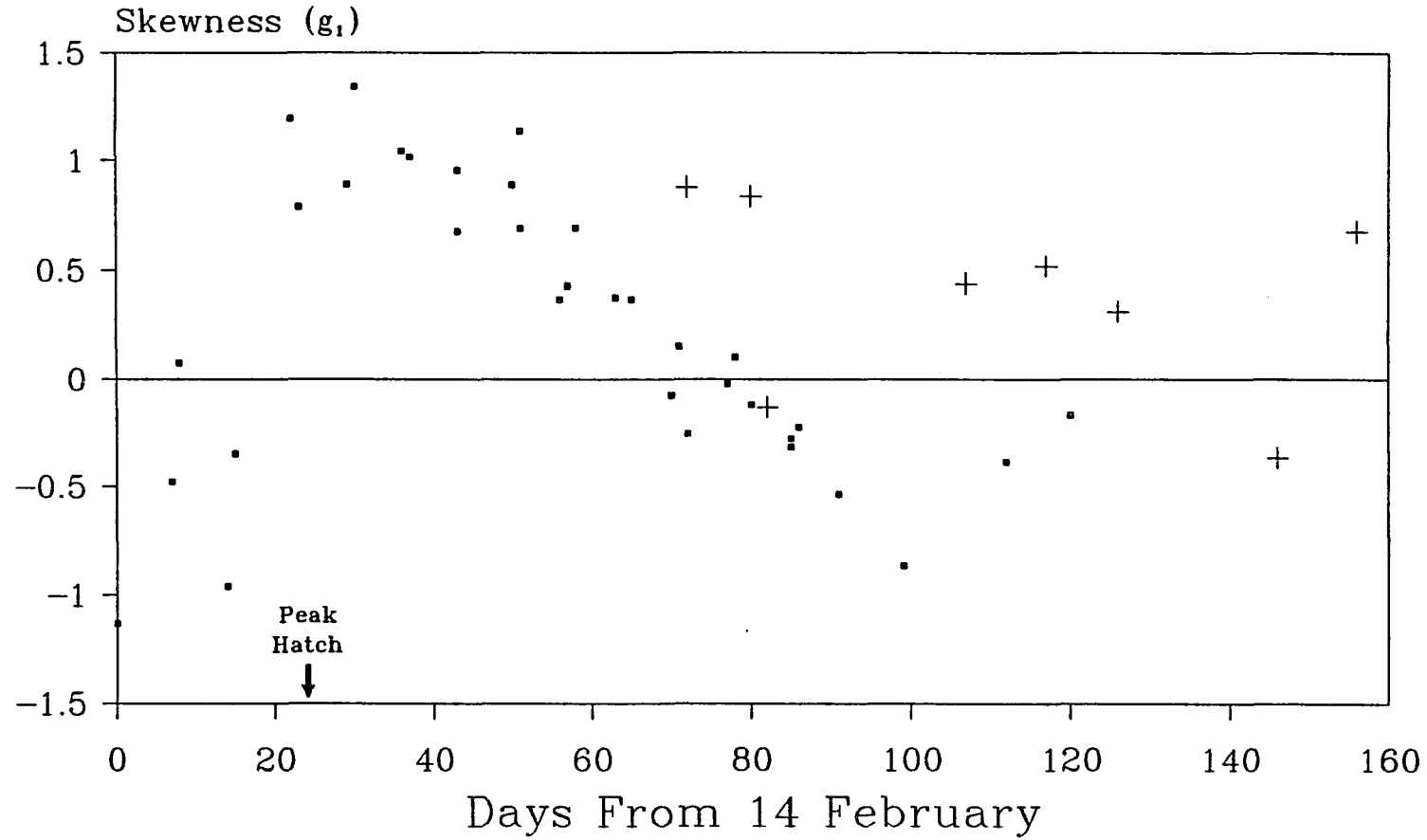
c. Kolmogorov-Smirnov Divergence

The Kolmogorov-Smirnov two-sample test is a test of whether two independent samples have been drawn from the same population or from populations with the same distribution. The two-tailed test is sensitive to any kind of difference in the distributions from which the two samples were drawn, e.g. differences in central tendency, dispersion, skewness, etc. (Siegel 1956). Moreover, from step-wise examination of the absolute value of divergences, $|d|$, between the two cumulative frequency distributions, the location of greatest divergence can be ascertained. Length-frequency distributions from meter nets and bottom trawls were compared and found to be significantly ($\alpha=0.05$) different for the two dates when both methods were employed (Fig.41). The calculation of K-S $|d|$ values for one of the sampling dates, 27 April 1974, are found in Table 20. Examination of K-S divergences (Fig.41) shows that significant differences resulted from the fact that the relatively large-mesh trawl did not collect smaller tomcod in proportion to their abundance in the population. Significant differences were not apparent to the right of the length-frequency modes, and this demonstrated that meter net avoidance by larger fish was not a factor in the trend toward negative skewness noted above. Instead, it was evident from this limited comparison that, within this life-history stage, meter-net collections were more representative of the parametric length distribution for tomcod than were bottom-trawl collections.

Figure 40. Trend in skewness for tomcod length-frequency distributions with time for 1974-1976 collections.

Trend In Skewness With Time

1974 - 1976



• Meter Nets + Bottom Trawls

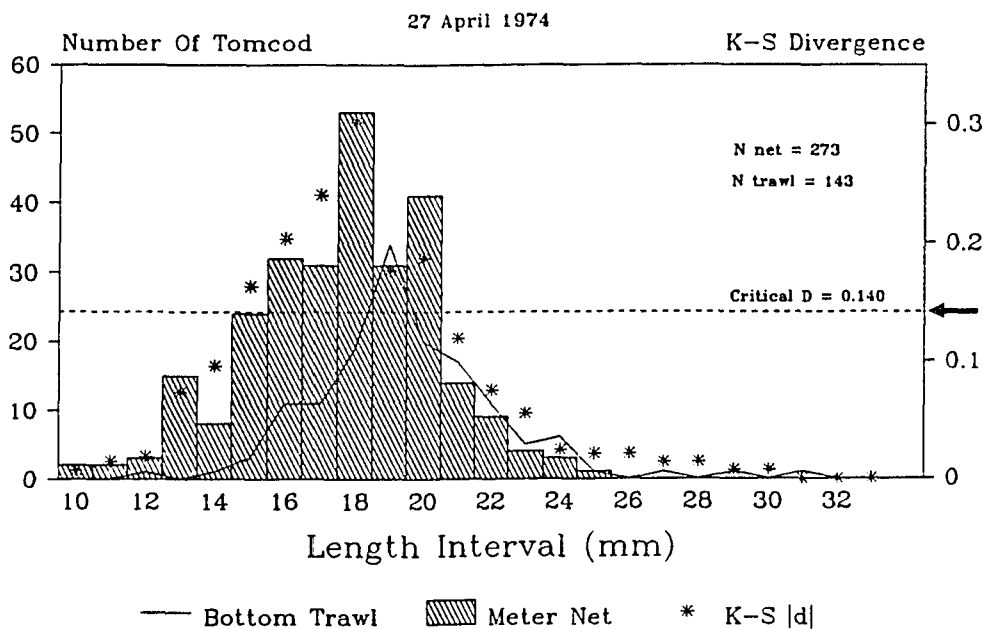
Collectively these analyses suggest a continuous trailing behind of slower-growing fish after hatching, a process which tended to increase both CV and negative skewness. During May, size-selective mortality directed against these small, slow-growing fish effected a reduction of relative variation (CV) within the population and eventually decimated the individuals that comprised the left-hand tail and that were responsible for the significant negative skewness. Figure 42 shows the end-product of this on-going interaction between growth and mortality for representative dates during 1976.

C. Individual Growth

Analysis of growth for early life stages was used to provide information for biomass production estimates and insight into between-year variability resulting from density-independent parameters such as temperature, as well as used to provide age-at-length data for mortality analysis. Inasmuch as biomass production and growth changes from year to year are both population-level responses, they can be investigated satisfactorily using population growth rates (G_x), confounded as they may be by recruitment effect. However, mortality analysis is sensitive to changes in estimates of length at time t (L_t), i.e., age estimates for larvae of a given length; therefore rates should be based on the growth of individual cohorts rather than the comparatively gross resolution provided by population growth rates. Distillation of growth rates representative for

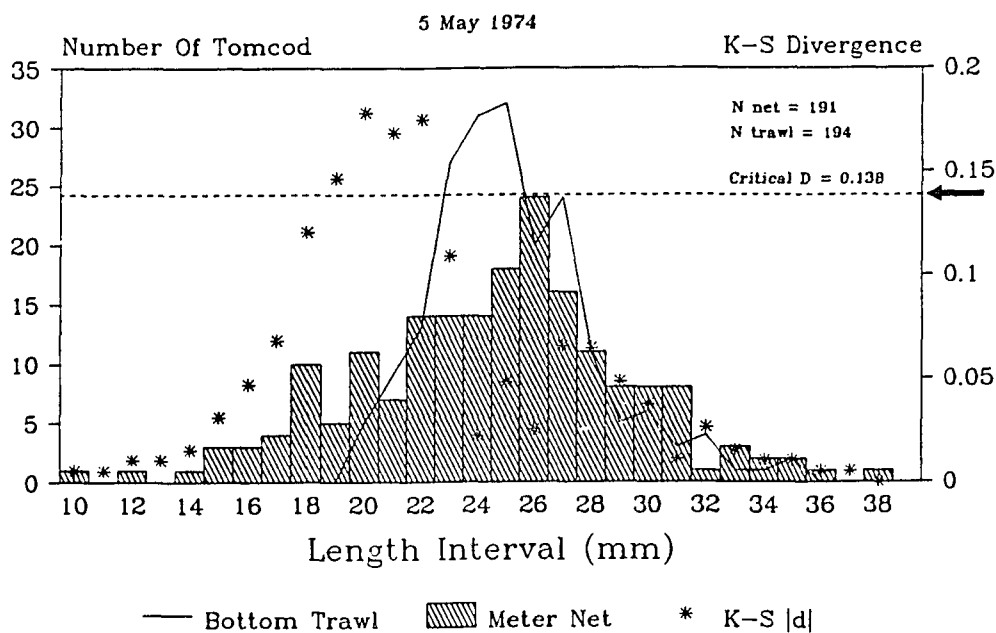
Figure 41. Kolmogorov-Smirnov divergence for tomcod length-frequency distributions from meter nets and bottom trawls.

Tomcod Length-Frequency Distributions Meter Net vs Bottom Trawl



K-S |d| = Kolmogorov-Smirnov Divergence

Tomcod Length-Frequency Distributions Meter Net vs Bottom Trawl



K-S |d| = Kolmogorov-Smirnov Divergence

Table 20. Kolmogorov-Smirnov two-sample test, testing differences in distributions of tomcod lengths from bottom-trawl and meter-net collections on 27 April 1974.

Table 20. Kolmogorov-Smirnov two-sample test, testing differences in the continuous distributions of tomcod lengths from bottom-trawl and meter-net collections. Sample sizes: trawl (N1)=143 tomcod; meter net (N2)=273 tomcod.

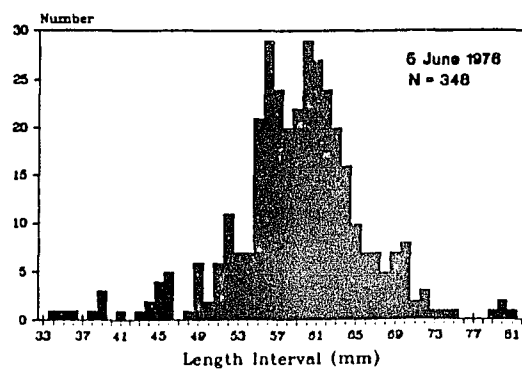
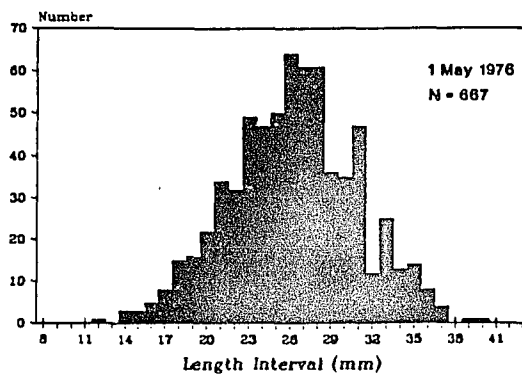
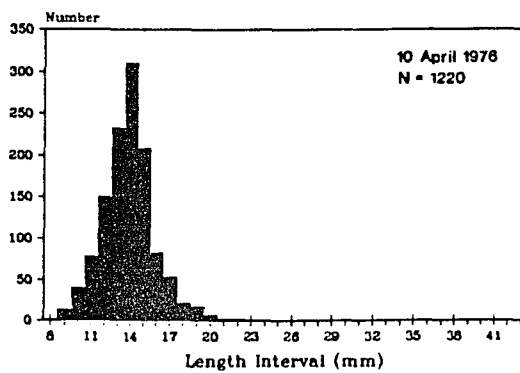
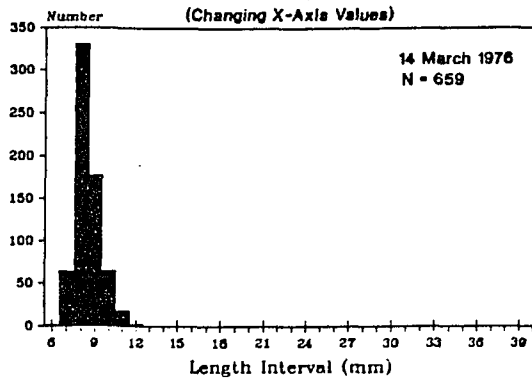
27 April 1974					
Tomcod Length Interval	Cumulative Frequency		F1/N1	F2/N2	d= (F1/N1)-(F2/N2)
	Bottom Trawl (F1)	Meter Net (F2)			
10	0	2	0.000	0.007	0.007
11	0	4	0.000	0.015	0.015
12	1	7	0.007	0.026	0.019
13	1	22	0.007	0.081	0.074
14	2	30	0.014	0.110	0.096
15	5	54	0.035	0.198	0.163 *
16	16	86	0.112	0.315	0.203 *
17	27	117	0.189	0.429	0.240 *
18	46	170	0.322	0.623	0.301 **
19	80	201	0.559	0.736	0.177 *
20	100	242	0.699	0.886	0.187 *
21	117	256	0.818	0.938	0.120
22	128	265	0.895	0.971	0.076
23	133	269	0.930	0.985	0.055
24	139	272	0.972	0.996	0.024
25	140	273	0.979	1.000	0.021
26	140	273	0.979	1.000	0.021
27	141	273	0.986	1.000	0.014
28	141	273	0.986	1.000	0.014
29	142	273	0.993	1.000	0.007
30	142	273	0.993	1.000	0.007
31	143	273	1.000	1.000	0.000
32	143	273	1.000	1.000	0.000
33	143	273	1.000	1.000	0.000

* K-S divergence (d) significant at P=0.05

** K-S divergence (d) significant at P=0.01

Figure 42. Tomcod length-frequency distributions from March-June 1976 meter net collections.

Tomcod Length-Frequency Distributions
Meter Net Collections
(Changing X-Axis Values)



individual tomcod required removing, as much as possible, the effects of recruitment and of size-selective movement and accumulation within the estuary.

To this end, the sampled population was sorted into 1.0-mm length-cohorts to determine the density distribution of a given length-cohort over time, from its first appearance to its disappearance from the population. The methods used are similar to those of Hackney and Webb (1978) and DeAngelis et al. (1980). The density-weighted mean date for the distribution of a given length-cohort through time was the date on which an average larva attained that length. For example, from Sec. III.A. (Length at Hatching), it was determined that the mean length of a newly-hatched larvae in 1975 and 1976 was 7.0 mm. A riverwide average density (Appendix III) of all larvae less than 7.5 mm was calculated for each sampling date. Multiplying density (weighting factor) by sampling date (expressed as number of days from beginning of hatching), summing the cross-products, and dividing this by the sum of the densities, resulted in the weighted mean date upon which the average larva attained 7.0 mm (Appendix IV). For the newly-hatched 7 mm category (5.7-7.4 mm), this was also the average hatching date, or Day 0. This procedure was repeated for subsequent 1-mm length cohorts in order to obtain the date (now expressed in number of days from Day 0) on which the average larva of that cohort attained its length (the mid-point of the length interval). For 1976, data and calculations for estimates of Day 0, ages

of larvae within selected 1-mm length intervals from 7.5-8.4 to 62.5-63.4 mm, and duration within each length interval may be found in Appendix IV and in Table 21. Data and calculations for 1975 are in Table 22. Data from the 1974 sampling program, which are relatively incomplete compared with 1975 and 1976, have not been included in this analysis.

Riverwide average densities for selected length-cohorts were plotted by date and are shown in Fig.43 with their associated t_L values, which represent the average age in days from hatching for larvae within the L^{th} length interval. A plot of length (mid-point of each length interval) vs. t_L , in which the slope represents the average growth rate of individuals, suggested that 1976 growth was exponential from hatching in early March (Day 0 = 11 March) through 53 mm in late May (Fig.44). The straight line

$$\ln L_t = 1.8058 + 0.0285t$$

explains 99.1% of the variation in length with time and thus shows that the fish's growth conformed to the exponential function

$$L_t = L_0 e^{Gt}$$

where

L_t = length (mm) at Day t

L_0 = calculated length at hatching = 6.085

G = growth coefficient = 0.0285.

Table 21. Data for analysis of individual growth (G) for tomcod larvae and early juveniles during 1976.

Table 21. Data for analysis of individual growth (G) for 7-53 and 54-63 mm Atlantic tomcod larvae and early juveniles during 1976.

7-53 mm Stanza						
Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained	LOGe Predicted Length**	Predicted Length	Duration In Length Interval+ (Days)
7	1.9459	0.0	11-Mar-76	1.8058	6.1	4.691
8	2.0794	8.8	20-Mar-76	2.0554	7.8	4.138
9	2.1972	14.0	25-Mar-76	2.2048	9.1	3.701
10	2.3026	17.9	29-Mar-76	2.3165	10.1	3.348
11	2.3979	22.4	02-Apr-76	2.4422	11.5	3.057
12	2.4849	25.1	05-Apr-76	2.5193	12.4	2.812
13	2.5649	28.5	08-Apr-76	2.6160	13.7	2.603
14	2.6391	31.8	12-Apr-76	2.7123	15.1	2.424
15	2.7081	33.0	13-Apr-76	2.7455	15.6	2.267
16	2.7726	36.0	16-Apr-76	2.8303	17.0	2.130
17	2.8332	38.3	18-Apr-76	2.8960	18.1	2.008
18	2.8904	39.6	20-Apr-76	2.9316	18.8	1.899
19	2.9444	41.6	22-Apr-76	2.9899	19.9	1.802
20	2.9957	43.7	24-Apr-76	3.0501	21.1	1.714
21	3.0445	45.4	25-Apr-76	3.0983	22.2	1.634
22	3.0910	46.7	27-Apr-76	3.1340	23.0	1.562
23	3.1355	47.5	27-Apr-76	3.1577	23.5	1.495
24	3.1781	48.8	29-Apr-76	3.1960	24.4	1.434
25	3.2189	50.7	01-May-76	3.2492	25.8	1.378
26	3.2581	50.8	01-May-76	3.2517	25.8	1.326
27	3.2958	51.8	02-May-76	3.2795	26.6	1.278
28	3.3322	51.8	02-May-76	3.2806	26.6	1.233
29	3.3673	53.4	03-May-76	3.3249	27.8	1.191
30	3.4012	53.6	04-May-76	3.3328	28.0	1.152
31	3.4340	53.2	03-May-76	3.3190	27.6	1.115
32	3.4657	55.3	05-May-76	3.3797	29.4	1.081
33	3.4965	55.9	06-May-76	3.3967	29.9	1.049
34	3.5264	57.5	08-May-76	3.4429	31.3	1.018
35	3.5553	59.6	10-May-76	3.5018	33.2	0.990
36	3.5835	60.2	10-May-76	3.5206	33.8	0.963
37	3.6109	62.9	13-May-76	3.5966	36.5	0.937
38	3.6376	63.6	14-May-76	3.6151	37.2	0.913
39	3.6636	64.8	15-May-76	3.6503	38.5	0.889
40	3.6889	66.1	16-May-76	3.6874	39.9	0.867
41	3.7136	66.7	17-May-76	3.7051	40.7	0.847
42	3.7377	67.4	17-May-76	3.7234	41.4	0.827
43	3.7612	68.1	18-May-76	3.7455	42.3	0.808
44	3.7842	68.9	19-May-76	3.7664	43.2	0.789
45	3.8067	73.5	24-May-76	3.8981	49.3	0.772

* Days from 11 March 1976 (Day 0)

** $\ln Lt = 1.8058 + 0.0285t$

+ $(\ln Lt+1 - \ln Lt)/0.0285$

Table 21 (cont.)

7-53 mm Stanza (cont.)						
Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained	LOGe Predicted Length**	Predicted Length	Duration In Length Interval+ (Days)
46	3.8286	71.5	22-May-76	3.8423	46.6	0.756
47	3.8501	73.1	23-May-76	3.8854	48.7	0.740
48	3.8712	73.6	24-May-76	3.9011	49.5	0.724
49	3.8918	73.7	24-May-76	3.9045	49.6	0.710
50	3.9120	75.3	25-May-76	3.9481	51.8	0.696
51	3.9318	75.9	26-May-76	3.9665	52.8	0.682
52	3.9512	76.3	26-May-76	3.9778	53.4	0.669
53	3.9703	75.6	26-May-76	3.9572	52.3	0.657

* Days from 11 March 1976 (Day 0)

** $\ln Lt = 1.8058 + 0.0285t$

+ $(\ln Lt+1 - \ln Lt)/0.0285$

54-63 mm Stanza

Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained	LOGe Predicted Length**	Predicted Length	Duration In Length Interval+ (Days)
54	3.9890	79.9	30-May-76	3.9841	53.7	1.384
55	4.0073	81.8	01-Jun-76	4.0088	55.1	1.359
56	4.0254	83.9	03-Jun-76	4.0368	56.6	1.335
57	4.0431	86.7	06-Jun-76	4.0743	58.8	1.312
58	4.0604	89.6	09-Jun-76	4.1123	61.1	1.290
59	4.0775	86.4	05-Jun-76	4.0706	58.6	1.268
60	4.0943	87.2	06-Jun-76	4.0811	59.2	1.247
61	4.1109	87.2	06-Jun-76	4.0811	59.2	1.227
62	4.1271	89.9	09-Jun-76	4.1163	61.3	1.207
63	4.1431	89.6	09-Jun-76	4.1126	61.1	1.007

* Days from 11 March 1976 (Day 0)

** $\ln Lt = 2.9251 + 0.0133t$

+ $(\ln Lt+1 - \ln Lt)/0.0133$

Table 22. Data for analysis of individual growth (G) for tomcod larvae and early juveniles during 1975.

Table 22. Data for analysis of individual growth (G) for Atlantic tomcod larvae and early juveniles during 1975.

Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained	LOGe Predicted Length**	Predicted Length	Duration In Length Interval+ (Days)
7	1.9459	0.0	05-Mar-75	1.9061	6.7	5.880
8	2.0794	3.9	09-Mar-75	1.9942	7.3	5.186
9	2.1972	12.4	17-Mar-75	2.1875	8.9	4.639
10	2.3026	20.1	25-Mar-75	2.3621	10.6	4.197
11	2.3979	25.2	30-Mar-75	2.4791	11.9	3.831
12	2.4849	28.2	02-Apr-75	2.5464	12.8	3.524
13	2.5649	31.2	05-Apr-75	2.6158	13.7	3.263
14	2.6391	34.2	08-Apr-75	2.6819	14.6	3.038
15	2.7081	36.1	10-Apr-75	2.7253	15.3	2.842
16	2.7726	38.0	12-Apr-75	2.7684	15.9	2.669
17	2.8332	40.4	14-Apr-75	2.8246	16.9	2.517
18	2.8904	41.7	16-Apr-75	2.8540	17.4	2.381
19	2.9444	44.7	19-Apr-75	2.9224	18.6	2.259
20	2.9957	46.3	20-Apr-75	2.9570	19.2	2.148
21	3.0445	48.7	23-Apr-75	3.0119	20.3	2.048
22	3.0910	50.6	25-Apr-75	3.0553	21.2	1.957
23	3.1355	51.7	26-Apr-75	3.0807	21.8	1.874
24	3.1781	52.5	27-Apr-75	3.0988	22.2	1.797
25	3.2189	53.0	27-Apr-75	3.1088	22.4	1.721

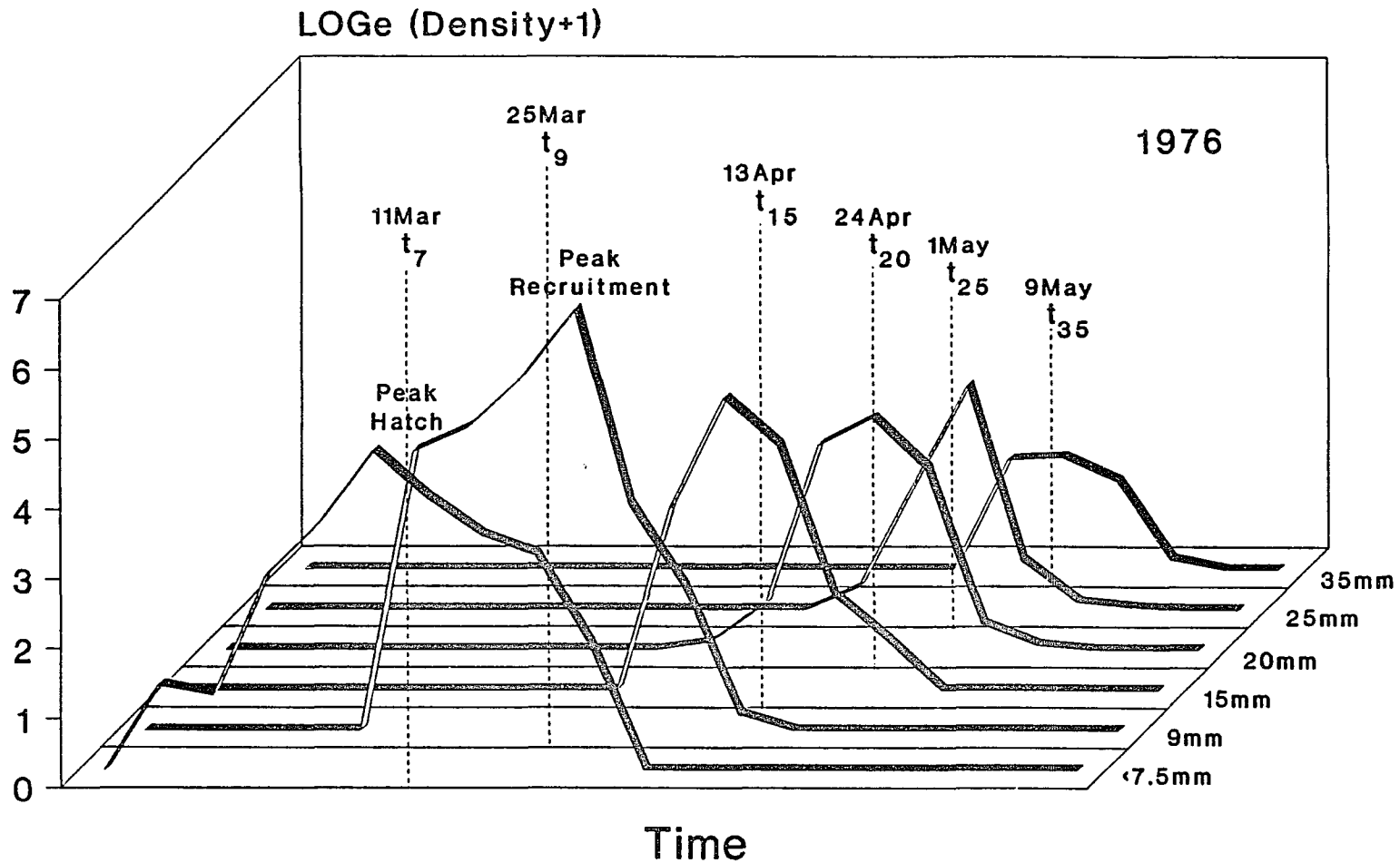
* Age = days from peak hatch (Day 0 = 5 March)

** $\ln Lt = 1.9061 + 0.0227t$

+ $(\ln Lt+1 - \ln Lt)/0.0227$

Figure 43. Riverwide average tomcod densities ($\log_e[\text{Density} + 1]$) for selected length-cohorts plotted by 1976 sample date. Shown with weighted mean date (t_l) upon which average larvae attained a given length. Data from Appendix IV.

Density Of Atlantic Tomcod Through Time For Selected Length Cohorts



t_L = Date on which average larvae attained length L

The time constant of the exponential growth rate was $1/G = 35.088$ days, i.e., L_t increased to e times its original value after 35 days during the 76-day period from 11 March to 26 May 1976. Upon reaching 53 mm on 25 May, G decreased by 53% to 0.0133. Density-weighted water temperature, as interpolated between the sampling dates of 23 May and 5 June, was 56°F (13.3°C) on 25 May, with 4322 degree-days accumulated since 21 February 1976.

Sampling ceased on 10 May 1975 (in contrast to 13 June 1976), and the 22-mm cohort was the last length-cohort in 1975 with a complete density distribution through time. Growth was exponential from hatching through 22 mm on 25 April (Fig.45), and the straight line

$$\ln L_t = 1.9061 = 0.0227t$$

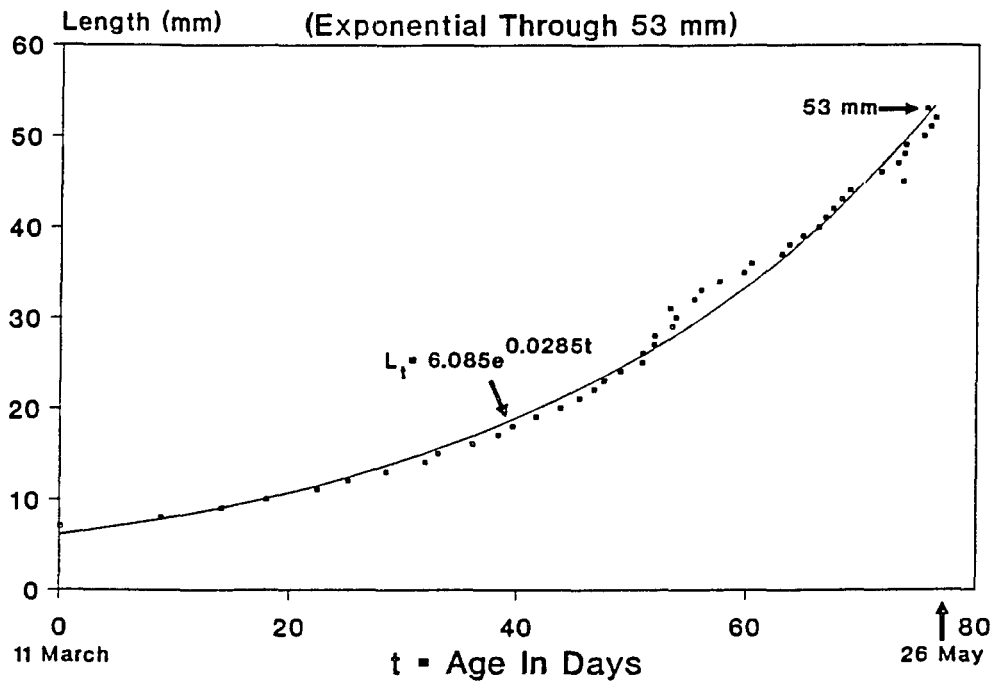
explains 98.2% of the variation in length with time. The growth coefficient (G) was 0.0227, denoting that L_t increased to e times its original value after 44 days. The instantaneous rate of growth (G) during March-April was approximately 20% lower in 1975 than in 1976.

1. Comparison of G vs. G_x

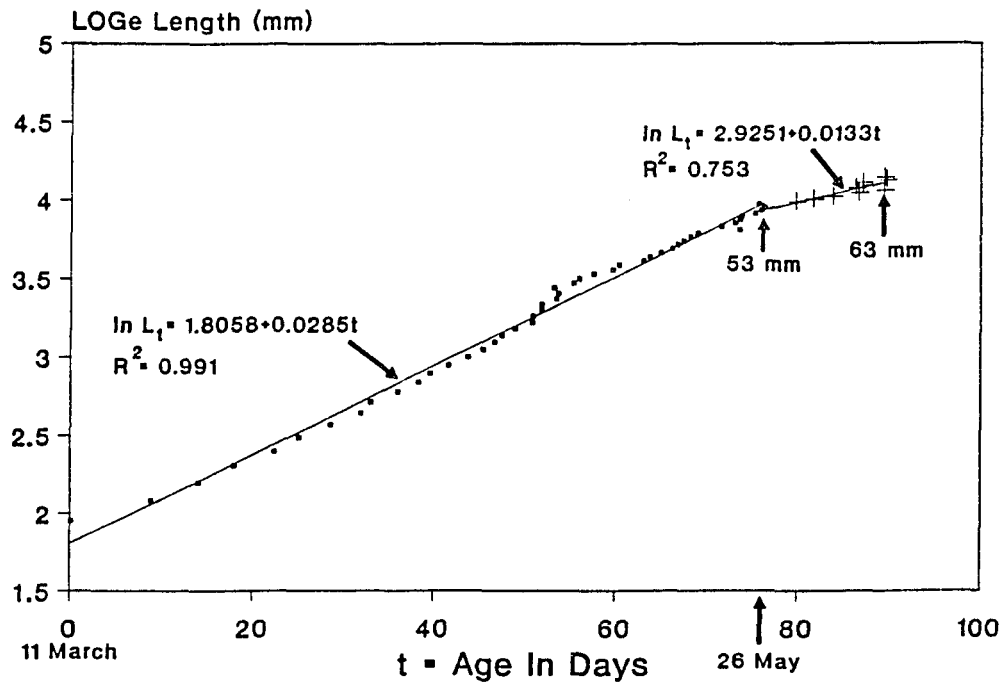
Indirect evidence has been provided in Section III.B.2 that because of recruitment effect, estimates of tomcod growth based on population (G_x) rates underestimated the true growth rate. In contrast, individual growth rate

Figure 44. Growth of Atlantic tomcod larvae and early juveniles for 1976.

Growth Of Atlantic Tomcod Larvae And Early Juveniles 1976



(Linearized for 7-53 mm and 54-63 mm)



(G) analysis tracks individual length cohorts and assigns a mean age to each cohort that is based on its density distribution through time, thereby avoiding the downward bias in growth rate estimates caused by recruitment when all cohorts are combined. The linear equations representing G and G_x for 1975 and 1976 follow:

$$1975 \text{ G (7-22mm): } \ln L_t = 1.9061 + 0.0227t \text{ (R}^2=0.982\text{)}.$$

$$G_x \text{ (7-28mm): } \ln L_t = 1.4512 + 0.0183t \text{ (R}^2=0.937\text{)}.$$

$$1976 \text{ G (7-53mm): } \ln L_t = 1.8058 + 0.0285t \text{ (R}^2=0.991\text{)}.$$

$$G_x \text{ (7-48mm): } \ln L_t = 1.6276 + 0.0204t \text{ (R}^2=0.924\text{)}.$$

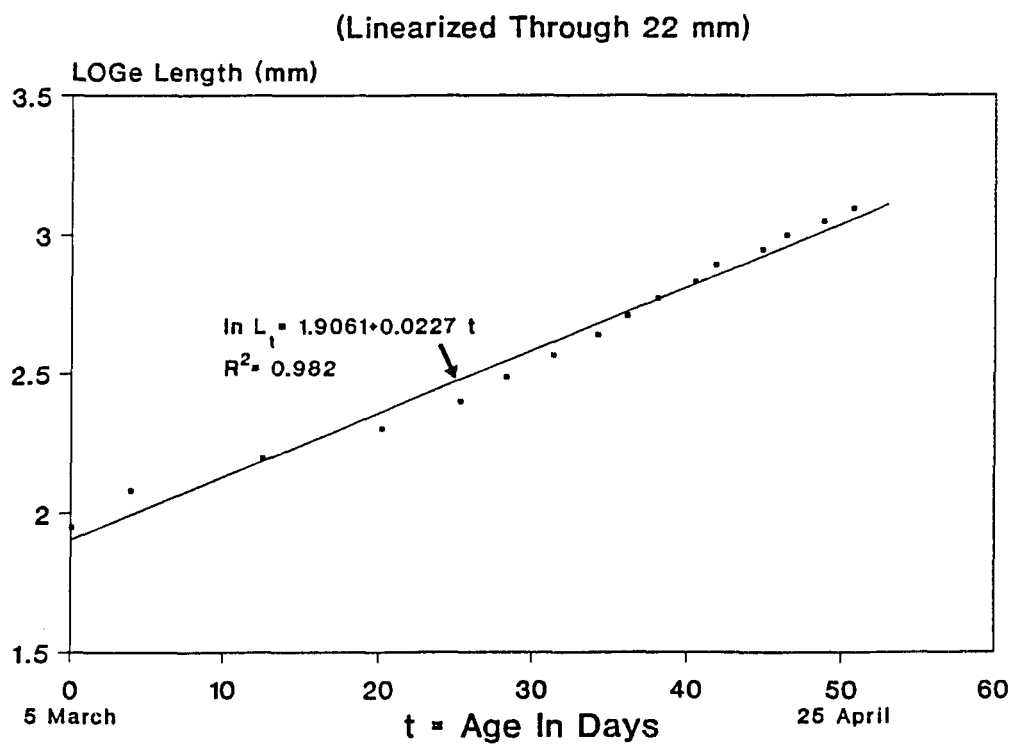
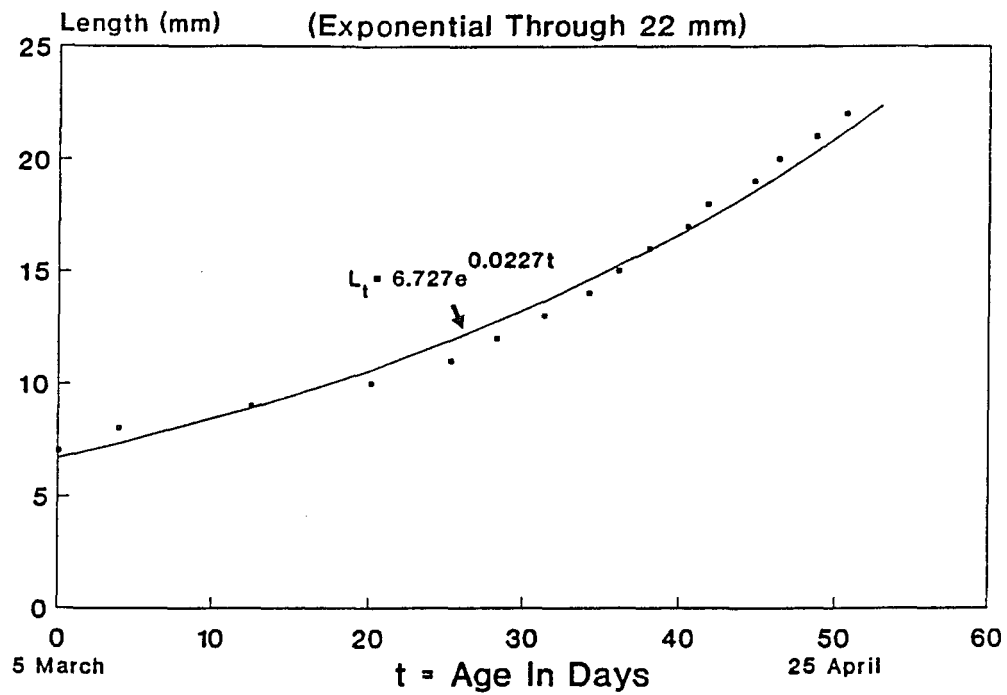
The 1975 G growth rate was 24% higher than the G_x growth rate, and that for 1976 was higher by 40% (Fig.46). These results show that G_x is a negatively biased estimator of true growth rates within larval populations and, for a given magnitude and duration of recruitment, this bias is more pronounced in years of higher growth rates.

2. Comparison of 1975 and 1976 Growth Rates (G)

Quantitative comparisons between 1975 and 1976 were based on a common growth stanza from 7 to 22 mm. For the regression of $\ln L_t$ vs. time (in days) from 1 March (Fig.47), a test for equality of slopes (Zar 1974) showed that the regression coefficients (G) for 1975 and 1976 were significantly different (Table 23), with the 1976 G 12% higher than 1975 G. Thus it is clear that factors other than

Figure 45. Growth of Atlantic tomcod larvae and early juveniles for 1975.

Growth Of Atlantic Tomcod Larvae And Early Juveniles 1975



the mere passage of time influenced tomcod growth rates in these years.

A test for equality of slopes showed that the regression coefficients for $\ln L_t$ vs. temperature were not significantly different for 1975 and 1976. However, an examination of the residuals for the 1975 regression indicated that the data were not linear, a fact made obvious by the transition to a negative relationship between length and temperature during a cold snap in late March-early April 1975 (Fig.47). My conclusion is that the relationship between growth and temperature was not the same for 1975 and 1976, and that temperature alone does not serve well as a predictor variable for tomcod growth rates.

A more useful predictor variable would be one that showed a relationship with growth that was the same for each year, despite different hatching times, cold snaps, etc. Cumulative degree-days, a measure of the area under a time-temperature curve, would appear a priori to be a better predictor variable than either time or temperature alone. Analysis of covariance showed that the slopes, which are equivalent to G , were virtually identical for the 1975 and 1976 regressions of $\ln L_t$ on cumulative degree-days (CDD) from 21 February, the earliest date common to both years (Table 24; Fig.47). Intercepts for the two years were

Figure 46. Comparison of individual (G) vs. population (G_x) growth rates for 1975 and 1976.

Comparison Of Individual (G) vs Population (Gx) Growth Rates

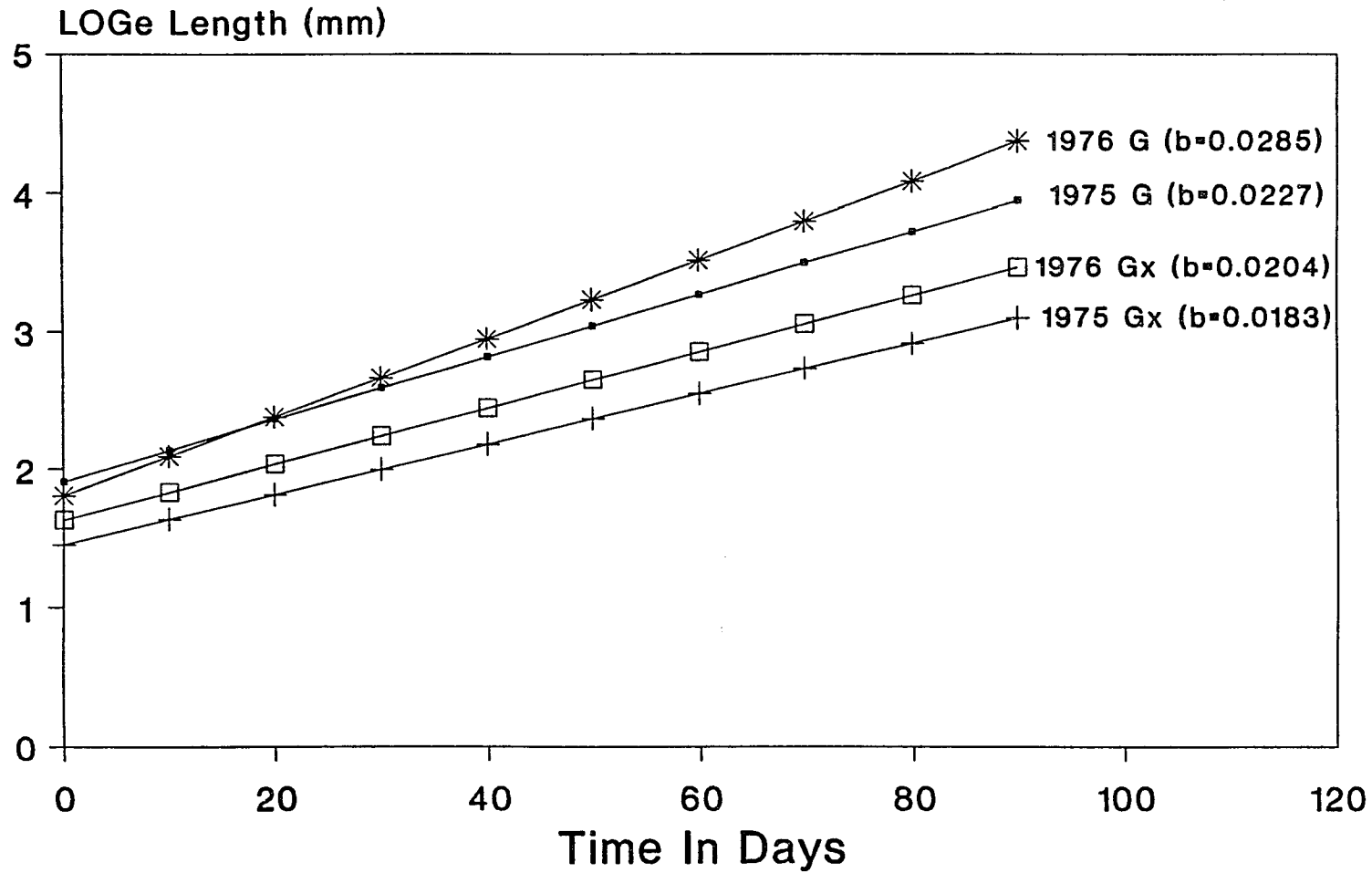


Figure 47. Comparison of 1975-1976 Age-0 tomcod growth with time, temperature, and cumulative degree days.

Tomcod Growth Rates From Hatch To 22 mm

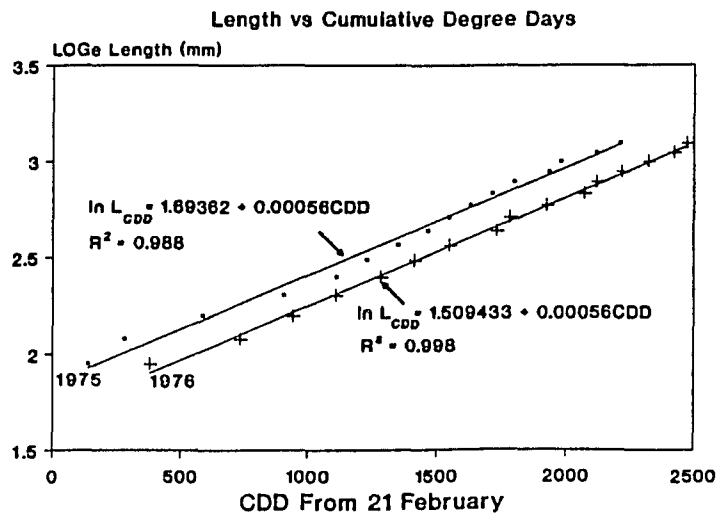
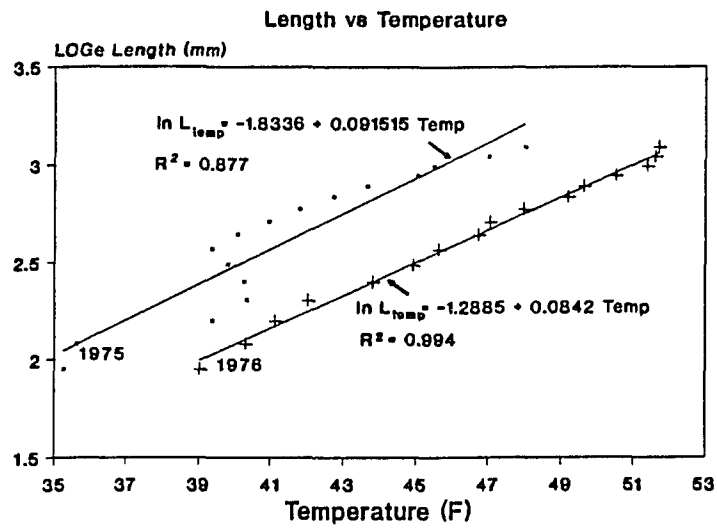
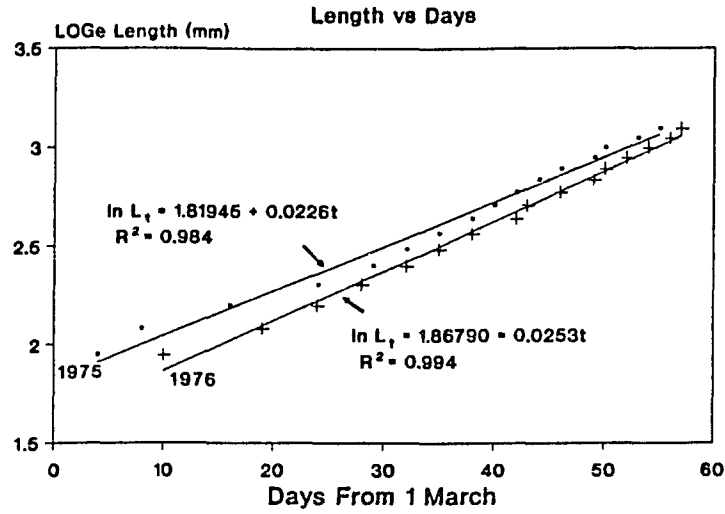


Table 23. Testing for equality of slopes for 1975 and 1976 growth equations (ln Length vs. Days from 1 March).

Table 23. ANCOVA testing for significant difference between slopes (b) and intercepts for regressions of ln Length (Y) on Days from 1 March (X).

	Sum x sq	Sum xy	Sum y sq	n	b	Residual SS	Residual DF
1975	3645.44	82.462	1.90	16	0.02262	0.0298	14
1976	2947.44	74.495	1.90	16	0.02527	0.0123	14
<u>Pooled Regression</u>						0.04210	28
<u>Common Regression</u>	6592.88	156.96	3.79			0.05358	29

<p>F = 7.64 Therefore reject Ho: B1=B2 Slopes are significantly (0.005<P<0.01) different, therefore intercepts were not tested.</p>

significantly different, primarily because the peak hatching date calculated for the larvae of 1975 (5 March = 419 CDD) was 7 days earlier than that for 1976 (11 March = 700 CDD).

The fact that G , as mediated by CDD, was the same for two very different March-April temperature trends (Fig.35), has some practical significance. For example, taking a single pair of values X_1, Y_1 for any year under investigation, the CDD at hatching could be estimated based on the common slope ($b_c = G = 0.0005614$) calculated for 1975 and 1976 (Table 24), and a common hatching size of 7 mm. The date-temperature record then could be used to estimate the hatching date coincident with CDD at a Y -value of 1.9459 ($\ln 7$ mm). The equation for determining a line of known slope from a single pair of values X_1, Y_1 is

$$Y = (Y_1 - bX_1) + bX$$

in which

$$Y = \ln L_0 = 1.9459$$

$$X = \text{CDD at hatching and}$$

$$b = 0.0005614.$$

Transposing this equation to read

$$X = [Y - (Y_1 - bX_1)] / b,$$

Table 24. ANCOVA testing for significant difference between regression functions and intercepts for 1975 and 1976 equations of \ln Length vs. CDD from 21 February of each year.

Table 24. ANCOVA testing for significant difference between slopes (b) and intercepts (a) for regressions of In Length on Cumulative Degree-Days (CDD) from 21 February

	Sum x sq	Sum xy	Sum y sq	n	b	Residual SS	Residual DF
1975	5961604.45	3341.329	1.90	16	0.0005605	0.0224	14
1976	5977111.96	3361.477	1.90	16	0.0005624	0.0047	14
<u>Pooled Regression</u>						0.02708	28
<u>Common Regression</u>	11938716.41	6702.80582	3.79		0.0005614	0.02709	29
<u>Total Regression</u>	12767580.08	6702.80582	3.79	32		0.27140	30

F(slope) =	0.01	Therefore do not reject Ho: B1=B2 Slopes (b) are not significantly different
F(intcp) =	261.50	Therefore reject Ho: A1=A2 Intercepts (a) are significantly (P<0.001) different

and substituting hypothetical values of $X_1 = 2030$ CDD and $Y_1 = \ln 15.0 \text{ mm} = 2.7080$,

$$\begin{aligned} X &= 1.9459 - [2.7080 - (0.0005614 \times 2030)] / 0.0005614 \\ &= 672.5 \text{ CDD.} \end{aligned}$$

This value for the CDD at hatching falls between 10-13 March, when either the 1975 or 1976 date-temperature data in Table 25 are used. Moreover, use of this generic growth coefficient results in the observation that tomcod in both years attained 19 mm in length (e x 7.0 mm) when 1781 degree-days ($1/G = 1/0.0005614 = 1781$) had accumulated after hatching, i.e., on 18-19 April 1975 ($418.55 + 1781 = 2199.55$ CDD) and 20-21 April 1976 ($699.66 + 1781 = 2480.66$ CDD) (Table 25). Results obtained from this generic CDD method are equivalent to those obtained from the length-cohort method outlined on pp 200-201. The purpose of these examples is not only to provide a practical method, but to emphasize the unifying concept of searching for variables that influence growth rates similarly in different years, thus providing some capability for predicting events.

Table 25. Interpolated temperatures, degree-days, cumulative degree-days, and calculated, date-specific ln length for the 1976 and 1975 sampling seasons.

Table 25. Interpolated temperatures, cumulative degree days, and date-specific larval length calculated for the 1976 sampling season.

1976 Date	Temp (Deg.F)	Cum. Degree Days	Larval Length**	1976 Date	Temp (Deg.F)	Cum. Degree Days	Larval Length**
* 21-Feb-76	34.8	0.00		* 17-Apr-76	48.3	2288.15	
* 28-Feb-76	35.6	246.40		18-Apr-76	48.7	2336.67	
29-Feb-76	36.0	282.20		19-Apr-76	49.2	2385.64	17.0
01-Mar-76	36.4	318.40		20-Apr-76	49.6	2435.04	18.0
02-Mar-76	36.8	355.00		21-Apr-76	50.1	2484.89	
03-Mar-76	37.2	392.00		22-Apr-76	50.5	2535.19	19.0
04-Mar-76	37.6	429.40		23-Apr-76	51.0	2585.92	
05-Mar-76	38.0	467.20		* 24-Apr-76	51.4	2637.10	20.0
06-Mar-76	38.4	505.40		25-Apr-76	51.5	2688.55	
* 07-Mar-76	38.8	544.00		26-Apr-76	51.6	2740.10	21.0
08-Mar-76	38.9	582.83		27-Apr-76	51.7	2791.75	22.0
09-Mar-76	38.9	621.71		28-Apr-76	51.8	2843.50	23.0
10-Mar-76	39.0	660.66		29-Apr-76	51.9	2895.35	
11-Mar-76	39.0	699.66	7.0	30-Apr-76	52.0	2947.30	24.0
12-Mar-76	39.1	738.71		* 01-May-76	52.1	2999.35	25.5
13-Mar-76	39.1	777.83		02-May-76	52.4	3051.58	27.5
* 14-Mar-76	39.2	817.00		03-May-76	52.6	3104.08	30.0
15-Mar-76	39.4	856.29		04-May-76	52.9	3156.83	32.5
16-Mar-76	39.6	895.77		05-May-76	53.2	3209.85	
17-Mar-76	39.8	935.44		06-May-76	53.4	3263.13	34.0
18-Mar-76	39.9	975.29		07-May-76	53.7	3316.68	
19-Mar-76	40.1	1015.32		08-May-76	53.9	3370.48	36.0
20-Mar-76	40.3	1055.54	8.0	* 09-May-76	54.2	3424.55	35.0
* 21-Mar-76	40.5	1095.95		10-May-76	54.8	3479.04	
22-Mar-76	40.7	1136.53		11-May-76	55.4	3534.12	
23-Mar-76	40.8	1177.26		12-May-76	56.0	3589.78	
24-Mar-76	41.0	1218.16		13-May-76	56.5	3646.02	38.5
25-Mar-76	41.1	1259.21	9.0	14-May-76	57.1	3702.84	38.0
26-Mar-76	41.3	1300.41		* 15-May-76	57.7	3760.25	39.0
27-Mar-76	41.4	1341.78		16-May-76	57.4	3817.78	
* 28-Mar-76	41.6	1383.30		17-May-76	57.0	3874.95	
29-Mar-76	42.0	1425.12	10.0	18-May-76	56.7	3931.78	
30-Mar-76	42.5	1467.39		19-May-76	56.3	3988.25	
31-Mar-76	42.9	1510.09		20-May-76	56.0	4044.38	
01-Apr-76	43.4	1553.24		21-May-76	55.6	4100.15	
02-Apr-76	43.8	1596.84	11.0	22-May-76	55.3	4155.58	
03-Apr-76	44.3	1640.87		* 23-May-76	54.9	4210.65	
* 04-Apr-76	44.7	1685.35		24-May-76	55.5	4265.83	
05-Apr-76	44.9	1730.17	12.0	25-May-76	56.0	4321.57	
06-Apr-76	45.2	1775.22		26-May-76	56.6	4377.88	
07-Apr-76	45.4	1820.50		27-May-76	57.1	4434.74	
08-Apr-76	45.6	1866.02	13.0	28-May-76	57.7	4492.17	
09-Apr-76	45.9	1911.77		29-May-76	58.3	4550.16	
* 10-Apr-76	46.1	1957.75		30-May-76	58.8	4608.71	
11-Apr-76	46.4	2004.01		31-May-76	59.4	4667.82	
12-Apr-76	46.7	2050.58	14.0	01-Jun-76	60.0	4727.49	
13-Apr-76	47.0	2097.46	15.0	02-Jun-76	60.5	4787.73	
14-Apr-76	47.4	2144.66		03-Jun-76	61.1	4848.52	
15-Apr-76	47.7	2192.18		04-Jun-76	61.6	4909.88	
16-Apr-76	48.0	2240.01	16.0	* 05-Jun-76	62.2	4971.80	

Table 25 (cont. for 1975 season).

1975 Date	Temp (Deg.F)	Cum. Degree Days	Larval Length**	1975 Date	Temp (Deg.F)	Cum. Degree Days	Larval Length**
21-Feb-75	34.6	0.00		05-Apr-75	39.4	1621.53	13.0
22-Feb-75	34.7	34.65		* 06-Apr-75	39.2	1660.80	
* 01-Mar-75	34.9	278.25		07-Apr-75	39.6	1700.22	
* 02-Mar-75	35.0	313.19		08-Apr-75	40.1	1740.07	14.0
03-Mar-75	35.1	348.23		09-Apr-75	40.5	1780.35	
04-Mar-75	35.2	383.34		10-Apr-75	40.9	1821.07	15.0
05-Mar-75	35.2	418.55	7.0	11-Apr-75	41.4	1862.22	
06-Mar-75	35.3	453.84		* 12-Apr-75	41.8	1903.80	16.0
07-Mar-75	35.4	489.23		13-Apr-75	42.3	1945.83	
08-Mar-75	35.5	524.69		14-Apr-75	42.7	1988.33	17.0
09-Mar-75	35.6	560.25	8.0	15-Apr-75	43.2	2031.28	
* 10-Mar-75	36.1	596.11		16-Apr-75	43.6	2074.70	18.0
11-Mar-75	36.6	632.48		17-Apr-75	44.1	2118.58	
12-Mar-75	37.1	669.36		18-Apr-75	44.6	2162.93	
13-Mar-75	37.7	706.76		19-Apr-75	45.0	2207.73	19.0
14-Mar-75	38.2	744.68		* 20-Apr-75	45.5	2253.00	20.0
15-Mar-75	38.7	783.11		21-Apr-75	46.0	2298.75	
16-Mar-75	39.2	822.05		22-Apr-75	46.5	2345.00	
* 17-Mar-75	39.4	861.33	9.0	23-Apr-75	47.0	2391.75	21.0
18-Mar-75	39.5	900.76		24-Apr-75	47.5	2439.00	
19-Mar-75	39.7	940.36		25-Apr-75	48.0	2486.75	22.0
20-Mar-75	39.8	980.11		* 26-Apr-75	48.5	2535.00	
21-Mar-75	40.0	1020.01		27-Apr-75	48.6	2583.57	
22-Mar-75	40.1	1060.08		28-Apr-75	48.8	2632.29	
23-Mar-75	40.3	1100.30		29-Apr-75	48.9	2681.14	
* 24-Mar-75	40.3	1140.61		30-Apr-75	49.1	2730.14	
25-Mar-75	40.3	1180.93	10.0	01-May-75	49.2	2779.29	
26-Mar-75	40.4	1221.28		02-May-75	49.4	2828.57	
27-Mar-75	40.4	1261.63		* 03-May-75	49.5	2878.00	
28-Mar-75	40.4	1302.01		04-May-75	50.0	2927.74	
29-Mar-75	40.4	1342.40		05-May-75	50.4	2977.94	
* 30-Mar-75	40.3	1382.73	11.0	06-May-75	50.9	3028.62	
31-Mar-75	40.1	1422.90		07-May-75	51.4	3079.77	
01-Apr-75	40.0	1462.93		08-May-75	51.9	3131.39	
02-Apr-75	39.8	1502.80	12.0	09-May-75	52.3	3183.49	
03-Apr-75	39.7	1542.53		* 10-May-75	52.8	3236.05	
04-Apr-75	39.5	1582.10					

* Actual density-weighted temperature measured on sampling date.
All other temperatures estimated by interpolation.

** Length at date calculated using the length-cohort method outlined on pp 200-201.

IV. MORTALITY

Mortality as a function of time was determined as the slope of the line

$$\ln N_t = \ln N_0 - Zt$$

which takes the exponential form

$$N_t = N_0 e^{-Zt}$$

where

t = age in days from peak hatch (t_0)

N_t = riverwide standing crop of tomcod at Age t

N_0 = riverwide standing crop of newly hatched larvae
estimated by the Y-intercept

Z = instantaneous mortality rate.

Data and calculations for N_t may be found in Appendices II, III, and IV. In the interest of saving space, only six out of 47 length intervals for which the 1976 cohort N_t values were calculated are presented in Appendix IV, and none of the 19 length-interval N_t values for 1975 is shown. Condensed data from these two appendices for 1975 and 1976 are provided in Tables 26 and 27, and linear and exponential plots are shown in Figs. 48 and 49. Both of these indicate that newly hatched larvae of less than 7.5 mm were underrepresented in the net catches compared with their true

abundance in the population, consistent with the fact that no tomcod eggs were collected during February of 1975 and 1976. This leads to the conclusion that tomcod larvae hatch from eggs on or very near the bottom and are moved up into the water column by currents. Upward vertical water movement is at a minimum near the bottom (Abood 1974), so it takes an appreciable length of time for larvae to be moved up into the net-sampled layer, approximately 1-2 m from bottom. Assuming that the time from hatch to passive attainment of a uniform density distribution within the bottom 1-2 m of the water column was the same for 1975 and 1976, we would expect full recruitment into the nets at a larger size in the year of higher growth rates. Size at full recruitment, denoted by the domes of the catch curves that are traced by the data points in Figs.48-49, occurred at 8 mm for 1975 and at 9 mm for 1976. As determined from the previous section, growth rate for 1976 (7-22mm) was 12% higher than for 1975, and this is consistent with the observation of greater size at recruitment for 1976.

The decline in the 1975 tomcod population during the first 53 days after peak hatch (5 March) was estimated as

$$\ln N_t = 21.3242 - 0.0382t \quad (R^2=0.855)$$

or

$$N_t = 1.824 \times 10^9 e^{-0.0382t}$$

for larvae 8-24 mm long. Using this relationship between

Table 26. Standing crop estimates for 7-25 mm tomcod larvae and early juveniles from peak hatch on 5 March to 27 April 1975.

Table 26. Standing crop estimates for 7 to 25 mm tomcod larvae and early juveniles from peak hatch on 5 March to 27 April 1975.

Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained*	Duration In Length Interval* (Days)	Standing Crop*	LOGe Standing Crop	LOGe Predict Standing Crop**	Predicted Standing Crop
7	1.9459	0.0	05-Mar-75	5.880	605,159,096	20.22100	21.32418	1,823,786,231
8	2.0794	3.9	09-Mar-75	5.186	1,713,541,458	21.26183	21.17618	1,572,893,725
9	2.1972	12.4	17-Mar-75	4.639	745,242,096	20.42922	20.85126	1,136,548,682
10	2.3026	20.1	25-Mar-75	4.197	707,151,354	20.37676	20.55776	847,466,272
11	2.3979	25.2	30-Mar-75	3.831	821,604,379	20.52677	20.36109	696,157,283
12	2.4849	28.2	02-Apr-75	3.524	705,115,034	20.37387	20.24796	621,694,681
13	2.5649	31.2	05-Apr-75	3.263	713,791,687	20.38610	20.13127	553,220,699
14	2.6391	34.2	08-Apr-75	3.038	672,964,471	20.32720	20.02013	495,030,849
15	2.7081	36.1	10-Apr-75	2.842	520,474,947	20.07025	19.94726	460,241,690
16	2.7726	38.0	12-Apr-75	2.669	501,552,848	20.03322	19.87478	428,064,727
17	2.8332	40.4	14-Apr-75	2.517	457,941,727	19.94225	19.78020	389,433,705
18	2.8904	41.7	16-Apr-75	2.381	305,198,503	19.53647	19.73092	370,704,521
19	2.9444	44.7	19-Apr-75	2.259	269,961,829	19.41379	19.61586	330,414,930
20	2.9957	46.3	20-Apr-75	2.148	257,282,524	19.36569	19.55768	311,738,610
21	3.0445	48.7	23-Apr-75	2.048	190,448,232	19.08489	19.46538	284,254,014
22	3.0910	50.6	25-Apr-75	1.957	264,569,612	19.39361	19.39241	264,250,079
23	3.1355	51.7	26-Apr-75	1.874	290,906,368	19.48851	19.34984	253,237,165
24	3.1781	52.5	27-Apr-75	1.797	263,335,522	19.38894	19.31940	245,646,618
25	3.2189	53.0	27-Apr-75	1.721	287,871,914	19.47803	19.30256	241,544,051

* From Appendix 75-Age.

** Standing Crop 7-25 mm: $\ln Nt = 21.32418 - 0.03818 t$ (based on data for 8-25 mm larvae)

Table 27. Standing crop estimates for 7-53 mm tomcod larvae and early juveniles from peak hatch on 11 March to 26 May 1976.

Table 27. Standing crop estimates for 7 to 53 mm tomcod larvae and early juveniles from peak hatch on 11 March to 26 May 1976.

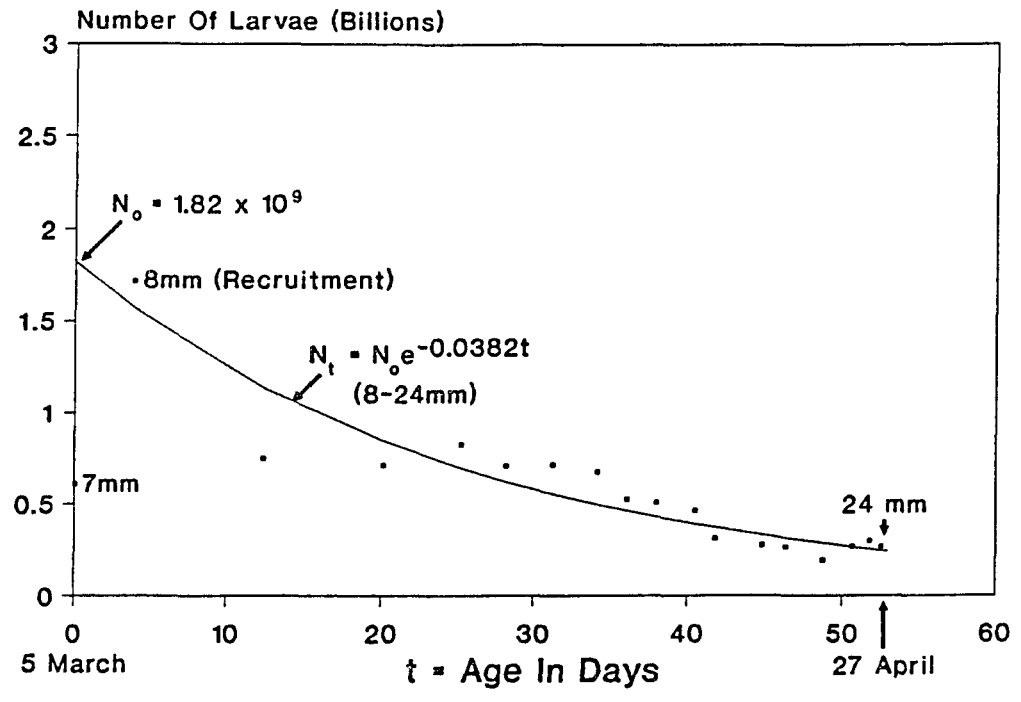
Mid-Point Of Length Interval	LOGe Length	Age* (Days)	Date Length Attained*	Duration In Length Interval* (Days)	Standing Crop*	LOGe Standing Crop	LOGe Predict Standing Crop**	Predicted Standing Crop
7	1.9459	0.0	11-Mar-76	4.691	566,317,467	20.15467	21.81615	2,982,862,368
8	2.0794	8.8	20-Mar-76	4.138	1,590,594,312	21.18737	21.37529	1,919,416,099
9	2.1972	14.0	25-Mar-76	3.701	1,977,898,579	21.40530	21.11134	1,474,137,891
10	2.3026	17.9	29-Mar-76	3.348	1,182,855,968	20.89120	20.91403	1,210,179,231
11	2.3979	22.4	02-Apr-76	3.057	913,345,199	20.63262	20.69207	969,283,205
12	2.4849	25.1	05-Apr-76	2.812	810,695,782	20.51340	20.55584	845,843,200
13	2.5649	28.5	08-Apr-76	2.603	764,623,909	20.45489	20.38494	712,961,877
14	2.6391	31.8	12-Apr-76	2.424	531,783,787	20.09175	20.21495	601,507,631
15	2.7081	33.0	13-Apr-76	2.267	472,863,405	19.97432	20.15631	567,248,485
16	2.7726	36.0	16-Apr-76	2.130	431,477,987	19.88273	20.00651	488,332,477
17	2.8332	38.3	18-Apr-76	2.008	395,455,281	19.79555	19.89045	434,821,228
18	2.8904	39.6	20-Apr-76	1.899	354,414,603	19.68598	19.82755	408,313,456
19	2.9444	41.6	22-Apr-76	1.802	364,372,107	19.71369	19.72451	368,336,104
20	2.9957	43.7	24-Apr-76	1.714	316,354,626	19.57237	19.61822	331,194,450
21	3.0445	45.4	25-Apr-76	1.634	338,343,266	19.63957	19.53318	304,195,846
22	3.0910	46.7	27-Apr-76	1.562	323,328,374	19.59418	19.46999	285,588,817
23	3.1355	47.5	27-Apr-76	1.495	314,083,143	19.56517	19.42811	273,855,099
24	3.1781	48.8	29-Apr-76	1.434	287,236,137	19.47582	19.38055	255,963,474
25	3.2189	50.7	01-May-76	1.378	147,281,705	18.80786	18.98770	176,301,112
26	3.2581	50.8	01-May-76	1.326	220,001,057	19.20914	18.98210	175,316,598
27	3.2958	51.8	02-May-76	1.278	232,747,897	19.26547	18.91834	164,486,050
28	3.3322	51.8	02-May-76	1.233	252,964,523	19.34876	18.91582	164,071,863
29	3.3673	53.4	03-May-76	1.191	176,039,257	18.98622	18.81448	148,260,757
30	3.4012	53.6	04-May-76	1.152	197,387,345	19.10068	18.79627	145,585,082
31	3.4340	53.2	03-May-76	1.115	158,703,450	18.88255	18.82796	150,271,892
32	3.4657	55.3	05-May-76	1.081	89,505,338	18.30981	18.68893	130,767,562
33	3.4965	55.9	06-May-76	1.049	83,582,953	18.24135	18.64999	125,773,684
34	3.5264	57.5	08-May-76	1.018	102,937,036	18.44963	18.54415	113,141,627
35	3.5553	59.6	10-May-76	0.990	109,818,167	18.51434	18.40915	98,853,878
36	3.5835	60.2	10-May-76	0.963	82,121,191	18.22371	18.36607	94,685,394
37	3.6109	62.9	13-May-76	0.937	57,435,377	17.86617	18.19206	79,562,949
38	3.6376	63.6	14-May-76	0.913	55,966,705	17.84027	18.14954	76,251,080
39	3.6636	64.8	15-May-76	0.889	72,843,612	18.10383	18.08899	70,349,420
40	3.6889	66.1	16-May-76	0.867	57,950,417	17.87510	17.98395	64,614,216
41	3.7138	66.7	17-May-76	0.847	57,510,449	17.86748	17.94352	62,054,295
42	3.7377	67.4	17-May-76	0.827	47,390,508	17.67393	17.90143	59,496,382
43	3.7612	68.1	18-May-76	0.808	41,442,163	17.53981	17.85094	56,567,421
44	3.7842	68.9	19-May-76	0.789	36,154,666	17.40332	17.80297	53,917,937
45	3.8067	73.5	24-May-76	0.772	39,564,154	17.49343	17.50143	39,881,689
46	3.8286	71.5	22-May-76	0.756	37,871,570	17.44971	17.62923	45,318,544
47	3.8501	73.1	23-May-76	0.740	54,902,998	17.82108	17.53036	41,052,360
48	3.8712	73.6	24-May-76	0.724	98,272,972	18.40326	17.49437	39,601,147
49	3.8918	73.7	24-May-76	0.710	60,504,045	17.91822	17.48676	39,301,115
50	3.9120	75.3	25-May-76	0.696	36,890,519	17.42347	17.38673	35,559,786
51	3.9318	75.9	26-May-76	0.682	40,480,968	17.51659	17.34470	34,096,426
52	3.9512	76.3	26-May-76	0.669	32,260,185	17.28934	17.31864	33,219,085
53	3.9703	75.6	26-May-76	0.657	24,839,598	17.02795	17.36587	34,826,004

* From Appendix 76-Age

** Standing Crop 7-24 mm: $\ln N_t = 21.81615 - 0.05028 t$ (based on data for 9-24 mm larvae)
 Standing Crop 25-53 mm: $\ln N_t = 22.29443 - 0.06521 t$

Figure 48. Atlantic tomcod mortality from 5 March hatch to 27 April 1975.

1975 Atlantic Tomcod Mortality (Exponential)



1975 Atlantic Tomcod Mortality (Linearized)

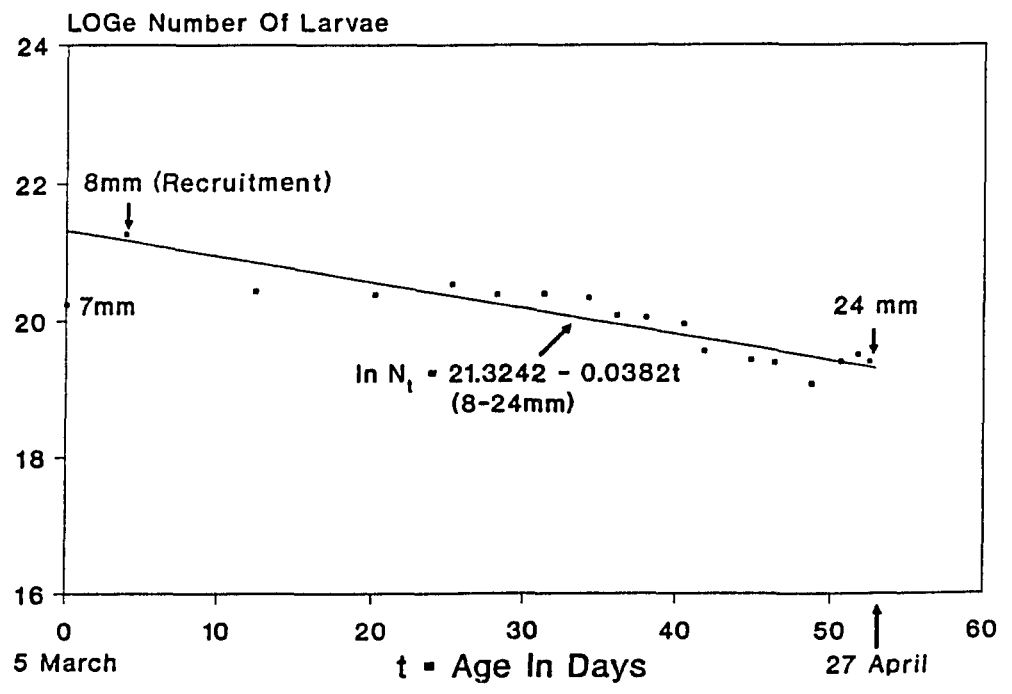
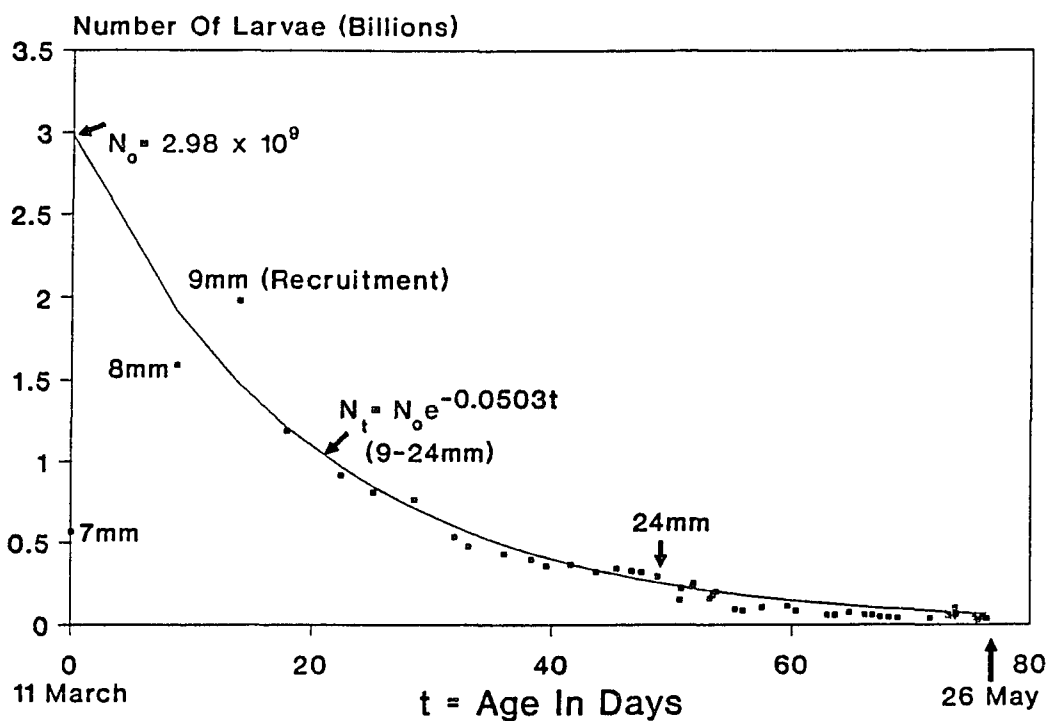
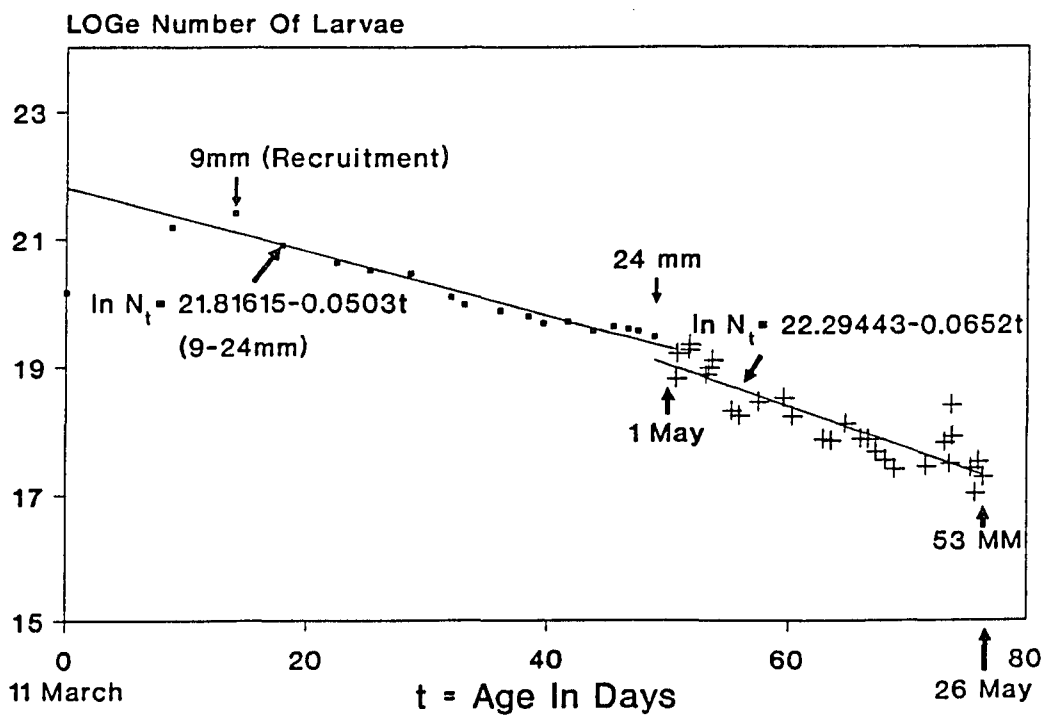


Figure 49. Atlantic tomcod mortality from 11 March hatch to 26 May 1976.

1976 Atlantic Tomcod Mortality (Exponential)



1976 Atlantic Tomcod Mortality (Linearized)



numbers and time, an initial standing crop of 1.824 billion newly hatched larvae died at a rate of $A = 1 - e^{-z} = 3.75\%$ per day to the level of about 241 million fish by 27 April. Thus, within 7-8 weeks from peak hatch, the population had been reduced by about 87%, during which the larvae grew from 7 to 24 mm in length.

In 1976, the decline in population during the first 50 days after peak hatch (11 March) was estimated as

$$\ln N_t = 21.8162 - 0.0503t \quad (R^2=0.947)$$

or

$$N_t = 2.983 \times 10^9 e^{-0.0503t}$$

for larvae 9-24 mm in length. In 1976, an initial standing crop of 2.983 billion larvae died at a rate of 4.9% per day to reach the level of about 255 million fish by 30 April, thus reducing the population by 91% within 7 weeks from peak hatch, while the fish grew from 7 to 25 mm.

After 30 April 1976, while growing from 25 to 53 mm, the larvae suffered an increase in mortality of about 27% to a level described by the equation

$$\ln N_t = 22.2944 - 0.0652t \quad (R^2=0.781).$$

From 30 April through 26 May the population died at a rate of 6.3% per day, reaching a level of about 34 million fish.

Thus, from peak hatch (Day 0) to the end of May (Day 80), the 1976 tomcod population was reduced by approximately 99% through natural mortality.

V. BIOMASS PRODUCTION

Production may be defined, in this case, as the biomass or total tissue elaborated by the 1976 tomcod cohort during the period from peak hatch (11 March) to early June, including the biomass contribution from the fish that died before the end of the period (Ricker 1946; Allen 1950; Chapman 1966). These production estimates do not include biomass lost to respiration and excretion, and thus should be considered equivalent to "net production" estimates. The term "productivity" should not be considered here as a synonym for "production", inasmuch as productivity is the characteristic property of a particular population, community, or water body which is responsible for a given level of production (Winberg 1971).

The instantaneous growth (G) and mortality (Z) values used to generate production estimates have been derived in previous sections. The possibility exists that the increase in mortality after 30 April (Fig.49), may be an artifact of gear avoidance or emigration by post-larvae greater than 24 mm in length. Therefore production was estimated for the situation where Z increased from -0.0503 to -0.0652 after 30

April (Table 28), as well as for a constant mortality rate at $Z = -0.0503$ (Table 28). All production estimates resulted from model-smoothed data, as suggested by Winberg (1971).

For the regime of changing Z , total production from peak hatch to early June was 174,344 kg, with greatest production occurring in the third week of April (Table 28; Fig.50). Under a constant Z , the estimate of total production increased by 43% to 248,761 kg, with peak production occurring around 21 May (Table 29; Fig.50). Peak population biomass under both mortality regimes coincided with the peak rate of biomass production on 21 May, although population biomass was 79% higher under the regime of constant Z .

The quantity Z/G is the rate coefficient of the power function that describes the decrease in tomcod numbers with average individual weight, expressed as

$$N = aW^{-Z/G}$$

which was derived by Hackney and Webb (1977). Rather abrupt decreases in production and biomass occurred whenever the $Z:G$ ratio increased, and the greatest decrease occurred in late May, as the result of a slowdown in growth rather than an increase in mortality (Fig.50). A summer depression in growth rate is characteristic for this boreal species which finds the southern limit of its breeding range in the Hudson River. It might therefore be expected that the 1976 produc-

Table 28. Estimation of biomass production from 11 March peak hatch to early June for the 1976 cohort of Atlantic tomcod in the Hudson River estuary. Mortality (Z) increases after 24 mm.

Table 28. Estimation of biomass production from 11 March peak hatch to early June for the 1976 cohort of Atlantic tomcod in the Hudson River estuary. Mortality (Z) increases after 24mm.

Days From Peak Hatch	Calculated Date	Larv. Lngth (mm)	**Mean Weight (g)	Daily Instant. Growth (Gw)	Daily Instant. Mortality (Z)	Standing Stock Numbers	Standing Stock Biomass (kg)	Mean Biomass (B*)	Daily Prod. (P=GB*)	Production For Period (kg)	Z:G Ratio
0	11-Mar-76	7	0.0013			2,982,864,746	3903		0		
5	15-Mar-76	8	0.0020	0.0954	-0.0503	2,356,583,660	4822	4362	416	1950	0.53
9	19-Mar-76	9	0.0030	0.0954	-0.0503	1,914,269,796	5810	5316	507	2096	0.53
13	23-Mar-76	10	0.0043	0.0954	-0.0503	1,589,443,849	6864	6337	605	2235	0.53
16	26-Mar-76	11	0.0059	0.0954	-0.0503	1,343,354,800	7981	7422	708	2368	0.53
19	29-Mar-76	12	0.0080	0.0954	-0.0503	1,152,118,728	9159	8570	818	2496	0.53
22	01-Apr-76	13	0.0104	0.0954	-0.0503	1,000,334,318	10396	9778	933	2620	0.53
24	04-Apr-76	14	0.0133	0.0954	-0.0503	877,691,768	11690	11043	1054	2740	0.53
27	06-Apr-76	15	0.0168	0.0954	-0.0503	777,068,965	13039	12364	1180	2856	0.53
29	09-Apr-76	16	0.0208	0.0954	-0.0503	693,411,956	14441	13740	1311	2968	0.53
31	11-Apr-76	17	0.0255	0.0954	-0.0503	623,050,227	15895	15168	1447	3078	0.53
33	13-Apr-76	18	0.0309	0.0954	-0.0503	563,263,502	17400	16647	1588	3185	0.53
35	15-Apr-76	19	0.0370	0.0954	-0.0503	511,999,499	18954	18177	1734	3290	0.53
37	16-Apr-76	20	0.0440	0.0954	-0.0503	467,685,229	20557	19755	1885	3392	0.53
39	18-Apr-76	21	0.0518	0.0954	-0.0503	429,097,910	22207	21382	2040	3492	0.53
40	20-Apr-76	22	0.0605	0.0954	-0.0503	395,274,862	23903	23055	2200	3590	0.53
42	21-Apr-76	23	0.0702	0.0954	-0.0503	365,449,431	25646	24774	2364	3686	0.53
43	23-Apr-76	24	0.0809	0.0954	-0.0503	339,004,685	27432	26539	2532	3781	0.53
45	24-Apr-76	25	0.0928	0.0954	-0.0578	287,248,873	26648	27040	2580	3695	0.61
46	26-Apr-76	26	0.1058	0.0954	-0.0652	239,129,517	25296	25972	2478	3410	0.68
47	27-Apr-76	27	0.1200	0.0954	-0.0652	219,349,433	26328	25812	2463	3261	0.68
49	28-Apr-76	28	0.1356	0.0954	-0.0652	201,838,340	27363	26846	2561	3268	0.68
50	29-Apr-76	29	0.1525	0.0954	-0.0652	186,268,278	28400	27881	2660	3275	0.68
51	01-May-76	30	0.1708	0.0954	-0.0652	172,367,833	29438	28919	2759	3282	0.68
52	02-May-76	31	0.1906	0.0954	-0.0652	159,910,910	30479	29959	2858	3288	0.68
53	03-May-76	32	0.2120	0.0954	-0.0652	148,708,012	31522	31001	2958	3295	0.68
54	04-May-76	33	0.2350	0.0954	-0.0652	138,599,408	32567	32045	3057	3301	0.68
55	05-May-76	34	0.2597	0.0954	-0.0652	129,449,730	33614	33091	3157	3307	0.68
56	06-May-76	35	0.2861	0.0954	-0.0652	121,143,679	34663	34138	3257	3313	0.68
57	07-May-76	36	0.3144	0.0954	-0.0652	113,582,587	35713	35188	3357	3318	0.68
58	08-May-76	37	0.3446	0.0954	-0.0652	106,681,638	36765	36239	3457	3324	0.68
59	09-May-76	38	0.3768	0.0954	-0.0652	100,367,614	37819	37292	3558	3329	0.68
60	10-May-76	39	0.4110	0.0954	-0.0652	94,577,061	38875	38347	3658	3334	0.68
61	11-May-76	40	0.4474	0.0954	-0.0652	89,254,776	39932	39403	3759	3339	0.68
62	12-May-76	41	0.4859	0.0954	-0.0652	84,352,560	40990	40461	3860	3344	0.68
63	12-May-76	42	0.5268	0.0954	-0.0652	79,828,192	42051	41521	3961	3349	0.68
64	13-May-76	43	0.5699	0.0954	-0.0652	75,644,562	43112	42582	4062	3354	0.68
65	14-May-76	44	0.6155	0.0954	-0.0652	71,768,954	44176	43644	4164	3359	0.68
65	15-May-76	45	0.6636	0.0954	-0.0652	68,172,442	45240	44708	4265	3363	0.68
66	16-May-76	46	0.7143	0.0954	-0.0652	64,829,376	46307	45773	4367	3368	0.68
67	16-May-76	47	0.7676	0.0954	-0.0652	61,716,954	47374	46840	4469	3372	0.68
68	17-May-76	48	0.8237	0.0954	-0.0652	58,814,851	48443	47908	4571	3376	0.68
68	18-May-76	49	0.8825	0.0954	-0.0652	56,104,905	49513	48978	4673	3381	0.68
69	18-May-76	50	0.9443	0.0954	-0.0652	53,570,852	50585	50049	4775	3385	0.68
70	19-May-76	51	1.0090	0.0954	-0.0652	51,198,092	51657	51121	4877	3389	0.68
70	20-May-76	52	1.0767	0.0954	-0.0652	48,973,490	52731	52194	4979	3393	0.68
71	21-May-76	53	1.1476	0.0954	-0.0652	46,885,207	53807	53269	5082	3397	0.68
72	22-May-76	54	1.2217	0.0455	-0.0652	42,866,294	52371	53089	2417	3322	1.43
74	23-May-76	55	1.2991	0.0445	-0.0652	39,178,717	50898	51634	2299	3172	1.46
75	25-May-76	56	1.3799	0.0445	-0.0652	35,866,451	49492	50195	2235	3028	1.46
76	26-May-76	57	1.4641	0.0445	-0.0652	32,885,587	48148	48820	2174	2893	1.46

Table 28 (cont.)

Days From Peak Hatch	Calculated Date	Larv. Lngh (mm)	*Mean Weight (g)	Daily Instant. Growth (Gw)	Daily Instant. Mortality (Z)	Standing Stock Numbers	Standing Stock Biomass (kg)	Mean Biomass (B*)	Daily Prod. Kg/Day (P=GB*)	Production For Period (kg)	Z:G Ratio
78	27-May-76	58	1.5519	0.0445	-0.0652	30,198,001	46864	47506	2115	2766	1.46
79	29-May-76	59	1.6433	0.0445	-0.0652	27,770,504	45635	46249	2059	2647	1.46
80	30-May-76	60	1.7384	0.0445	-0.0652	25,574,139	44458	45046	2006	2534	1.46
82	31-May-76	61	1.8373	0.0445	-0.0652	23,583,582	43330	43894	1954	2429	1.46
83	01-Jun-76	62	1.9401	0.0445	-0.0652	21,776,634	42248	42789	1905	2329	1.46
84	02-Jun-76	63	2.0468	0.0445	-0.0652	20,133,796	41210	41729	1858	2235	1.46

Total Production
March to June 1976 174,344 kg

Seasonal Mean
Biomass 32,564 kg

Average Rate 2,076 kg/day

Avg. Rate/cu.m. 0.0025 g/day/cu.m. (Milepoint 0-42)

Avg. Rate/sq.m. 0.0136 g/day/sq.m. (Milepoint 0-42)

Seasonal P:B 5.35

** $\log W = -5.71214 + 3.34748 \log L$ (Dew and Hecht 1976)

$\ln W = -13.1527 + 3.34748 \ln L$

Table 29. Estimation of biomass production from 11 March peak hatch to early June for the 1976 cohort of Atlantic tomcod in the Hudson River estuary. Mortality (Z) remains constant.

Table 29. Estimation of biomass production from 11 March peak hatch to early June for the 1976 cohort of Atlantic tomcod in the Hudson River estuary. Mortality (Z) remains constant.

Days From Peak Hatch	Calculated Date	Larv. Lngth (mm)	**Mean Weight (g)	Daily Instant. Growth (Gw)	Daily Instant. Mortality (Z)	Standing Stock Numbers	Standing Stock Biomass (kg)	Mean Biomass (B*)	Daily Prod. Kg/Day (P=GB*)	Production For Period (kg)	Z:G Ratio
0	11-Mar-76	7	0.0013			2,982,864,746	3903				
5	15-Mar-76	8	0.0020	0.0954	-0.0503	2,356,583,660	4822	4362	416	1950	0.53
9	19-Mar-76	9	0.0030	0.0954	-0.0503	1,914,269,798	5810	5316	507	2096	0.53
13	23-Mar-76	10	0.0043	0.0954	-0.0503	1,589,443,849	6864	6337	605	2235	0.53
16	26-Mar-76	11	0.0059	0.0954	-0.0503	1,343,354,800	7981	7422	708	2368	0.53
19	29-Mar-76	12	0.0080	0.0954	-0.0503	1,152,118,728	9159	8570	818	2496	0.53
22	01-Apr-76	13	0.0104	0.0954	-0.0503	1,000,334,318	10398	9778	933	2620	0.53
24	04-Apr-76	14	0.0133	0.0954	-0.0503	877,691,768	11690	11043	1054	2740	0.53
27	06-Apr-76	15	0.0168	0.0954	-0.0503	777,068,965	13039	12364	1180	2856	0.53
29	09-Apr-76	16	0.0203	0.0954	-0.0503	693,411,956	14441	13740	1311	2968	0.53
31	11-Apr-76	17	0.0255	0.0954	-0.0503	623,050,227	15895	15168	1447	3078	0.53
33	13-Apr-76	18	0.0309	0.0954	-0.0503	563,263,502	17400	16647	1588	3185	0.53
35	15-Apr-76	19	0.0370	0.0954	-0.0503	511,999,499	18954	18177	1734	3290	0.53
37	16-Apr-76	20	0.0440	0.0954	-0.0503	467,685,229	20557	19755	1885	3392	0.53
39	18-Apr-76	21	0.0518	0.0954	-0.0503	429,097,910	22207	21382	2040	3492	0.53
40	20-Apr-76	22	0.0605	0.0954	-0.0503	395,274,862	23903	23055	2200	3590	0.53
42	21-Apr-76	23	0.0702	0.0954	-0.0503	365,449,431	25646	24774	2364	3686	0.53
43	23-Apr-76	24	0.0809	0.0954	-0.0503	339,004,685	27432	26539	2532	3781	0.53
45	24-Apr-76	25	0.0928	0.0954	-0.0503	315,439,432	29263	28348	2704	3874	0.53
46	26-Apr-76	26	0.1058	0.0954	-0.0503	294,342,946	31137	30200	2881	3965	0.53
47	27-Apr-76	27	0.1200	0.0954	-0.0503	275,375,935	33053	32095	3062	4055	0.53
49	28-Apr-76	28	0.1356	0.0954	-0.0503	258,256,041	35011	34032	3247	4143	0.53
50	29-Apr-76	29	0.1525	0.0954	-0.0503	242,746,672	37011	36011	3436	4230	0.53
51	01-May-76	30	0.1708	0.0954	-0.0503	228,648,327	39051	38031	3628	4316	0.53
52	02-May-76	31	0.1906	0.0954	-0.0503	215,791,782	41130	40091	3825	4400	0.53
53	03-May-76	32	0.2120	0.0954	-0.0503	204,032,706	43250	42190	4025	4484	0.53
54	04-May-76	33	0.2350	0.0954	-0.0503	193,247,360	45408	44329	4229	4566	0.53
55	05-May-76	34	0.2597	0.0954	-0.0503	183,329,149	47605	46506	4437	4647	0.53
56	06-May-76	35	0.2861	0.0954	-0.0503	174,185,828	49840	48722	4648	4728	0.53
57	07-May-76	36	0.3144	0.0954	-0.0503	165,737,229	52112	50976	4863	4807	0.53
58	08-May-76	37	0.3448	0.0954	-0.0503	157,913,402	54421	53266	5082	4885	0.53
59	09-May-76	38	0.3768	0.0954	-0.0503	150,653,075	56767	55594	5304	4963	0.53
60	10-May-76	39	0.4110	0.0954	-0.0503	143,902,390	59149	57958	5529	5040	0.53
61	11-May-76	40	0.4474	0.0954	-0.0503	137,613,841	61567	60358	5758	5115	0.53
62	12-May-76	41	0.4859	0.0954	-0.0503	131,745,393	64021	62794	5991	5190	0.53
63	12-May-76	42	0.5268	0.0954	-0.0503	126,259,732	66509	65265	6226	5265	0.53
64	13-May-76	43	0.5699	0.0954	-0.0503	121,123,645	69033	67771	6466	5338	0.53
65	14-May-76	44	0.6155	0.0954	-0.0503	116,307,483	71590	70311	6708	5411	0.53
65	15-May-76	45	0.6636	0.0954	-0.0503	111,784,709	74182	72886	6954	5483	0.53
66	16-May-76	46	0.7143	0.0954	-0.0503	107,531,512	76808	75495	7202	5554	0.53
67	16-May-76	47	0.7676	0.0954	-0.0503	103,526,475	79487	78137	7455	5625	0.53
68	17-May-76	48	0.8237	0.0954	-0.0503	99,750,289	82159	80813	7710	5695	0.53
68	18-May-76	49	0.8825	0.0954	-0.0503	96,185,510	84884	83522	7968	5765	0.53
69	18-May-76	50	0.9443	0.0954	-0.0503	92,816,341	87642	86263	8230	5834	0.53
70	19-May-76	51	1.0090	0.0954	-0.0503	89,628,452	90432	89037	8494	5902	0.53
70	20-May-76	52	1.0767	0.0954	-0.0503	86,608,815	93254	91843	8762	5970	0.53
71	21-May-76	53	1.1476	0.0954	-0.0503	83,745,564	96108	94681	9033	6037	0.53
72	22-May-76	54	1.2217	0.0455	-0.0503	78,151,296	95479	95794	4361	5994	1.10
74	23-May-76	55	1.2991	0.0445	-0.0503	72,911,839	94721	95100	4234	5841	1.13
75	25-May-76	56	1.3799	0.0445	-0.0503	68,108,761	93983	94352	4201	5691	1.13
76	26-May-76	57	1.4641	0.0445	-0.0503	63,698,871	93263	93623	4168	5547	1.13

Table 29 (cont.)

Days From Peak Hatch	Calculated Date	Larv. Lngh (mm)	*Mean Weight (g)	Daily Instant. Growth (Gw)	Daily Instant. Mortality (Z)	Standing Stock Numbers	Standing Stock Biomass (kg)	Mean Biomass (B*)	Daily Prod. Kg/Day (P=GB*)	Production For Period (kg)	Z:G Ratio
78	27-May-76	58	1.5519	0.0445	-0.0503	59,643,911	92561	92912	4137	5409	1.13
79	29-May-76	59	1.6433	0.0445	-0.0503	55,909,912	91876	92218	4106	5277	1.13
80	30-May-76	60	1.7384	0.0445	-0.0503	52,466,660	91207	91541	4078	5150	1.13
82	31-May-76	61	1.8373	0.0445	-0.0503	49,287,221	90554	90881	4046	5029	1.13
83	01-Jun-76	62	1.9401	0.0445	-0.0503	46,347,543	89917	90236	4017	4912	1.13
84	02-Jun-76	63	2.0468	0.0445	-0.0503	43,626,106	89294	89605	3989	4799	1.13

Total Production
March to June 1976 248,761 kg

Seasonal Mean
Biomass 51,488 kg

Average Rate 2,962 kg/day

Avg. Rate/cu.m. 0.0036 g/day/cu.m. (Milepoint 0-42)

Avg. Rate/sq.m. 0.0194 g/day/sq.m. (Milepoint 0-42)

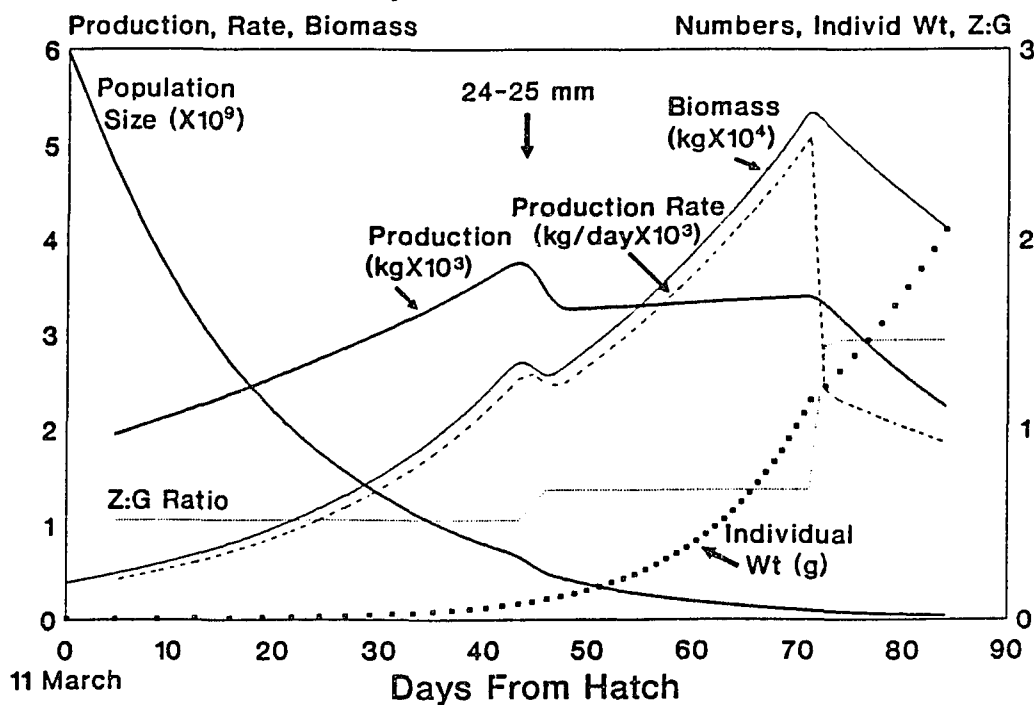
Seasonal P:B 4.83

** $\log W = -5.71214 + 3.34746 \log L$ (Dew and Hecht 1976)

$\ln W = -13.1527 + 3.34746 \ln L$

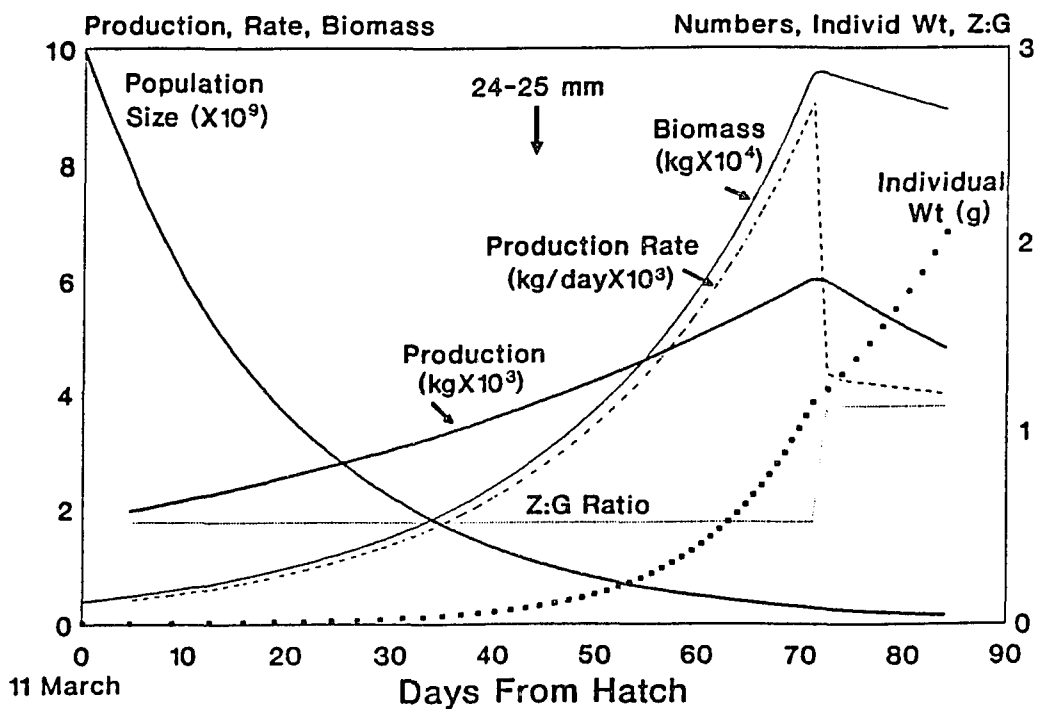
Figure 50. Relationship between tomcod population size, mortality, individual growth, biomass, and production, from 11 March hatching to early June 1976.

Relationship Between Population Size, Production And Biomass Mortality (Z) Increase At 24-25 mm



Z : G = Ratio of Mortality to Growth

Mortality (Z) Constant



Z : G = Ratio of Mortality to Growth

tion declined further and remained at low levels until cold-water growth rates resumed in October (Dew and Hecht 1976; McLaren et al. 1988).

The daily rate of production was calculated by multiplying the daily instantaneous rate of increase in weight (G) by the average biomass present during each time interval (B^*); so, if $P=GB^*$, the production-biomass (P/B^*) ratio is then equal to G , as pointed out by Allen (1971). From 11 March to 21 May the P/B^* ratio was 0.0954, a value that translates into 0.1 kg of fish flesh produced daily for each 1.0 kg of biomass present. This resulted in peak rates of biomass production on 21 May of 9,033 kg/day (constant Z) (Table 29) and 5,082 kg/day (increasing Z) (Table 28). After 21 May, the daily P/B^* ratio dropped to 0.04 as growth slowed. The seasonal P/B^* ratio, calculated as the total seasonal production divided by the mean seasonal biomass, was 4.8 under constant mortality (Table 29), and 5.4 for the situation where mortality increased after Day 43 (Table 28). This indicates a production of about 5 kg fish flesh per kg of biomass present during the March-June period of this study.

DISCUSSION

During the 1970's, portions of the Hudson River were studied intensely by consultants to the three electric utilities that used Hudson River water for once-through cooling⁴. Most of this study effort was directed toward the striped bass and, as a result, river segments and time periods relevant to other fish species were often ignored. Much of the information about Hudson River tomcod, which until recently resided largely in the "gray literature" of consultant reports to the utilities, has been distilled into two scientific papers (Klauda et al. 1988; McLaren et al. 1988). These papers presently represent the most detailed expositions to be found in the established scientific literature on the distribution, growth, and mortality of Hudson River tomcod larvae and early juveniles. I will rely heavily on these papers to compare and contrast findings from the present study.

I. HATCHING

Klauda et al. (1988) used box-trap catch-trends for adult males and running-ripe females to estimate the time of tomcod spawning. They deduced that the spawning period generally extended from mid-December through the end of January, and data they presented suggested that peak

⁴Consolidated Edison Co. of New York
Orange and Rockland Utilities
Central Hudson Gas and Electric Co.

spawning, during 1975-1976, occurred from late December to mid-January. They presented no data for the winter of 1974-1975. Results from my study have indicated, for both 1975 and 1976, an early February hatching pulse of small magnitude, followed by the initiation of sustained hatching in mid-February. In both years, hatching rates peaked during early March, and hatching was complete by mid-March. Using the data of Klauda et al. (1988) to assign the first week of January as the time of peak spawning, and using data from my work to establish the first week of March for time of peak hatch, a reasonable estimate for time of egg incubation in 1976 is 60 days. Peterson et al. (1980) reported that the median time needed to hatch tomcod eggs that were laboratory-incubated in freshwater at 2.0-4.5°C was 54 days. The average temperature of the bottom water in the Hudson River from Tappan Zee to Indian Point (MP 30-43) was 1.2°C at the initiation of my sampling on 14 February 1976, thus suggesting incubation temperatures colder than in the laboratory study. An egg-incubation period of 60 days in the Hudson is therefore consistent with the combined data from these three studies.

Klauda et al. (1988), again using December-February box-trap catches of sexually mature adults, determined that the West Point sampling region (MP 47-55) was the spawning epicenter for Hudson River tomcod during the winter of 1975-1976. They presented no data for the winter of 1974-1975. My results show that the location of greatest hatching

activity in 1975 and 1976, estimated from the abundance of larvae with full yolk sacs, centered around the Indian Point-Con Hook region (MP 42-54), and that hatching production upstream from MP 54 was low in both years. Results from these two independent studies are consistent and lead to the conclusion that tomcod eggs did not move far from where they were spawned during their approximate 60-day incubation period in 1976.

However, it is quite evident that tomcod do not spawn in the same part of the Hudson River each year. Dovel (1981) showed that tomcod larvae were distributed from MP 66 to MP 14 on 27 March 1972, denoting major spawning production upriver from MP 66 for that winter. A larval survey conducted on 13 March 1973 by my co-investigator, Jack Hecht of LMS, showed peak tomcod larvae concentrations in the vicinity of MP 78, thus indicating substantial spawning production upstream from Poughkeepsie during the winter of 1972-73 (LMS, unpub. data). Vladykov (1955) emphasized that, contrary to published data indicating that tomcod can spawn in either brackish or salt water, they prefer to breed in the freshwater region of the St. Lawrence River and often travel considerable distances to do so. This observation is probably true for the Hudson River population as well; therefore tomcod would have to travel farther upriver during dry autumns and /or cold winters in order to spawn above the salt front, which can reach Poughkeepsie (MP 76) during drought periods.

II. DISTRIBUTION

Quantifying the distribution of an organism in both space and time is a fundamental prerequisite to understanding its ecology and its vulnerability to man-made impacts within the ecosystem under study. Ostensibly this was one of the basic objectives of the riverwide assessment program, initiated by the Hudson River utilities and their consultants in the early 1970's, and directed toward target fish species such as striped bass, white perch, and Atlantic tomcod.

The tomcod comprises a major component of the Hudson River biological community, consistently ranking among the top five fish species in terms of numbers collected during annual field surveys and numbers killed by annual power plant impingement. It is a winter-spawning species whose larvae appear in early February and are soon swept downstream by freshwater flows at their annual maximum. The riverwide assessment by the utilities and their consultant, Texas Instruments, Inc. (TI), 1) limited systematic sampling of ichthyoplankton to all but the winter months, and 2) limited systematic sampling of ichthyoplankton to that portion of the estuary upstream from km 22 (MP 14) near Yonkers (Klauda et al. 1988). These limitations rendered the sampling design inadequate to describe quantitatively the basic distribution patterns in time and space for early life stages of the Atlantic tomcod, a representative and important species.

Results from my study indicate that the tomcod year-

classes of 1975 and 1976 hatched in a river segment upstream from the Indian Point (MP 42), Lovett (MP 41), and Bowline (MP 37) power plants, which collectively withdraw more than 3.1 million gallons/min (7000 cfs) of Hudson River water when operating at full capacity (McDowell 1986). Virtually all of the tomcod larvae hatched in river regions upstream from Indian Point had to pass by these plants while being moved downstream by spring freshwater flows. Shortly after their initial surge downstream from freshwater regions, tomcod movements were entrained into the dynamics of the 1.0 ppt salinity front, and passive movement by the larvae was no longer unidirectionally downstream. In other words, after having passed by the power plants once on their way downstream, the same larvae were brought back upstream to river regions influenced by large cooling-water withdrawals. The frequency and duration of exposure of planktonic tomcod larvae to power plant entrainment therefore was entirely dependent on the magnitude and variability of freshwater flow during February, March, and April.

The dynamics of this situation are illustrated in Fig.51, which shows a 24-mile upstream movement by the bulk of the tomcod population⁵ within a span of 7 days, between

⁵This represented the entire future reproductive tomcod population in the Hudson River estuary, inasmuch as only negligible numbers of adults that spawned the 1976 year-class would return to spawn a second time. This is, in essence, a single-age spawning population (McLaren et al. 1988; LMS, unpub. data).

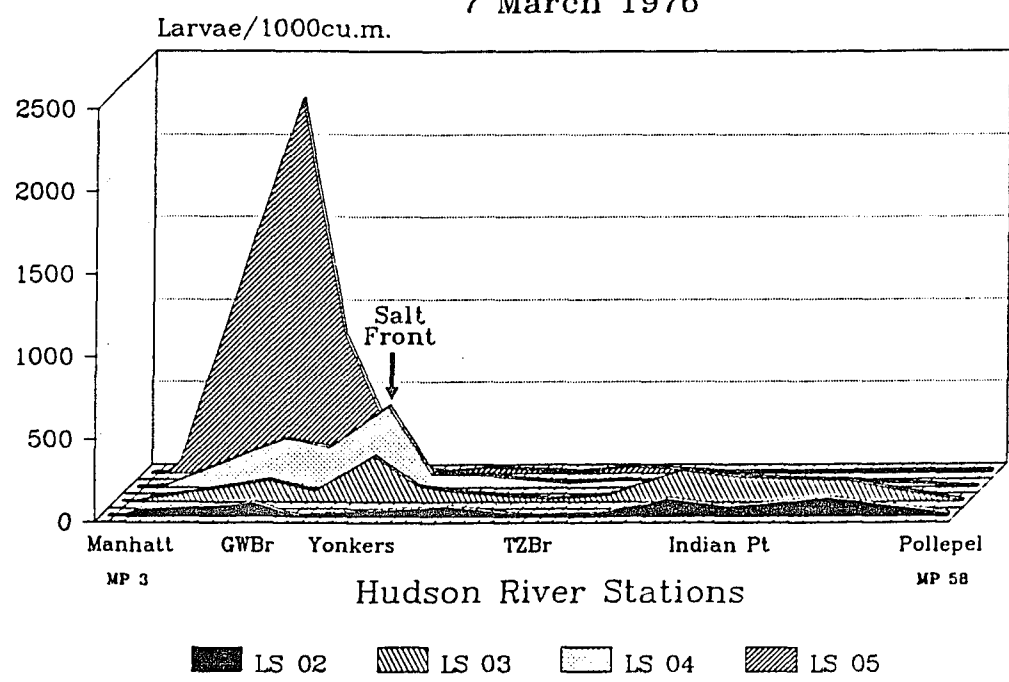
7-14 March 1976. Judging by the rapidity of this mass movement, a minimum of weekly sampling during February-April would be necessary to document, in any meaningful fashion, the spatiotemporal distribution of the tomcod population and its attendant vulnerability to power plant entrainment. Klauda et al. (1988), employing a biweekly (once every 2 weeks) sampling design, show in their Table 46 and Fig.60 that source population density of tomcod yolk-sac and post yolk-sac larvae within TI's Indian Point region (MP 39-46) did not exceed 320 larvae/1000 cu.m. during March 1976; in contrast, my data show concentrations at North Haverstraw Bay (MP 39) and Indian Point (MP 43) of 500-3500 larvae/1000cu.m. on 14 March 1976. Such order-of-magnitude differences demonstrate the necessity for increased sampling frequency during periods when large changes occur rapidly.

Regarding the movements of tomcod larvae during February-May 1976, Klauda et al. (1988) stated, "There appeared to be a gradual displacement of larvae from the spawning area into the downstream regions (km 19-53) [MP 12-33] by early May." My data, instead, showed saltatory movement both downstream and upstream during this time, and also showed that peak population densities greater than 2700/1000 cu.m. already existed at MP 11 by 7 March 1976. It is understandable, however, that data from a biweekly sampling regime during this period might well have given the appearance of a gradual downstream movement that took approximately two months to be completed.

Figure 51. Distribution of four tomcod life stages in relation to salt front movement during 7-14 March 1976.

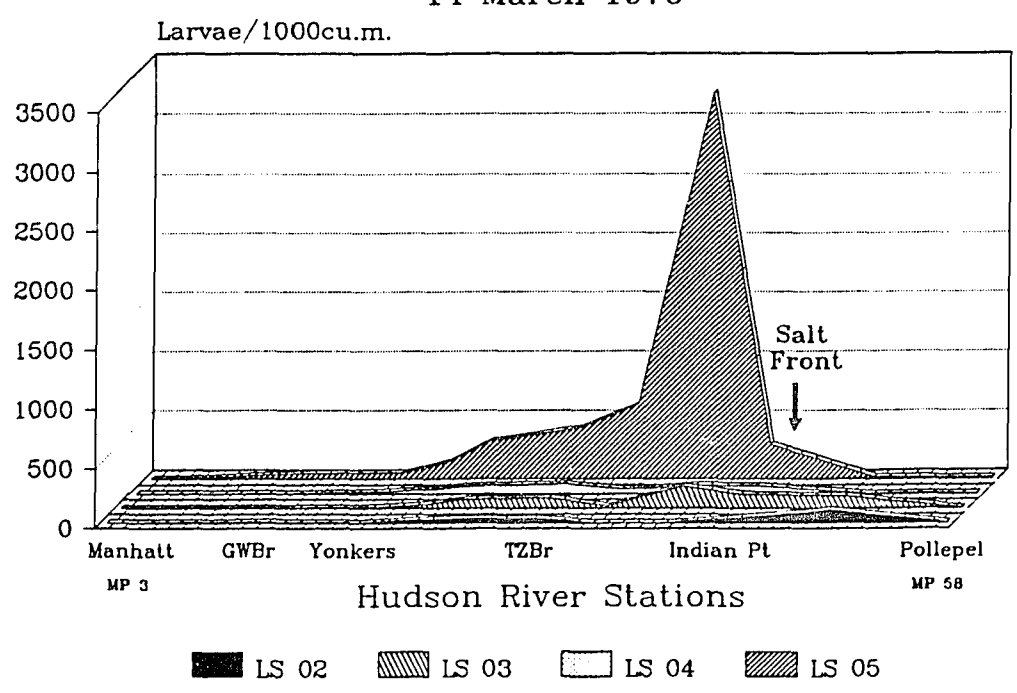
Tomcod Distribution With Salt Front At MP 19-20

7 March 1976



Tomcod Distribution With Salt Front At MP 43-44

14 March 1976



In their Materials and Methods section, Klauda et al. (1988) stated that TI's sampling effort within river regions was "allocated by a stratified random design keyed to the observed distributions of tomcod early life stages in prior years". In 1976, Dew and Hecht had published a Hudson River symposium paper which showed the occurrence of peak tomcod concentrations at Manhattan (MP 3) and George Washington Bridge (MP 11) during 1973-1975, but it is apparent that the allocation of sampling effort by Klauda et al. (1988) took no cognizance of these observations. During 1976 I found substantial proportions of the total tomcod population residing seaward of the Klauda et al. (1988) downstream sampling boundary (MP 14) on 8 of 14 sampling dates from mid-February to mid-May 1976. The modal geographical location for high-density (avg > 2300/1000 cu.m.) bottom collections during 1976 was the George Washington Bridge-Harlem River segment (MP 11-14) (Fig.29).

It is one thing to implement a sophisticated, large-scale sampling design with knowledge that it does not representatively sample a given population; but it is quite another then to model the extent of downriver displacement of this same population by weighted mean daily freshwater flow, as was done in Klauda et al. (1988). To estimate the extent of downriver displacement of the tomcod population for a given year, they used the percent of total standing crop found in the Yonkers region, their most downstream sampling region. When the Yonkers percent of total standing crop was

high for a given year, they concluded that the population had undergone greater downstream displacement via February-April freshwater flows in that year. The tacit assumption, of course, was that the greatest proportion of the actual total standing crop always resided in those river regions upstream from MP 14. In reality, according to my 1975 and 1976 data, a large proportion of the tomcod population, for a large part of the time from March through May, resided downstream from those river regions that were the focus of TI's 1500-tow, March-May sampling program. It is apparent from Figs. 60 and 62 in Klauda et al. (1988) that the years for which the greatest downstream displacement was estimated actually were periods when the landward fringe of the population epicenter had moved upriver into their sampling area, and were therefore periods of relatively low downriver displacement. This helps to explain the disconcerting conclusion by Klauda et al. (1988) that downriver displacement of the tomcod population was approximately 3.3 times greater in 1975, as compared with 1976, despite the observation that average freshwater flow for February-April 1976 was about 45% greater than the comparable flow for 1975.

III. GROWTH

Results from my study showed that population growth rate (G_x) was a negatively biased estimator of true growth rates within larval populations, and that individual growth rate (G) was a better estimator. Recruitment effect was the primary cause of this negative bias, although I showed that

some correction could be made for this bias early in the season by including only those older larvae from Yonkers (MP 18) and below in G_x calculations. McLaren et al. (1988), using data from the same ichthyoplankton collections as Klauda et al. (1988), analyzed growth only for that portion of the tomcod population present upriver from Milepoint 14. McLaren et al. (1988) presented their growth data in the form of an absolute increase or growth increment (mm/day), rather than as an instantaneous rate. They did not relate these daily increments to fish size, although increment size necessarily increased with fish size despite the constant instantaneous rate of growth. Therefore it was not feasible to compare rates between growth stanzas presented for the same year class (their Table 37), or to compare their findings with mine, without first transforming their incremental data into instantaneous rates. This transformation was accomplished by using their daily increments to reconstruct length-at-age data beginning with my calculated dates of peak hatch (5 March 75; 11 March 76). Then, using the same L_0 values calculated from my data for 1975 and 1976, I obtained the McLaren et al. (1988) G_x as the slope for \ln length (mm) vs. days from hatch. The growth equations resulting from this exercise (Table 30) are plotted in Fig.52. Consistent with expectation, the G_x values of McLaren et al.(1988), estimated for March to mid-May, were lower than my G values by 18% for 1975 and by 21% for 1976. Estimated length-at-age for 30 June 1976 was only 6.1% less for McLaren et al. (1988) fish (Table 30), but substantive

differences in how the population arrived at this end-point (Fig.52) would profoundly affect biomass production estimates.

Inasmuch as the relationship between growth and temperature was not the same for 1974, 1975, and 1976, (because change in length per unit change in temperature [slope] was not the same [Table 17; Fig.34]), a conclusion of my study was that temperature alone was not a good predictor of tomcod growth rates during the period from hatch to 22 mm. Nevertheless, my correlations between length and temperature were always highly significant, as expected for a temperate-zone organism beginning life in early spring. McLaren et al. (1988) described at length how tomcod yolk-sac larvae began a period of growth that was highly correlated with prevailing water temperatures; but if the authors had pursued this analysis into the autumn, they would have just as surely described a negative correlation between growth and temperature. Such correlations may be irrelevant, and Sokal and Rohlf (1981) call attention to this problem with the following admonition:

"Some correlations have time as the common factor, and processes that change with time are frequently likely to be correlated, not because of any functional biological reasons but simply because the change with time in the two variables under consideration happens to be in the same direction. Thus, size of an insect population building up through the summer may be correlated with the height of some weeds, but this may simply be a function of the passage of time. There may be no ecological relation between the plant and the insects."

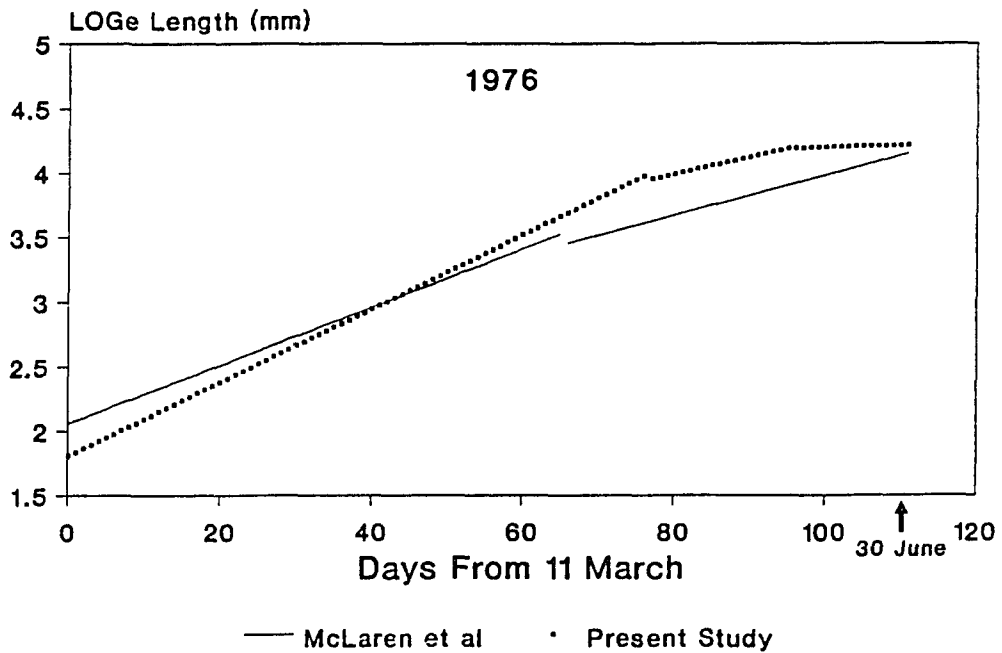
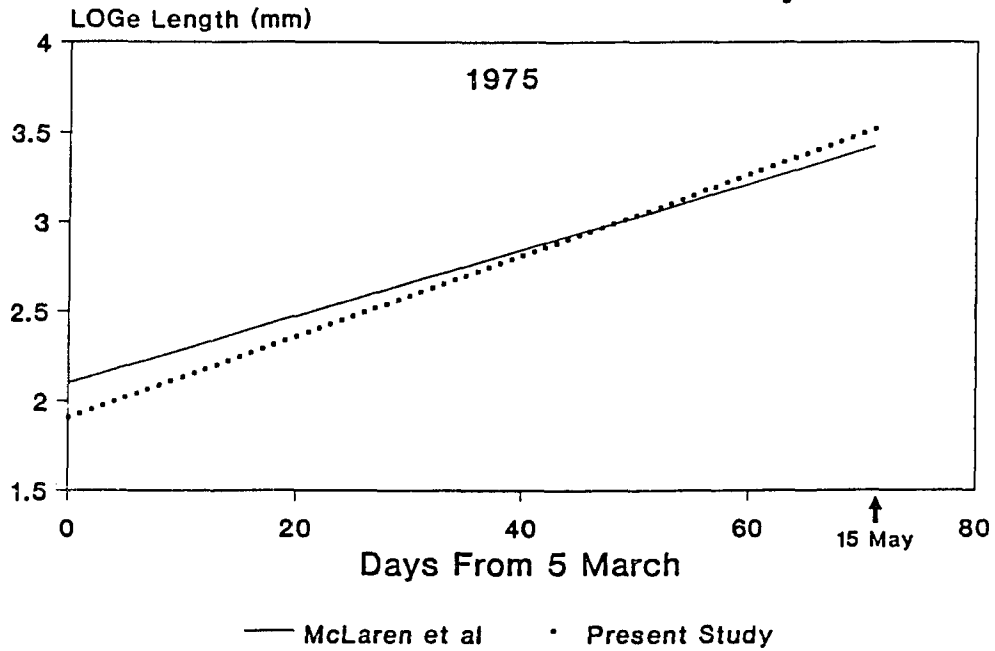
Table 30. Tomcod growth for the 1975 and 1976 cohorts reconstructed from McLaren et al. (1988) (Table 37), as compared to growth data from the present study.

Table 30. Tomcod growth for the 1975 and 1976 cohorts reconstructed from McLaren et al. (1988, Table 37), as compared to data from the present study.

		1975	
		<u>McLaren et al (1988)</u>	<u>Present Study</u>
5 March-15 May:		$\ln Lt = 2.1035 + 0.0186t$	5 March-15 May: $\ln Lt = 1.9061 + 0.0227t$
Final Length (mm)			
15 May		30.7 (-9.8%)	33.7
		1976	
		<u>McLaren et al (1988)</u>	<u>Present Study</u>
11 March-15 May:		$\ln Lt = 2.0595 + 0.0225t$	11 March-26 May: $\ln Lt = 1.8058 + 0.0285t$
16 May-30 June:		$\ln Lt = 2.4293 + 0.0155t$	27 May-15 June: $\ln Lt = 2.9251 + 0.0133t$
			16 June-30 June: $\ln Lt = 4.0255 + 0.0017t$
Final Length (mm)			
30 June		63.5 (-6.5%)	67.6

Figure 52. Comparison of tomcod growth for the 1975 and 1976 cohorts as estimated by McLaren et al. (1988) using G_x , and the present study using G .

Comparison Of Tomcod Growth McLaren et al. vs. Present Study



IV. MORTALITY

With regard to mortality analysis, Beverton and Holt (1956) have stated:

"In general, the estimation of mortality parameters makes a greater demand on the sampled data, with regard to both their extent and reliability, than does the analysis of any other factor; and it is probably true to say that if an adequate sampling system can be devised for this purpose it will almost certainly provide satisfactory measures of other parameters."

The corollary of this may be that if a population sampling program is unable to provide meaningful information on relative abundance and distribution, it must certainly be inadequate to provide useful estimates of absolute abundance and mortality. McLaren et al. (1988), using the same data base for abundance and distribution as Klauda et al. (1988), calculated mortality as the rate of decline in the February-July population of larval and early juvenile tomcod, as estimated from TI's Tucker trawl and epibenthic sled sampling program. In choosing to use these data to provide mortality estimates, McLaren et al. (1988) had to assume that the sampling was representative of the entire tomcod population (or a constant fraction of that population) from one sampling date to the next, from late February into July. Evidence suggests that this crucial assumption was unfulfilled, and comparisons between mortality rates from my study and those from McLaren et al. (1988) probably are not meaningful.

Results from the present study showed that the Hudson River Atlantic tomcod population during 1975 and 1976 sustained mortality rates estimated to range between 3.8-6.3% per day ($Z = 0.0382$ to 0.0652) within the first 2-3 months (76 days) after hatching, while growing from 7-63 mm in total length. Such rates are low in comparison with those of published studies for other species. Hackney and Webb (1977), using computational methods similar to mine, obtained a Z-value of 0.1068 for a population of larval crappie (Pomoxis sp.) in a Tennessee reservoir. This value was reduced to $Z = 0.0704$ for the same population in a subsequent paper (DeAngelis et al. 1980). Pearcy (1962) estimated a loss rate, attributed mainly to natural mortality, of 20% per day ($Z = 0.2231$) and 4% per day ($Z = 0.0408$) for small larvae and post-larvae, respectively, of an estuarine population of winter flounder (Pseudopleuronectes americanus). Sundby et al. (1988) reported a Z-value range of 0.0685-0.1315 during the period from hatch to post-larvae for Arcto-Norwegian cod (Gadus morhua).

It is common for mortality estimates to be biased high because of emigration of the fish out of the sampling area and/or increasing gear avoidance as their swimming ability increases with growth. Only two sources of error can cause mortality estimates to be biased low: 1) immigration of additional organisms into the sampling area, and 2) recruitment of new organisms produced within the sampling area. Based on the aspects of tomcod life-history documented

by this and other studies, recruitment of new larvae into the sampling area after late March, to a degree that could bias mortality estimates, is a most unlikely event.

As far as immigration and emigration are concerned, sampling within the Verrazzano Narrows (MP -6) during 1975 was initiated to detect such movements, but no tomcod ever were collected at this station. Moreover, my program was designed to move with the tomcod population and to sample the entire longitudinal distribution present on each sampling date. The goal for each date was to begin sampling at one tail of the distribution, and to move upriver (or downriver) through the main body of the population to the other tail. Near the beginning of hatch, this goal was accomplished with mixed success, as pointed out in footnotes to Appendix III. The task became more straightforward as association was established between the main body of the population and the salt front. I am convinced that recruitment, immigration, and emigration did not cause any significant bias to the mortality curves I calculated for February-May 1975 and 1976.

The substantial increase in mortality that became apparent after 30 April 1976 (Fig.49) deserves some comment. In Sec.III.3 of the Results, an analysis of sampling gear bias provided evidence of increasing mortality directed toward smaller fish beginning in early May 1976. This analysis was based on length data independent from the mortality analysis, thus providing some reassurance that the

observed increase in tomcod mortality was not a sampling artifact caused by gear avoidance. Furthermore, the abundance and distribution data indicated that the observed increase in rate of decline for estimates of tomcod standing crop was not caused by upstream emigration out of the sampling region. Data in Table 12-76 through 15-76 in Appendix I show that the location of peak tomcod abundance during May was between the Statue of Liberty (MP 0) and the Tappan Zee Bridge (MP 30), and that tomcod density upstream from Croton Point (MP 34) was zero after 1 May. It is also doubtful that May water temperature directly caused the increased mortality observed during that month. Density-weighted average water temperature on 1 May 1976 was 52.1°F (11.2°C), well below the upper lethal temperature of 79.7°F (26.5°C) reported for tomcod (EA 1978; cited in McLaren et al. 1988).

The overall picture is one of an apparently healthy population whose individual members had passed through the more commonly postulated "critical phases" and were experiencing exponential growth in a nutrient-enriched environment where food items were continually being replenished by tidal and freshwater mixing. If environmental factors such as lethal temperatures or toxicity were primary causes of tomcod mortality during the March-May periods for which I have data, I would expect to see a straight-line mortality curve, the cause of which was the daily death of a constant number of fish representing a constant fraction of

the initial population. In such a situation, the larger fish would have a greater probability of dying than the smaller ones. Instead, the mortality curves I have calculated for the 1975 and 1976 tomcod cohorts indicate that a constant fraction of the number of fish present at the beginning of each day were dying during that day, i.e., the number of individuals dying each day was decreasing with increasing age and length. Size-selective predation is a likely explanation for such a mortality pattern.

Upon hatching, fish larvae are typically vulnerable to a large variety of predators which may include predaceous invertebrates as well as vertebrates. For example, Percy (1962) reported that predation by Sarsia tubulosa, a small, numerically dominant hydromedusa, appeared to be an important source of mortality for newly-hatched flounders. Envisioning a predator pyramid of numbers by size (Elton 1966; Odum 1971), with its base composed of the smallest and most numerous predators, fish larvae would rapidly escape predation pressure through exponential growth. Depending on the components and shape of the predator pyramid, this "escape" would not necessarily represent a smooth curve, especially since some predators may become more active at threshold temperatures.

The most likely predators to cause discontinuity in the survival curve for juvenile tomcod that are growing away from their predator base are yearling striped bass, which begin a

cycle of intensive foraging in the spring, after a relatively inactive overwintering period. Striped bass are known to change from an invertebrate diet in their first year of life to an increasingly piscivorous one as yearlings (Markle and Grant 1970; Manooch 1973). In the Hudson, during a cursory field examination in July 1971, I found young-of-the-year tomcod in the stomachs of yearling striped bass from Haverstraw Bay (MP 37), and one 175-mm specimen contained 13 tomcod, each of which was 25-30 mm long. Data from Gardinier and Hoff (1982) showed that tomcod comprised 23% of the diet of yearling (76-200 mm) striped bass during June 1974, but that no tomcod were found in striped bass stomachs during April-May. All striped bass examined by Gardinier and Hoff (1982) were collected between Croton Bay (MP 33) and Bear Mountain Bridge (MP 46). My data indicate that 0-age tomcod were rarely found upstream of the Tappan Zee Bridge (MP 30) during April-May 1974-1976, and it is expected that no tomcod would be found in stomachs of striped bass collected from MP 33-46 during these months. Although we know from Gardinier and Hoff (1982), as well as my own observations, that yearling striped bass from the middle reaches of the estuary utilized tomcod as forage fish when they were available, it appears that no sampling program has been designed to provide any direct answers to the question of whether or not yearling striped bass exert substantial predation pressure on young-of-the-year tomcod during April and May, i.e., enough pressure so that an increase in the feeding rate of striped bass could result in the mortality

rate increase observed for tomcod after 30 April 1976. I must therefore approach this question by drawing upon circumstantial evidence.

The purpose of the following discussion is not to provide an answer to the question of whether a significant predator-prey relationship exists between yearling striped bass and young-of-the-year Atlantic tomcod. Instead, drawing upon known details of the life histories of these two species, this discussion represents a framework within which to formulate a guideline hypothesis to be tested in future studies. Certain details of tomcod life history, as brought to light in this thesis, e.g., spatiotemporal distribution of tomcod and their pattern of growth, are merely consistent with, but provide no evidence for the hypothesis that Atlantic tomcod serve as a primary forage fish for striped bass. On the other hand, data from the mortality analysis, in conjunction with length-frequency data, provide indirect, quantitative evidence for size-selective predation on Atlantic tomcod. I will present, in some detail, relevant aspects of striped bass life history to show that they are the most likely predator to have caused the observed mortality trend, and to suggest reasons why previous studies may have overlooked an ecological link between these coexisting fish species.

First of all, it is important to determine whether it is reasonable to assume that yearling striped bass remained in

the estuary during late winter-early spring in sufficient numbers to have been able to cause the increase in tomcod mortality noted after 30 April 1976. The prevailing scenario, based on TI's striped bass sampling program during the 1970's, was that young-of-the-year striped bass remained in the Hudson River until early fall when they dispersed seaward from the estuary to continue their life cycle (Dey 1981; Young et al. 1988). Although some proportion of the young-of-the-year striped bass population, especially in years of strong year-classes, may leave the estuary, the concept of an annual, large-scale, autumnal exodus of young-of-the-year from the lower estuary to overwinter in a marine environment is not supported by tagging studies reported in the older literature. Alperin (1966) reviewed all available tagging records for Hudson River striped bass and found no evidence that the river stock reached the south shore of Long Island to any appreciable extent, except in the vicinity of New York City. Alperin (1966) pointed out that "...it is well established that small striped bass, particularly those less than 2 years old, are relatively non-migratory. Vladykov and Wallace (1938; 1952), Merriman (1941), Raney (1952; 1957), Mansueti (1961), and Massman and Pacheco (1961) have all commented on the non-migratory behavior of small striped bass and their tendency to remain in or near restricted river systems."

Nor is the concept of a large-scale, autumnal emigration by young-of-the-year striped bass supported by more recent

data collected from the spatiotemporal domain of interest, i.e., that region of the estuary seaward of the George Washington Bridge (MP 12) in winter. In 1980, I authored the Westway report (LMS 1980), which showed that during October 1979, young-of-the-year and yearling striped bass, presumably coming from upstream, began to move into the river region near Manhattan (MP 1-4). After increasing during November and December, the Manhattan population of juvenile striped bass peaked in January at average catch levels of approximately 330 fish per 10-min bottom trawl, a level that was greater than I had observed during 10 years of trawling throughout the lower estuary from above Kingston (MP 95) to Piermont (MP 24). On 21 April 1980, trawl concentrations of juvenile striped bass in the vicinity of Manhattan remained at an average level of approximately 150 fish per 10-min trawl. To define the distribution of overwintering juvenile striped bass more accurately, Mr. Jack Hecht of LMS and I conducted an exploratory bottom-trawl survey during the week of 20-27 February 1980 from MP -11.5, outside the estuary, to Haverstraw Bay (MP 37.5). This showed peak striped bass concentrations at Manhattan (MP 1.8) with lesser peaks at Yonkers (MP 18) and Piermont (MP 24.4). Bar graphs of data from these investigations, showing the spatial and temporal distributions for juvenile striped bass in the lower estuary, have been reproduced in Moran and Kiefer (1986) and indicate a substantial presence for young-of-the-year and yearling striped bass overwintering within the estuary during 1979-80.

Several sources point to the fact that, in other years, juvenile (and adult) striped bass have heavily utilized Hudson River areas other than Manhattan for overwintering. Impingement rates during the 1970's for juvenile striped bass at power plants located between MP 37 and MP 43 were typically greatest, often by orders of magnitude, during the months of December-April, as documented in numerous reports to the utilities, e.g., Orange and Rockland Utilities (1973, 1974, 1975), U.S. Nuclear Regulatory Comm. (1975), McFadden (1977), McFadden and Lawler (1977), Barnthouse et al. (1979), and as shown for 1975 in McDowell (1986). Clark (1968) reported the presence of large overwintering populations of striped bass in the Haverstraw Bay region of the Hudson, as confirmed by data from tag returns, bottom-trawl catches during 6-8 March 1968, and by an extensive impingement kill of striped bass at the Indian Point plant (MP 42) in February 1963. A detailed account of the 6-8 March 1968 survey, provided by Dr. Edward C. Raney⁶ (pers. comm.), showed that approximately 40% of the 580 overwintering striped bass collected in the vicinity of MP 39 were juvenile fish. A January-April 1983 bottom-trawl survey conducted by LMS Engineers revealed that overwintering striped bass from the 1982 year-class were distributed from the Bear Mountain Bridge to Upper New York Harbor, with the population epicenter located between MP 22 (Jan-Feb) and MP 13 (April) (LMS 1984).

⁶Dr. Edward C. Raney, Director, Ichthyological Associates, 301 Forest Drive, Ithaca, NY 14850.

Based on these sources of information, it is apparent that juvenile (and adult) striped bass typically utilize a large segment of the Hudson River from MP 0 to MP 47 for overwintering. Optimal overwintering locations within the lower Hudson vary from one year to the next, or within a single year, based on changes in the longitudinal salinity distribution; salinity distribution, in turn, is governed by the freshwater runoff which is strongly influenced by the winter temperature and precipitation regimes of the entire Hudson River watershed.

Freshwater flows during January-May 1976 were high as compared with the long-term average flows for 1918-1976 (Table 7). If we accept the premise that striped bass seek some optimum salinity range within which to overwinter, as hypothesized by Clark (1968), it would follow that this salinity range would occur farther downriver in January-May 1976 than in years of lesser flows, such as those of colder winters when proportionally more watershed precipitation was locked up as snow and ice. Based on Westway data for winter-spring 1979-1980, it is reasonable to assume that a large proportion of the overwintering juvenile striped bass population was located downriver from the George Washington Bridge (MP 12) during March-April 1976, as well. Young et al. (1988) have provided a late fall population estimate for 1975 young-of-the-year striped bass of 2.2 million (95% CI 1.5-3.6 million); this may have been reduced through mortality to, say, 1.0-1.5 million by April-May 1976. Thus,

through the synchrony of estuarine hydrodynamics, seasonal activity levels, and reproductive timing, the stage appears to have been set for a classic predator-prey interaction.

During April and May of each year there is no species of forage fish available to Hudson River yearling striped bass as abundant or suitable, in terms of size and morphometric characteristics (e.g., soft rays vs. spiny rays), as the Atlantic tomcod. In the York and Rappahannock Rivers, Virginia, where Markle and Grant (1970) conducted their study, the naked goby, Gobiosoma bosci, served as the principal forage fish for young striped bass. They concluded that the ability of striped bass to change to a fish diet, as they grew larger, depended on the availability of this small, benthic fish. Manooch (1973) showed that soft-rayed fishes were much preferred by striped bass over spiny-rayed fishes such as white perch, and that in Albemarle Sound, NC, juvenile clupeids (herring) and anchovy, Anchoa mitchilli, were the principal forage groups. Both are available in the Hudson, but not during April and May. Manooch (1973) described the relationship between the size of striped bass predators and the size of their preferred forage fish as

$$Y = .22X - .25$$

where X = total length of striped bass (inches) and Y = total length of forage fish (inches). For Hudson River yearling striped bass 100-150 mm (3.94-5.91 inches) in length, a

preferred forage-fish size according to this equation would be 16-27 mm. The increased mortality rate noted for Hudson River tomcod after 1 May 1976 occurred at a length of 24-25 mm (Fig.49). Markle and Grant (1970) pointed out that much of the variation in food habits evident in published studies of young striped bass may simply reflect differences among collection sites, with salinity being the primary varying factor between sites. They found that the percentage of fish in diets of striped bass was greater in waters of higher salinities. This may be true for the Hudson River as well, given that young tomcod were most abundant downriver from the salt front (1.0 ppt) during April-May 1975 and 1976.

Based on my mortality analysis for the 1976 tomcod cohort, the population sustained a 27% increase in mortality, beginning in late April. Given that the bulk of the striped bass population did not leave the estuary immediately after the first year of life, and that they overwintered mostly downriver of the George Washington Bridge (MP 12), there must have been more than one million yearlings present in early April, ready to move upstream into those river segments where the Atlantic tomcod population, estimated at about 500 million in mid-April (Table 27), was concentrated in a relatively small volume of water associated with the 1.0 ppt salinity front. It now remains to be determined if the timing of the observed increase in mortality for tomcod is congruent with known seasonal feeding and growth patterns for striped bass.

Setzler et al. (1980) have presented data from Scofield (1931) and Vladykov and Wallace (1952) for California and Chesapeake Bay striped bass which showed a sharp resumption of growth in April after their first winter. Otwell and Merriner (1975) showed in the laboratory that growth for Age-0 striped bass was <1.0% at 12°C (53.6°F) and that growth was significantly higher at a salinity of 12 ppt vs. 4 ppt or 20 ppt. Koo and Ritchie (1973) reported that tagged Age 0-I striped bass in the Patuxent River, Maryland, showed no growth during November through April. They also found that monthly growth in the laboratory of yearling striped bass (avg. 176 mm FL) was 0% during December-April and 4.6% during May. They observed no growth or feeding at water temperatures <10.0°C (<50.0°F). Mean bottom water temperature from Manhattan (MP 3) to Hook Mountain (MP 32) was 48.7°F (9.3°C) on 17 April and 51.4°F (10.8°C) on 24 April 1976, a mean temperature of 50.0°F (10.0°C) for the two dates combined. The facts at hand present a plausible argument for accepting the observed increase in tomcod mortality as a real phenomenon, possibly associated with increased predation by striped bass, rather than an artifact of sampling.

Temperate-zone species of fishes most commonly exhibit a growth pattern in which the greatest increment in length is achieved during the first year of life. For example, such a growth pattern was found in Hudson River white perch (Morone americana) by Bath and O'Conner (1982) and by Klauda et al. (1988a). Hudson River striped bass, however, typically

exhibit a growth curve for which the greatest incremental change in length occurs during the second year of life, between Ages I and II (e.g., Table 31; LMS, unpub. data). Other authors have reported a similar growth pattern for striped bass from the Hudson River (TI 1974a; cited in Westin and Rogers 1978), from Chesapeake Bay (Mansueti 1961), from California (Scofield 1931; Robinson 1960), and from the St. Lawrence River (Magnin and Beaulieu 1968). For the striped bass, a species known to switch as yearling fish to a piscivorous diet, the availability of suitable forage fish may affect the degree to which maximum growth occurs in the second year of life, generally acknowledged to be the last year of continuous residence within an estuary, especially in the case of successful year classes (Merriman 1937, 1941; Raney and Weller 1972). Young tomcod are the only abundant, suitably-sized forage fish available in the Hudson from April to July-August, after which young anchovy and clupeids increase in availability. Inasmuch as size is important to survival within any marine ecosystem, maximized growth within the relatively protected confines of the estuary may help to ensure the annual return of an adequate number of spawners to perpetuate the Hudson River stock of striped bass.

Table 31. Back-calculated growth from scale analysis for 963 striped bass of Ages I-V collected from MP 37-95 during 1971-1978. Average annual increment shows greatest growth in second year of life.

Table 31. Back-calculated growth from scale analysis for 963 striped bass of Ages I-V collected from MP 37-95 during 1971-1978. Average annual increment (mm) shows greatest growth in the second year of life (from Dew/LMS, unpub. data).

Year Class	N	Mean Capture Length (Age)	Calculated Total Length At End Of Year					
			1	2	3	4	5	
1977	313	143.8 (I)	88.4					
1976	43	210.0 (II)	91.6	154.8				
1975	124	319.3 (III)	102.4	197.5	313.3			
1974	63	380.5 (IV)	103.5	212.3	299.6	345.0		
1973	199	462.5 (V)	101.4	205.2	300.8	385.9	461.0	
1972	56		91.3	204.9	342.9	413.0		
1971	105		111.3	178.1	301.8	362.9	391.8	
1970	50		107.7	214.0	235.4			
1969	9		132.8	250.2	354.3	310.0		
1968	1		117.4	246.3	352.4	460.0		
Grand Average			98.1	205.3	303.1	368.5	426.4	
Sample Size			963	261	68	20	2	
Avg. Annual Increment			98.1	107.2	97.8	65.5	57.9	

V. BIOMASS PRODUCTION

A species of fish that grows rapidly through the range of sizes preferred by its predators usually does not qualify as an important forage fish. For example, although gizzard shad, Dorosoma cepedianum, have some value as forage fish, their rapid growth soon makes them too large for many predatory fishes (Swingle 1946; Bodola 1966). An ideal forage fish might have the following characteristics:

- 1) To be present at the time when its predators are physiologically ready to begin a stanza of rapid growth.
- 2) To be present at the time when other suitable forage species are mostly absent.
- 3) To exhibit a growth curve that brings it rapidly to optimum prey-size, and then abates.

As a forage fish for yearling striped bass, the Atlantic tomcod shows all of these attributes. Attribute 3 is illustrated in Fig.50, which shows the relationship between tomcod population size, biomass production, and standing biomass for two scenarios: 1) the data as analyzed, with a mortality increase after Day 43, and 2) constant mortality from hatching to Day 84.

Postulating that the observed increase in mortality resulted from intensified cropping by striped bass, it can be seen from Fig.50 that cropping began when juvenile tomcod

were at a length of 24-25 mm, while production, production rate, and standing biomass were accelerating due to an exponential rate of growth in weight. After the hypothesized cropping began on Day 44-45, daily rates of production and accumulation of biomass, after showing a downward jog (caused by the artificially sudden change in mortality rate used in the model), resumed their accelerative pace, still driven by exponential growth. On the other hand, total production, i.e., the integral of (or the area under) the production rate curve, was reduced to a new, lower level. This relationship between accelerating rates and semi-stable total production continued until late May (Day 71). Then, at a length of 53-54 mm, tomcod growth rate decreased by 53%, sending the Z:G ratio above 1.0, thus beginning a period of decline in both production and biomass. According to Dew and Hecht (1976), tomcod growth rate continued its decline after mid-June, and periods of negative growth may have occurred in response to maximum summer water temperatures during July-September (McLaren et al. 1988). In summary, it is evident that within approximately one month of attaining optimal forage-fish size for yearling striped bass with a length of 100-150 mm, tomcod growth rate abated, thus extending the fish's vulnerability and availability to the primary piscivorous fish species resident to the Hudson River.

CONCLUSIONS

1) Data from 1975 and 1976 indicated an early February hatching pulse of small magnitude, followed by initiation of sustained hatching in mid-February. In both years hatching rates peaked during the first week of March, and hatching had been completed by mid-March. Egg incubation from peak spawn to peak hatch was estimated as 60 days at winter water temperatures of about 1.0-1.5°C. The river location with the greatest hatching activity in both years was the Indian Point-Con Hook region (MP 42-54), and hatching production upstream from MP 54 was low in both years.

2) Larvae were hatched from eggs on or near the bottom and subsequently were distributed passively throughout the water column; then, as post yolk-sac larvae, the fish moved actively into the bottom layer as they approached the 1.0 ppt salinity intrusion boundary, several miles downriver from hatching locations.

3) For 1973-1976, peak tomcod density during the post-hatch period was observed most frequently at the George Washington Bridge station (MP 11). Magnitude of peak densities was highest in water of 9500-13000 umhos/cm conductivity (8.0-11.0 ppt salinity), and peak densities for all post-hatch sampling dates were located seaward of the 1.0 ppt (1200 umhos/cm) salinity front.

4) The calculated relationship between tomcod population location and freshwater flow predicted ($R^2 = 0.71$) that the population epicenter will be located seaward of the Tappan Zee Bridge (MP 30), under all normal flow regimes, from mid-March to early May. Under flow regimes approaching or exceeding 40,000 cfs, the epicenter will be located near or downstream from the George Washington Bridge (MP 11).

5) Mean length for recently-hatched larvae during 1975 and 1976 was 7.0 mm. Because the larvae hatched on or near the bottom, they were not fully recruited to the above-bottom sampling nets until they reached a length of 8-9 mm, after they had been passively distributed up into the water column by vertical turbulence.

6) The growth rates (G_x) calculated from changes in mean length through time for the entire year-class population, without accounting for age differences between cohorts, were negatively biased estimators of true or individual growth rates (G) within the larval tomcod population. For a given magnitude and duration of recruitment, this bias will be more pronounced in years of higher growth rates.

7) Tomcod growth rates (G_x) from early April to mid-May were significantly ($P < 0.001$) different for 1974, 1975, and 1976; G_x was lowest during the coldest spring of 1975.

8) Cumulative degree-days, a measure of area under a time-temperature curve, explained the between-year variation in tomcod growth (G) better than either time or temperature alone. Upon reaching 53 mm on 25 May 1976, with 4322 degree-days accumulated in the system since 21 February, the tomcod G decreased by 53% as water temperatures surpassed 13°C.

9) Analysis of length-frequency distributions, including changes in coefficient of variation and skewness, suggested a continuous trailing behind of slower-growing fish after hatching. Size-selective mortality apparently thinned the ranks of these smaller fish during May 1976.

10) Standing crop and mortality estimates showed initial standing crops of 1.8 billion tomcod larvae for 1975 and 3.0 billion for 1976. The larval standing crop was reduced to a level of 241 million and 256 million by the end of April 1975 and 1976, respectively. After 30 April 1976, while the tomcod grew from 25 to 53 mm, mortality increased by about 27%, and the population died at a rate of 6.3% per day and was reduced to the level of approximately 34 million fish by late May 1976.

11) The Atlantic tomcod was determined to have the characteristics of an ideal forage fish for yearling striped bass on the basis of the following criteria:

- a. It was present at the time when yearling striped bass were physiologically ready to begin a stanza of rapid growth
- b. It was present at the time when other species of suitable forage fishes were largely absent
- c. Its growth curve brought it rapidly to optimum prey size, and then abated.

12) In mid-April 1976, shortly before tomcod mortality was observed to increase by 27%, there were approximately 500 million tomcod of optimum prey size concentrated in a relatively small volume of water estimated to be in the same river segment as some 1 million yearling striped bass, ready to begin a season of maximum lifetime growth.

APPENDIX I

I. Physical data, tomcod abundance, and mean length by sampling station and date for 1974, 1975, and 1976. 35p.

Table 1-74. Physical data and tomcod abundance for stations sampled on 6-7 April 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-6														
2 Statue Liberty	0														
3 Manhattan	3		45.5		16.0		17500		8		334.4		23.9		9.6
4 79thSt Boat Basin	6														
5 Geo. Washington Br	11		45.5		11.1		21090		213		280.2		760.2		9.7
6 Harlem River	14														
7 Yonkers	18														
9 Piermont Shallows	24		44.6		2.0		3502		14		235.5		59.4		7.6
9 Piermont Channel	24		43.2		1.1		1665		234		244.9		955.5		8.2
10 Tappan Zee Br	30														
11 Hook Mountain	32														
12 Croton Point	34														
13 Bowline	37		42.4		0.2		300		29		334.4		86.7		7.5
14 No. Haverstraw Bay	39														
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
										Wtd					
										Avg		377.1		Avg	
										Tot		0 498		8.7	

* MP = Milepoint as measured from the Manhattan Battery.

Table 2-74. Physical data and tomcod abundance for stations sampled on 13 April 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-6														
2 Statue Liberty	0														
3 Manhattan	3		45.5		22.1		26250		185		164.9		1121.9		10.5
4 79thSt Boat Basin	6														
5 Geo. Washington Br	11		44.6		18.2		21615		260		191.9		1354.9		10.9
6 Harlem River	14														
7 Yonkers	18														
9 Piermont Shallows	24														
9 Piermont Channel	24		45.5		0.1		182		0		261.4		0.0		
10 Tappan Zee Br	30				0.2		206		0		193.1		0.0		
11 Hook Mountain	32														
12 Croton Point	34														
13 Bowline	37														
14 No. Haverstraw Bay	39														
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
												Wtd			
		Tot	0	445		0	811.3	Avg		619.2	Avg		10.7		

* MP = Milepoint as measured from the Manhattan Battery.

Table 3-74. Physical data and tomcod abundance for stations sampled on 27 April 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)					
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom				
1 Verrazano Narrows	-6																		
2 Statue Liberty	0																		
3 Manhattan	3		49.8		25.9		30800		56		193.1		290.0		17.0				
4 79thSt Boat Basin	6																		
5 Geo. Washington Br	11		50.1		5.7		13200		215		166.0		1295.2		17.3				
6 Harlem River	14																		
7 Yonkers	18																		
9 Piermont Shallows	24		49.8		0.4		550		13		240.2		54.1		15.5				
9 Piermont Channel	24		50.0		1.0		1660		1045		217.8		4798.0		17.7				
10 Tappan Zee Br	30																		
11 Hook Mountain	32																		
12 Croton Point	34		50.7		0.1		180		2		222.5		9.0		12.4				
13 Bowline	37																		
14 No. Haverstraw Bay	39																		
15 Indian Point	43																		
16 Con Hook	50																		
17 Pollepel Island	58																		
18 Newburgh-Beacon Br	62																		
19 Danskammer North	69																		
											Wtd								
											Tot	0	1331	0	1039.6	Avg	1289.3	Avg	17.5

* MP = Milepoint as measured from the Manhattan Battery.

Table 4-74. Physical data and tomcod abundance for stations sampled on 4-5 May 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom						
1 Verrazzano Narrows	-8																				
2 Statue Liberty	0																				
3 Manhattan	3		51.6		27.0		32100		2		237.9		8.4		23.6						
4 79thSt Boat Basin	6																				
5 Geo. Washington Br	11		52.4		21.6		25700		83		222.5		373.0		23.6						
6 Harlem River	14																				
7 Yonkers	18																				
9 Piermont Shallows	24	53.6	55.6	2.3	1.7	2700	2000	0	31	226.1	190.8	0.0	162.5		23.9						
9 Piermont Channel	24		53.6		2.3		2700		61		264.9		230.3		24.2						
10 Tappan Zee Br	30	53.5	53.5	0.2	1.1	190	1300	1	13	227.3	260.2	4.4	50.0	30.1	26.3						
11 Hook Mountain	32																				
12 Croton Point	34		52.5		0.2		180		0		226.1		0.0								
13 Bowline	37																				
14 No. Haverstraw Bay	39																				
15 Indian Point	43																				
16 Con Hook	50																				
17 Pollepel Island	58																				
18 Newburgh-Beacon Br	62																				
19 Danskammer North	69																				
											Wtd										
											Tot	1	190	453.4	1402.4	Avg	2.2	137.4	Avg	30.1	24.0

* MP = Milepoint as measured from the Manhattan Battery.

Table 5-74. Physical data and tomcod abundance for stations sampled on 11 May 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-6														
2 Statue Liberty	0														
3 Manhattan	3		53.5		27.3		32400		0		244.9		0.0		
4 79thSt Boat Basin	6														
5 Geo. Washington Br	11		54.1		23.6		28000		113		222.5		507.9		29.5
6 Harlem River	14														
7 Yonkers	18														
9 Piermont Shallows	24														
9 Piermont Channel	24		56.0		7.8		9300		69		243.7		283.1		30.4
10 Tappan Zee Br	30		58.1		0.3		400		33		223.7		147.5		31.6
11 Hook Mountain	32														
12 Croton Point	34		57.0		0.1		170		2		232.0		8.6		39.2
13 Bowline	37														
14 No. Haverstraw Bay	39														
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
										Wtd					
		Tot	0	217			0	1166.8	Avg		189.4	Avg		30.2	

* MP = Milepoint as measured from the Manhattan Battery.

Table 6-74. Physical data and tomcod abundance for stations sampled on 19 May 1974.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-8														
2 Statue Liberty	0														
3 Manhattan	3		54.4		22.7		27000		3		262.6		11.4		42.2
4 79thSt Boat Basin	6														
5 Geo. Washington Br	11		58.9		14.6		17325		0		234.3		0.0		
6 Harlem River	14														
7 Yonkers	18														
9 Piermont Shallows	24														
9 Piermont Channel	24		60.2		5.7		6720		1		282.6		3.5		45.3
10 Tappan Zee Br	30		61.0		2.7		3255		43		207.2		207.5		37.4
11 Hook Mountain	32														
12 Croton Point	34														
13 Bowline	37														
14 No. Haverstraw Bay	39														
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
											Wtd				
											Avg				
Tot		0	47					0	986.7	Avg		55.6	Avg		37.8

* MP = Milepoint as measured from the Manhattan Battery.

Table 1-75. Physical data and tomcod abundance for stations sampled on 22 February 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)				
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom			
1 Verrazzano Narrows	-8																	
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975													
3 Manhattan	3																	
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975													
5 Geo. Washington Br	11																	
6 Harlem River	14	NOT	SAMPLED	DURING	1975													
7 Yonkers	18																	
8 Hastings	21	NOT	SAMPLED	DURING	1975													
9 Piermont	24																	
10 Tappan Zee Br	30	35.7	36.0	4.4	13.2	3400	12900	0	10	229.6	142.5	0.0	70.2		7.0			
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975													
12 Croton Point	34	34.4	35.5	4.0	11.0	2000	11000	0	8	176.6	195.5	0.0	40.9		7.2			
13 Bowline	37	NOT	SAMPLED	DURING	1975													
14 No. Haverstraw Bay	39	35.8	35.5	3.1	9.4	2280	9400	0	8	155.4	164.9	0.0	48.5		7.6			
15 Indian Point	43	34.4	34.2	2.5	3.9	1700	2910	0	20	208.4	151.9	0.0	131.7		7.5			
16 Con Hook	50	34.0	34.0	1.3	1.8	610	1100	6	23	276.7	203.7	21.7	112.9	6.7	8.8			
17 Pollepel Island	58	34.4	34.2	1.2	1.2	490	430	1	0	184.9	174.3	5.4	0.0	7.1				
18 Newburgh-Beacon Br	62	34.7	34.3	1.1	1.2	240	211	2	7	184.9	182.5	10.8	38.4	6.4	6.5			
19 Danskammer North	69																	
												Vtd						
												Avg						
								Tot	9	76	1416.5	1215.3	Avg	5.4	63.2	Avg	6.7	7.1

* MP = Milepoint as measured from the Manhattan Battery.

Table 2-75. Physical data and tomcod abundance for stations sampled on 1 March 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom						
1 Verrazzano Narrows	-6																				
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975																
3 Manhattan	3																				
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975																
5 Geo. Washington Br	11																				
6 Harlem River	14	NOT	SAMPLED	DURING	1975																
7 Yonkers	18																				
8 Hastings	21	NOT	SAMPLED	DURING	1975																
9 Piermont	24	35.2	35.3	1.0	1.0	230	272	9	3	224.9	179.0	40.0	16.8	7.1	7.1						
10 Tappan Zee Br	30	35.8	35.9	0.0	0.0	152	175	11	22	197.8	176.6	55.6	124.6	6.9	7.0						
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975																
12 Croton Point	34	34.6	34.4	0.0	0.0	138	160	12	15	201.4	187.2	59.6	80.1	6.5	6.2						
13 Bowline	37	NOT	SAMPLED	DURING	1975																
14 No. Haverstraw Bay	39	34.5	34.4	0.0	0.0	200	212	6	25	227.3	196.6	26.4	127.2	7.1	7.0						
15 Indian Point	43	34.6	34.4	0.0	0.0	132	150	15	31	220.2	209.6	68.1	147.9	7.1	6.7						
16 Con Hook	50	35.0	35.1	0.0	0.0	150	150	12	14	227.3	216.7	52.8	64.6	7.2	7.1						
17 Pollepel Island	58	35.8	35.7	0.0	0.0	150	150	2	2	202.5	174.3	9.9	11.5	7.0	7.1						
18 Newburgh-Beacon Br	62																				
19 Danskammer North	69	36.2	36.1	0.0	0.0	150	150	1	2	220.2	188.4	4.5	10.6	7.0	6.5						
											Wtd										
											Tot	68	114	1721.6	1528.4	Avg	39.6	72.9	Avg	6.9	6.7

* MP = Milepoint as measured from the Manhattan Battery.

Table 3-75. Physical data and tomcod abundance for stations sampled on 9 March 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-6														
2 Statue Liberty	0	NOT	SAMPLED DURING		1975										
3 Manhattan	3														
4 79thSt Boat Basin	6	NOT	SAMPLED DURING		1975										
5 Geo. Washington Br	11														
6 Harlem River	14	NOT	SAMPLED DURING		1975										
7 Yonkers	18														
8 Hastings	21	NOT	SAMPLED DURING		1975										
9 Piermont	24	35.6	37.6	2.9	8.1	2800	6200	0	60	186.0	230.8	0.0	260.0		8.2
10 Tappan Zee Br	30														
11 Hook Mountain	32	NOT	SAMPLED DURING		1975										
12 Croton Point	34														
13 Bowline	37	NOT	SAMPLED DURING		1975										
14 No. Haverstraw Bay	39	35.2	35.4	1.0	2.1	790	2150	95	266	155.4	140.1	611.3	1898.6	7.9	7.8
15 Indian Point	43	35.0	35.1	0.3	1.1	185	1000	83	194	160.1	235.5	518.4	823.8	7.8	7.5
16 Con Hook	50	36.3	36.3	0.0	0.0	160	170	45	60	138.9	162.5	324.0	369.2	7.3	7.3
17 Pollepel Island	58	36.3	36.3	0.0	0.0	158	160	8	14	143.7	171.9	55.7	81.4	7.4	7.3
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
												Wtd			
		Tot	231	594		784.1	940.8	Avg	301.9	636.6	Avg	7.7	7.7		

* MP = Milepoint as measured from the Manhattan Battery.

Table 4-75. Physical data and tomcod abundance for stations sampled on 16 March 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom					
1 Verrazzano Narrows	-6																			
2 Statue Liberty	0	NOT	SAMPLED DURING		1975															
3 Manhattan	3																			
4 79thSt Boat Basin	6	NOT	SAMPLED DURING		1975															
5 Geo. Washington Br	11	37.2	43.2	8.3	9.8	8300	10200	5	178	160.1	214.3	31.2	830.6	8.5	9.7					
6 Harlem River	14	NOT	SAMPLED DURING		1975															
7 Yonkers	18	39.2	40.1	4.9	6.2	5300	6500	0	435	167.2	253.2	0.0	1718.0		8.2					
8 Hastings	21	NOT	SAMPLED DURING		1975															
9 Piermont	24	38.3	41.0	3.8	6.0	3520	6200	0	812	11.8	261.4	0.0	3106.4		8.2					
10 Tappan Zee Br	30	37.8	38.7	3.3	4.2	3320	4180	2	494	187.2	159.0	10.7	3106.9	8.6	8.1					
11 Hook Mountain	32	NOT	SAMPLED DURING		1975															
12 Croton Point	34	37.4	37.0	1.7	2.1	1480	2020	2	181	199.0	182.5	10.1	991.8	8.0	7.9					
13 Bowline	37	NOT	SAMPLED DURING		1975															
14 No. Haverstraw Bay	39	37.8	37.4	0.3	1.0	460	980	2	409	186.0	197.8	10.8	2067.7	7.9	7.7					
15 Indian Point	43	37.2	37.0	0.5	0.5	300	289	27	71	176.6	173.1	152.9	410.2	7.8	7.5					
16 Con Hook	50	36.5	36.3	0.0	0.0	118	120	36	90	168.4	216.7	213.8	415.3	7.1	7.2					
17 Pollepel Island	58	36.5	36.0	0.0	0.0	253	230	18	11	159.0	167.2	113.2	65.8	7.5	7.3					
18 Newburgh-Beacon Br	62																			
19 Danskammer North	69																			
										Wtd										
										Tot	92	2681	1415.3	1825.2	Avg	60.3	1412.5	Avg	7.5	8.1

* MP = Milepoint as measured from the Manhattan Battery.

Table 5-75. Physical data and tomcod abundance for stations sampled on 23 March 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
1 Verrazzano Narrows	-6														
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975										
3 Manhattan	3	40.2	41.5	6.0	22.0	6000	23200	0	2	199.0	129.5	0.0	15.4	9.8	
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975										
5 Geo. Washington Br	11	40.1	40.1	2.8	17.0	2680	16000	0	130	422.7	228.4	0.0	569.2	9.0	
6 Harlem River	14	NOT	SAMPLED	DURING	1975										
7 Yonkers	18	39.8	40.6	1.5	9.5	1250	10500	0	764	230.8	194.3	0.0	3932.1	8.8	
8 Hastings	21	NOT	SAMPLED	DURING	1975										
9 Piermont	24	39.9	39.7	1.0	2.5	375	2100	21	271	202.5	193.1	103.7	1403.4	7.4 8.1	
10 Tappan Zee Br	30	40.0	40.0	0.8	0.8	340	340	14	9	195.5	186.0	71.6	48.4	7.0 7.1	
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975										
12 Croton Point	34	39.8	39.5	0.7	0.8	288	290	10	14	202.5	176.8	49.4	79.3	7.4 7.3	
13 Bowline	37	NOT	SAMPLED	DURING	1975										
14 No. Haverstraw Bay	39	38.4	38.5	0.0	0.0	310	323	7	9	176.6	177.8	39.6	50.6	7.1 7.3	
15 Indian Point	43	38.0	38.2	0.0	0.0	250	250	3	9	180.2	229.6	16.6	39.2	7.1 7.3	
16 Con Hook	50	39.1	39.0	0.0	0.0	232	230	2	2	207.2	221.4	9.7	9.0	7.6 7.6	
17 Pollepel Island	58	40.0	39.0	0.0	0.0	218	222	4	2	204.9	240.2	19.5	8.3	7.6 7.6	
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
											Wtd				
		Tot	61	1212				2221.9	1976.9	Avg	31.0	615.5	Avg	7.3	8.6

* MP = Milepoint as measured from the Manhattan Battery.

Table 6-75. Physical data and tomcod abundance for stations sampled on 29 March 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)								
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom							
1 Verrazano Narrows	-6																					
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975																	
3 Manhattan	3	40.4	41.0	8.0	15.7	8600	16500	0	303	215.5	398.0	0.0	761.3		10.4							
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975																	
5 Geo. Washington Br	11	39.5	40.4	3.8	7.5	3900	8500	0	200	179.0	201.4	0.0	993.0		10.4							
6 Harlem River	14	NOT	SAMPLED	DURING	1975																	
7 Yonkers	18	38.7	40.0	1.0	4.5	1080	4650	1	122	181.3	190.8	5.5	639.4	8.4	9.2							
8 Hastings	21	NOT	SAMPLED	DURING	1975																	
9 Piermont	24	38.3	38.8	0.5	0.5	230	230	0	2	181.3	200.2	0.0	10.0		7.0							
10 Tappan Zee Br	30	37.7	37.7	0.0	0.0	200	230	0	2	299.1	144.8	0.0	13.8		7.8							
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975																	
12 Croton Point	34	37.7	38.3	0.0	0.0	210	240	4	5	169.6	123.6	23.8	40.5	7.4	6.3							
13 Bowline	37	NOT	SAMPLED	DURING	1975																	
14 No. Haverstraw Bay	39	38.9	39.0	0.0	0.0	210	235	0	3	186.0	167.2	0.0	17.9		7.9							
15 Indian Point	43	39.0	39.0	0.0	0.0	210	240	0	2	166.0	194.3	0.0	10.3		7.8							
16 Con Hook	50																					
17 Pollepel Island	58																					
18 Newburgh-Beacon Br	62																					
19 Danskammer North	69																					
												Wtd										
												Tot	5	639	1577.8	1620.3	Avg	3.6	310.8	Avg	7.6	9.9

* MP = Milepoint as measured from the Manhattan Battery.

Table 7-75. Physical data and tomcod abundance for stations sampled on 6 April 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom					
1 Verrazzano Narrows	-6	39.5	40.0	13.0	19.0	16000	21000	0	0	481.6	203.7	0.0	0.0							
2 Statue Liberty	0	NOT	SAMPLED DURING	1975																
3 Manhattan	3	40.0	40.7	5.0	9.9	4900	17000	0	9	353.3	177.8	0.0	50.6		10.7					
4 79thSt Boat Basin	6	NOT	SAMPLED DURING	1975																
5 Geo. Washington Br	11	39.4	40.7	2.5	7.2	2350	13000	0	14	343.8	302.6	0.0	46.3		12.1					
6 Harlem River	14	NOT	SAMPLED DURING	1975																
7 Yonkers	18	38.8	41.0	1.5	?	1100	12000	0	339	268.5	140.1	0.0	2419.7		12.5					
8 Hastings	21	NOT	SAMPLED DURING	1975																
9 Piermont	24	38.4	38.5	1.5	9.5	1100	11000	0	1513	186.0	210.8	0.0	7177.4		10.8					
10 Tappan Zee Br	30	38.9	39.3	1.2	7.5	900	8500	0	880	232.0	179.0	0.0	4916.2		10.6					
11 Hook Mountain	32	NOT	SAMPLED DURING	1975																
12 Croton Point	34	39.3	39.3	1.0	1.0	300	305	0	5	189.6	176.6	0.0	28.3		11.3					
13 Bowline	37	NOT	SAMPLED DURING	1975																
14 No. Haverstraw Bay	39	38.4	38.6	1.0	1.0	280	320	0	0	194.3	203.7	0.0	0.0							
15 Indian Point	43																			
16 Con Hook	50																			
17 Pollepel Island	58																			
18 Newburgh-Beacon Br	62																			
19 Danskammer North	69																			
											Wtd									
											Tot	0	2760	2249.1	1594.3	Avg	0.0	1829.8	Avg	11.0

* MP = Milepoint as measured from the Manhattan Battery.

Table 8-75. Physical data and tomcod abundance for stations sampled on 12 April 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom						
1 Verrazzano Narrows	-6																				
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975																
3 Manhattan	3	41.9	42.3	13.0	20.0	14000	22500	0	2	131.9	259.1	0.0	7.7		13.6						
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975																
5 Geo. Washington Br	11	41.8	41.9	9.3	15.5	11000	16800	0	86	173.1	149.5	0.0	575.3		14.7						
6 Harlem River	14	NOT	SAMPLED	DURING	1975																
7 Yonkers	18	42.7	42.0	7.0	11.3	8000	12500	0	920	175.4	201.4	0.0	4568.0		13.0						
8 Hastings	21	NOT	SAMPLED	DURING	1975																
9 Piermont	24	42.1	41.5	6.0	7.8	6800	8800	1	322	151.9	207.2	6.6	1554.1	8.5	13.5						
10 Tappan Zee Br	30	43.0	41.6	5.2	6.8	6000	7500	2	28	188.4	214.3	10.6	130.7	12.7	12.8						
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975																
12 Croton Point	34	43.2	41.6	3.5	5.3	4000	6000	0	51	154.3	157.8	0.0	323.2		12.9						
13 Bowline	37	NOT	SAMPLED	DURING	1975																
14 No. Haverstraw Bay	39	43.0	41.6	2.3	4.0	2800	4700	0	97	173.1	127.2	0.0	762.6		11.7						
15 Indian Point	43	42.7	40.9	1.3	2.5	880	2200	1	4	162.5	171.9	6.2	23.3	15.1	13.3						
16 Con Hook	50																				
17 Pollepel Island	58																				
18 Newburgh-Beacon Br	62																				
19 Danskammer North	69																				
											Wtd										
											Tot	4	1510	1310.8	1488.4	Avg	2.9	993.1	Avg	12.1	13.1

* MP = Milepoint as measured from the Manhattan Battery.

Table 9-75. Physical data and tomcod abundance for stations sampled on 20 April 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom
1 Verrazano Narrows	-6	**46.3	45.2	**18.2	25.1	**20000	27000	**0	0	**427.4	320.3	**0.0	0.0		
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975										
3 Manhattan	3	45.4	45.4	20.9	20.9	22000	22000	47	76	226.1	215.5	207.9	352.7	17.2	16.8
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975										
5 Geo. Washington Br	11	45.4	45.4	12.5	12.5	13200	13200	1273	1179	161.3	189.6	7892.1	6218.4	15.5	15.5
6 Harlem River	14	NOT	SAMPLED	DURING	1975										
7 Yonkers	18	45.3	45.3	8.0	8.0	9000	9000	50	81	169.6	157.8	294.8	513.3	14.0	14.6
8 Hastings	21	NOT	SAMPLED	DURING	1975										
9 Piermont	24	45.7	45.7	4.0	4.0	3700	3700	210	203	195.5	191.9	1074.2	1057.8	14.3	13.8
10 Tappan Zee Br	30	45.9	45.9	2.2	2.2	2020	2020	146	132	214.3	197.8	681.3	667.3	14.4	14.9
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975										
12 Croton Point	34	44.4	44.4	1.0	1.0	780	780	26	19	200.2	160.1	129.9	118.7	15.7	15.3
13 Bowline	37	NOT	SAMPLED	DURING	1975										
14 No. Haverstraw Bay	39		43.8		1.0		620		0		255.5		0.0		
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
											Wtd				
Tot		1752	1690			1167	1688.5	Avg	1468.6	1116.0	Avg	15.3	15.2		

* MP = Milepoint as measured from the Manhattan Battery.
 ** Surface sample. Replicate bottom sampling at all other stations.

Table 10-75. Physical data and tomcod abundance for stations sampled on 26 April 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom				
1 Verrazzano Narrows	-6	**47.5	46.4	**22	25.0	**24000	26500	**0	0	**222.5	160.1	**0.0	0.0							
2 Statue Liberty	0	NOT	SAMPLED DURING	1975																
3 Manhattan	3	48.0	48.0	20.0	20.0	20000	20000	4	1	237.9	220.2	16.8	4.5	22.3	16.2					
4 79thSt Boat Basin	6	NOT	SAMPLED DURING	1975																
5 Geo. Washington Br	11	49.4	49.4	15.0	15.0	16500	16500	78	24	186.0	195.5	419.4	122.8	19.8	18.7					
6 Harlem River	14	NOT	SAMPLED DURING	1975																
7 Yonkers	18	48.4	48.4	5.0	5.0	6000	6000	343	247	170.7	180.2	2009.4	1370.7	18.1	17.9					
8 Hastings	21	NOT	SAMPLED DURING	1975																
9 Piermont	24	48.6	48.6	1.0	1.0	950	950	58	59	206.1	214.3	281.4	275.3	17.7	18.1					
10 Tappan Zee Br	30	BOAT	SINKING						2		80.0		25.0		21.8					
11 Hook Mountain	32	NOT	SAMPLED DURING	1975																
12 Croton Point	34																			
13 Bowline	37	NOT	SAMPLED DURING	1975																
14 No. Haverstraw Bay	39																			
15 Indian Point	43																			
16 Con Hook	50																			
17 Pollepel Island	58																			
18 Newburgh-Beacon Br	62																			
19 Danskammer North	69																			
											Wtd									
Tot											483	333	800.7	1050.3	Avg	545.4	299.7	Avg	18.3	18.1

* MP = Milepoint as measured from the Manhattan Battery.
 ** Surface sample. Replicate bottom sampling at all other stations.

Table 11-75. Physical data and tomcod abundance for stations sampled on 3 May 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)					
		Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom				
1 Verrazzano Narrows	-6	**51.5	47.0	**12.5	27.0	**15000	28200	**0	0	**463.9	350.9	**0.0	0.0						
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975														
3 Manhattan	3	**50.6	48.9	**5	20.0	**5500	20500	**0	20	**309.7	136.6	**0.0	146.4		25.8				
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975														
5 Geo. Washington Br	11	49.3	49.3	16.0	16.0	17200	17200	101	90	195.5	166.0	516.6	542.2	24.9	24.9				
6 Harlem River	14	NOT	SAMPLED	DURING	1975														
7 Yonkers	18	49.5	49.5	13.0	13.0	15000	15000	726	759	156.6	154.3	4636.0	4919.0	23.3	22.9				
8 Hastings	21	NOT	SAMPLED	DURING	1975														
9 Piermont	24	49.3	49.3	9.0	9.0	10500	10500	83	83	232.0	224.9	357.8	369.1	21.7	21.6				
10 Tappan Zee Br	30	49.5	49.5	7.0	7.0	8100	8100	130	133	181.3	190.8	717.0	697.1	21.1	20.2				
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975														
12 Croton Point	34	51.2	51.2	0.5	0.5	480	480	0	0	149.5	154.3	0.0	0.0						
13 Bowline	37	NOT	SAMPLED	DURING	1975														
14 No. Haverstraw Bay	39	50.8	50.8	0.5	0.5	465	465	0	0	180.2	163.7	0.0	0.0						
15 Indian Point	43																		
16 Con Hook	50																		
17 Pollepel Island	58																		
18 Newburgh-Beacon Br	62																		
19 Danskammer North	69																		
										Wtd									
Tot										1040	1085	1095.1	1541.5	Avg	778.4	834.2	Avg	23.1	22.7

* MP = Milepoint as measured from the Manhattan Battery.
 ** Surface sample. Replicate bottom sampling at all other stations.

Table 12-75. Physical data and tomcod abundance for stations sampled on 10 May 1975.

Station	* MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom	Bottom
1 Verrazzano Narrows	-6	**52.5	51.6	**18.0	23.0	**22000	26000	**0	0	**440.4	416.8	**0.0	0.0		
2 Statue Liberty	0	NOT	SAMPLED	DURING	1975										
3 Manhattan	3	51.8	51.8	20.0	20.0	23000	23000	0	0	215.5	174.3	0.0	0.0		
4 79thSt Boat Basin	6	NOT	SAMPLED	DURING	1975										
5 Geo. Washington Br	11	52.4	52.4	14.0	14.0	17000	17000	322	304	191.9	194.3	1678.0	1564.6	30.1	30.4
6 Harlem River	14	NOT	SAMPLED	DURING	1975										
7 Yonkers	18	53.3	53.3	8.0	8.0	9800	9800	111	112	186.0	170.7	596.8	656.1	26.0	26.4
8 Hastings	21	NOT	SAMPLED	DURING	1975										
9 Piermont	24	53.6	53.6	6.0	6.0	8500	8500	31	31	191.9	187.2	161.5	165.6	27.8	27.8
10 Tappan Zee Br	30	54.2	54.2	5.5	5.5	7000	7000	0	3	167.2	166.0	0.0	18.1		21.7
11 Hook Mountain	32	NOT	SAMPLED	DURING	1975										
12 Croton Point	34	53.6	53.6	4.0	4.0	4800	4800	1	1	199.0	182.5	5.0	5.5	12.0	20.1
13 Bowline	37	NOT	SAMPLED	DURING	1975										
14 No. Haverstraw Bay	39	54.5	54.5	2.0	2.0	2180	2180	17	20	203.7	182.5	83.5	109.6	23.3	22.8
15 Indian Point	43	54.2	54.2	0.0	0.0	600	600	18	8	201.4	197.8	89.4	40.4	28.3	28.5
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62														
19 Danskammer North	69														
											Wtd				
Tot		500	479			1556.6	1872.1	Avg		290.5	284.4	Avg		28.7	28.8

* MP = Milepoint as measured from the Manhattan Battery.
 ** Surface sample. Replicate bottom sampling at all other stations.

Table 1-76. Physical data and tomcod abundance for stations sampled on 14 February 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom					
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976																
2 Statue Liberty	0																			
3 Manhattan	3																			
4 79thSt Boat Basin	6																			
5 Geo. Washington Br	11																			
6 Harlem River	14																			
7 Yonkers	18																			
8 Hastings	21																			
9 Piermont	24																			
10 Tappan Zee Br	30	35.0	34.5	2.7	5.5	2340	5000	0	1	283.8	171.9	0.0	5.8		7.6					
11 Hook Mountain	32																			
12 Croton Point	34	34.8	33.9	2.0	3.3	1780	3690	0	3	228.4	215.5	0.0	13.9		7.3					
13 Bowline	37																			
14 No. Haverstraw Bay	39	34.2	34.2	1.1	1.4	930	1270	0	3	237.9	189.8	0.0	15.8		7.5					
15 Indian Point	43	33.7	34.0	0.0	0.5	112	418	1	2	229.6	199.0	4.4	10.1	7.4	6.8					
16 Con Hook	50																			
17 Pollepel Island	58																			
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976																
19 Danskammer North	69	NOT	SAMPLED DURING	1976																
											Wtd									
Tot											1	9	979.7	776.0	Avg	1.1	11.4	Avg.	7.4	7.3

* MP = Milepoint as measured from the Manhattan Battery.

Table 2-76. Physical data and tomcod abundance for stations sampled on 21 February 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)								
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom							
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976																		
2 Statue Liberty	0																					
3 Manhattan	3																					
4 79thSt Boat Basin	6																					
5 Geo. Washington Br	11																					
6 Harlem River	14																					
7 Yonkers	18																					
8 Hastings	21																					
9 Piermont	24																					
10 Tappan Zee Br	30	35.5	35.7	0.2	0.3	118	147	2	5	183.7	150.7	10.9	33.2	7.3	7.0							
11 Hook Mountain	32																					
12 Croton Point	34	34.9	35.2	0.2	0.2	110	138	2	13	184.9	175.4	10.8	74.1	NM	6.7							
13 Bowline	37																					
14 No. Haverstraw Bay	39	34.7	34.4	0.2	0.3	122	150	8	14	212.0	190.8	37.7	73.4	7.3	7.4							
15 Indian Point	43	34.7	35.6	0.2	0.3	185	240	1	0	199.0	176.6	5.0	0.0	7.4								
16 Con Hook	50	33.7	34.1	0	0	110	158	0	7	187.2	191.9	0.0	36.5		7.0							
17 Pollepel Island	58																					
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976																		
19 Danskammer North	69	NOT	SAMPLED DURING	1976																		
												Wtd										
												Tot	13	39	966.8	885.4	Avg	12.9	43.4	Avg.	7.3	7.0

* MP = Milepoint as measured from the Manhattan Battery.
 NM = Not Measured

Table 3-76. Physical data and tomcod abundance for stations sampled on 28 February 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom					
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976															
2 Statue Liberty	0																			
3 Manhattan	3																			
4 79thSt Boat Basin	6																			
5 Geo. Washington Br	11																			
6 Harlem River	14																			
7 Yonkers	18	36.6	36.4	0	0	125	160	15	28	188.4	159.0	79.6	176.1	7.4	7.1					
8 Hastings	21																			
9 Piermont	24																			
10 Tappan Zee Br	30	36.3	36	0	0	120	150	4	2	166.0	155.4	24.1	12.9	7.3	NM					
11 Hook Mountain	32																			
12 Croton Point	34	35.3	34.7	0	0	118	148	0	4	180.2	156.6	0.0	25.5		7.3					
13 Bowline	37																			
14 No. Haverstraw Bay	39	34.5	33.8	0	0	117	142	5	1	157.8	168.4	31.7	5.9	7.1	7.3					
15 Indian Point	43	34.7	34.0	0	0	120	188	2	24	193.1	175.4	10.4	136.8	7.4	6.9					
16 Con Hook	50	36.3	35.3	0	0	113	168	10	14	150.7	197.8	66.4	70.8	7.3	6.9					
17 Pollepel Island	58	36.8	36.1	0	0	120	147	2	5	250.8	277.9	8.0	18.0	6.5	7.1					
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976															
19 Danskammer North	69	NOT	SAMPLED	DURING	1976															
* MP = Milepoint as measured from the Manhattan Battery. NM = Not Measured																				
Tot		38	78			1287	1290.5	Avg	31.5	63.7	Avg.	7.3	7.0							

Table 4-76. Physical data and tomcod abundance for stations sampled on 7 March 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom						
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976																
2 Statue Liberty	0																				
3 Manhattan	3	38.3	41.0	3.7	20.0	3700	19000	0	27	299.1	171.9	0.0	157.1		8.1						
4 79thSt Boat Basin	6																				
5 Geo. Washington Br	11	37.3	38.8	1.0	11.4	1000	11500	1	313	228.4	113.0	4.4	2769.9	NM	8.6						
6 Harlem River	14	38.3	39.3	0.5	8.8	530	9000	1	250	272.0	216.7	3.7	1153.7	7.3	7.9						
7 Yonkers	18	38.4	37.9	0.0	1.5	145	550	2	155	195.5	179.0	10.2	865.9	7.7	7.3						
8 Hastings	21	40.0	39.6	0.0	0.0	129	165	8	48	186.0	204.9	43.0	234.3	7.7	7.3						
9 Piermont	24	40.0	39.7	0.0	0.0	125	151	12	49	168.4	212.0	71.3	231.1	7.5	7.2						
10 Tappan Zee Br	30	38.7	39.0	0.0	0.0	125	159	24	13	171.9	237.9	139.6	54.6	7.4	7.5						
11 Hook Mountain	32																				
12 Croton Point	34	37.7	37.3	0.0	0.0	117	145	24	31	170.7	215.5	140.8	143.9	7.4	7.3						
13 Bowline	37																				
14 No. Haverstraw Bay	39	36.4	36.6	0.0	0.0	120	139	51	93	203.7	273.2	250.4	340.4	7.4	7.3						
15 Indian Point	43	41.2	40.9	0.0	0.0	119	173	18	49	177.8	202.5	101.2	242.0	7.0	7.2						
16 Con Hook	50	39.1	38.7	0.0	0.0	122	162	24	67	189.6	227.3	128.8	294.8	7.2	7.2						
17 Pollepel Island	58	37.7	38.0	0.0	0.0	119	142	3	7	182.5	220.2	16.4	31.8	7.0	7.3						
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976																
19 Danskammer North	69	NOT	SAMPLED	DURING	1976																
											Wtd										
											Tot	168	1102	2445.6	2474.1	Avg	75.8	543.3	Avg.	7.3	7.8

* MP = Milepoint as measured from the Manhattan Battery.

Table 5-76. Physical data and tomcod abundance for stations sampled on 14 March 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom						
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976																
2 Statue Liberty	0																				
3 Manhattan	3	38.0	39.3	7.8	13.0	8200	13000	0	0	137.8	252.0	0.0	0.0								
4 79thSt Boat Basin	6																				
5 Geo. Washington Br	11	38.2	38.5	6.9	8.3	7300	8900	0	11	235.5	201.4	0.0	54.6		8.6						
6 Harlem River	14																				
7 Yonkers	18	38.3	38.3	5.9	6.9	6300	7300	1	18	200.2	226.1	5.0	79.6	7.1	8.2						
8 Hastings	21	38.2	38.2	5.0	5.8	5100	6100	5	37	199.0	164.9	25.1	224.4	7.7	8.1						
9 Piermont	24	38.3	38.2	4.8	5.6	4900	5900	0	76	181.3	154.3	0.0	492.5		7.9						
10 Tappan Zee Br	30	38.4	38.5	3.4	4.6	3700	4900	0	155	159.0	244.9	0.0	632.9		8.0						
11 Hook Mountain	32																				
12 Croton Point	34	39.5	39.0	1.9	2.9	1870	2990	9	122	166.0	179.0	54.2	681.6	8.8	8.4						
13 Bowline	37																				
14 No. Haverstraw Bay	39	40.0	39.8	1.2	2.8	1220	2770	1	597	199.0	170.7	5.0	3497.4	7.1	8.4						
15 Indian Point	43	41.2	39.0	0.0	1.0	270	930	4	104	166.0	204.9	24.1	507.6	7.7	7.7						
16 Con Hook	50	38.9	38.1	0.0	0.0	124	172	11	49	175.4	207.2	62.7	236.5	7.4	7.0						
17 Pollepel Island	58	38.1	37.7	0.0	0.0	121	147	3	2	186.0	163.7	16.1	12.2	7.4	6.4						
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976																
19 Danskammer North	69	NOT	SAMPLED	DURING	1976																
											Wtd										
											Tot	34	1171	2005.2	2169.1	Avg	17.5	583.6	Avg.	7.8	8.2

* MP = Milepoint as measured from the Manhattan Battery.

Table 6-76. Physical data and tomcod abundance for stations sampled on 21 March 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)						
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom					
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976															
2 Statue Liberty	0																			
3 Manhattan	3	39.7	39.5	10.0	16.3	11200	18100	9	14	227.3	201.4	39.6	69.5	10.1	10.8					
4 79thSt Boat Basin	6																			
5 Geo. Washington Br	11	38.0	38.5	5.6	8.9	6100	9600	116	598	335.8	190.8	344.4	3134.2	9.4	9.7					
6 Harlem River	14	40.5	41.0	3.7	6.9	3800	7300	749	569	200.2	179.0	3741.3	3178.8	8.8	9.2					
7 Yonkers	18	40.8	41.4	2.5	3.5	2620	3710	135	23	169.6	167.2	796.0	137.6	8.6	8.4					
8 Hastings	21	40.0	40.6	2.0	2.7	1980	2740	151	62	160.1	201.4	943.2	307.8	8.6	8.4					
9 Piermont	24	40.7	41.5	1.3	1.8	1460	1930	6	40	157.8	168.4	38.0	237.5	8.2	8.8					
10 Tappan Zee Br	30	41.2	41.5	0.8	1.0	830	1010	219	183	155.4	157.8	1409.3	1159.7	7.7	7.9					
11 Hook Mountain	32																			
12 Croton Point	34	41.6	41.8	0.8	1.0	790	920	29	52	149.5	156.6	194.0	332.1	NM	NM					
13 Bowline	37																			
14 No. Haverstraw Bay	39	40.7	41.4	0.0	0.0	204	235	15	17	144.8	161.3	103.6	105.4	NM	NM					
15 Indian Point	43	40.5	41.3	0.0	0.0	169	215	15	23	162.5	206.1	92.3	111.6	NM	NM					
16 Con Hook	50	39.3	40.1	0.0	0.0	150	202	12	13	162.5	213.1	73.8	61.0	NM	NM					
17 Pollepel Island	58																			
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976															
19 Danskammer North	69	NOT	SAMPLED	DURING	1976															
										Wtd										
										Tot	1456	1594	2026.5	2003.1	Avg	706.9	803.2	Avg.	8.6	9.2

* MP = Milepoint as measured from the Manhattan Battery.
 NM = Not Measured

Table 7-76. Physical data and tomcod abundance for stations sampled on 28 March 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)							
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom						
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976																	
2 Statue Liberty	0																				
3 Manhattan	3																				
4 79thSt Boat Basin	6																				
5 Geo. Washington Br	11	43.4	42.6	6.0	8.6	7000	10300	1	319	176.6	229.6	5.7	1389.4	9.0	10.1						
6 Harlem River	14																				
7 Yonkers	18	42.7	41.7	2.8	8.0	3200	9800	376	1884	177.8	222.5	2114.7	8467.4	9.4	9.8						
8 Hastings	21	44.0	42.8	2.4	4.8	2670	6000	881	2392	179.0	313.2	4921.8	7637.3	9.3	9.1						
9 Piermont	24	42.8	42.7	0.9	2.8	920	3100	99	310	208.4	156.6	475.0	1979.6	9.1	8.6						
10 Tappan Zee Br	30	36.0	35.7	0.2	0.3	290	440	21	526	191.9	138.9	109.4	3788.9	8.7	8.8						
11 Hook Mountain	32																				
12 Croton Point	34	42.0	42.0	0.0	0.0	140	170	0	5	195.5	169.8	0.0	29.5		7.0						
13 Bowline	37																				
14 No. Haverstraw Bay	39																				
15 Indian Point	43																				
16 Con Hook	50																				
17 Pollepel Island	58																				
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976																	
19 Danskammer North	69	NOT	SAMPLED DURING	1976																	
											Wtd										
											Tot	1378	5436	1129.2	1230.4	Avg	1271.1	3881.7	Avg.	9.3	9.3

* MP = Milepoint as measured from the Manhattan Battery.

Table 8-76. Physical data and tomcod abundance for stations sampled on 4 April 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)								
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom							
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976																		
2 Statue Liberty	0	44.2	45.3	2.6	16.2	3200	20000	16	71	305.0	343.8	52.5	206.5	11.0	11.1							
3 Manhattan	3	44.2	45.5	1.4	14.2	1620	17900	28	323	328.2	196.6	85.8	1642.9	11.1	11.9							
4 79thSt Boat Basin	6	44.1	45.5	0.8	14.0	1050	17200	1254	75	247.3	212.0	5070.8	353.8	10.8	14.2							
5 Geo. Washington Br	11	44.3	44.8	2.9	10.0	3580	12500	81	1675	171.9	170.7	471.2	9812.5	10.1	11.7							
6 Harlem River	14	43.8	44.4	0.1	5.5	163	6200	1	1892	146.0	196.6	6.8	9623.6	9.0	11.0							
7 Yonkers	18	44.1	44.1	0.0	0.2	152	182	0	0	171.9	164.9	0.0	0.0									
8 Hastings	21	44.2	44.2	0.0	0.0	158	185	0	0	150.7	167.2	0.0	0.0									
9 Piermont	24	44.9	44.5	0.0	0.0	151	195	0	0	160.1	171.9	0.0	0.0									
10 Tappan Zee Br	30																					
11 Hook Mountain	32																					
12 Croton Point	34																					
13 Bowline	37																					
14 No. Haverstraw Bay	39																					
15 Indian Point	43																					
16 Con Hook	50																					
17 Pollepel Island	58																					
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976																		
19 Danskammer North	69	NOT	SAMPLED DURING	1976																		
												Wtd										
												Tot	1380	4036	1679.1	1623.7	Avg	710.9	2704.9	Avg.	10.8	11.4

* MP = Milepoint as measured from the Manhattan Battery.

Table 9-76. Physical data and tomcod abundance for stations sampled on 10 April 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976										
2 Statue Liberty	0	45.6	44.9	10.0	23.0	11200	24800	0	0	230.8	181.3	0.0	0.0		
3 Manhattan	3	45.8	45.2	6.0	23.0	6800	24500	0	2	197.8	181.3	0.0	11.0		12.9
4 79thSt Boat Basin	6	46.2	45.2	5.0	21.5	5800	23500	0	2	204.9	181.3	0.0	11.0		14.9
5 Geo. Washington Br	11	46.7	45.7	3.7	22.0	3450	20500	0	14	202.5	82.4	0.0	169.9		15.1
6 Harlem River	14	46.7	45.7	3.0	19.9	3500	21500	2	35	263.8	212.0	7.6	165.1	16.6	14.9
7 Yonkers	18	47.8	46.2	2.5	17.4	2800	19000	0	139	279.1	295.6	0.0	470.2		14.3
8 Hastings	21	46.9	46.1	1.8	16.8	1850	18000	2	621	196.6	307.3	10.2	2020.8	11.9	13.3
9 Piermont	24	46.7	46.1	1.8	15.0	1800	16100	123	1112	261.4	292.0	470.5	3808.2	13.5	14.1
10 Tappan Zee Br	30	47.0	45.9	1.0	14.0	1090	15100	103	1189	209.6	247.3	491.4	4807.9	12.7	13.6
11 Hook Mountain	32														
12 Croton Point	34	46.9	46.0	0.8	12.5	750	12800	1073	719	203.7	275.5	5267.6	2609.8	12.4	13.1
13 Bowline	37														
14 No. Haverstraw Bay	39	45.5	45.7	1.0	2.8	1150	2070	50	47	203.7	191.9	245.5	244.9	13.0	13.3
15 Indian Point	43	45.2	45.4	0.0	0.0	118	160	1	14	159.0	262.6	6.3	53.3	NM	12.9
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976										
19 Danskammer North	69	NOT	SAMPLED	DURING	1976										

* MP = Milepoint as measured from the Manhattan Battery.
 NM = Not Measured

	Tot		Wtd Avg.		Wtd Avg.		Wtd Avg.	
	1354	3894	2612.9	2710.5	541.6	1197.7	12.6	13.6

Table 10-76. Physical data and tomcod abundance for stations sampled on 17 April 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976											
2 Statue Liberty	0														
3 Manhattan	3	48.8	48.8	18.5	20.0	20900	22100	0	1	354.4	259.1	0.0	3.9	22.2	
4 79thSt Boat Basin	6	49.0	48.7	17.0	19.2	18000	21200	2	39	188.4	196.6	10.6	198.4	18.5	19.4
5 Geo. Washington Br	11	48.8	49.0	11.2	16.1	12700	17900	56	151	161.3	166.0	347.2	909.6	16.4	18.1
6 Harlem River	14	49.1	47.4	7.9	10.0	9100	11500	66	616	196.6	187.2	335.7	3290.6	17.0	17.4
7 Yonkers	18	49.7	49.3	5.0	5.2	5800	6200	7	53	177.8	157.8	39.4	335.9	13.9	18.0
8 Hastings	21	48.6	48.8	3.7	3.8	3930	4050	58	32	155.4	155.4	373.2	205.9	16.0	16.2
9 Piermont	24	48.6	48.8	2.7	2.8	2830	2950	3	4	63.6	163.7	47.2	24.4	13.6	14.3
10 Tappan Zee Br	30	48.8	48.9	1.8	1.9	1820	1950	222	177	266.1	189.6	834.3	1043.6	16.3	16.4
11 Hook Mountain	32	48.7	49.0	1.0	1.2	1600	1280	353	239	147.2	191.9	2398.1	1245.4	16.7	16.6
12 Croton Point	34	46.8	46.8	0.5	0.5	S 360	410	107	80	161.3	166.0	663.4	481.9	NM	16.3
13 Bowline	37														
14 No. Haverstraw Bay	39	46.0	46.2	0.0	0.0	S 130	160	2	1	146.0	157.8	13.7	6.3	14.7	17.0
15 Indian Point	43	45.8	46.0	0.0	0.0	S 111	200	1	2	200.2	153.1	5.0	13.1	13.7	17.7
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976											
19 Danskammer North	69	NOT	SAMPLED DURING	1976											
												Wtd			
Tot		877	1395	2218.3	2124.2	Avg	422.3	646.6	Avg.	16.5	17.2				

* MP = Milepoint as measured from the Manhattan Battery.
 NM = Not Measured
 S = Surface Measurement

Table 11-76. Physical data and tomcod abundance for stations sampled on 24 April 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976											
2 Statue Liberty	0														
3 Manhattan	3														
4 79thSt Boat Basin	6	51.7	51.4	18.5	20.0	23300	24900	0	11	190.8	223.7	0.0	49.2		23.1
5 Geo. Washington Br	11	S 53.2	51.4	17.0	19.0	21500	24000	0	63	203.7	233.1	0.0	270.3		22.2
6 Harlem River	14	51.8	51.5	12.4	14.5	17000	19000	1	37	167.2	149.5	6.0	247.5	17.5	20.3
7 Yonkers	18	51.5	51.4	11.1	11.2	14800	16400	0	111	191.9	123.6	0.0	898.1		20.7
8 Hastings	21	51.4	51.3	9.5	10.7	10800	14600	33	442	184.9	122.5	178.5	3608.2	18.2	21.3
9 Piermont	24	52.8	51.5	2.0	9.0	3090	12200	22	250	194.3	188.4	113.2	1327.0	22.1	19.7
10 Tappan Zee Br	30	52.3	51.6	1.6	8.1	2080	10900	12	112	169.8	155.4	70.8	720.7	18.6	19.5
11 Hook Mountain	32	51.8	51.3	2.8	6.5	3470	9000	6	68	194.3	118.9	30.9	571.9	18.4	19.7
12 Croton Point	34	51.8	51.3	0.8	5.0	880	5000	8	191	212.0	167.2	37.7	1142.3	16.7	20.3
13 Bowline	37														
14 No. Haverstraw Bay	39	50.8	50.8	0.0	0.0	152	149	0	0	147.2	169.6	0.0	0.0		
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976											
19 Danskammer North	69	NOT	SAMPLED DURING	1976											

* MP = Milepoint as measured from the Manhattan Battery.
S = Surface Measurement

			Wtd							
Tot	82	1285	1855.9	1651.9	Avg	43.7	883.5	Avg.	19.2	20.6

Table 12-76. Physical data and tomcod abundance for stations sampled on 1 May 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)								
		Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom							
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976																	
2 Statue Liberty	0	50.9	50.1	17.2	20.1	20500	22900	0	0	193.1	229.6	0.0	0.0									
3 Manhattan	3	51.7	51.6	9.5	15.0	11400	17500	1	292	212.0	267.3	4.7	1092.4	30.8	29.3							
4 79thSt Boat Basin	6	51.8	51.5	10.0	15.9	15000	19000	37	39	214.3	171.9	172.7	226.9	29.4	29.8							
5 Geo. Washington Br	11	52.0	51.8	8.9	11.2	10900	13800	4	127	241.4	137.8	16.6	921.6	23.3	28.6							
6 Harlem River	14	51.9	52.1	5.8	9.3	7800	12200	2	195	193.1	140.1	10.4	1391.9	24.5	27.5							
7 Yonkers	18	52.2	52.0	4.3	6.3	5800	8300	466	847	212.0	230.8	2198.1	3669.8	26.2	25.8							
8 Hastings	21	52.2	52.1	3.5	4.3	4690	5800	36	91	181.3	168.4	198.6	540.4	24.1	22.9							
9 Piermont	24	52.1	52.2	2.4	2.6	3200	3410	36	20	186.0	195.5	193.5	102.3	23.4	24.3							
10 Tappan Zee Br	30	52.3	52.3	1.7	1.8	2180	2210	7	3	175.4	161.3	39.9	18.6	23.9	24.7							
11 Hook Mountain	32																					
12 Croton Point	34	52.8	52.8	0.8	0.8	800	820	94	46	166.0	148.4	568.3	310.0	20.0	23.0							
13 Bowline	37																					
14 No. Haverstraw Bay	39	52.3	52.3	0.0	0.0	230	203	0	32	177.8	149.5	0.0	214.0		25.5							
15 Indian Point	43																					
16 Con Hook	50																					
17 Pollepel Island	58																					
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976																	
19 Danskammer North	69	NOT	SAMPLED	DURING	1976																	
												Wtd										
												Tot	683	1692	2152.4	2000.6	Avg	309.2	771.6	Avg.	25.2	26.5

* MP = Milepoint as measured from the Manhattan Battery.

Table 13-76. Physical data and tomcod abundance for stations sampled on 9 May 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Volume Sampled (cubic meters)		Larvae/1000cu.m.		Mean Length(mm)	
		Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom	Mid	Bottom
1 Verrazzano Narrows	-6	NOT	SAMPLED DURING	1976											
2 Statue Liberty	0														
3 Manhattan	3	50.8	50.5	21.5	22.3	25100	26800	0	0	209.6	213.1	0.0	0.0		
4 79thSt Boat Basin	6	53.5	51.7	16.7	20.9	22200	24700	0	50	174.3	140.1	0.0	356.9	36.8	
5 Geo. Washington Br	11	53.8	52.6	11.5	17.1	16500	20200	0	26	287.3	138.9	0.0	187.2	NM	
6 Harlem River	14	54.0	53.3	13.3	15.2	16000	18200	0	27	220.2	153.1	0.0	176.4	33.8	
7 Yonkers	18	54.0	54.0	10.9	11.4	13200	13800	0	32	196.6	131.9	0.0	242.6	31.7	
8 Hastings	21	55.9	54.8	5.9	8.3	7100	10200	0	75	230.8	250.8	0.0	299.0	31.5	
9 Piermont	24	56.8	56.0	3.0	5.5	3510	6800	0	120	151.9	297.9	0.0	402.8	29.5	
10 Tappan Zee Br	30	57.5	57.0	0.4	1.8	310	1900	0	22	199.0	141.3	0.0	155.7	28.7	
11 Hook Mountain	32														
12 Croton Point	34	58.2	58.2	0.0	0.2	191	179	0	2	169.6	170.7	0.0	11.7	NM	
13 Bowline	37														
14 No. Haverstraw Bay	39	57.1	57.1	0.0	0.0	168	172	0	0	235.5	215.5	0.0	0.0		
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED DURING	1976											
19 Danskammer North	69	NOT	SAMPLED DURING	1976											
<div style="border: 1px solid black; padding: 2px; display: inline-block;"> * MP = Milepoint as measured from the Manhattan Battery. NM = Not Measured </div>											Wtd Avg.				
Tot	0	354				2074.8	1853.3	Avg	0.0	183.2				31.6	

Table 14-76. Physical data and tomcod abundance for stations sampled on 15 May 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Replicate Volume Sampled (cubic meters)		Replicate Larvae/1000cu.m.		Replicate Mean Length(mm)					
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000				
1 Verrazzano Narrows	-8	NOT	SAMPLED	DURING	1976														
2 Statue Liberty	0	57.4	54.4	17.0	24.0	20000	27800	0	0	254.3	263.8	0.0	0.0						
3 Manhattan	3	58.8	56.3	8.5	18.8	10200	22000	98	93	232.0	220.2	422.4	422.3	38.9	39.5				
4 79thSt Boat Basin	6	60.0	56.6	7.0	17.0	8300	20400	11	94	253.2	229.6	43.4	409.4	41.8	40.8				
5 Geo. Washington Br	11	61.4	57.7	5.0	13.0	6000	16200	113	138	202.5	199.0	558.0	693.5	38.6	38.8				
6 Harlem River	14	63.3	59.6	3.5	7.0	4100	8500	31	51	191.9	173.1	161.5	294.6	38.3	37.6				
7 Yonkers	18	62.7	60.6	1.5	3.1	2000	4000	27	15	212.0	194.3	127.4	77.2	36.5	34.7				
8 Hastings	21	61.5	61.0	1.0	1.1	1200	1500	0	0	183.7	171.9	0.0	0.0						
9 Piermont	24	62.5	61.3	0.8	1.0	750	1000	1	2	209.6	174.3	4.8	11.5	45.0	43.2				
10 Tappan Zee Br	30	61.8	61.4	0.0	0.2	205	258	2	6	184.9	166.0	10.8	38.1	42.5	32.5				
11 Hook Mountain	32																		
12 Croton Point	34	61.8	60.7	0.0	0.2	215	210	0	0	181.3	157.8	0.0	0.0						
13 Bowline	37																		
14 No. Haverstraw Bay	39	64.3	59.5	0.0	0.0	151	203	0	0	166.0	130.7	0.0	0.0						
15 Indian Point	43																		
16 Con Hook	50																		
17 Pollepel Island	58																		
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976														
19 Danskammer North	69	NOT	SAMPLED	DURING	1976														
										Wtd									
Tot										283	399	2271.4	2080.7	Avg	120.8	176.8	Avg.	38.6	39.1

* MP = Milepoint as measured from the Manhattan Battery.
Replicate net mesh sizes: 571 and 3000 microns.

Table 15-76. Physical data and tomcod abundance for stations sampled on 23 May 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Replicate Volume Sampled (cubic meters)		Replicate Larvae/1000cu.m.		Replicate Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000u	Bottom 571u	Bottom 3000
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976										
2 Statue Liberty	0														
3 Manhattan	3	57.8	51.0	3.0	23.6	3650	28500	1	2	254.9	227.3	3.8	8.8	47.0	46.8
4 79thSt Boat Basin	6	58.4	52.3	2.1	22.2	2550	26900	7	3	197.8	203.7	35.4	14.7	46.1	52.0
5 Geo. Washington Br	11	59.0	54.6	0.9	17.7	1100	21600	193	79	274.4	257.9	703.4	306.3	47.1	47.5
6 Harlem River	14	59.8	55.1	0.0	17.1	300	21000	115	132	254.3	233.1	452.2	566.3	47.8	49.6
7 Yonkers	18	61.5	57.3	0.0	14.0	230	17300	22	16	275.5	256.7	79.9	62.3	46.8	50.9
8 Hastings	21	61.2	58.8	0.0	9.1	162	10500	2	NQD	361.5	NQD	5.5	NQD	46.5	NQD
9 Piermont	24	59.8	59.8	0.0	0.3	152	207	0	0	183.7	179.0	0.0	0.0		
10 Tappan Zee Br	30	60.3	59.8	0.0	0.0	146	203	0	0	184.9	162.5	0.0	0.0		
11 Hook Mountain	32														
12 Croton Point	34														
13 Bowline	37														
14 No. Haverstraw Bay	39														
15 Indian Point	43														
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976										
19 Danskammer North	69	NOT	SAMPLED	DURING	1976										
<div style="border: 1px solid black; padding: 5px; display: inline-block;"> * MP = Milepoint as measured from the Manhattan Battery. NQD = No Quantitative Data Replicate net mesh sizes: 571 and 3000 microns. </div>															
<hr/> Wtd Tot 340 232 1997 1520.2 Avg 160.0 119.8 Avg. 47.3 49.0															

Table 17-76. Physical data and tomcod abundance for stations sampled on 13 June 1976.

Station	*MP	Temperature (Degrees F)		Salinity (parts/1000)		Conductivity (micromhos)		Number Of Larvae		Replicate Volume Sampled (cubic meters)		Replicate Larvae/1000cu.m.		Replicate Mean Length(mm)	
		Surface	Bottom	Surface	Bottom	Surface	Bottom	Bottom Net	Bottom Sled	Bottom Net	Bottom Sled	Bottom Net	Bottom Sled	Bottom Net	Bottom Sled
1 Verrazzano Narrows	-6	NOT	SAMPLED	DURING	1976										
2 Statue Liberty	0														
3 Manhattan	3														
4 79thSt Boat Basin	6	68.1	65.2	11.0	16.5	15100	22000	NS	2		303.8		6.8		63.0
5 Geo. Washington Br	11	65.9	66.5	6.9	12.2	9500	16500	3	29	200.2	216.7	15.0	133.8	62.0	62.6
6 Harlem River	14	67.5	66.2	5.0	12.0	6800	16500	NS	4		256.7		15.6		73.5
7 Yonkers	18	67.7	66.4	4.0	10.4	5500	14200	NS	14		233.1		60.1		69.1
8 Hastings	21	67.9	67.6	3.0	4.8	4200	6800	NS	6		263.8		22.7		66.8
9 Piermont	24	68.4	68.3	2.0	2.0	2750	2750	NS	6		264.9		22.7		64.7
10 Tappan Zee Br	30	68.0	67.9	1.0	1.3	1550	2000	NS	2		234.3		8.5		NM
11 Hook Mountain	32														
12 Croton Point	34	67.8	67.4	0.3	0.2	480	430	NS	8		209.6		38.2		66.5
13 Bowline	37	66.2	65.4	0.0	0.0	155	150	NS	3	(10-min)	423.9		7.1		69.0
14 No. Haverstraw Bay	39	66.2	65.4	0.0	0.0	155	150	NS	1		224.9		4.4		70.0
15 Indian Point	43	65.4	64.5	0.0	0.0	150	150	NS	0		249.6		0.0		
16 Con Hook	50														
17 Pollepel Island	58														
18 Newburgh-Beacon Br	62	NOT	SAMPLED	DURING	1976										
19 Danskammer North	69	NOT	SAMPLED	DURING	1976										

* MP = Milepoint as measured from the Manhattan Battery.
 NM = Not Measured
 NS = No Sample
 Bottom net and sled both 3000 micron mesh.
 (10 min) = a 10-min tow vs 5-min.

Tot	3	75	200.2	2881.3	Avg	15.0	29.1	Avg.	62.0	65.8
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APPENDIX II

II. River segment volumes used for estimates of larval standing stock. 1p.

Table II-1. River segment volumes used for estimates of larvae standing stock

Segment	Stations (No.) Represented	River Miles	Segment Length (mi)	Average Depth (ft)*	Average Width (ft) (B core)*	Total Core* Volume (1000cu.m.)
Manhattan	StatLib (2) Manhattan (3) 79thSt (4)	0-8	8.0	41.6	3119.0	155212.203
GW Br	GWBr (5) HarlRiv (6)	8-16	8.0	30.4	4407.0	160263.194
Yonkers	Yonkers (7) Hastings (8)	16-24	8.0	28.2	4997.0	168568.187
Piermont	Piermont (9)	24-28	4.0	18.2	9550.0	103958.959
Tappan Zee	TZBr (10) Hook Mtn (11)	28-32	4.0	17.0	11638.0	118335.333
Croton	Croton (12) Bowline (13)	32-36	4.0	20.0	9313.0	111405.533
Haverstraw	Haverstraw (14)	36-42	6.0	27.4	8509.0	209173.907
Indian Pt	IndianPt (15)	42-46	4.0	55.8	3063.0	102227.646
Con Hook	ConHook (16)	46-50	4.0	77.6	1819.0	84427.044
Pollepel Is	Pollepel (17) NBBr (18) Danskammer (19)	50-58	8.0	54.0	3135.0	202510.928
Total Core Volume (1000cu.m.) from MP 0 to MP 58 :						1416082.934

* Unpub. data from Lawler, Matusky, and Skelly Engineers
Core = schematized channel geometry, excluding nearshore shoal area

APPENDIX III

III. Tomcod density, standard error, and standing crop estimates by 1.0 mm length interval for sampling dates during 1975 and 1976. 23p.

Table 1-75. Density and standing crop estimated for newly hatched tomcod larvae on 15 February 1975.

Length Interval (mm)	Sampling Area Average Density*	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	12.55	N/A	N/A	828080.39	10,392,409	932039.35	11,697,094	8.260
7.5-8.4	0.00							

* No sampling occurred on 15Feb75. Density of newly hatched, 7-mm larvae on 15 Feb estimated as $N_0 = N_t/e^{-Zt} = 9.61/@EXP(-0.0382 \times 7 \text{ days})$

where 9.61 = density of larvae in next 1.0-mm length interval on 22 Feb.

** Adjusted to include Piermont segment volume.

Table 2-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 22 February 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	24.71	14	8.191	828080.39	20,460,880	932039.35	23,029,582	16.263
7.5-8.4	9.61	14	5.732	828080.39	7,960,022	932039.35	8,959,340	6.327
8.5-9.4	0.00							

* Adjusted to include Piermont segment volume where larvae were probably present, but where no sampling occurred on this date.

Table 3-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 1 March 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	52.03	16	10.880	932039.35	48,495,371	1100607.54	57,266,220	40.440
7.5-8.4	4.23	16	1.175	932039.35	3,943,493	1100607.54	4,656,712	3.288
8.5-9.4	0.00							

* Adjusted to include Yonkers segment volume where larvae were probably present, but where no sampling occurred on this date.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 4-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 9 March 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	146.14	10	39.677	932039.35	136,209,867	1100607.54	160,844,718	113.584
7.5-8.4	319.18	10	135.567	932039.35	297,492,478	1100607.54	351,296,825	248.076
8.5-9.4	27.01	10	13.788	932039.35	25,175,636	1100607.54	29,728,889	20.994
9.5-10.4	1.90	10	1.902	932039.35	1,773,148	1100607.54	2,093,839	1.479
10.5-11.4	0.00							

** Adjusted to include Yonkers segment volume where larvae were probably present, but where no sampling occurred on this date.

Table 5-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 16 March 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	119.71	18	34.114	1260870.73	150,942,370	1416082.93	169,523,257	119.713
7.5-8.4	458.86	18	174.176	1260870.73	578,562,799	1416082.93	649,783,427	458.860
8.5-9.4	110.45	18	46.602	1260870.73	139,267,141	1416082.93	156,410,817	110.453
9.5-10.4	36.74	18	19.444	1260870.73	46,320,249	1416082.93	52,022,235	36.737
10.5-11.4	9.23	18	9.229	1260870.73	11,636,436	1416082.93	13,068,872	9.229
11.5-12.4	1.42	18	1.420	1260870.73	1,790,221	1416082.93	2,010,596	1.420
12.5-13.4	0.00							

** Adjusted to include Manhattan segment volume where larvae were probably present, but where no sampling occurred on this date.

Table 6-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 23 March 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	41.35	20	14.718	1416082.93	58,554,200	1416082.93	58,554,200	41.349
7.5-8.4	121.69	20	72.436	1416082.93	172,329,456	1416082.93	172,329,456	121.694
8.5-9.4	100.37	20	80.177	1416082.93	142,125,973	1416082.93	142,125,973	100.366
9.5-10.4	46.90	20	38.841	1416082.93	66,414,298	1416082.93	66,414,298	46.900
10.5-11.4	6.69	20	3.949	1416082.93	9,473,164	1416082.93	9,473,164	6.690
11.5-12.4	6.25	20	4.676	1416082.93	8,851,716	1416082.93	8,851,716	6.251
12.5-13.4	0.00							

** No unsampled segment volume adjustment.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 7-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 29 March 1975.

Length Interval (mm)	Sampling Area Average Density*	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	7.82	16	4.493	1129144.96	8,828,376	1129144.96	8,828,376	6.234
7.5-8.4	22.13	16	10.105	1129144.96	24,993,513	1129144.96	24,993,513	17.650
8.5-9.4	35.41	16	19.571	1129144.96	39,983,292	1129144.96	39,983,292	28.235
9.5-10.4	34.47	16	18.631	1129144.96	38,921,593	1129144.96	38,921,593	27.485
10.5-11.4	30.20	16	18.753	1129144.96	34,101,780	1129144.96	34,101,780	24.082
11.5-12.4	16.27	16	10.445	1129144.96	18,369,356	1129144.96	18,369,356	12.972
12.5-13.4	8.16	16	5.577	1129144.96	9,213,576	1129144.96	9,213,576	6.506
13.5-14.4	1.40	16	1.399	1129144.96	1,580,180	1129144.96	1,580,180	1.116
14.5-15.4	0.00	16	0.000	1129144.96	0	1129144.96	0	0.000
15.5-16.4	0.00	16	0.000	1129144.96	0	1129144.96	0	0.000
16.5-17.4	0.00	16	0.000	1129144.96	0	1129144.96	0	0.000
17.5-18.4	0.70	16	0.700	1129144.96	790,090	1129144.96	790,090	0.558
18.5-19.4	0.00							

Table 8-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 6 April 1975.

Length Interval (mm)	Sampling Area Average Density*	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	11.96	14	6.867	1026917.31	12,277,345	1026917.31	12,277,345	8.670
7.5-8.4	40.36	14	25.099	1026917.31	41,448,505	1026917.31	41,448,505	29.270
8.5-9.4	122.17	14	79.968	1026917.31	125,454,894	1026917.31	125,454,894	88.593
9.5-10.4	230.93	14	147.557	1026917.31	237,147,958	1026917.31	237,147,958	167.468
10.5-11.4	293.69	14	178.458	1026917.31	301,592,249	1026917.31	301,592,249	212.976
11.5-12.4	168.15	14	105.094	1026917.31	172,679,285	1026917.31	172,679,285	121.942
12.5-13.4	86.57	14	46.206	1026917.31	88,900,125	1026917.31	88,900,125	62.779
13.5-14.4	42.23	14	24.458	1026917.31	43,365,245	1026917.31	43,365,245	30.623
14.5-15.4	24.74	14	21.524	1026917.31	25,408,337	1026917.31	25,408,337	17.943
15.5-16.4	16.82	14	9.599	1026917.31	17,276,155	1026917.31	17,276,155	12.200
16.5-17.4	3.32	14	3.324	1026917.31	3,413,231	1026917.31	3,413,231	2.410
17.5-18.4	4.66	14	3.317	1026917.31	4,788,746	1026917.31	4,788,746	3.382
18.5-19.4	0.00							

* No unsampled segment volume adjustment.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 9-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 12 April 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	0.00	16	0.000	1129144.96	0	1129144.96	0	0.000
7.5-8.4	2.62	16	2.619	1129144.96	2,957,531	1129144.96	2,957,531	2.089
8.5-9.4	6.07	16	3.974	1129144.96	6,850,608	1129144.96	6,850,608	4.838
9.5-10.4	21.67	16	13.987	1129144.96	24,469,337	1129144.96	24,469,337	17.280
10.5-11.4	63.57	16	40.254	1129144.96	71,782,817	1129144.96	71,782,817	50.691
11.5-12.4	82.59	16	46.192	1129144.96	93,254,816	1129144.96	93,254,816	65.854
12.5-13.4	133.01	16	87.221	1129144.96	150,188,756	1129144.96	150,188,756	106.059
13.5-14.4	92.33	16	52.028	1129144.96	104,253,068	1129144.96	104,253,068	73.621
14.5-15.4	51.44	16	32.858	1129144.96	58,087,032	1129144.96	58,087,032	41.020
15.5-16.4	21.62	16	13.458	1129144.96	24,416,994	1129144.96	24,416,994	17.243
16.5-17.4	16.46	16	8.442	1129144.96	18,584,606	1129144.96	18,584,606	13.124
17.5-18.4	4.36	16	2.982	1129144.96	4,922,892	1129144.96	4,922,892	3.476
18.5-19.4	1.13	16	0.794	1129144.96	1,276,608	1129144.96	1,276,608	0.902
19.5-20.4	0.00	16	0.000	1129144.96	0	1129144.96	0	0.000
20.5-21.4	1.14	16	1.143	1129144.96	1,290,297	1129144.96	1,290,297	0.911
21.5-22.4	0.00							

* No unsampled segment volume adjustment.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 10-75. Average tomod density, standard error, and standing crop estimated for each tomod length interval present on 20 April 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	0.00	13	0.000	1026917.31	0	513458.655	0	0.000
7.5-8.4	0.00	13	0.000	1026917.31	0	513458.655	0	0.000
8.5-9.4	2.69	13	1.627	1026917.31	2,759,875	513458.655	1,379,938	0.974
9.5-10.4	14.57	13	5.234	1026917.31	14,960,851	513458.655	7,480,426	5.282
10.5-11.4	33.64	13	12.566	1026917.31	34,546,834	513458.655	17,273,417	12.198
11.5-12.4	114.46	13	55.050	1026917.31	117,541,186	513458.655	58,770,593	41.502
12.5-13.4	156.69	13	65.390	1026917.31	160,903,888	513458.655	80,451,944	56.813
13.5-14.4	268.59	13	122.085	1026917.31	275,818,553	513458.655	137,909,277	97.388
14.5-15.4	209.64	13	89.743	1026917.31	215,287,807	513458.655	107,643,904	76.015
15.5-16.4	243.65	13	126.132	1026917.31	250,208,292	513458.655	125,104,146	88.345
16.5-17.4	194.90	13	114.389	1026917.31	200,150,723	513458.655	100,075,361	70.671
17.5-18.4	92.41	13	48.170	1026917.31	94,894,264	513458.655	47,447,132	33.506
18.5-19.4	63.94	13	36.344	1026917.31	65,657,053	513458.655	32,828,526	23.183
19.5-20.4	46.58	13	29.218	1026917.31	47,834,481	513458.655	23,917,241	16.890
20.5-21.4	16.71	13	9.849	1026917.31	17,158,582	513458.655	8,579,291	6.058
21.5-22.4	12.02	13	9.454	1026917.31	12,345,844	513458.655	6,172,922	4.359
22.5-23.4	7.08	13	6.358	1026917.31	7,273,184	513458.655	3,636,592	2.568
23.5-24.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 1/2 Total Core Volume to reflect bottom sampling only.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 11-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 26 April 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	0.00	9	0.000	706337.87	0	353168.94	0	0.000
7.5-8.4	0.00	9	0.000	706337.87	0	353168.94	0	0.000
8.5-9.4	0.00	9	0.000	706337.87	0	353168.94	0	0.000
9.5-10.4	0.00	9	0.000	706337.87	0	353168.94	0	0.000
10.5-11.4	2.79	9	2.791	706337.87	1,971,271	353168.94	985,636	0.696
11.5-12.4	4.96	9	2.769	706337.87	3,500,588	353168.94	1,750,294	1.236
12.5-13.4	4.94	9	2.760	706337.87	3,486,020	353168.94	1,743,010	1.231
13.5-14.4	12.94	9	7.746	706337.87	9,140,780	353168.94	4,570,390	3.227
14.5-15.4	36.85	9	19.546	706337.87	26,026,274	353168.94	13,013,137	9.190
15.5-16.4	46.22	9	23.519	706337.87	32,646,462	353168.94	16,323,231	11.527
16.5-17.4	67.17	9	40.901	706337.87	47,444,256	353168.94	23,722,128	16.752
17.5-18.4	92.91	9	44.339	706337.87	65,627,723	353168.94	32,813,862	23.172
18.5-19.4	90.31	9	41.875	706337.87	63,790,027	353168.94	31,895,014	22.523
19.5-20.4	73.17	9	38.779	706337.87	51,682,674	353168.94	25,841,337	18.248
20.5-21.4	29.12	9	12.695	706337.87	20,567,014	353168.94	10,283,507	7.262
21.5-22.4	22.35	9	11.332	706337.87	15,789,293	353168.94	7,894,647	5.575
22.5-23.4	10.50	9	4.369	706337.87	7,413,074	353168.94	3,706,537	2.617
23.5-24.4	4.62	9	2.800	706337.87	3,263,468	353168.94	1,631,734	1.152
24.5-25.4	2.47	9	1.639	706337.87	1,743,571	353168.94	871,785	0.616
25.5-26.4	1.04	9	1.037	706337.87	732,410	353168.94	366,205	0.259
26.5-27.4	0.47	9	0.467	706337.87	329,624	353168.94	164,812	0.116
27.5-28.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 1/2 Total Core Volume to reflect bottom sampling only.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 12-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 3 May 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	0.00	13	0.000	1026917.31	0	513458.66	0	0.000
7.5-8.4	0.00	13	0.000	1026917.31	0	513458.66	0	0.000
8.5-9.4	0.00	13	0.000	1026917.31	0	513458.66	0	0.000
9.5-10.4	0.00	13	0.000	1026917.31	0	513458.66	0	0.000
10.5-11.4	4.20	13	4.195	1026917.31	4,308,406	513458.66	2,154,203	1.521
11.5-12.4	0.00	13	0.000	1026917.31	0	513458.66	0	0.000
12.5-13.4	4.42	13	3.718	1026917.31	4,543,191	513458.66	2,271,595	1.604
13.5-14.4	1.19	13	0.889	1026917.31	1,218,753	513458.66	609,376	0.430
14.5-15.4	15.72	13	8.894	1026917.31	16,140,101	513458.66	8,070,050	5.699
15.5-16.4	17.74	13	11.119	1026917.31	18,222,273	513458.66	9,111,137	6.434
16.5-17.4	38.86	13	18.287	1026917.31	39,902,282	513458.66	19,951,141	14.089
17.5-18.4	29.17	13	11.740	1026917.31	29,959,713	513458.66	14,979,856	10.578
18.5-19.4	43.49	13	21.912	1026917.31	44,663,729	513458.66	22,331,865	15.770
19.5-20.4	58.18	13	21.155	1026917.31	59,747,956	513458.66	29,873,978	21.096
20.5-21.4	68.51	13	32.869	1026917.31	70,357,923	513458.66	35,178,962	24.842
21.5-22.4	114.51	13	51.089	1026917.31	117,587,893	513458.66	58,793,946	41.519
22.5-23.4	131.71	13	66.636	1026917.31	135,259,750	513458.66	67,629,875	47.758
23.5-24.4	122.79	13	70.277	1026917.31	126,099,100	513458.66	63,049,550	44.524
24.5-25.4	126.05	13	70.499	1026917.31	129,446,416	513458.66	64,723,208	45.706
25.5-26.4	105.55	13	64.984	1026917.31	108,386,401	513458.66	54,193,201	38.270
26.5-27.4	46.71	13	26.378	1026917.31	47,963,680	513458.66	23,981,840	16.935
27.5-28.4	31.35	13	16.712	1026917.31	32,190,179	513458.66	16,095,090	11.366
28.5-29.4	6.38	13	2.850	1026917.31	6,551,593	513458.66	3,275,796	2.313
29.5-30.4	14.28	13	5.427	1026917.31	14,664,912	513458.66	7,332,456	5.178
30.5-31.4	7.08	13	4.191	1026917.31	7,270,629	513458.66	3,635,314	2.567
31.5-32.4	1.15	13	0.851	1026917.31	1,177,501	513458.66	588,750	0.416
32.5-33.4	2.21	13	1.678	1026917.31	2,268,882	513458.66	1,134,441	0.801
33.5-34.4	1.15	13	0.779	1026917.31	1,181,478	513458.66	590,739	0.417
34.5-35.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 1/2 Total Core Volume to reflect bottom sampling only.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 13-75. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 10 May 1975.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density+
0.0-7.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
7.5-8.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
8.5-9.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
9.5-10.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
10.5-11.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
11.5-12.4	0.31	16	0.313	1129144.96	352,858	564572.48	176,429	0.125
12.5-13.4	0.34	16	0.343	1129144.96	386,732	564572.48	193,366	0.137
13.5-14.4	0.34	16	0.339	1129144.96	382,883	564572.48	191,441	0.135
14.5-15.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
15.5-16.4	0.71	16	0.482	1129144.96	796,294	564572.48	398,147	0.281
16.5-17.4	2.11	16	1.015	1129144.96	2,386,664	564572.48	1,193,332	0.843
17.5-18.4	1.41	16	0.829	1129144.96	1,596,436	564572.48	798,218	0.564
18.5-19.4	3.71	16	1.733	1129144.96	4,193,069	564572.48	2,096,535	1.481
19.5-20.4	4.16	16	2.147	1129144.96	4,697,993	564572.48	2,348,997	1.659
20.5-21.4	4.02	16	2.087	1129144.96	4,535,266	564572.48	2,267,633	1.601
21.5-22.4	5.95	16	2.799	1129144.96	6,718,858	564572.48	3,359,429	2.372
22.5-23.4	11.24	16	4.154	1129144.96	12,689,166	564572.48	6,344,583	4.480
23.5-24.4	10.82	16	3.098	1129144.96	12,221,731	564572.48	6,110,865	4.315
24.5-25.4	18.56	16	6.340	1129144.96	20,960,478	564572.48	10,480,239	7.401
25.5-26.4	23.55	16	9.268	1129144.96	26,587,620	564572.48	13,293,810	9.388
26.5-27.4	20.92	16	7.846	1129144.96	23,622,025	564572.48	11,811,012	8.341
27.5-28.4	34.96	16	16.684	1129144.96	39,469,891	564572.48	19,734,945	13.936
28.5-29.4	32.97	16	16.231	1129144.96	37,231,362	564572.48	18,615,681	13.146
29.5-30.4	32.35	16	15.287	1129144.96	36,532,561	564572.48	18,266,280	12.899
30.5-31.4	33.47	16	18.870	1129144.96	37,787,590	564572.48	18,893,795	13.342
31.5-32.4	26.73	16	15.517	1129144.96	30,178,253	564572.48	15,089,126	10.656
32.5-33.4	22.41	16	13.877	1129144.96	25,304,283	564572.48	12,652,141	8.935
33.5-34.4	7.38	16	4.394	1129144.96	8,337,630	564572.48	4,168,815	2.944
34.5-35.4	11.90	16	7.101	1129144.96	13,433,597	564572.48	6,716,798	4.743
35.5-36.4	2.87	16	2.556	1129144.96	3,238,776	564572.48	1,619,388	1.144
36.5-37.4	3.82	16	2.767	1129144.96	4,312,090	564572.48	2,156,045	1.523
37.5-38.4	3.82	16	2.767	1129144.96	4,312,090	564572.48	2,156,045	1.523
38.5-39.4	0.00	16	0.000	1129144.96	0	564572.48	0	0.000
39.5-40.4	1.27	16	1.270	1129144.96	1,433,977	564572.48	716,989	0.506
40.5-41.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 1/2 Total Core Volume to reflect bottom sampling only.

+ Riverwide Average Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 1-76. Density and standing crop estimated for newly hatched tomcod larvae on 7 February 1976.

Length Interval (mm)	Sampling Area			River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
	Average Density*	N	Std. Error					
0.0-7.4	4.08	*	*	541142.42	2,208,557	828080.39	3,379,633	2.387
7.5-8.4	0.00							

* No sampling occurred on 7Feb76. Density of newly hatched, 7-mm larvae on 7 Feb estimated as $No = Nt/e^{-Zt} = 2.87/@EXP(-0.0503 \times 7 \text{ days})$

where 2.87 = density of larvae in next 1.0-mm length interval on 14 Feb.

** Adjusted to include Con Hook and Pollepel segment volumes.

Table 2-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 14 February 1976.

Length Interval (mm)	Sampling Area			River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
	Average Density	N	Std. Error					
0.0-7.4	3.38	8	1.426	541142.42	1,828,610	828080.39	2,798,222	1.976
7.5-8.4	2.87	8	1.439	541142.42	1,553,530	828080.39	2,377,281	1.679
8.5-9.4	0.00							

** Surface to bottom sampling.

Sum of total core volume for sampled segments used to calculate standing crop estimates.

Adjusted to include Con Hook and Pollepel segment volumes where larvae were probably present, but where no sampling occurred on this date.

Table 3-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 21 February 1976.

Length Interval (mm)	Sampling Area			River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
	Average Density*	N	Std. Error					
0.0-7.4	26.55	10	8.772	625569.46	16,611,059	828080.39	21,988,433	15.528
7.5-8.4	1.61	10	1.091	625569.46	1,004,977	828080.39	1,330,311	0.939
8.5-9.4	0.00							

** Surface to bottom sampling.

Sum of total core volume for sampled segments used to calculate standing crop estimates.

Adjusted to include Pollepel segment volume where larvae were probably present, but where no sampling occurred on this date.

+ Average Riverwide Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 4-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 28 February 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	38.88	14	12.538	1100607.54	42,788,739	1260870.73	49,019,352	34.616
7.5-8.4	8.71	14	3.531	1100607.54	9,584,457	1260870.73	10,980,083	7.754
8.5-9.4	0.00							

** Adjusted to include GWBr segment volume where larvae were probably present, but where no sampling occurred on this date.

Table 5-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 7 March 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	98.37	24	24.366	1416082.93	139,299,468	1416082.93	139,299,468	98.370
7.5-8.4	142.17	24	59.563	1416082.93	201,321,788	1416082.93	201,321,788	142.168
8.5-9.4	54.62	24	48.804	1416082.93	77,344,498	1416082.93	77,344,498	54.619
9.5-10.4	12.66	24	11.082	1416082.93	17,933,976	1416082.93	17,933,976	12.664
10.5-11.4	1.63	24	1.206	1416082.93	2,313,033	1416082.93	2,313,033	1.633
11.5-12.4	0.00							

** No unsampled segment volume adjustment.

Table 6-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 14 March 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume** (1000cu.m.)	Adjusted Standing Crop**	Riverwide Average Density+
0.0-7.4	50.22	22	15.381	1416082.93	71,115,502	1416082.93	71,115,502	50.220
7.5-8.4	143.15	22	78.986	1416082.93	202,718,035	1416082.93	202,718,035	143.154
8.5-9.4	77.25	22	54.233	1416082.93	109,394,142	1416082.93	109,394,142	77.251
9.5-10.4	23.51	22	13.109	1416082.93	33,295,752	1416082.93	33,295,752	23.513
10.5-11.4	5.04	22	3.162	1416082.93	7,133,502	1416082.93	7,133,502	5.037
11.5-12.4	1.35	22	1.085	1416082.93	1,908,172	1416082.93	1,908,172	1.347
12.5-13.4	0.00							

** No unsampled segment volume adjustment.

+ Average Riverwide Density = Adjusted Standing Crop/1416082.933
 1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 7-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 21 March 1976.

Length Interval (mm)	Sampling Area		Std. Error	River Volume In Sampling Area (1000cu.m.)		Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
	Average Density	N		Area	Area				
0.0-7.4	50.88	22	23.092	1213572.0	61,746,564	809048.0	41,164,376	29.069	
7.5-8.4	249.98	22	64.925	1213572.0	303,364,419	809048.0	202,242,946	142.819	
8.5-9.4	275.44	22	117.597	1213572.0	334,271,141	809048.0	222,847,427	157.369	
9.5-10.4	108.65	22	49.115	1213572.0	131,859,157	809048.0	87,906,105	62.077	
10.5-11.4	43.55	22	21.832	1213572.0	52,847,232	809048.0	35,231,488	24.880	
11.5-12.4	19.17	22	15.173	1213572.0	23,268,922	809048.0	15,512,615	10.955	
12.5-13.4	6.40	22	4.188	1213572.0	7,769,924	809048.0	5,179,949	3.658	
13.5-14.4	0.95	22	0.950	1213572.0	1,152,599	809048.0	768,399	0.543	
14.5-15.4	0.00								

* No unsampled segment volume adjustment.

Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.

Table 8-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 28 March 1976.

Length Interval (mm)	Sampling Area		Std. Error	River Volume In Sampling Area (1000cu.m.)		Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
	Average Density	N		Area	Area				
0.0-7.4	56.47	12	20.193	662531.2	37,415,532	545162.3	30,787,284	21.741	
7.5-8.4	506.69	12	182.043	662531.2	335,696,777	545162.3	276,227,317	195.064	
8.5-9.4	1079.67	12	346.656	662531.2	715,314,363	545162.3	588,594,770	415.650	
9.5-10.4	518.76	12	202.552	662531.2	343,696,662	545162.3	282,810,004	199.713	
10.5-11.4	227.40	12	114.337	662531.2	150,659,391	545162.3	123,969,731	87.544	
11.5-12.4	122.88	12	61.063	662531.2	81,411,139	545162.3	66,988,968	47.306	
12.5-13.4	51.91	12	21.673	662531.2	34,389,985	545162.3	28,297,720	19.983	
13.5-14.4	12.61	12	11.161	662531.2	8,356,013	545162.3	6,875,726	4.855	
14.5-15.4	0.00								

* Adjusted to include Manhattan segment volume where larvae were probably present, but no sampling occurred on this date.

Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 9-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 4 April 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	18.32	16	13.724	588002.54	10,772,282	392001.69	7,181,522	5.071
7.5-8.4	67.30	16	36.825	588002.54	39,573,609	392001.69	26,382,406	18.631
8.5-9.4	89.57	16	45.086	588002.54	52,666,697	392001.69	35,111,131	24.795
9.5-10.4	295.14	16	141.353	588002.54	173,540,364	392001.69	115,693,576	81.700
10.5-11.4	481.89	16	256.735	588002.54	283,351,393	392001.69	188,900,929	133.397
11.5-12.4	405.68	16	224.094	588002.54	238,543,787	392001.69	159,029,192	112.302
12.5-13.4	215.88	16	113.882	588002.54	126,937,874	392001.69	84,625,249	59.760
13.5-14.4	46.80	16	21.238	588002.54	27,521,367	392001.69	18,347,578	12.957
14.5-15.4	45.28	16	32.391	588002.54	26,626,734	392001.69	17,751,156	12.535
15.5-16.4	23.99	16	13.597	588002.54	14,104,196	392001.69	9,402,798	6.640
16.5-17.4	13.95	16	7.874	588002.54	8,205,257	392001.69	5,470,171	3.863
17.5-18.4	0.63	16	0.462	588002.54	367,558	392001.69	245,039	0.173
18.5-19.4	3.03	16	2.607	588002.54	1,783,473	392001.69	1,188,982	0.840
19.5-20.4	0.43	16	0.434	588002.54	254,945	392001.69	169,963	0.120
20.5-21.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 10-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 10 April 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	0.00	24	0.000	1129145.0	0	752763.3	0	0.000
7.5-8.4	4.79	24	3.507	1129145.0	5,411,298	752763.3	3,607,532	2.548
8.5-9.4	13.10	24	6.705	1129145.0	14,787,704	752763.3	9,858,469	6.962
9.5-10.4	45.38	24	25.613	1129145.0	51,236,435	752763.3	34,157,623	24.121
10.5-11.4	68.58	24	31.691	1129145.0	77,438,870	752763.3	51,625,914	36.457
11.5-12.4	119.25	24	51.077	1129145.0	134,647,289	752763.3	89,764,859	63.390
12.5-13.4	217.55	24	82.424	1129145.0	245,642,463	752763.3	163,761,642	115.644
13.5-14.4	174.05	24	68.228	1129145.0	196,526,720	752763.3	131,017,813	92.521
14.5-15.4	121.95	24	45.374	1129145.0	137,694,179	752763.3	91,796,120	64.824
15.5-16.4	55.35	24	25.291	1129145.0	62,501,438	752763.3	41,667,625	29.425
16.5-17.4	24.81	24	10.662	1129145.0	28,010,276	752763.3	18,673,517	13.187
17.5-18.4	14.91	24	8.905	1129145.0	16,832,822	752763.3	11,221,881	7.925
18.5-19.4	6.08	24	2.363	1129145.0	6,869,483	752763.3	4,579,655	3.234
19.5-20.4	1.75	24	1.321	1129145.0	1,973,908	752763.3	1,315,939	0.929
20.5-21.4	2.10	24	1.203	1129145.0	2,369,211	752763.3	1,579,474	1.115
21.5-22.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 11-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 17 April 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	0.00	24	0.000	1129144.96	0	752763.31	0	0.000
7.5-8.4	0.00	24	0.000	1129144.96	0	752763.31	0	0.000
8.5-9.4	0.50	24	0.345	1129144.96	562,987	752763.31	375,325	0.265
9.5-10.4	3.77	24	3.024	1129144.96	4,256,349	752763.31	2,837,566	2.004
10.5-11.4	7.24	24	3.712	1129144.96	8,175,751	752763.31	5,450,500	3.849
11.5-12.4	10.07	24	2.351	1129144.96	11,372,719	752763.31	7,581,813	5.354
12.5-13.4	23.14	24	7.031	1129144.96	26,124,528	752763.31	17,416,352	12.299
13.5-14.4	36.00	24	9.903	1129144.96	40,654,378	752763.31	27,102,919	19.139
14.5-15.4	61.36	24	18.414	1129144.96	69,280,930	752763.31	46,187,287	32.616
15.5-16.4	91.03	24	26.742	1129144.96	102,790,101	752763.31	68,526,734	48.392
16.5-17.4	88.86	24	28.165	1129144.96	100,333,627	752763.31	66,889,085	47.235
17.5-18.4	77.20	24	29.791	1129144.96	87,170,694	752763.31	58,113,796	41.038
18.5-19.4	58.29	24	21.173	1129144.96	65,815,870	752763.31	43,877,247	30.985
19.5-20.4	33.75	24	11.972	1129144.96	38,106,687	752763.31	25,404,458	17.940
20.5-21.4	17.13	24	10.702	1129144.96	19,347,812	752763.31	12,898,542	9.109
21.5-22.4	8.44	24	2.414	1129144.96	9,533,705	752763.31	6,355,803	4.488
22.5-23.4	9.76	24	3.911	1129144.96	11,024,714	752763.31	7,349,809	5.190
23.5-24.4	6.27	24	2.523	1129144.96	7,081,743	752763.31	4,721,162	3.334
24.5-25.4	0.73	24	0.552	1129144.96	825,567	752763.31	550,378	0.389
25.5-26.4	0.21	24	0.212	1129144.96	239,340	752763.31	159,560	0.113
26.5-27.4	0.47	24	0.329	1129144.96	534,679	752763.31	356,453	0.252
27.5-28.4	0.21	24	0.212	1129144.96	239,340	752763.31	159,560	0.113
28.5-29.4	0.00							

* No unsampled segment volume adjustment.

Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933

1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 12-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 24 April 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	0.00	20	0.000	1026917.31	0	684611.54	0	0.000
7.5-8.4	0.00	20	0.000	1026917.31	0	684611.54	0	0.000
8.5-9.4	0.00	20	0.000	1026917.31	0	684611.54	0	0.000
9.5-10.4	0.84	20	0.649	1026917.31	865,538	684611.54	577,025	0.407
10.5-11.4	1.79	20	1.068	1026917.31	1,840,027	684611.54	1,226,685	0.866
11.5-12.4	3.86	20	2.216	1026917.31	3,966,402	684611.54	2,644,268	1.867
12.5-13.4	4.15	20	1.637	1026917.31	4,259,146	684611.54	2,839,431	2.005
13.5-14.4	13.80	20	4.919	1026917.31	14,175,110	684611.54	9,450,074	6.673
14.5-15.4	6.11	20	2.303	1026917.31	6,269,784	684611.54	4,179,856	2.952
15.5-16.4	19.29	20	6.918	1026917.31	19,810,148	684611.54	13,206,765	9.326
16.5-17.4	23.76	20	8.087	1026917.31	24,401,635	684611.54	16,267,757	11.488
17.5-18.4	34.40	20	15.317	1026917.31	35,328,410	684611.54	23,552,273	16.632
18.5-19.4	51.96	20	21.555	1026917.31	53,361,848	684611.54	35,574,565	25.122
19.5-20.4	55.89	20	19.844	1026917.31	57,392,329	684611.54	38,261,553	27.019
20.5-21.4	65.19	20	37.285	1026917.31	66,946,765	684611.54	44,631,177	31.517
21.5-22.4	64.47	20	29.792	1026917.31	66,206,048	684611.54	44,137,365	31.169
22.5-23.4	44.85	20	22.689	1026917.31	46,057,828	684611.54	30,705,219	21.683
23.5-24.4	27.86	20	11.117	1026917.31	28,606,808	684611.54	19,071,205	13.468
24.5-25.4	10.33	20	4.393	1026917.31	10,609,608	684611.54	7,073,072	4.995
25.5-26.4	14.76	20	6.437	1026917.31	15,156,026	684611.54	10,104,017	7.135
26.5-27.4	6.63	20	2.429	1026917.31	6,807,398	684611.54	4,538,265	3.205
27.5-28.4	9.06	20	6.164	1026917.31	9,299,968	684611.54	6,199,979	4.378
28.5-29.4	1.20	20	0.701	1026917.31	1,232,005	684611.54	821,337	0.580
29.5-30.4	0.00	20	0.000	1026917.31	0	684611.54	0	0.000
30.5-31.4	3.41	20	2.214	1026917.31	3,501,436	684611.54	2,334,291	1.648
31.5-32.4	0.00							

* Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.
No unsampled segment volume adjustment.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 13-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 1 May 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
7.5-8.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
8.5-9.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
9.5-10.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
10.5-11.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
11.5-12.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
12.5-13.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
13.5-14.4	1.69	22	0.950	1026917.31	1,730,848	684611.54	1,153,899	0.815
14.5-15.4	1.46	22	1.172	1026917.31	1,496,395	684611.54	997,597	0.704
15.5-16.4	2.89	22	1.501	1026917.31	2,969,736	684611.54	1,979,824	1.398
16.5-17.4	10.72	22	4.864	1026917.31	11,006,213	684611.54	7,337,475	5.182
17.5-18.4	5.25	22	2.504	1026917.31	5,394,945	684611.54	3,596,630	2.540
18.5-19.4	11.93	22	4.826	1026917.31	12,249,929	684611.54	8,166,619	5.767
19.5-20.4	15.95	22	4.939	1026917.31	16,374,947	684611.54	10,916,632	7.709
20.5-21.4	27.26	22	12.634	1026917.31	27,994,509	684611.54	18,663,006	13.179
21.5-22.4	28.24	22	12.048	1026917.31	29,002,892	684611.54	19,335,261	13.654
22.5-23.4	37.49	22	18.044	1026917.31	38,499,082	684611.54	25,666,054	18.125
23.5-24.4	45.91	22	21.018	1026917.31	47,146,887	684611.54	31,431,258	22.196
24.5-25.4	26.52	22	7.363	1026917.31	27,237,606	684611.54	18,158,404	12.823
25.5-26.4	40.07	22	12.548	1026917.31	41,145,229	684611.54	27,430,153	19.370
26.5-27.4	48.16	22	24.501	1026917.31	49,459,528	684611.54	32,973,019	23.285
27.5-28.4	47.23	22	20.114	1026917.31	48,505,699	684611.54	32,337,133	22.836
28.5-29.4	33.15	22	15.227	1026917.31	34,039,273	684611.54	22,692,848	16.025
29.5-30.4	37.45	22	16.057	1026917.31	38,462,251	684611.54	25,641,501	18.107
30.5-31.4	25.37	22	11.496	1026917.31	26,048,797	684611.54	17,365,865	12.263
31.5-32.4	12.81	22	6.024	1026917.31	13,159,050	684611.54	8,772,700	6.195
32.5-33.4	9.93	22	4.548	1026917.31	10,199,569	684611.54	6,799,713	4.802
33.5-34.4	9.26	22	3.983	1026917.31	9,513,153	684611.54	6,342,102	4.479
34.5-35.4	6.15	22	3.266	1026917.31	6,318,846	684611.54	4,212,564	2.975
35.5-36.4	4.12	22	2.184	1026917.31	4,226,918	684611.54	2,817,945	1.990
36.5-37.4	0.59	22	0.589	1026917.31	605,214	684611.54	403,476	0.285
37.5-38.4	0.29	22	0.295	1026917.31	302,607	684611.54	201,738	0.142
38.5-39.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
39.5-40.4	0.00	22	0.000	1026917.31	0	684611.54	0	0.000
40.5-41.4	0.00							

* Adjusted to 2/3 Total Core Volume to reflect mid and bottom sampling only.
No unsampled segment volume adjustment.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 14-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 9 May 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
0.0-7.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
7.5-8.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
8.5-9.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
9.5-10.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
10.5-11.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
11.5-12.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
12.5-13.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
13.5-14.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
14.5-15.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
15.5-16.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
16.5-17.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
17.5-18.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
18.5-19.4	0.69	10	0.694	1026917.31	713,176	342305.77	237,725	0.168
19.5-20.4	1.83	10	0.974	1026917.31	1,883,960	342305.77	627,987	0.443
20.5-21.4	0.00	10	0.000	1026917.31	0	342305.77	0	0.000
21.5-22.4	2.28	10	1.604	1026917.31	2,341,567	342305.77	780,522	0.551
22.5-23.4	4.24	10	2.134	1026917.31	4,350,366	342305.77	1,450,122	1.024
23.5-24.4	4.02	10	2.286	1026917.31	4,129,108	342305.77	1,376,369	0.972
24.5-25.4	4.87	10	2.753	1026917.31	4,998,504	342305.77	1,666,168	1.177
25.5-26.4	4.81	10	2.581	1026917.31	4,938,703	342305.77	1,646,234	1.163
26.5-27.4	5.24	10	2.254	1026917.31	5,382,393	342305.77	1,794,131	1.267
27.5-28.4	9.33	10	6.246	1026917.31	9,578,950	342305.77	3,192,983	2.255
28.5-29.4	13.54	10	5.294	1026917.31	13,906,727	342305.77	4,635,576	3.274
29.5-30.4	12.23	10	5.446	1026917.31	12,562,458	342305.77	4,187,486	2.957
30.5-31.4	10.11	10	3.943	1026917.31	10,378,412	342305.77	3,459,471	2.443
31.5-32.4	10.25	10	3.079	1026917.31	10,528,079	342305.77	3,509,360	2.478
32.5-33.4	13.91	10	4.256	1026917.31	14,281,491	342305.77	4,760,497	3.362
33.5-34.4	17.99	10	5.599	1026917.31	18,475,365	342305.77	6,158,455	4.349
34.5-35.4	20.66	10	5.818	1026917.31	21,211,234	342305.77	7,070,411	4.993
35.5-36.4	12.80	10	4.232	1026917.31	13,146,479	342305.77	4,382,160	3.095
36.5-37.4	9.82	10	3.505	1026917.31	10,088,626	342305.77	3,362,875	2.375
37.5-38.4	8.49	10	6.279	1026917.31	8,720,598	342305.77	2,906,866	2.053
38.5-39.4	7.49	10	3.024	1026917.31	7,694,023	342305.77	2,564,674	1.811
39.5-40.4	3.95	10	2.835	1026917.31	4,054,628	342305.77	1,351,543	0.954
40.5-41.4	2.14	10	2.141	1026917.31	2,199,041	342305.77	733,014	0.518
41.5-42.4	1.11	10	0.778	1026917.31	1,142,411	342305.77	380,804	0.269
42.5-43.4	0.71	10	0.714	1026917.31	733,014	342305.77	244,338	0.173
43.5-44.4	0.71	10	0.714	1026917.31	733,014	342305.77	244,338	0.173
44.5-45.4	0.00							

* Adjusted to 1/3 Total Core Volume to reflect bottom sampling only.
No unsampled segment volume adjustment

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 15-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 15 May 1976.

Length Interval (mm)	Sampling Area		Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
	Average Density	N						
14.5-15.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
15.5-16.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
16.5-17.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
17.5-18.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
18.5-19.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
19.5-20.4	0.27	22	0.273	1026917.31	280,846	342305.77	93,615	0.066
20.5-21.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
21.5-22.4	0.41	22	0.409	1026917.31	420,103	342305.77	140,034	0.099
22.5-23.4	0.23	22	0.234	1026917.31	240,236	342305.77	80,079	0.057
23.5-24.4	0.00	22	0.000	1026917.31	0	342305.77	0	0.000
24.5-25.4	0.48	22	0.331	1026917.31	489,886	342305.77	163,295	0.115
25.5-26.4	1.08	22	0.526	1026917.31	1,109,030	342305.77	369,677	0.261
26.5-27.4	1.35	22	0.932	1026917.31	1,385,380	342305.77	461,793	0.326
27.5-28.4	0.76	22	0.531	1026917.31	783,957	342305.77	261,319	0.185
28.5-29.4	0.53	22	0.525	1026917.31	539,269	342305.77	179,756	0.127
29.5-30.4	1.94	22	0.841	1026917.31	1,989,740	342305.77	663,247	0.468
30.5-31.4	2.59	22	1.236	1026917.31	2,663,633	342305.77	887,878	0.627
31.5-32.4	2.14	22	1.096	1026917.31	2,198,510	342305.77	732,837	0.518
32.5-33.4	1.39	22	0.698	1026917.31	1,426,007	342305.77	475,336	0.336
33.5-34.4	5.91	22	1.914	1026917.31	6,064,210	342305.77	2,021,403	1.427
34.5-35.4	10.50	22	4.754	1026917.31	10,786,021	342305.77	3,595,340	2.539
35.5-36.4	11.36	22	4.231	1026917.31	11,668,963	342305.77	3,889,654	2.747
36.5-37.4	10.77	22	3.210	1026917.31	11,062,917	342305.77	3,687,639	2.604
37.5-38.4	11.36	22	4.134	1026917.31	11,667,628	342305.77	3,889,209	2.746
38.5-39.4	18.47	22	6.436	1026917.31	18,964,562	342305.77	6,321,521	4.464
39.5-40.4	15.75	22	5.651	1026917.31	16,171,806	342305.77	5,390,602	3.807
40.5-41.4	13.81	22	4.290	1026917.31	14,183,904	342305.77	4,727,968	3.339
41.5-42.4	11.04	22	3.550	1026917.31	11,338,149	342305.77	3,779,383	2.669
42.5-43.4	8.31	22	3.252	1026917.31	8,529,170	342305.77	2,843,057	2.008
43.5-44.4	6.05	22	2.087	1026917.31	6,216,874	342305.77	2,072,291	1.463
44.5-45.4	2.18	22	1.045	1026917.31	2,235,537	342305.77	745,179	0.526
45.5-46.4	2.94	22	1.233	1026917.31	3,017,838	342305.77	1,005,946	0.710
46.5-47.4	1.94	22	1.290	1026917.31	1,989,206	342305.77	663,069	0.468
47.5-48.4	2.57	22	1.074	1026917.31	2,641,683	342305.77	880,561	0.622
48.5-49.4	1.61	22	0.841	1026917.31	1,657,254	342305.77	552,418	0.390
49.5-50.4	0.67	22	0.475	1026917.31	689,737	342305.77	229,912	0.162
50.5-51.4	0.35	22	0.351	1026917.31	360,566	342305.77	120,189	0.085
51.5-52.4	0.00							

* Adjusted to 1/3 Total Core Volume to reflect bottom sampling only.
No unsampled segment volume adjustment

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 16-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 23 May 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
23.5-24.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
24.5-25.4	0.23	16	0.227	706337.87	160,331	235445.96	53,444	0.038
25.5-26.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
26.5-27.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
27.5-28.4	0.24	16	0.244	706337.87	172,170	235445.96	57,390	0.041
28.5-29.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
29.5-30.4	0.45	16	0.454	706337.87	320,661	235445.96	106,887	0.075
30.5-31.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
31.5-32.4	0.51	16	0.514	706337.87	362,961	235445.96	120,987	0.085
32.5-33.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
33.5-34.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
34.5-35.4	0.98	16	0.579	706337.87	694,456	235445.96	231,485	0.163
35.5-36.4	0.00	16	0.000	706337.87	0	235445.96	0	0.000
36.5-37.4	0.58	16	0.580	706337.87	409,835	235445.96	136,612	0.096
37.5-38.4	0.81	16	0.598	706337.87	569,271	235445.96	169,757	0.134
38.5-39.4	0.76	16	0.553	706337.87	534,125	235445.96	178,042	0.126
39.5-40.4	0.51	16	0.514	706337.87	362,961	235445.96	120,987	0.085
40.5-41.4	4.23	16	2.833	706337.87	2,986,587	235445.96	995,529	0.703
41.5-42.4	3.82	16	2.834	706337.87	2,695,826	235445.96	898,609	0.635
42.5-43.4	4.54	16	2.396	706337.87	3,210,213	235445.96	1,070,071	0.756
43.5-44.4	4.49	16	2.443	706337.87	3,169,479	235445.96	1,056,493	0.746
44.5-45.4	9.77	16	4.045	706337.87	6,899,902	235445.96	2,299,967	1.624
45.5-46.4	8.73	16	4.366	706337.87	6,163,581	235445.96	2,054,527	1.451
46.5-47.4	14.30	16	6.952	706337.87	10,103,014	235445.96	3,367,671	2.378
47.5-48.4	26.06	16	11.703	706337.87	18,410,020	235445.96	6,136,673	4.334
48.5-49.4	14.98	16	6.275	706337.87	10,582,897	235445.96	3,527,632	2.491
49.5-50.4	8.23	16	3.296	706337.87	5,816,146	235445.96	1,938,715	1.369
50.5-51.4	9.00	16	3.907	706337.87	6,360,194	235445.96	2,120,065	1.497
51.5-52.4	7.99	16	4.100	706337.87	5,643,989	235445.96	1,881,330	1.329
52.5-53.4	5.88	16	2.607	706337.87	4,155,179	235445.96	1,385,060	0.978
53.5-54.4	3.41	16	1.379	706337.87	2,405,561	235445.96	801,854	0.566
54.5-55.4	3.41	16	2.912	706337.87	2,412,137	235445.96	804,046	0.568
55.5-56.4	1.65	16	1.175	706337.87	1,163,004	235445.96	387,668	0.274
56.5-57.4	1.16	16	1.160	706337.87	819,670	235445.96	273,223	0.193
57.5-58.4	0.82	16	0.614	706337.87	582,005	235445.96	194,002	0.137
58.5-59.4	0.58	16	0.580	706337.87	409,835	235445.96	136,612	0.096
59.5-60.4	1.08	16	0.737	706337.87	761,069	235445.96	253,690	0.179
60.5-61.4	0.70	16	0.501	706337.87	492,831	235445.96	164,277	0.116
61.5-62.4	0.00							

* Adjusted to 1/3 Total Core Volume to reflect bottom sampling only.
No unsampled segment volume adjustment

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 17-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 5 June 1976.

Length Interval (mm)	Sampling		Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
	Area Average Density	N						
37.5-38.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
38.5-39.4	0.25	17	0.249	817743.40	203,233	272581.13	67,744	0.048
39.5-40.4	0.43	17	0.431	817743.40	352,087	272581.13	117,362	0.083
40.5-41.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
41.5-42.4	0.22	17	0.215	817743.40	176,044	272581.13	58,681	0.041
42.5-43.4	0.22	17	0.215	817743.40	176,044	272581.13	58,681	0.041
43.5-44.4	0.43	17	0.431	817743.40	352,087	272581.13	117,362	0.083
44.5-45.4	0.22	17	0.215	817743.40	176,044	272581.13	58,681	0.041
45.5-46.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
46.5-47.4	0.22	17	0.215	817743.40	176,044	272581.13	58,681	0.041
47.5-48.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
48.5-49.4	0.71	17	0.530	817743.40	584,061	272581.13	194,687	0.137
49.5-50.4	1.30	17	0.914	817743.40	1,059,349	272581.13	353,116	0.249
50.5-51.4	1.58	17	0.839	817743.40	1,289,780	272581.13	429,927	0.304
51.5-52.4	0.43	17	0.434	817743.40	355,189	272581.13	118,396	0.084
52.5-53.4	0.62	17	0.442	817743.40	504,036	272581.13	168,012	0.119
53.5-54.4	1.21	17	0.655	817743.40	987,337	272581.13	329,112	0.232
54.5-55.4	0.43	17	0.298	817743.40	351,212	272581.13	117,071	0.083
55.5-56.4	2.21	17	1.199	817743.40	1,808,366	272581.13	602,789	0.426
56.5-57.4	2.19	17	0.908	817743.40	1,790,928	272581.13	596,976	0.422
57.5-58.4	2.23	17	0.797	817743.40	1,824,684	272581.13	608,228	0.430
58.5-59.4	2.43	17	0.829	817743.40	1,987,419	272581.13	662,473	0.468
59.5-60.4	7.60	17	3.414	817743.40	6,213,927	272581.13	2,071,309	1.463
60.5-61.4	5.26	17	2.097	817743.40	4,304,671	272581.13	1,434,890	1.013
61.5-62.4	5.98	17	2.189	817743.40	4,887,756	272581.13	1,629,252	1.151
62.5-63.4	4.99	17	2.131	817743.40	4,077,825	272581.13	1,359,275	0.960
63.5-64.4	6.13	17	2.653	817743.40	5,014,308	272581.13	1,671,436	1.180
64.5-65.4	7.75	17	2.814	817743.40	6,339,148	272581.13	2,113,049	1.492
65.5-66.4	8.18	17	3.026	817743.40	6,688,180	272581.13	2,229,393	1.574
66.5-67.4	6.51	17	2.920	817743.40	5,326,740	272581.13	1,775,580	1.254
67.5-68.4	3.82	17	1.073	817743.40	3,125,343	272581.13	1,041,781	0.736
68.5-69.4	4.29	17	1.586	817743.40	3,510,917	272581.13	1,170,306	0.826
69.5-70.4	2.15	17	1.017	817743.40	1,758,435	272581.13	586,145	0.414
70.5-71.4	1.11	17	0.521	817743.40	906,405	272581.13	302,135	0.213
71.5-72.4	1.33	17	0.581	817743.40	1,089,047	272581.13	363,016	0.256
72.5-73.4	1.04	17	0.599	817743.40	849,465	272581.13	283,155	0.200
73.5-74.4	1.54	17	0.898	817743.40	1,263,393	272581.13	421,131	0.297
74.5-75.4	2.63	17	0.961	817743.40	2,149,511	272581.13	716,504	0.506
75.5-76.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
76.5-77.4	0.94	17	0.423	817743.40	765,252	272581.13	255,084	0.180
77.5-78.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000

Table 17-76 (cont.)

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
78.5-79.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
79.5-80.4	0.21	17	0.214	817743.40	174,700	272581.13	58,233	0.041
80.5-81.4	0.22	17	0.217	817743.40	177,595	272581.13	59,198	0.042
81.5-82.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
82.5-83.4	0.00	17	0.000	817743.40	0	272581.13	0	0.000
83.5-84.4	0.25	17	0.247	817743.40	202,031	272581.13	67,344	0.048
84.5-85.4	0.44	17	0.300	817743.40	358,558	272581.13	119,519	0.084

* Adjusted to 1/3 Total Core Volume to reflect bottom sampling only.
No unsampled segment volume adjustment

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

Table 18-76. Average tomcod density, standard error, and standing crop estimated for each tomcod length interval present on 13 June 1976.

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
38.5-39.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
39.5-40.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
40.5-41.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
41.5-42.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
42.5-43.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
43.5-44.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
44.5-45.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
45.5-46.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
46.5-47.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
47.5-48.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
48.5-49.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
49.5-50.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
50.5-51.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
51.5-52.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
52.5-53.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
53.5-54.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
54.5-55.4	1.08	12	0.804	1129144.96	1,224,268	376381.65	408,089	0.288
55.5-56.4	0.42	12	0.417	1129144.96	470,477	376381.65	156,826	0.111
56.5-57.4	0.99	12	0.524	1129144.96	1,115,815	376381.65	371,938	0.263
57.5-58.4	2.11	12	1.007	1129144.96	2,388,139	376381.65	796,046	0.562
58.5-59.4	0.36	12	0.358	1129144.96	403,938	376381.65	134,646	0.095
59.5-60.4	1.14	12	0.596	1129144.96	1,287,381	376381.65	429,127	0.303
60.5-61.4	0.74	12	0.501	1129144.96	838,747	376381.65	279,582	0.197
61.5-62.4	2.21	12	1.544	1129144.96	2,496,480	376381.65	832,160	0.588
62.5-63.4	1.57	12	0.892	1129144.96	1,773,699	376381.65	591,233	0.418
63.5-64.4	0.77	12	0.769	1129144.96	868,274	376381.65	289,425	0.204
64.5-65.4	1.29	12	0.577	1129144.96	1,462,129	376381.65	487,376	0.344
65.5-66.4	0.70	12	0.475	1129144.96	790,131	376381.65	263,377	0.186
66.5-67.4	1.17	12	0.614	1129144.96	1,323,721	376381.65	441,240	0.312
67.5-68.4	0.58	12	0.416	1129144.96	656,829	376381.65	218,943	0.155
68.5-69.4	1.27	12	0.546	1129144.96	1,437,419	376381.65	479,140	0.338
69.5-70.4	1.88	12	1.190	1129144.96	2,120,368	376381.65	706,789	0.499
70.5-71.4	1.09	12	0.807	1129144.96	1,235,246	376381.65	411,749	0.291
71.5-72.4	0.71	12	0.480	1129144.96	801,109	376381.65	267,036	0.189
72.5-73.4	1.46	12	0.624	1129144.96	1,643,375	376381.65	547,792	0.387
73.5-74.4	0.87	12	0.471	1129144.96	982,625	376381.65	327,542	0.231
74.5-75.4	1.03	12	0.755	1129144.96	1,163,871	376381.65	387,957	0.274
75.5-76.4	0.32	12	0.315	1129144.96	355,994	376381.65	118,665	0.084
76.5-77.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
77.5-78.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000

Table 18-76 (cont.)

Length Interval (mm)	Sampling Area Average Density	N	Std. Error	River Volume In Sampling Area (1000cu.m.)	Estimated Standing Crop	Adjusted River Volume* (1000cu.m.)	Adjusted Standing Crop*	Riverwide Average Density**
78.5-79.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
79.5-80.4	0.00	12	0.000	1129144.96	0	376381.65	0	0.000
80.5-81.4	0.38	12	0.384	1129144.96	434,137	376381.65	144,712	0.102
81.5-82.4	0.33	12	0.325	1129144.96	366,972	376381.65	122,324	0.086
82.5-83.4	0.36	12	0.358	1129144.96	403,938	376381.65	134,646	0.095
83.5-84.4	0.76	12	0.510	1129144.96	853,244	376381.65	284,415	0.201
84.5-85.4	0.00							

* Adjusted to 1/3 Total Core Volume to reflect bottom sampling only.
No unsampled segment volume adjustment.

** Average Riverwide Density = Adjusted Standing Crop/1416082.933
1416082.933 = Total River Core Volume (in 1000cu.m.) from MP 0 to MP 58.

APPENDIX IV

IV. Data for age, densities, and standing crops for tomcod
in selected length intervals during 1976. 6p.

Table 1-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Length Interval:		0.0-7.4				
Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	2.387	2.387	3,380,190	7.161	10,140,570
14-Feb-76	8	1.976	15.808	2,798,180	15.271	21,624,294
21-Feb-76	15	15.528	232.920	21,988,936	61.264	86,754,905
28-Feb-76	22	34.616	761.552	49,019,127	175.504	248,528,219
07-Mar-76	30	98.370	2951.100	139,300,078	531.944	753,276,820
14-Mar-76	37	50.220	1858.140	71,115,685	520.065	736,455,171
21-Mar-76	44	29.069	1279.036	41,164,115	277.512	392,979,299
28-Mar-76	51	21.741	1108.791	30,787,059	177.835	251,829,108
04-Apr-76	58	5.071	294.118	7,180,957	93.842	132,888,055
10-Apr-76	64	0.000	0.000	0	15.213	21,542,870
17-Apr-76	71	0.000	0.000	0	0.000	0
24-Apr-76	78	0.000	0.000	0	0.000	0
01-May-76	85	0.000	0.000	0	0.000	0
09-May-76	93	0.000	0.000	0	0.000	0
15-May-76	99	0.000	0.000	0	0.000	0
23-May-76	107	0.000	0.000	0	0.000	0
05-Jun-76	120	0.000	0.000	0	0.000	0
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		258.978	8503.852	(Larvae-Days) =		2,656,019,310
Days From 7 Feb For Average Larvae To Reach 7mm (Age 0)			32.836	Duration In Length Interval (Days) =		4.69
Therefore Day 0 =			11-Mar-76	Standing Crop Adjusted For Life Stage Duration (Larvae) =		566,195,812

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

Table 3-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Length Interval:		8.5-9.4				
Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	0.000	0.000	0	0.000	0
14-Feb-76	8	0.000	0.000	0	0.000	0
21-Feb-76	15	0.000	0.000	0	0.000	0
28-Feb-76	22	0.000	0.000	0	0.000	0
07-Mar-76	30	54.619	1638.570	77,345,034	218.476	309,380,135
14-Mar-76	37	77.251	2858.287	109,393,823	461.545	653,585,997
21-Mar-76	44	157.369	6924.236	222,847,555	821.170	1,162,844,822
28-Mar-76	51	415.650	21198.150	588,594,871	2005.567	2,840,048,492
04-Apr-76	58	24.795	1438.110	35,111,776	1541.558	2,182,973,266
10-Apr-76	64	6.962	445.568	9,858,769	95.271	134,911,637
17-Apr-76	71	0.265	18.815	375,262	25.295	35,819,110
24-Apr-76	78	0.000	0.000	0	0.928	1,313,417
01-May-76	85	0.000	0.000	0	0.000	0
09-May-76	93	0.000	0.000	0	0.000	0
15-May-76	99	0.000	0.000	0	0.000	0
23-May-76	107	0.000	0.000	0	0.000	0
05-Jun-76	120	0.000	0.000	0	0.000	0
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		736.911	34521.736	(Larvae-Days) =		7,320,876,876
Days From 11 March For Average Larvae To Reach 9mm (Age)			14.010	Duration In Length Interval (Days) =		3.70
			25-Mar-76	Standing Crop Adjusted For Life Stage Duration (Larvae) =		1,977,898,579

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

Table 9-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	0.000	0.000	0	0.000	0
14-Feb-76	8	0.000	0.000	0	0.000	0
21-Feb-76	15	0.000	0.000	0	0.000	0
28-Feb-76	22	0.000	0.000	0	0.000	0
07-Mar-76	30	0.000	0.000	0	0.000	0
14-Mar-76	37	0.000	0.000	0	0.000	0
21-Mar-76	44	0.000	0.000	0	0.000	0
28-Mar-76	51	0.000	0.000	0	0.000	0
04-Apr-76	58	12.535	727.030	17,750,600	43.873	62,127,098
10-Apr-76	64	64.824	4148.736	91,796,160	232.077	328,640,279
17-Apr-76	71	32.616	2315.736	46,186,961	341.040	482,940,923
24-Apr-76	78	2.952	230.256	4,180,277	124.488	176,285,332
01-May-76	85	0.704	59.840	996,922	12.796	18,120,197
09-May-76	93	0.000	0.000	0	2.816	3,987,690
15-May-76	99	0.000	0.000	0	0.000	0
23-May-76	107	0.000	0.000	0	0.000	0
05-Jun-76	120	0.000	0.000	0	0.000	0
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		113.631	7481.598	(Larvae-Days) =		1,072,101,520
Days From 11 March For Average Larvae To Reach 15mm (Age)		33.005 13-Apr-76		Duration In Length Interval (Days) =		2.27
				Standing Crop Adjusted For Life Stage Duration (Larvae) =		472,863,405

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

Table 14-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Length Interval:		19.5-20.4				
Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	0.000	0.000	0	0.000	0
14-Feb-76	8	0.000	0.000	0	0.000	0
21-Feb-76	15	0.000	0.000	0	0.000	0
28-Feb-76	22	0.000	0.000	0	0.000	0
07-Mar-76	30	0.000	0.000	0	0.000	0
14-Mar-76	37	0.000	0.000	0	0.000	0
21-Mar-76	44	0.000	0.000	0	0.000	0
28-Mar-76	51	0.000	0.000	0	0.000	0
04-Apr-76	58	0.120	6.960	169,930	0.420	594,755
10-Apr-76	64	0.929	59.456	1,315,541	3.147	4,456,413
17-Apr-76	71	17.940	1273.740	25,404,528	66.042	93,520,241
24-Apr-76	78	27.019	2107.482	38,261,145	157.357	222,829,854
01-May-76	85	7.709	655.265	10,916,583	121.548	172,122,048
09-May-76	93	0.443	41.199	627,325	32.608	46,175,632
15-May-76	99	0.066	6.534	93,461	1.527	2,162,359
23-May-76	107	0.000	0.000	0	0.264	373,846
05-Jun-76	120	0.000	0.000	0	0.000	0
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		54.226	4150.636	(Larvae-Days) =		542,235,148

Days From 11 March For Average Larvae To Reach 20mm (Age) 43.707
24-Apr-76

Duration In Length Interval (Days) = 1.71

Standing Crop Adjusted For Life Stage Duration (Larvae) = 316,354,626

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

Table 19-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Length Interval: 24.5-25.4

Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	0.000	0.000	0	0.000	0
14-Feb-76	8	0.000	0.000	0	0.000	0
21-Feb-76	15	0.000	0.000	0	0.000	0
28-Feb-76	22	0.000	0.000	0	0.000	0
07-Mar-76	30	0.000	0.000	0	0.000	0
14-Mar-76	37	0.000	0.000	0	0.000	0
21-Mar-76	44	0.000	0.000	0	0.000	0
28-Mar-76	51	0.000	0.000	0	0.000	0
04-Apr-76	58	0.000	0.000	0	0.000	0
10-Apr-76	64	0.000	0.000	0	0.000	0
17-Apr-76	71	0.389	27.619	550,856	1.362	1,927,997
24-Apr-76	78	4.995	389.610	7,073,334	18.844	26,684,667
01-May-76	85	12.823	1089.955	18,158,431	62.363	88,311,180
09-May-76	93	1.177	109.461	1,666,730	56.000	79,300,644
15-May-76	99	0.115	11.385	162,850	3.876	5,488,737
23-May-76	107	0.038	4.066	53,811	0.612	866,643
05-Jun-76	120	0.000	0.000	0	0.247	349,772
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		19.537	1632.096		(Larvae-Days) =	202,929,641

Days From 11 March For Average Larvae
To Reach 25mm (Age) 50.703
01-May-76

Duration In
Length Interval (Days) = 1.38

Standing Crop Adjusted For
Life Stage Duration (Larvae) = 147,281,705

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

Table 29-76 Age. Data for age, densities, and numbers of Atlantic tomcod.

Length Interval: 34.5-35.4

Date	Study Day	Riverwide Average Density	Day Weighted By Density	Estimated Standing Crop*	Trapezoidal Summation Of Density	Trapezoidal Summation Of Numbers
01-Feb-76		0.000	0.000	0	0.000	0
07-Feb-76	1	0.000	0.000	0	0.000	0
14-Feb-76	8	0.000	0.000	0	0.000	0
21-Feb-76	15	0.000	0.000	0	0.000	0
28-Feb-76	22	0.000	0.000	0	0.000	0
07-Mar-76	30	0.000	0.000	0	0.000	0
14-Mar-76	37	0.000	0.000	0	0.000	0
21-Mar-76	44	0.000	0.000	0	0.000	0
28-Mar-76	51	0.000	0.000	0	0.000	0
04-Apr-76	58	0.000	0.000	0	0.000	0
10-Apr-76	64	0.000	0.000	0	0.000	0
17-Apr-76	71	0.000	0.000	0	0.000	0
24-Apr-76	78	0.000	0.000	0	0.000	0
01-May-76	85	2.975	252.875	4,212,847	10.413	14,744,964
09-May-76	93	4.993	464.349	7,070,502	31.872	45,133,395
15-May-76	99	2.539	251.361	3,595,435	22.596	31,997,810
23-May-76	107	0.163	17.441	230,822	10.808	15,305,024
05-Jun-76	120	0.000	0.000	0	1.060	1,500,340
13-Jun-76	128	0.000	0.000	0	0.000	0
TOTALS		10.670	986.026	(Larvae-Days) =		108,681,533

Days From 11 March For Average Larvae
To Reach 35mm (Age) 59.575
10-May-76

Duration In
Length Interval (Days) = 0.99

Standing Crop Adjusted For
Life Stage Duration (Larvae) = 109,818,167

* Riverwide Average Density (#Larvae/1000 cu.m.) X Total Core Vol. (1,416,082,933 cu.m.)

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AUTOBIOGRAPHICAL STATEMENT

Carter Braxton Dew graduated in 1962 with a B.A. degree in History from Washington and Lee University in Lexington, Virginia. After serving as an officer with the U.S. Marine Corps from 1962 to 1965, he graduated in 1970 from the University of Connecticut with an M.S. degree in Biology. His Master's thesis on the life history of the cunner (Tautogolabrus adspersus), a northern wrasse of the family Labridae, was published in 1976. From 1970 to 1981 he worked as a fisheries biologist on the Hudson River for the environmental consulting firm of Lawler, Matusky, and Skelly Engineers. During 1977-1980 he provided substantive oral and written testimony on fisheries issues as an expert witness in the Hudson River adjudicatory hearings. In 1980 he authored the Westway report, which presented Hudson River fisheries data leading to the demise of a proposed \$4.5 billion project to restore Manhattan's Westside Highway. In 1981 he moved to Alaska and worked as a biologist studying the impact of oil-related development on the arctic fish populations of the nearshore Beaufort Sea and North Slope tundra streams and rivers. He joined the National Marine Fisheries Service (NOAA) at Kodiak, Alaska in 1984, where he is the task leader for underwater research. His most recent paper, an in situ study of the behavioral ecology of juvenile red king crab, Paralithodes camtschatica, was published in October 1990 in the Canadian Journal of Fisheries and Aquatic Sciences.

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